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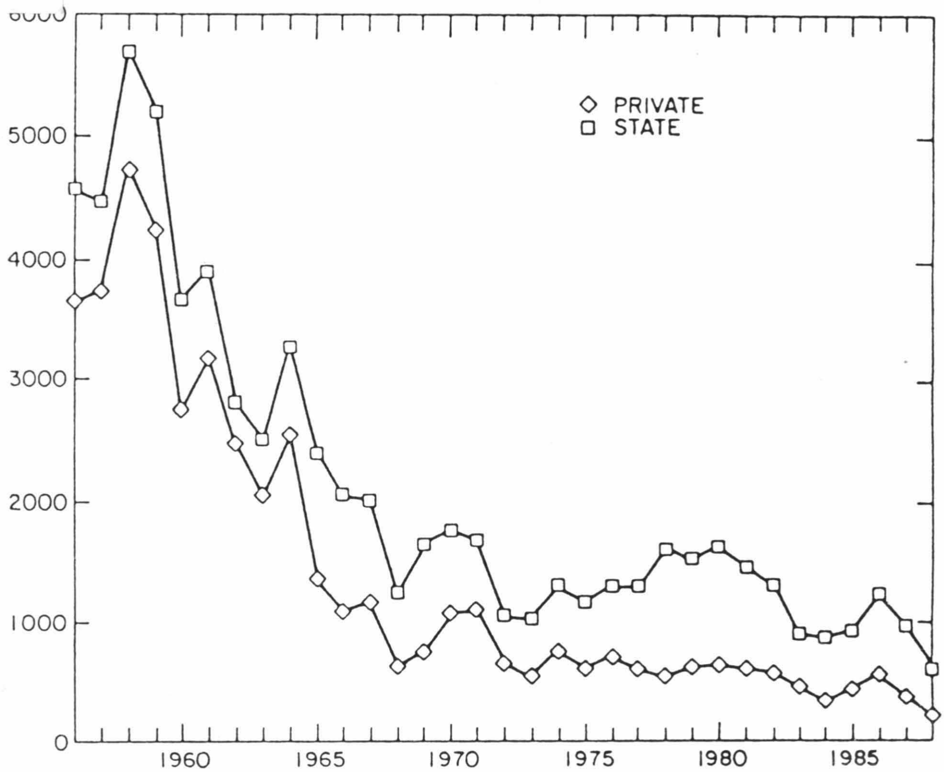

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Reversing the Decline of Private Oyster Planting in the Chesapeake Bay: An Evaluation of Policy Strategies

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Private oyster production in Virginia has declined steadily over the past 30 years. This decline is responsible for much of Virginia's overall reduction in production. In an effort to revive oyster production, Virginia has participated in developing a Chesapeake Bay Oyster Management Plan (Fisheries Management Plan Workgroup, 1989) which contains a goal to increase private oyster production. If this goal is to be achieved, policies to stimulate increased private planting will be needed. In this study, the economics of private planting are analyzed to identify the important factors limiting profitability. The analysis is based on private interviews with oyster biologists and planters, mail surveys of oyster grounds leaseholders, and a bioeconomic model of oyster production. The analysis is used to identify effective policies for stimulating increased private planting and production. While portions of the research have been reported elsewhere (Bosch and Shabman, 1990a; 1990b), this bulletin presents a complete description of the research methods and results.

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Reversing the Decline of Private Oyster Planting in the Chesapeake Bay: An Evaluation of Policy Strategies

Section 1.0: Introduction

Oyster production in Virginia occurs on two types of grounds, public and private. Public or "Baylor" grounds are managed by the state for both market and seed oyster production. Baylor grounds were defined late in the 1800s as the "naturally productive" areas and are intended to be available to all citizens of the state subject to prescribed regulations on harvest gear (generally only hand tongs are allowed except for specific areas where dredges and/or patent tongs may be used) and harvest season. The harvest season generally lasts from October 1 to March 31 in most Virginia waters except for the James River where harvest lasts until May 31 (Barth, 1990). Those areas not defined as Baylor grounds are available for leasing by private individuals who may place shell and plant seed oysters on the bottoms and harvest and sell the market oysters at maturity. There are no gear or season restrictions on private grounds harvest.

Virginia oyster production has been declining in recent years. This decline began in 1959, the year the disease Haplosporidium nelsoni (MSX) was discovered in the Virginia Chesapeake Bay (Haven, Hargis, and Kendall, 1981). The extent of the decline can be seen in Figure 1. In 1958, total harvest of oysters in the Virginia Chesapeake Bay from private and public oyster grounds was 5.7 million U.S. standard bushels; 4.74 million bushels (83%) came from privately planted grounds. By 1988 total harvest had declined to 0.6 million bushels, of which 0.22 million bushels (36%) came from privately leased grounds (Virginia Marine Resources Commission, 1988 and 1979). Nearly 90% of the 4.44 million bushel decline is accounted for by reduced private grounds harvests. The decline in private harvests has occurred in spite of arguments that private grounds production is more efficient than production on publicly managed grounds (Agnello and Donnelly, 1975, 1976, and 1984; Hargis and Haven, 1988).

Private Oyster Planting

Planting of oysters is an aquacultural enterprise in which immature oysters, called seed, are planted on the bottom of saline rivers and bays and allowed to mature to market size. The time to maturity is correlated with the salinity of the overlying waters. Salinity is positively related to the growth rate of the seed because it is associated with a wide range of favorable growing conditions including food availability and temperature (Kennedy and Breisch, 1981). Growth rates approach zero at salinity levels of five parts per thousand (ppt) or less, with maximum growth rates at salinity levels above 12 to 13 ppt (Loosanoff, 1953; Chanley, 1958). Even month to month variations in salinity will cause growth rates to vary. In higher salinity waters, market size oysters

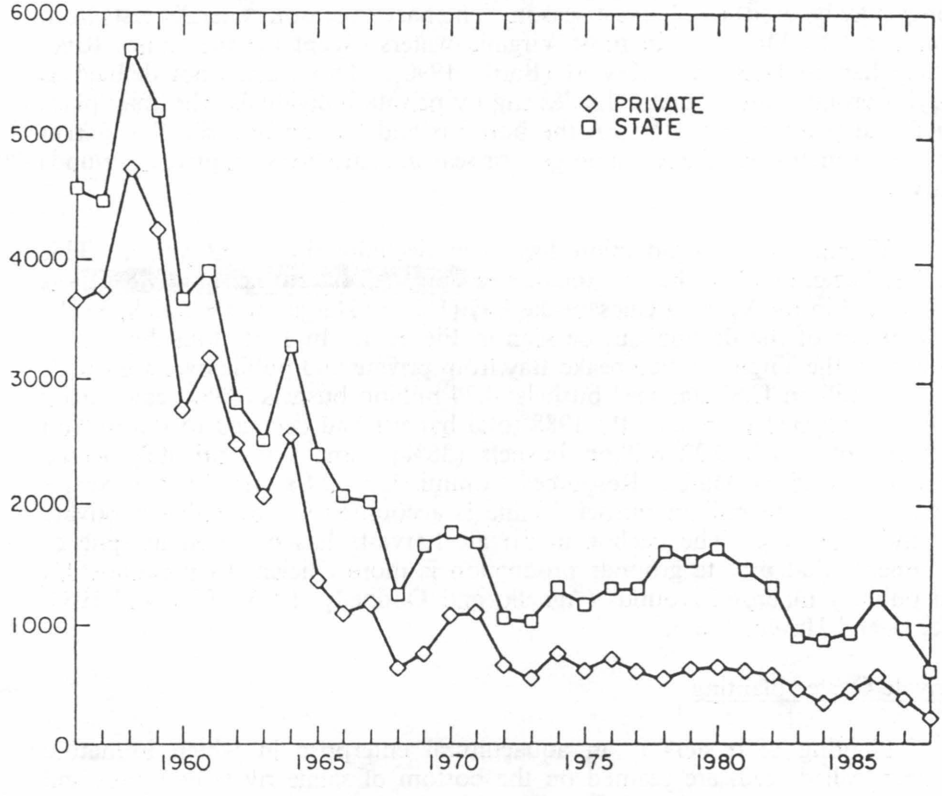

Figure 1. Virginia annual private and state total market oyster harvests. Data are presented in thousands of U.S. standard bushels (Virginia Marine Resources Commission 1988).

may be realized in as little as two years, but longer periods of up to four years are to be expected in lower-salinity waters. Areas with faster growth rates are economically preferable because the investment return is realized sooner there. However, higher salinity waters are more likely to be associated with oyster diseases.

MSX Disease as a Cause of Decline

In an effort to gain insight into the economics of private planting and possible causes of the decline in private harvests, the investigators conducted personal interviews in April 1987 with selected planters in the Rappahannock River, one of the largest sources of market oysters in Virginia (Haven and Whitcomb, 1986). The planters indicated that returns from planting have declined and have become "riskier." They blamed declining returns on increased problems with oyster diseases such as MSX and predators as well as increasing input costs, particularly for seed. A follow-up mail survey of private grounds leaseholders in the Rappahannock River found that 69% "agreed strongly" or "agreed" with the statement that "Losses caused by MSX make planting risky on my grounds."

Initial MSX infection and subsequent mortality are related to salinity and season. Initial infection occurs only in the months of May through October, if salinities are above a "trigger" level. The infection is incubated and spreads in the oysters for a period before oyster mortalities begin. The level to which salinities must rise before MSX causes mortality (mortality threshold) is also likely to be higher than the salinity level that triggers infection. After an incubation period and if salinities exceed the mortality threshold, mortality will occur until the onset of colder water temperatures of winter (Andrews, 1979). MSX mortalities each month will average 20% of the standing crop during the months of June through September (Andrews, 1979). Once salinity is above the mortality threshold level, growth ceases. The precise level of salinity which triggers infection and the threshold salinity at which mortality occurs are not known but are believed to lie between 15 and 25 ppt (Andrews, 1979). If salinity falls below the mortality threshold but remains above 10 ppt, normal growth occurs until salinity rises to the mortality threshold. If salinity falls below 10 ppt, the MSX infection itself is eliminated (Sprague, Dunnington, and Drobeck, 1969).

There is currently no way to combat loss from MSX other than to remove infected oysters to grounds where salinities remain below the mortality threshold or to avoid planting these grounds. However, avoiding MSX is difficult because the salinity at a location is likely to vary by season and year depending on precipitation and streamflows in the drainage basin. As a result, the planter is confronted with a risk-return tradeoff in selecting a planting location. A planter might prefer grounds with higher salinities in order to achieve faster growth rates, but these grounds are also more likely to incur mortality due to MSX.

Because MSX is generally held responsible for the decline in private production (Haven, Hargis, and Kendall, 1981), much oyster research since 1960 has been devoted to finding MSX-resistant seed in order to restore the industry's productivity. The disease was responsible for the significant reduction in oyster harvests in 1959, as shown in Figure 1. Average harvests in the three pre-MSX years (1956-1958) were 4.04 million bushels compared with 2.8 million bushels in 1960-1962. However, once the initial MSX losses were realized, the decline in private harvests persisted, as shown in Figure 1. Average private harvests for 1964-1966 were 1.66 million bushels; for 1974-1976, 0.68 million bushels; and for 1984-1986, 0.45 million bushels. Thus, increased incidence of MSX or other causes may be responsible for the continued decline since the initial outbreak of MSX. Another possible cause is the disease Perkinsus marinus (Dermo) which has caused significant loss of oysters in the Bay. This disease was not analyzed in this study because of the availability of management options to control losses to Dermo (Andrews and Burreson, 1987).

Economic Factors as a Cause of Decline

Interviews with private planters revealed that oyster planting has been subject to a cost-price squeeze. They noted that the price of the most important production input, seed, has risen substantially relative to the price of market oysters. Seed production is a process that occurs when mature oysters release sperm and eggs into the water column. Fertilization in the water results in free swimming larvae, which may swim and/or be carried by currents great distances before permanently attaching themselves to the bottom (setting). In order to set, larvae require a relatively clean, firm surface, usually old shell. If larvae have not found a suitable surface after about two weeks of age, they will die (Bailey and Biggs, 1968).

Most seed is obtained from state-managed seedbeds, particularly those in the James River, which accounted for 59% of total state seed harvests in the 1986-1987 season (Pritchard, 1988) and which has also been opened recently to commercial harvests. State management of the seed beds includes limits on season and harvest technology (only harvest by hand or hand tongs is allowed for seed to be sold to private planters). More recent efforts have focused upon placing shell in the seed beds to enhance setting rates. At the same time, a number of changes in practices of waste water treatment plant along the James River have been made to enhance larval survival. Most notably, use of chlorine as a disinfectant has been restricted.

Increased seed prices may be acting as a disincentive to planting oysters. The relative effects of increasing seed prices as well as MSX disease on profitability of planting need to be considered. Such analysis is needed to make policy recommendations for restoring incentives for private production.

State Oyster Management Goals

In order to deal with the problem of declining productivity, the state of Virginia has participated in development of a Chesapeake Bay Oyster Fishery Management Plan (Fisheries Management Plan Workgroup, 1989). The plan includes goals of increasing both public and private grounds production and contains strategies to achieve these goals.

Objectives of the Study

If the state is to achieve its goal of increasing private harvests, it will need a clear understanding of the factors contributing to the 30-year decline of private production. The objectives of this study are to evaluate economic and biological factors affecting private planting in order to identify the reasons for reduced private harvests. These findings can then be used to make policy recommendations for restoring private production.

In order to gain a better understanding of problems facing oyster production, the investigators interviewed oyster biologists and private oyster planters. Information gained from these personal interviews and from a review of literature was used to develop a bioeconomic model of oyster production. This model was then used to evaluate the economics of private production and the relative importance within the model of changes in seed prices and other input costs, disease behavior, and output prices on changes in profitability over time. To complement the model insights, a mail survey was sent to private grounds leaseholders in the Rappahannock River. Leaseholders' knowledge of oyster production, attitudes toward their grounds, intentions for the use of their grounds, and views of the future of the oyster industry in Virginia are essential to defining effective policy implementation strategies.

Section 2.0: A Survey of Private Grounds Leaseholders

To gain a better understanding of leaseholders' attitudes and perceptions of oyster production, a mail survey of Rappahannock River leaseholders was administered during January of 1989. Administration of the survey was based on Dillman's method. A cover letter and survey were mailed to all individuals owning leases in the Rappahannock River. Two weeks after the initial mailing, a reminder letter was mailed to all respondents requesting them to complete the survey if they had not done so already. Four weeks after the initial mailing, another copy of the survey and a second cover letter were mailed to non-respondents to encourage additional responses. Copies of the survey, cover letter, and reminder letter are shown in Appendix A.

Of 540 surveys mailed to leaseholders, 299 usable responses were received for a response rate of about 55%. Respondents held two types of leases: riparian and regular. Forty-nine respondents (17%) held riparian leases, which are small (0.5 acres or less) leases issued to owners of the adjacent shoreline. These leases are generally held to provide for household use rather than commercial production. Two hundred and forty eight respondents (83%) held regular leases, which are subject to an annual lease payment. Regular leases include large acreage holdings that are used for commercial production.

Responses from riparian leaseholders were eliminated from this analysis because they are unlikely to be involved or to have been involved in commercial oyster production. The characteristics of regular leaseholders were of greater interest because the study is focused on problems and opportunities facing private commercial production of oysters. The results reported hereafter refer to the responses from the 248 regular leaseholders only. The sample survey shown in Appendix A contains the summarized responses from the 248 regular leaseholders.

Respondents' lease sizes ranged from less than one acre to well over 20 acres. The distribution by size was as follows (percentages do not sum to 100 due to rounding):

Size range (acres)		No. respondents	% of total
< 1.0		25	10
1.0 - 4.99		95	38
5.0 - 9.99		63	25
10.0 - 19.99		32	13
> 20.0		33	13
	Total	248	99

Fifty-six respondents were identified as currently planting their grounds and are referred to in the following discussion as "planters," 121 were identified as not planting their grounds and are referred to as "nonplanters," and 71 could not be identified.

Lease and Leaseholder Characteristics

Responses to several questions indicated that many regular leaseholders had some past experience with oyster production. Forty-eight percent had harvested oysters from public grounds in the past, and 35% had worked for another planter at some time.[1] Sixty-nine percent (170) said they had at one time planted oyster seed or shell; however, the number of current planters is much smaller. In fact, of the 177 respondents whose current planting status could be determined, only 56 (32%) were identified as still planting.

Survey results indicate that the leaseholders were relatively old; 64% of regular leaseholders were 55 years or older. Among those identified as planters, 51% were 55 or older while 63% of those identified as nonplanters were above 55 years of age. This result may indicate that due to their advanced age many current leaseholders lack the long-term investment perspective regarding oyster planting that will be needed to increase private production.

Education levels among leaseholders were relatively high. Of all respondents, 54% had completed at least some college. Of those identified as planters, 47% had completed some college and, of those identified as nonplanters, 71% had completed at least some college.

Leaseholders' Knowledge of Oyster Production

Several questions were asked to determine leaseholders' knowledge of factors promoting oyster growth and disease. Sixty-seven percent of all respondents agreed with the statement that MSX is more likely to occur in high salinity waters, a view held by oyster biologists (Haven, Hargis, and Kendall, 1981). Planters did even better, as 84% agreed with this statement. Seventy-five percent of all regular leaseholders and 88% of planters agreed with the statement, "MSX disease is more of a problem during drought years." Since salinities are likely to be higher in dry years due to reduced streamflow, this statement is consistent with the reasoning that MSX is more likely when salinities are higher.

When asked if the disease Perkinsus marinus (Dermo) could be avoided by proper management of oyster grounds, only 9% of all respondents and 5% of planters agreed. Oyster biologists (Andrews and Burreson, 1987) state that the disease can be controlled using good management practices, which include avoiding infected seed, harvesting and fallowing beds before replanting, isolating planted beds from beds with infected oysters, and early harvest of infected oysters to avoid spreading the disease. Respondents were asked if oysters would grow faster in higher salinity waters, a view held by oyster biologists (Haven, Hargis, and Kendall, 1981). Only 22% of all respondents (34% of planters) agreed with this statement.

Further analysis was done to determine what factors influenced leaseholders' knowledge of oyster growth and disease. A total score for each respondent was calculated by summing their responses for each of the four questions. One point was given for each correct answer and total scores from zero to four were possible. Table 1 shows that planters' mean scores (2.14) were higher than nonplanters' scores (1.52) and that the difference was significant at the 0.0001 level. Additionally, those who indicated they had at some time in the past planted oysters had a higher mean score than those who had never planted oysters.

Table 1. Factors Determining Leaseholders' Understanding of Oyster Growth and Disease

Leaseholder characteristic	Number of respondents	Mean score	Significance[a] level
Planter[b]	56	2.14	0.0001
Nonplanter	121	1.52	
Planted in past[c]	170	1.85	0.0000
Never planted	75	1.12	
No extension contact[d]	180	1.54	0.0000
Extension contact	50	2.26	
Planter and extension contact[e]	23	2.48	0.0003
Planter and no extension contact	30	1.90	

[a]Significance levels refer to the test that the mean responses of the two classes are significantly different. One-sided significance levels reported here were calculated using the Wilcoxon Rank Sum procedure (Hollander and Wolfe, 1973; Pirie, 1984).

[b]Planters and nonplanters are defined in the text.

[c]"Planted in past" indicates respondents who had planted oyster seed or shell on their own or someone else's grounds at some time in the past.

[d]"No extension contact" refers to respondents who had never sought or received oyster planting advice from the Marine Advisory Service at VIMS.

[e]"Planter and extension contact" refers to planters who had at some time received oyster planting advice from the Marine Advisory Service at VIMS.

Contact with the Marine Advisory Service also resulted in higher knowledge scores. Those who had contacted the advisory service for advice had a mean score of 2.26 compared with 1.54 for those who had never contacted the advisory service. This difference is not surprising given that those using advisory services are more likely to be planters and planters have better knowledge than nonplanters. However, as Table 1 shows, the mean scores of planters who had contacted the advisory service for advice on oyster planting were higher than the scores of planters who had not done so. Neither age not education were significantly correlated with the knowledge score.

In summary, current planting status and contact with the Marine Advisory Service were found to be the most important factors affecting respondents' knowledge about oyster growth and disease. The relationship between respondents' knowledge and their attitudes toward oyster production problems are discussed in a later section.

Leaseholders' Views of Oyster Production Problems

Leaseholders were asked about potential problems (question 8) limiting the production potential of their grounds in the next five years or so. Seventy-five percent of planters and 72% of nonplanters agreed or strongly agreed that losses from MSX would make planting risky on their grounds. Concern with losses from Dermo was also evident, although more so among planters than nonplanters, as 75% of planters and 53% of nonplanters agreed that Dermo losses would make planting risky on their grounds. Forty-three percent of planters and 42% of nonplanters felt that losses to water pollution would make planting risky on their grounds, while 41 and 21% of planters and nonplanters, respectively, felt that losses to Cownose rays made planting risky. Concern with other factors was less evident, as only 32% of planters (25% of nonplanters) felt that shelling costs were too high for profitable production on their grounds, and 13% of planters (15% of nonplanters) felt that oysters did not grow fast enough for profitable production on their grounds.

Question 10 asked those currently planting their grounds to list important reasons why planting may be less profitable in the future. Of those who responded, 62% listed losses to MSX and 11% listed losses to Dermo as the most important reason. Lack of seed and high-priced seed were listed as most important by 10 and 4%, respectively, while water pollution was listed as the most important reason by 8%. Question 11 asked nonplanters to list important reasons why they chose not to plant their grounds. Of those who answered, 56% listed losses to MSX, 17% listed losses to water pollution, 7% listed lack of knowledge, and 6% said lack of time was the most important reason for not planting. Losses to Dermo were listed by only 3% of respondents as the reason for not planting.

The results emphasize the primary importance of disease as an important constraint to oyster production in the minds of most leaseholders. This concern is somewhat higher among those currently planting their leases compared with those not planting. Lack of time and knowledge are also important barriers to planting among nonplanters.

Leaseholders' Views of the Future of Oyster Production

Many leaseholders are currently producing or have produced oysters on their leases and have knowledge about oyster production and its problems. However, in the past it was possible to own a lease without ever producing oysters since only payment of a nominal acreage lease fee was required each year in order to maintain ownership of the lease. As of 1990, in order to maintain ownership of the lease, leaseholders will be required to show "proof of use," meaning evidence of oyster production or evidence of an effort to produce oysters (Code of Virginia 28.1-109).[2]

Leaseholders were asked how they planned to respond to the proof of use requirement for renewing leases which takes effect in 1990 (question 9). Of those who responded, 47% (99 leaseholders out of 211) said they would produce oysters on their grounds as long as production is feasible even if the law did not require it. Eleven percent said they would produce oysters in order to renew their leases, 4% planned to sell their leases, 7% planned to rent their leases to other planters, and 1% said they would forfeit their leases back to the state. Seventeen percent did not know how they would respond and 13% gave other responses.[3] Thus, of the 112 respondents that did not already plan to produce oysters, about 43% (49 respondents) plan to take some action to comply with proof of use requirements by either producing oysters or selling or subleasing their leases.

When asked about problems facing the oyster industry in the future (question 6), a large number of respondents agreed that lack of seed or high-priced seed threatened to limit profitability of private planting. Forty three percent of regular leaseholders agreed or strongly agreed that lack of seed could limit private planting, and 37% agreed that the price of oyster seed threatened profitability. Concern was higher among planters, as 51% of planters compared to 31% of nonplanters agreed that the price of oyster seed was making planting unprofitable. Similarly, 57% of planters agreed that the availability of seed was limiting planting compared with 36% of nonplanters.

Survey results also indicated some tendency for those who are more knowledgeable about oyster growth and disease to be more concerned about seed supplies and availability. As shown in Table 2, correlations between respondents' knowledge about oyster growth and disease and their concern about seed prices and seed availability were low but positive and significant at the 0.05 level.

Thirty-five percent of regular leaseholders agreed that theft of oysters from planted grounds limited incentives to plant oysters. About the same proportion

Table 2. Leaseholders' Understanding of Oyster Growth and Disease Related to Other Attitudes

Attitudinal characteristic	Sample size	One-sided correlation coefficient[a]	Significance level
Seed price[b] concern	154	0.083	0.039
Seed availability[c] concern	155	0.090	0.025
Planting expanded[d] if public grounds leased	158	0.121	0.003

[a]Correlation was calculated using the Kendall Rank Correlation Test (Pirie, 1984), a nonparametric test. Correlations refer to the relationship between indicated attitudes in column 1 and respondent's score on knowledge of oyster growth and disease.

[b]Leaseholders' agreement with the statement that high oyster prices are making planting unprofitable (survey question 6-1).

[c]Leaseholders' agreement with the statement that lack of seed limits private planting (survey question 6-3).

[d]Leaseholders' agreement with the statement that leasing public grounds to planters would cause private planting to increase.

of planters and nonplanters agreed with this question. Twenty-five percent of regular leaseholders agreed that difficulty in borrowing capital could limit planting. Less than 20% of the respondents agreed that low market prices, competition from other oyster-producing regions, lack of an outlet for selling oysters, and shortages of harvest labor were threats to the profitability of oyster production.

A potential stimulus to private production would be to make some part of Baylor (public) grounds available for private planting.[4] Only 21% of all respondents agreed that such an action would increase private planting. However, 34% of private planters (compared to only 15% of nonplanters) agreed with this statement. Also, as shown in Table 2, respondents with more knowledge about oyster growth and disease were more likely to agree that planting would expand if public grounds were leased.

Possibly, leaseholders who are more skeptical about the production potential of their own grounds would be more likely to agree that private planting would be increased by leasing public grounds. Survey results do not support this conjecture. Leaseholders' evaluations of their own leased grounds (question 8) were generally not significantly correlated with their responses to the question of leasing public grounds. The lack of a relationship may simply reflect the fact that availability of grounds for lease is not a constraint to production; consequently, leaseholders who view their own grounds as unsuitable for production can lease other private grounds if they desire to plant oysters.

<u>Summary</u>

If private planting is to increase, either existing planters must be induced to increase their plantings or new planters must be persuaded to begin production. Survey results indicate that the large majority of leaseholders do not plant their leases. As a result, a goal might be to induce more of these leaseholders to plant oysters. For example, the proof-of-use requirement aims to force leaseholders to either plant their grounds or give them up so that they can be made available to others. However, few respondents indicated that they would change the way they use their leased grounds because of this law. Another strategy to encourage planting might be to make more Baylor grounds available for private planting. However, the majority of leaseholders did not agree that this action would increase private planting.

Leaseholders are concerned with the effects of diseases, pollution, and the costs and availability of seed on the profitability and riskiness of private planting. Achieving an increase in private planting will require strategies to deal with these concerns. In addition, education of non-planting leaseholders will be needed to familiarize them with the opportunities and requirements of oyster production. More detailed analysis of the economic and biological forces affecting private planting is required to determine how these concerns can most effectively be addressed. In the next section, a bioeconomic simulation model is presented that can be used to analyze risks and returns to private planting and evaluate policies for promoting increased planting.[5]

Section 3.0: A Bioeconomic Model of Private Oyster Production

Consider a private oyster-planting enterprise on leased grounds in the Rappahannock River. The planter's objective may be to maximize the expected net present value (NPV) from the enterprise. Alternatively, he may be willing to accept a lower expected NPV if he can reduce risk by doing so.

The NPV depends on uncertain salinity, growth, and mortality over the life of the crop, which may take two to four years to mature. The NPV is defined as:

$$1) \quad NPV = Y(P - HC)/(1 + r)^n - (SC + T + SP)(SD)$$

where Y is the number of bushels harvested from the enterprise, P is the per-bushel market price, HC is the per-bushel harvest cost including delivery to the market location,[6] r is the monthly before-tax discount rate, and n is the number of months from planting to harvest. SC is the per-bushel seed purchase cost, T is the per-bushel seed tax, SP is the per-bushel cost for delivering and distributing seed on the planting grounds, and SD is the number of bushels planted.[7] The NPV is the net return from the oyster enterprise expressed in present value terms.[8]

The NPV of a crop is risky because of uncertainty about oyster growth and mortality rates. Growth and mortality depend on uncertain growing conditions such as salinity levels at the planted location. In this section a bioeconomic model is presented that can be used to evaluate the effects of uncertain growing conditions on returns from planting oysters at different locations. In later sections, the use of the model to evaluate planting in the Rappahannock River will be described.

Section 3.1: Bioeconomic Model

An overview of the oyster enterprise model that involves planting 1,000 bushels of seed is shown in Figure 2. The model moves in monthly time steps. Initially, a planting location, year, and month are selected. Planting cannot occur in July, August, or September because of unavailability of seed.

After planting, monthly salinity is established for a given location. A model relating salinity variations to streamflow and location was estimated using salinity measurements collected at various locations in the Rappahannock River from 1970 to 1983 (Virginia Institute of Marine Science, 1987) and daily streamflow measurements available through the Hydrologic Information Storage and Retrieval System (HISARS) (Virginia Water Resources Research Center, 1987). The estimated model based on 535 observations is the following (t-statistics are in parentheses):

$$2) \quad S = \underset{(96.78)}{19.588} - \underset{(-55.60)}{0.00251658K^2} - \underset{(-3.63)}{0.209454SF1} + \underset{(5.73)}{0.0000002SF1^2} - \underset{(-7.79)}{0.1732264SF2}$$

$$- \underset{(-6.08)}{0.1328310SF3} + \underset{(-2.15)}{0.0119554KT} \quad R^2 = .87$$

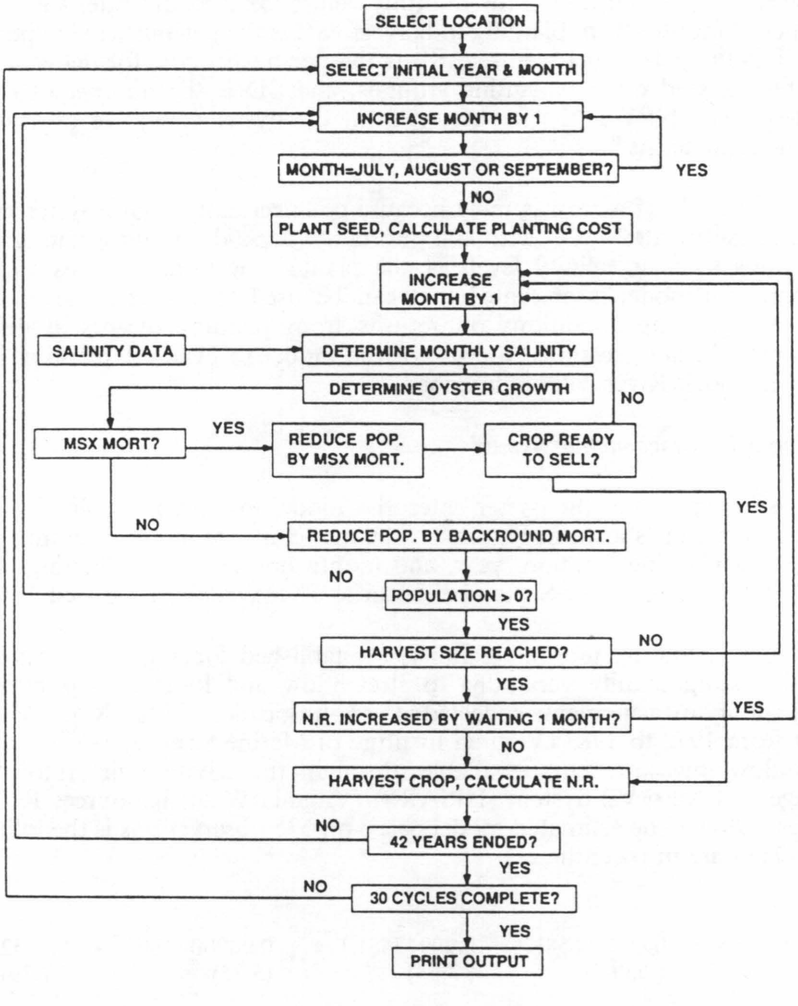

Figure 2. Oyster bioeconomic model.

where S is estimated salinity in ppt; K is kilometers upstream from the river mouth; SF1, SF2, and SF3 are the sums of daily streamflow readings (in 10,000's of cubic feet per second) for 0 to 30, 31 to 60, and 61 to 90 days, respectively, preceding the salinity measurement; and T is a dummy variable which takes a value of 1 for high tide and 0 for low tide. The coefficients have the expected sign, with salinity decreasing as streamflow and distance from the river mouth increase.

Monthly oyster growth is then calculated based upon level of salinity and other factors. Based in part on studies by Askew (1972, 1975, 1978), the following model was used to predict monthly oyster growth:

$$3) \quad W_t = W_0 e^{a_i b_j c_k}$$

where W_t is the oyster's weight at the end of month t, W_0 is the weight at the beginning of month t, e is the base of natural logarithms, and a_i represents the monthly growth parameters, b_j accounts for the effects of four different salinity levels, and c_K is a parameter that reduces growth rates as the weight at the beginning of the season increases. The a_i values, shown in Table 3, were calibrated using data from Virginia oyster growth studies (Andrews, unpublished data, Virginia Institute of Marine Science). As shown in Table 3, the fastest growth rates are realized in late spring and early summer and the slowest growth rates occur in winter.

c_k represents the instantaneous annual growth rate that depends on the oyster's initial weight k at the beginning of the season. The growth rates by oyster size, shown in Table 4, decline as oyster size increases. The values for c_k are based upon relationships derived by McHugh and Andrews (1954) for Chesapeake Bay oysters.

The parameter b_j was included to represent salinity effects. Salinity is positively related to the instantaneous growth rate of the seed because it is associated with a wide range of favorable growing conditions including food availability and temperature (Haven, Hargis, and Kendall, 1981; Kennedy and Breisch, 1981). Growth rates approach zero at salinity levels of five parts per thousand (ppt) or less, with maximum growth rates at salinity levels above 12 to 13 ppt (Loosanoff, 1953; Chanley, 1958). Even month-to-month variations in salinity will cause growth rates to vary. Values for b_j were derived with the help of scientists at the Virginia Institute of Marine Science (VIMS) and oyster producers. They were asked about the length of time required to produce a three-inch oyster from a one-inch seed taken from the James River and planted in the Rappahannock River on grounds of varying salinity. Their responses indicated that approximately two years are required for salinity levels greater than 13 parts per thousand (ppt), three years for salinity levels between ten and 13 ppt, and four years for salinity levels between six and ten ppt. No growth occurs for salinity levels less than six ppt. Values of b_j that would cause these growth rates to be

Table 3. Monthly Parameters Used in Oyster Growth Equation[a]

Month	Growth parameter (a^i)
January	0.0
February	0.0
March	0.0
April	0.021
May	0.221
June	0.323
July	0.178
August	0.108
September	0.106
October	0.077
November	0.052
December	0.012

[a]Parameters based on unpublished data obtained from J. Andrews, Virginia Institute of Marine Science, Gloucester Point, Virginia.

achieved for the given values of a_i and c_K were calculated and are shown in Table 5. Elicitation of growth rates was done using oyster length; however, within the model, growth and yield of oysters are expressed in grams. Oyster length was converted to grams based on information reported in McHugh and Andrews (1954) for Chesapeake Bay oysters. The relationship used is shown in equation 4, where LN indicates natural logarithm and weight and length are expressed in grams and millimeters, respectively.

Table 4. Relationship Between Oyster Weight and Instantaneous Annual Growth Rate[a]

Weight (gms)	Annual Growth rate (c_k)	Weight (gms)	Annual growth rate (c_k)
3.0-4.99	2.82	50.0-59.99	0.75
5.0 - 9.99	2.32	60.0-69.99	0.62
10.0-19.99	1.82	70.0-79.99	0.54
20.0-29.99	1.40	80.0-89.99	0.41
20.0-39.99	1.11	$\geq$ 90.0	0.36
40.0-49.99	0.83		

[a]Relationship calculated using data from McHugh and Andrews (1954).

4) $LN(weight) = -6.9944 + 2.53526LN(length)$

Two sources of oyster mortality considered are background factors and the disease MSX. Background factors, which include losses to predation and smothering by silt, are assumed to be independent of salinity. The inverse relationship between mortality and oyster size derived by Askew (1975) was used to calculate background mortality. Mortality factors by size are shown in Table 6.

A model of infection and mortality from MSX was constructed based on research summarized in Andrews (1979) as well as interviews with scientists at VIMS. Within the model, infection occurs only during May through October provided that salinities are high enough to trigger infection. After MSX infection, a period of incubation is required before mortalities begin. Mortalities occur only from June through September when salinities exceed a mortality threshold that is possibly higher than the level that triggers infection. Monthly mortalities equal 20% of the month's beginning population. If MSX mortalities occur during the June-September period, and salinities continue to equal or exceed the the mortality

Table 5. Salinity Levels, Time Required for Oysters to Reach Maturity, and Calculated b_j Values

Salinity level (ppt)	Time to maturity (years)	b_j value[a]
< 6	-[b]	-
6 - 9.99	4	0.33
10.0 - 12.99	3	0.42
≥ 13.0	2	0.595

[a]Value is that which, when inserted into the growth equation, causes oysters to reach maturity in the indicated number of years.

[b]No growth occurs at salinity levels below 6 ppt.

threshold during the June-September period of the second year, then the entire crop is eliminated in the second year.

No growth occurs during any month when the oyster has been infected and salinities are above the mortality threshold. If salinity falls below the mortality threshold but remains above 10 ppt, no MSX-related mortality occurs and normal growth resumes. However, the oyster remains infected and mortalities resume when salinity rises above the mortality threshold. If salinity falls below 10 ppt, the oyster eliminates all MSX infection (Sprague, Dunnington, and Drobeck, 1969).

MSX infection and mortality are based on salinity in the model. In fact, future research may reveal that food quality, water quality, temperature, and/or other factors react synergistically with salinity to determine the rate of infection and mortality. Nonetheless, current knowledge indicates that salinity is the major factor correlated with MSX mortality. However, the exact salinities that trigger the infection and subsequent mortality from MSX are uncertain. The specific uncertainties are discussed in detail below.

Oysters are harvested after they have reached three inches; however, harvest may be delayed if a higher price can be obtained by doing so. Net returns from

Table 6. Monthly Mortality Rates from Background Factors by Oyster Size[a]

Size (gms)	Mortality rate (%)	Size (gms)	Mortality rate (%)
1.0-1.99	5.25	8.0-9.99	2.15
2.0-2.99	4.10	10.0	2.10
3.0-3.99	3.55	20.0	1.40
4.0-4.99	3.20	30.0	1.0
5.0-5.99	2.90	40.0	0.6
6.0-6.99	2.70	50.0	0.5
7.0-7.99	2.45	> 60.0	0.4

[a]Background factors represent losses due to causes such as predation and smothering. Mortality rates are expressed as a percentage of the population at the beginning of the month. Mortality rates for weights of 10 grams or more were calculated by interpolation.

harvesting in the current month are compared with the discounted returns from waiting one month, recognizing the background mortality loss from leaving the oysters on the bottom another month. If the net harvest value can be increased by waiting, harvest is delayed by one month. This decision rule does not account for price uncertainty, the probability of disease loss, or added weight gains from waiting.[9] After the harvest is completed, the net present value of returns from the enterprise is calculated, another crop of oysters is planted at that location, and the process is repeated.

The length of time required to complete the oyster investment depends on seed size and salinity patterns at the grounds over the oyster's life. However, NPV's from planting different locations or times can only be compared if they come from investments with equal lives (Lee et al., 1980). In order to make the investment lives approximately equal, oyster returns were evaluated over a 42-year simulation period.[10] It is assumed that grounds are replanted after each harvest.

For example, if oysters require an average of three years to mature at a location, then a total of 14 crops would be harvested over the simulation period.

A distribution of NPV's for a given location was generated by repeating the 42-year simulation 30 times. For each replication, a random 42-year sequence of streamflows was synthetically generated and used to predict salinities. Synthetic streamflow sequences were generated using procedures suggested by Fiering and Jackson (1971). The logarithm of streamflow in year i and month j ($LSF_{i,j}$) was generated as follows:

$$5)\quad LSF_{i,j} = LSF_j + (r_j s_j / s_{j-1})\ DEV_{i,j-1} + t_{i,j} s_j (1 - r_j^2)^{0.5}$$

where LSF_j and s_j are the mean and standard deviations of the logarithms of flow for month j; r_j is the correlation between the logarithms of flow for month j and month j - 1;[11] t is a random normal deviate with mean 0 and variance 1; and $DEV_{i,j}$ is the deviation between $LSF_{i,j-1}$ and LSF_{j-1}. Means, standard deviations, and correlations of monthly flows were calculated from actual Rappahannock River data for 1910-1986. Flow logarithms were converted to streamflows and used to predict salinity.

In the study, it was assumed that availability of grounds in the Rappahannock River was not a constraint on the choice of planting location. This assumption was made because most private grounds are currently not being planted (Virginia Marine Resources Commission, 1989). Further, the "proof of use" requirement discussed earlier will put greater pressure on those who are not planting their leases to make them available to others for planting by subleasing, selling, or forfeiting the lease.

Section 3.2: Model Uncertainties

As noted previously, there is uncertainty about three aspects of MSX disease: 1) the salinity at which MSX infection begins to incubate in the oyster; 2) the number of months required for MSX to incubate in the oyster before mortalities begin; and 3) the mortality threshold, that is, the salinity level at which oyster mortalities occur from MSX. To determine the sensitivity of model results to these factors, appropriate parameters within the disease loss component of the simulation model were varied and the effects evaluated at several locations in the Rappahannock River. First, the number of months of MSX incubation required before mortality occurs were varied, with the infection trigger held constant at 15 ppt and the mortality threshold set at 18 ppt. Increasing the incubation period from one to three months caused relatively small increases in expected net returns in the downstream areas where salinities rose above the mortality threshold. For example, at 20 km the expected NPV was $4,808 for a three-month incubation compared with $3,781 for a one-month incubation. However, in upriver areas where salinity remained below the mortality threshold, the length of incubation had no effect on returns. Also, expected returns were maximized by planting in these upriver areas rather than further downstream regardless of the length of the incubation period.

Second, the salinity that triggers MSX infection was varied from 12 to 18 ppt, with the mortality threshold held constant at 18 ppt and the incubation period set at two months. Increasing the salinity trigger for infection had little effect on the location at which expected returns were maximized. Increasing the trigger caused small increases in returns in downstream areas where salinities were above the mortality threshold but did not affect returns in areas where salinities remained below the mortality threshold.

Third, the salinity threshold that induces mortality in infected oysters was varied between the values of 15 and 19 ppt. As noted, the threshold salinity may occur over a range from 15 to 25 ppt (Andrews, 1979); however, the upper bound of 19 ppt was chosen because salinity levels in the River seldom exceed 20 ppt at any location. The returns from planting at a location were significantly affected by the assumed mortality threshold.

In the application of the model, it was assumed that the salinity level that triggers MSX infection was 15 ppt, that the incubation period was two months, and that the salinity threshold for MSX mortality was 18 ppt. These were the most likely values suggested by interviews with biologists as well as published sources (Andrews, 1979). However, because of the sensitivity of model results to the mortality threshold, the effects of varying this parameter on returns by location will be discussed in a later section.

The bioeconomic model was used to analyze factors affecting returns to private oyster production and to evaluate policies that might improve profits from private planting. In the next section, results are reported from using the model to evaluate trends in returns to private production.

Section 4.0: Trends in Oyster Production Risks and Returns

Much of the decline in private production in Virginia occurred immediately after 1959 when MSX first appeared in the Virginia Chesapeake Bay. However, once the initial MSX losses were realized, the decline in private harvests persisted through the 1960s and into the 1980s as shown in Figure 1. With the aid of the insights gained from construction and use of the bioeconomic model, two possible explanations are evaluated here: 1) that MSX losses have become progressively more severe and have continued to drive down production; and 2) that an increasing cost-price ratio driven by increasing real seed prices has reduced profitability and increased risk of oyster planting and led to reduced production over time.

Section 4.1: MSX as a Cause of Decline

As noted, a possible explanation for the continued decline in private oyster harvests after the first appearance of the disease is that losses due to MSX have grown more severe since the post-1960 period. While there is no evidence that MSX is inducing mortality at even lower levels of salinity than previously (Burreson, 1989), salinity levels may have been increasing since the 1960 period as a result of random weather patterns. The possibility that higher salinity levels since 1960 were responsible for increased mortality was assessed by computing monthly salinity levels between 1957 and 1986 for locations in the Rappahannock River for June, July, August, and September, the months when oysters are susceptible to MSX mortalities. Salinity levels were calculated for a location 12 km from the river mouth. Table 7 shows the average number of times per year that monthly salinity levels exceeded the indicated mortality threshold between June and September in each 10-year period. Generally, the results do not indicate that salinity levels have increased since the disease first appeared in 1959. For example, the 17-ppt salinity threshold was exceeded on average 3.1 times per year in the 1957-1966 period compared with 2.4 times in the 1977-1986 period. Thus, it is doubtful that salinity conditions have become more conducive to losses from MSX in the years since MSX was first observed.

Section 4.2: Economic Forces as a Cause of Decline

An alternative explanation for the decline in private planting is that the increasing cost-price ratio has discouraged planting and led to declining output. Planters who were personally interviewed noted that costs of seed, the most important input used for private production, have increased over time. As shown in Table 8, in the 1980s seed costs were about $3.06 per bushel of seed or about 30% of total costs assuming, one bushel is harvested per bushel of seed. Planters contended that, as a result, net returns have fallen and the probability of large losses has increased because they must buy more bushels of seed to obtain a given level of expected net returns from the enterprise. As a result, they said planting had become "riskier." As discussed earlier, this view was also evident in the mail survey as 51% of the respondents who currently plant their grounds agreed or strongly agreed with the statement that "the price of oyster seed is making planting unprofitable."

The nominal price per bushel of seed from public grounds averaged $1.34 for the 1964-1967 seasons compared to $3.06 for the 1984-1987 seasons (Virginia Marine Resources Commission, 1988). When planting and tax costs shown in Table 8 are added, the total per-bushel costs increased from $1.97 to $5.29. However, the price per seed increased by much more than this because the number of seed per bushel has declined. The planters who were personally interviewed indicated that counts for James River oyster seed have declined from 1,500 to 2,000 seed per bushel in the 1960s to 400 to 800 per bushel at present. Surveys of the seed-producing bottoms of the James River support this assertion. Samples taken

Table 7. Average Number of Times Between June and September that Monthly Salinity Exceeded Alternative Thresholds at a Location 12 Kilometers From the Mouth of the Rappahannock River

	Salinity Threshold (ppt)				
Years	15	16	17	18	19
1957-1966	3.8	3.7	3.1	1.7	0.5
1967-1976	3.7	3.1	2.6	1.2	0.0
1977-1986	3.7	3.3	2.4	2.0	0.0
$\bar{x}$ =	3.73	3.37	2.7	1.63	0.17

in the fall (September-December) of the years 1962-1967 indicated an average count per bushel of 757 oysters of varying sizes (Andrews, unpublished data, Virginia Institute of Marine Science). By the fall of 1986, average counts were down to 366 per bushel (Whitcomb, 1987).[12] If the seed counts for the 1960s and 1980s are assumed to be 1,500 and 600, respectively, then, based on the figures in Table 8, the nominal seed and planting cost per 1,000 seed has increased over the period from $1.31 to $8.82, an increase of nearly 670%.[13] Harvest and interest costs are not affected by the declining seed count per bushel; consequently, these cost increases have been smaller. Over the same period, as shown in Table 8, the nominal market price has increased by slightly over 200%.

The increased cost per seed is due to reduced density of seed setting on seedbeds. Three theories have been offered as to why setting has declined in the James: 1) water pollution has reduced larval survival rates; 2) water pollution has made oysters less fertile; and 3) MSX has reduced the brood stock in downriver areas, thus reducing larval production. There is as yet no documented support for any of these theories (Haven and Fritz, 1985). In addition to the problems of reduced setting rates, seed costs have also been raised by continued reliance on labor-intensive hand tong methods for harvesting rather than mechanized harvest.

The exact effects of rising seed prices on returns and risks faced by producers are unclear. While the number of seed per bushel has declined, planters also indicated that seed size has increased. Larger seed will reach market size sooner and are less subject to losses from predation and other factors (Askew, 1975), thus compensating somewhat for the reduced seed numbers. Also, market oyster prices

Table 8. Economic and Physical Production Parameters Used for the 1980s, 1970s, and 1960s

Parameter	1980s	1970s	1960s
Seed count[a] (per bu.)	600	1050	1500
Seed size (inches)	1.5	1.25	1.0
Seed price[b] ($/bu)	3.06	1.74	1.34
Seed tax ($/bu)	.15	.10	.05
Plant cost[c] ($/bu)	2.08	1.10	.58
Transplant cost[d] ($/bu)	5.84	3.26	1.68
Harvest cost ($/bu)	4.54	2.57	1.32
Mkt price[e] ($/bu)	12.84	7.83	6.31
Monthly interest[f] (%)	.80	.324	.536

[a] Seed count and size estimates for the 1960s and 1980s were obtained from planter interviews, and 1970s values were obtained by linear interpolation between these values. Costs and market prices are expressed per Virginia bushel.

[b] Seed prices are a weighted average of prices for public grounds seed for the three years contained in each of the periods (Virginia Marine Resources Commission, 1988).

[c] Current planting and harvest costs were obtained from private planters and deflated to the earlier periods using the indices of wage rates and fuels and energy (U.S. Department of Agriculture, 1987).

[d] Current Transplant charge includes harvesting the premature oysters, transporting them upriver, and planting them on the new site. For example, in the 1980s the charge includes $4.54 per bu. for harvest and $1.30 for hauling and replanting the oysters. The $1.30 is less than the $2.08 planting charge for James River seed because the wharf fee of $.60 per bu. would not be paid on transplanted seed and because transport distances from lower to upper Rappahannock are less than from the James to the Rappahannock.

[e] Monthly harvest prices equal the seasonal average price for the 1984-1987, 1974-1987, and 1964-1967 periods, respectively, plus or minus a monthly adjustment obtained by taking the average deviation of each monthly price from the seasonal average price for the years 1981-1987. The percent deviations from the season average price were: January, -20.5; February, -9.1; March, -8.0; April, -2.1; May, 7.1; June, -12.0; July, 3.8; August, 2.1; September, -6.2; October, 5.5; November, -1.6; and December, 8.5.

[f] The interest rate used is a real, risk-adjusted rate. The one-year Treasury Bill rate (Board of Governors of the Federal Reserve System, 1987) was used as the risk-free nominal rate of interest. The inflation rate represented by the annual change in the implicit price deflator for gross national product (U.S. Department of Commerce, 1987) was subtracted, and a five percent per year risk premium added to account for risk.

have risen during this period. The bioeconomic model described in the previous section was used to analyze return to oyster production over the three time periods.[14]

Returns were measured as the net present value (NPV) of returns to a 1,000 bushel planting enterprise. Risk was measured as the coefficient of variation (C.V.) of NPV's. An alternative measure of risk, the breakeven probability, was also calculated. The model was applied to three time periods spaced 10 years apart: 1964-1967, 1974-1977, and 1984-1987. These periods were selected because, as noted earlier, they were characterized by common MSX hazard, but had much different seed cost-oyster price relationships. The physical and economic parameters used to represent each period are shown in Table 8.

Section 4.3: Trends in Oyster Yields and Returns

The model was used to determine whether the increased real cost of seed has led to less favorable returns to private planting. As noted, the probability of MSX disease is constant, as neither the disease behavior in terms of the salinities that instigate the disease nor the pattern of salinities, appears to have changed from 1960 to 1986. The effects of the increased seed cost were calculated for a 1,000 bushel enterprise assuming an 18-ppt salinity threshold for MSX mortality.[15]

Table 9 shows mean seed amounts and yield means and standard deviations by location and time period. Each simulated yield represents the total yield obtained when 1,000 bushels of seed are planted initially and each time oysters are harvested or lost to mortality for 42 years. The mean yield is the average total yield obtained from 30 simulation runs. Similarly the seed amounts shown are averages of the total bushels of seed planted for a 42-year simulation. Mean bushels of seed used in the enterprise increased from the 1960s simulations to the 1980s. For example, at 30 km, an average of 22,000 bushels were planted over the 42-year period in the 1980s compared to 18,530 bushels in the 1960s. In the 1980s the seed were larger and matured sooner; therefore more harvests were obtained and more seed replanted over the 42-year period.

As shown in Table 9, the reduced number of seed per bushel caused mean yields from the enterprise to decline from the 1960s to the 1980s. Maximum expected yields were 36,742 bushels for the 1960s compared with 30,632 bushels in the 1970s and 22,205 bushels in the 1980s. Because all three periods were subject to the same MSX hazards, the decline in yields is explained by reductions in the number of oysters per bushel of seed over time. Although oysters were larger and, as a result, less subject to background mortality in the 1980s, the increased size did not offset the reduced seed count per bushel.

For each time period, yields initially increased with distance from the river mouth. The increase occurred because: 1) salinities were lower for points further upriver; 2) lower salinities resulted in a lower probability of MSX mortality; and 3) the reduced MSX mortality more than offset any reduction in growth rate caused by lower salinity. At 30 km from the mouth, the probability of MSX loss was minimized; further movements upriver to lower salinity areas reduced yields

Table 9. Oyster Yields for Three Periods Assuming 18 ppt Salinity Threshold for Inducing MSX Mortality[a]

	1980s			1970s			1960s		
KM. from River Mouth	Mean Yield	Std. Dev. of Yield	Mean Total Seed[b]	Mean Yield	Std. Dev. of Yield	Mean Total Seed	Mean Yield	Std. Dev. of Yield	Mean Total Seed
0	8095	2032	21070	7830	2219	19030	7112	2502	17700
5	8689	2152	21000	8645	2413	18800	8222	2691	17500
10	9691	2296	21030	9668	2579	18570	9878	2865	17330
15	12324	1919	21330	13255	3010	18930	13874	3086	16970
20	17857	1377	21970	21008	3241	19800	22774	3239	17100
25	21840	382	22000	29312	1092	21500	34285	1550	18300
30	22205	317	22000	30632	655	21600	36742	1267	18530
35	21724	418	21970	30256	894	21070	35649	1451	18230
40	20646	512	21870	28018	1163	19470	32503	1390	17200
45	18968	562	21370	24023	1077	17270	27007	1336	15470
50	15808	699	18530	18872	743	14830	21276	977	13530

[a] Oyster yields are amounts harvested over a 42-year simulation period, assuming that 1000 bushels of seed are planted initially and each time the crop is harvested or lost to disease. Locations refer to distances upriver from the mouth of the Rappahannock River in Virginia.

[b] Total seed refers to the entire amount (bu) planted over the 42-year simulation. The mean is the average amount for the 30 simulations.

because the time required to reach maturity was increased, which in turn led to higher losses due to background mortality.

The changed cost-price ratio caused profitability to decline and risk to increase from the 1960s to the 1980s, as shown in Table 10. The table shows the NPVs of returns to an oyster-planting enterprise in which 1,000 bushels of seed are planted initially and after each time oysters are harvested or lost to mortality for a 42-year period. For example, in the 1980s at kilometer 20 an expected NPV of $4,169 is obtained. In other words, the average total net returns from 42 years of oyster plantings discounted to the present is $4,169. All returns reported are in nominal dollars; deflating would have increased the profitability advantage of the earlier periods over the 1980s. In the 1960s and 1980s, returns were maximized by planting the 30 km location, and in the 1970s returns were maximized at 35 km. At 30 km, expected returns in the 1960s were $48,801, nearly four times as large as the $12,727 expected return for the 1980s. Also, increasing seed costs led to a reduction in the availability of profitable grounds, as planting was no longer profitable at the 0, 5, and 10 km locations in the 1980s.

Relative variability as measured by the C.V. of NPVs increased from the 1960s to the 1980s, particularly for the locations closer to the river mouth where the probability of MSX mortality was greater. For example, at 20 km the C.V. was 0.27 in the 1960s compared with 0.97 in the 1980s. The increase in relative variability of returns occurred because the mean of NPVs declined faster than the standard deviation over the three periods. In the areas from 0 to 20 km, breakeven probabilities were also lower in the 1980s compared to the 1960s and 1970s.

The decline over time in expected returns and associated increases in measures of risk such as the C.V. can be attributed to several factors. First, the ratio of the sum of per-bushel seed, tax, and planting costs to market prices increased. As shown in Table 8, this ratio was 0.31:1 in the 1960s, 0.38:1 in the 1970s, and 0.41:1 in the 1980s. Second, declining yields means that the number of bushels of market oysters produced from a bushel of seed fell. Based on the yield figures of Table 9 and the total amount of seed planted over the 42-year period, the ratio was 1.98:1 in the 1960s, compared with 1.44:1 in the 1970s, and 1.01:1 in the 1980s.[16] The reduced ratio increased the seed expenditures required to produce a given level of expected yield and means that a planter in the 1980s who wished to maintain expected net income at earlier levels had to expand the enterprise by investing more in seed. The enterprise expansion would cause returns variability to increase. Third, the increase in real interest rates caused returns to be more heavily discounted in the 1980s.

One option available to planters is to closely monitor their planted grounds and transplant oysters to upriver locations of lower salinity when MSX mortalities begin to appear. This option is technically feasible since most private grounds are currently barren and could be made available for transplanting seed (Virginia Marine Resources Commission, 1986). The possibility of transplanting was evaluated with the model by transplanting oysters to an upriver location after one month of MSX mortalities were observed. The per-bushel charge for transplanting in each of the three periods is shown in Table 8. The transplant charge includes harvesting the premature oysters, transporting them upriver, and planting them on the new site. Transplanting increased returns in some but not all locations, as shown in Table 11. For example, under 1980s conditions, transplanting increased returns for the 0 to 15 km locations, but reduced returns for the 20 and 25 km locations, indicating that, in these areas, periods of MSX loss were usually not long enough to justify paying the transplanting charge. For locations 30 km and further upriver, transplanting had no effect on returns since MSX was not a problem there under the assumed 18 ppt salinity threshold for MSX mortality.

The results also show that the gains from transplanting were much smaller with 1980s seed prices than with 1970s or 1960s prices. For example, at 5 km and with 1980s prices, expected returns increased from \$-11,597 to \$-6,236 by

Table 10. Net Present Value of Oyster Returns for Three Periods Assuming 18 ppt Salinity Threshold for Inducing MSX Mortality[a]

KM from River Mouth	1980s Mean (Std. Dev.)	1980s B.E.[b] Prob.	1970s Mean (Std. Dev.)	1970s B.E. Prob.	1960s Mean (Std. Dev.)	1960s B.E. Prob.
0	-12827 (5281)	.0	-7502 (6302)	0.13	-36 (5510)	0.50
5	-11597 (5357)	.0	-4806 (6839)	0.23	2080 (5836)	0.63
10	-9985 (5720)	.0	-1793 (6949)	0.43	4550 (5796)	0.80
15	-5231 (5102)	0.23	7106 (7451)	0.83	10991 (6030)	0.97
20	4169 (4045)	0.77	26399 (8332)	1.0	26019 (7028)	1.0
25	11987 (1416)	1.0	45162 (2299)	1.0	45043 (3239)	1.0
30	12727 (758)	1.0	48288 (1588)	1.0	48801 (2116)	1.0
35	11921 (955)	1.0	48670 (2521)	1.0	47285 (2763)	1.0
40	9990 (986)	1.0	45423 (2601)	1.0	42202 (2186)	1.0
45	7532 (687)	1.0	37253 (2218)	1.0	33413 (2693)	1.0
50	4873 (995)	1.0	26202 (1478)	1.0	24815 (1462)	1.0

[a] Returns are stated as NPV's for a 42-year simulation period assuming that 1000 bushels of seed are planted initially and each time oysters are harvested or lost to disease. Locations refer to distances upriver from the mouth of the Rappahannock River in Virginia.

[b] Breakeven probability shows the probability of achieving a positive NPV.

transplanting. In contrast, transplanting increased returns at this location from $-4,806 to $17,343 under 1970s prices. Transplanting was more effective in earlier periods because many more seed per bushel were planted initially; thus, even with 20% loss from one month of MSX mortality, many oysters were left for transplanting. Some losses of the crop would likely be incurred when oysters are

Table 11. Net Present Value of Oyster Returns for Three Periods Assuming 18 ppt Salinity Threshold for Inducing MSX Mortality and with Transplanting[a]

KM from River Mouth	1980s Mean (Std. Dev.)	1980s B.E.[b] Prob.	1970s Mean (Std. Dev.)	1970s B.E. Prob.	1960s Mean (Std. Dev.)	1960s B.E. Prob.
0	-6508 (2839)	0.03	16738 (2916)	1.0	28798 (3256)	1.0
5	-6236 (2941)	0.03	17343 (2564)	1.0	27700 (3477)	1.0
10	-5622 (3193)	0.07	17468 (3019)	1.0	27803 (3692)	1.0
15	-3735 (3628)	0.17	19189 (3610)	1.0	27946 (3117)	1.0
20	2016 (3777)	0.70	26135 (4398)	1.0	32999 (3287)	1.0
25	10816 (2480)	1.0	42583 (3723)	1.0	43866 (3889)	1.0
30	12727 (758)	1.0	48288 (1588)	1.0	48801 (2116)	1.0
35	11921 (955)	1.0	48670 (2521)	1.0	47285 (2763)	1.0
40	9990 (986)	1.0	45423 (2601)	1.0	42202 (2186)	1.0
45	7532 (687)	1.0	37253 (2218)	1.0	33413 (2693)	1.0
50	4837 (995)	1.0	26202 (1478)	1.0	24815 (1462)	1.0

[a] Returns are stated as NPV's for a 42-year simulation period assuming that 1000 bushels of seed are planted initially and each time oysters are harvested. Locations refer to distances upriver from the mouth of the Rappahannock River in Virginia.

[b] Breakeven probability shows the probability of achieving a positive NPV.

moved; these losses were not considered here. Even with no losses, the results suggest that given current costs and prices, the current practice of not transplanting makes economic sense. However, if seed prices were reduced or if market oyster prices were increased, transplanting might be a profitable opportunity for private oyster planters.

The results presented in this section show that economic factors have greatly affected returns to oyster production. All three periods were assumed to be equally affected by MSX mortality conditions, yet the increasing real cost of seed caused returns to decline and the variability of returns relative to expected returns to increase even though average seed size increased. The results suggest that efforts to lower the cost of seed would be particularly effective in restoring the profitability of private planting. Strategies for encouraging private planting are considered in the next section.

Section 5.0: Strategies to Encourage Private Oyster Planting

Encouraging increased private production of oysters will require a mix of research and other types of policy strategies. The importance of research has been recognized as part of the Chesapeake Bay Oyster Management Plan (Fisheries Management Plan Workgroup, 1989). At the federal level, a 1988 bill proposed $68 million to fund 10 years of oyster production research (U.S. Congress, House, 1988). The result for 1989 is a federal appropriation of $500,000 (U.S. Congress, 1988). However, the increased research funding must now be followed by setting priorities for areas of study within an overall research budget. In this section, the bioeconomic model is used to evaluate alternative strategies for oyster production research.[17] The research strategies to be evaluated include those designed to achieve: 1) faster diagnosis of MSX, 2) better understanding of the relationship between MSX and salinity, 3) development of MSX-resistant seed, and 4) lower seed costs. After discussion of research strategies, other policy strategies will be reviewed including those pertaining to: 1) public seed bed management, 2) oyster transplanting, 3) access to private grounds, and 4) leaseholder education.

Section 5.1: Evaluation of Research Strategies

Faster Diagnosis of MSX

Planters face a tradeoff between achievement of higher growth rates in higher salinity waters and the greater chance of losses due to MSX disease in these waters. The risk involved in making this tradeoff might be more manageable if faster diagnosis of the disease were possible, enabling the planter to plant in higher salinity waters for faster growth and then salvage the crop for market or transplanting if salinities increase sufficiently to trigger the disease. MSX diagnosis currently requires extensive laboratory tests by shellfish pathologists (Dyckman, no date). Research could be directed toward developing simpler, faster tests to detect the disease.

The simulation model was used to examine the effects on NPV's of varying the length of time required to diagnose and harvest diseased market oysters from one half to two months.[18] Table 12 reports the results for several river locations, using a salinity of 18 ppt to trigger MSX mortalities. As noted previously, the trigger salinity at which mortalities occur is uncertain; however, the results reported in Table 12 were found to be insensitive to varying the trigger between 15 and 19 ppt. Mean net returns were increased only slightly at the 20 km location ($4,169 to $4,310) by faster diagnosis. At further upstream locations, transplanting was not economical, and hence faster diagnosis was not beneficial. However, the most important result is that the maximum expected NPV occurred at the 30 km location. The variance at this location also improved over that at 25 km. Thus, no matter how fast the diagnosis, the economically prudent location was at 30 km where MSX was avoided altogether. Increasing the risk of MSX disease loss in order to achieve higher growth rates was not an economically sound strategy. For setting disease research priorities, this simulation shows that planters would be best served by information telling them how to avoid MSX, which requires detailed understanding of the relationship of the disease to salinity, or by development of an MSX-resistant seed.

Research Area 2: Relating Salinity to MSX Mortality

Management of oyster planting in the presence of MSX is made difficult by uncertainty about three aspects of MSX disease: 1) the salinity at which MSX infection begins to incubate in the oyster; 2) the number of months required for MSX to incubate in the oyster before salinity-dependent mortalities begin; and 3) the mortality threshold, that is, the salinity level at which oyster mortalities occur from MSX. As discussed previously, only the mortality threshold significantly affects the returns from planting at a given location. Research trials in various sections of the River could be designed to monitor salinities and disease responses in order to more accurately specify the mortality threshold. The results could be used to determine which planting locations are most desirable from a risk-returns standpoint.

The salinity threshold that induces mortality in infected oysters was varied between the values of 15 and 19 ppt. For these simulations the trigger salinity for infection was held constant at 15 ppt and the incubation period for infection was maintained at two months. Table 13 shows that for each threshold salinity evaluated, the mean NPV increased with distance from the river mouth until a maximum was reached because moving further from the river mouth reduced salinity levels and, therefore, the chances of MSX infection. After net returns reached a maximum, further movements upriver reduced returns because the lower salinity caused oysters to grow more slowly and require longer to mature. Slower growth increased interest costs for the seed investment and reduced yield by increasing total background mortality.

As the salinity which triggers MSX mortality was increased from 15 to 19 ppt, the maximum expected NPV increased substantially and was realized closer to the river mouth. With a 15 ppt salinity trigger, the risk-efficient distance was

Table 12. Effects of Varying the Time Required to Harvest MSX-Infected Oysters on Net Present Values of Returns per 1,000 Bushels of Oysters[a]

KM from River Mouth[b]	Months Required to Diagnose MSX and Harvest Oysters 0.5	1.0	2.0
		Mean (Std. Dev.)	
		(dollars)	
0.0	-4379 (2639)	-6508 (2839)	-9425 (3304)
5.0	-4210 (2715)	-6236 (2941)	-8800 (3422)
10.0	-3665 (2931)	-5622 (3193)	-8228 (3550)
15.0	-1953 (3333)	-3735 (3628)	-5644 (4079)
20.0	4310 (3999)	4169 (4045)	4169 (4045)
25.0	11987 (1416)	11987 (1416)	11987 (1416)
30.0	12727 (758)	12727 (758)	12727 (758)
35.0	11921 (955)	11921 (955)	11921 (955)
40.0	9990 (986)	9990 (986)	9990 (986)
45.0	7532 (687)	7532 (687)	7532 (687)
50.0	4873 (995)	4873 (995)	4873 (995)

[a] Returns are stated as NPV's for a 42-year simulation period assuming that 1,000 bushels of seed are planted initially and each time oysters are harvested or lost to disease.

[b] Distances are kilometers from the mouth of the Rappahannock River.

45 km, with an expected NPV of $7,532 and a standard deviation of $687. With a 19 ppt salinity trigger, the risk efficient location was 20 km with an expected NPV of $13,512 and a standard deviation of $513. Thus, if research found that the salinity threshold was 19 ppt, planters could choose a location where expected returns are two to three times higher compared with upriver locations and where variability is essentially unchanged. However, research may find that the salinity

Table 13. Effects of Variations in the Threshold Salinity for MSX Mortality on the Net Present Value of Oyster Enterprise Returns[a]

KM from River Mouth[b]	Threshold Salinity for MSX Mortality (ppt) 15	16	17	18	19	Resistance
	Mean (Std. Dev.)					
	(dollars)					
0.0	-10881 (582)	-10649 (767)	-10315 (1213)	-6508 (2839)	8560 (2902)	13768 (465)
5.0	-10889 (566)	-10655 (777)	-10375 (1202)	-6236 (2941)	10016 (2371)	13752 (471)
10.0	-10853 (623)	-10589 (810)	-10305 (1389)	-5622 (3193)	11496 (1937)	13740 (467)
15.0	-10898 (642)	-10621 (783)	-9798 (1645)	-3735 (3628)	13120 (1069)	13677 (440)
20.0	-10827 (693)	-10587 (1011)	-8387 (2019)	4169 (4045)	13512 (513)	13512 (513)
25.0	-11003 (707)	-9797 (1620)	-4967 (3156)	11987 (1416)	13347 (543)	13347 (543)
30.0	-9977 (1720)	-6694 (2982)	7218 (2930)	12727 (758)	12727 (758)	12727 (758)
35.0	-6925 (2694)	2986 (3710)	11921 (955)	11921 (955)	11921 (955)	11921 (955)
40.0	3524 (3357)	9990 (986)	9990 (986)	9990 (986)	9990 (986)	9990 (986)
45.0	7532 (687)	7532 (687)	7532 (687)	7532 (687)	7532 (687)	7532 (687)
50.0	4873 (995)	4873 (995)	4873 (995)	4873 (995)	4873 (995)	4873 (995)

[a] Net present values refer to an enterprise in which 1,000 bushels of seed are planted initially and each time oysters are harvested.

[b] Distances are kilometers from the mouth of the Rappahannock River.

threshold is as low as 15 ppt. The implications of this possibility for research priority setting are considered below.

Research Area 3: Development of MSX-Resistant Seed

Research toward development of an MSX-resistant oyster has been underway for a number of years. In order to develop MSX-resistant seed, the host that spreads the MSX virus must be identified in order to replicate the disease in the laboratory. Then breeding or immunization strategies to induce resistance can be evaluated (Schmidt, 1984).

The last column in Table 13 reports the returns from planting MSX-resistant seed. This result was simulated by setting the MSX mortality threshold at a higher salinity level than was ever observed in the River. While MSX resistance will permit positive returns to be earned at all locations in the River, the number of locations where MSX resistance increases the mean and reduces the variability of NPV's diminishes with higher threshold mortalities. For example, at 19 ppt the payoff for MSX resistance in terms of increased expected NPV is $256 ($13,768 - $13,512). However, if the threshold salinity is 15 ppt, the payoff to MSX resistance increases to $6,236 ($13,768 - $7,532). The implications of this interdependence between the threshold salinity for mortality and the payoff from MSX resistance are considered below.

Research Area 4: Lower Seed Costs

Research that lowers the per unit cost of oyster seed might be conducted in lieu of spending funds on disease research. Seed production research could include evaluation of alternative technologies for facilitating the setting and harvest of seed from James River and other seed beds (Hargis and Haven, 1988). Using a mechanical or suction dredge to harvest seed rather than the currently employed labor-intensive, hand-tonging method could result in seed costs being lowered by 80% (Shabman and Thunberg, 1988). Mechanical oyster seed harvest already occurs in many other areas, such as in the Potomac River and Maryland. Possibly mechanical harvest could result in damage to seedbeds; however, the extent of this damage and the cost effectiveness of repairing it by shelling grounds after harvest could be evaluated by research.

Another possibility would be development of low-cost hatchery technology (Kennedy and Breisch, 1981). Seed hatchery technology for the Bay area has been under development for a number of years in both Maryland and Virginia. Recent prices for hatchery seed have averaged $3.50 per 1,000 seed (Webster and Meritt, no date) while costs of James River seed have averaged over $5.00 per 1,000 seed. In spite of its lower cost, hatchery seed is not yet a viable economic alternative because of its smaller size and lower survival rate.

The effects of research that lowers seed costs are evaluated by determining the reduction in seed costs required to match the increase in net returns resulting from the availability of an MSX-resistant seed. The model was rerun to determine the seed price reduction needed to make the expected NPV without resistance equal to $13,768, the expected NPV obtained with MSX resistance at the river mouth. As discussed previously, the return to MSX resistance depends on the salinity threshold that causes MSX mortality; therefore, the necessary seed price reduction also varies by mortality threshold. The necessary reductions by threshold are: 15 ppt, $1.12/bu; 16 ppt, $0.66/bu; 17 ppt, $0.33/bu; 18 ppt, $0.18/bu; and 19 ppt, $0.06/bu. These reductions vary from 2 to 37% of the $3.06/bu base price, meaning that relatively small percentage reductions in seed price are likely to match the benefits to planters from an MSX-resistant seed.[19] For example, if the mortality threshold were 15 ppt, then a planter would have to plant at 45 km in order to entirely escape the danger of MSX mortality. Net returns would be lower here compared to the river mouth due to slower growth rates. A $1.12/bu seed price reduction would offset the loss from the slower growth. However, it should be recognized that if the mortality threshold were as low as 15 ppt, planting would be profitable only in areas above 40 km from the mouth. Possibly the number of grounds capable of oyster production in these areas might be limited; this possibility is discussed in a later section.

Section 5.2: Setting Research Priorities

The simulation results eliminated from consideration some potential research priorities, including faster diagnosis of the disease, better knowledge of the salinity that triggers infection, and better knowledge of the time required for infection to incubate in the oyster before mortality. However, the simulation results support further consideration of seed harvest technology, seed hatchery technology, MSX-resistant seed, and the salinity threshold that causes MSX mortality. In order to set priorities among these possibilities, factors which lie outside the simulation model must be considered in ranking research projects.

Following Atkinson and Bobis (1969), where the administrator of research funds is risk neutral, the ranking can be based on the expected present value of the ratio of benefits and costs (B/C). The expected benefits of research depend on the joint probability that: 1) the research will be successful and 2) its results applied. Expected research benefits are calculated by multiplying this joint probability times the increase in the economic returns from the production process being studied if the research is successful and its results are applied. Research costs are the budget expenditures necessary to pursue research until its objectives are achieved or a decision can be made that the objectives are not achievable (Atkinson and Bobis, 1969). Simulation of the production process illustrates the economic benefits of research information if the research is successful in achieving its objectives, is adopted by producers, and is applied in a timely fashion. Clearly, the research administrator's expectations for the present value of benefits will depend not only upon the simulation results, but also upon his subjective estimate of the probability for timely success and adoption of the research. At the same time, the research administrator must also form some subjective estimate of the costs for successful completion of the research. Thus, four additional aspects of a potential research project outside the simulation model presented here affect the B/C. They are the probability of research success, the probability and rate of adoption, the timing of benefits, and annual research expenditures.

Seed Harvest Technology Research

The research objective is development of mechanical seed harvest techniques (in lieu of hand-tong harvest) that lower per unit seed production costs without harming the long-term productivity of the public seed-growing areas, particularly in the James River. Evaluation of alternative mechanical harvest techniques combined with shelling to repair any damage done to the seed-growing bottoms by such techniques could reduce seed costs in two ways. First, mechanical harvest would lower the cost per bushel of seed harvest. Second, replacing clean shell on harvested beds would promote more abundant setting of seed oysters on the beds. As was discussed previously, declining setting rates are thought to be due to fewer or less fertile brood stock or less favorable conditions for larval survival. The proposed strategy is likely to be effective in stimulating setting rates by creating more favorable conditions for attachment and growth of larvae, thus allowing more seed oysters to be produced from existing brood stocks. Because these techniques are used in Maryland, in the Potomac River, and on private seed grounds, the probability of research success for this project is high and the total cost will be low.

The probability of adoption of the new technology is more problematic. Historically there has been resistance by seed harvesters who use traditional hand tong technology to the introduction of mechanical harvesting in the basin. This resistance has been effective in the past, but given the declining number of hand tongers this resistance should erode over time (Santopietro, 1986). On balance, this research area should have the highest B/C ratio due, in particular, to the high simulated benefits, the high probability of immediate success, the prospects for adoption, and the low cost.

Other strategies besides mechanical harvest and reshelling could improve setting rates. These strategies include mechanically cleansing shell while on the bottoms, treating shell to make it more resistant to fouling, and the use of other substrate materials for setting (Hargis and Haven, 1988). However, environmental factors may also need to be considered. While current knowledge is unclear on whether environmental conditions limit seed production potential, future research may show that toxic substances, nutrient enrichment, and/or low dissolved oxygen in water may limit setting rates (Hargis and Haven, 1988). These possibilities warrant continued study.

MSX Threshold Research

The research objective would be to determine the salinity that results in MSX mortality. The research would require an experiment that plants seed oysters at several locations over a period of years, monitors salinity, MSX disease incidence, and mortality and then analyzes the data to isolate the relationships of interest. Recall that the benefits from successful research on this topic are uncertain and depend upon the research results. The results might indicate that the threshold for mortality is low, or they might indicate no relationship between MSX and salinity, thus contradicting current scientific knowledge. In these cases, the realized payoff from this research would be low, although such results would provide justification for continuing the development of MSX-resistant seed. If the threshold is high, the payoff from this research will be high. The expected costs for such research to support the scientific personnel and equipment required for monitoring several locations for an extended time would be high. However, the probability of success would be high since it is a standard experimental design research procedure to better quantify a parameter about which much is already known.

If the salinity relationship is more precisely quantified, adoption of the information for planting decisions will require education of planters about the results of the research. The B/C ratio for this project would likely be lower than for seed harvest technology research due to its higher cost and the uncertainty about the benefits. However, the B/C ratio would likely be higher than for hatchery technology and MSX research (discussed below) because of a high probability for research success.

Seed Hatchery Research

The objective of seed hatchery research is to provide seed at lower cost and with equal or better survival and growth potential than is currently available from natural seed-growing areas. Hatchery technology offers the potential to use breeding techniques to control seed size, shape, disease resistance, and other growth characteristics to produce a qualitatively better seed than is available from public bottoms (Austin, Dupuy, and Haven, 1979). Hatchery feasibility research has been conducted in the Chesapeake Bay area for several years (Greer, 1987), but as yet hatchery seed is not cost competitive with seed produced from public seed grounds even though hatcheries are already used in other areas such as the Pacific Northwest (Kennedy and Breisch, 1981). Thus, the probability of near-term success for hatchery production is unclear. Furthermore, the nature of the research makes hatchery technology studies more expensive than seed harvest research. In particular, hatchery research would involve genetic and environmental techniques to increase larval survival rates (Kennedy and Breisch, 1981), high-cost efforts due to their intensive use of scientific personnel and facilities. As a result, the expected cost of hatchery research is likely to be high. The probability of adoption given research success is likely to be high. Overall, the B/C ratio for hatchery research is likely to be lower than for public seed research primarily due to the high cost of hatchery research and lower probability of research success.

MSX Resistance Research

MSX research has the objective of developing an MSX- resistant seed available in quantity at a cost that would ideally be no higher than for non-resistant seed. However, planters might also be willing to pay a higher price for the MSX-resistant seed if the higher prices were more than offset by economic gains from reduced MSX mortalities. MSX resistance might also increase brood stocks in the James River, thereby increasing setting rates and lowering seed costs. The benefits of MSX resistance research depend upon the salinity threshold that induces mortality. If the mortality threshold is high, the benefits from MSX resistance will be low. The probability of immediate research success for this project is low. Researchers must isolate an intermediate host, induce the infection under laboratory conditions, and breed for resistance. MSX research has been conducted almost since the disease was first diagnosed in Virginia waters in 1959, and researchers still cannot replicate the disease in the laboratory. Therefore, expected costs of this research are high. Although the probability of successful development is low, if developed, the probability of adoption of MSX-resistant seed is high.

The B/C ratio for MSX resistance research is probably the lowest of the four project areas, primarily due to the low probability of success. However, the B/C ratio would be increased if the salinity threshold for MSX mortality were low and only limited grounds were available in areas where this threshold is not exceeded. For example, the lower limit on the salinity threshold for MSX mortality suggested by Andrews (1979) is 15 ppt. Table 13 shows that at a mortality threshold of 15 ppt, production would be unprofitable at locations below 40 km. If the mortality threshold were this low, would the limited availability of grounds above 40 km prevent oyster production in the river from rising even with lower seed prices? Unfortunately, there are no data on the extent of private grounds above 40 km capable of producing oysters. However, we can consider the situation on public grounds above 40 km. Haven, Whitcomb, and Kendall (1981) indicate that above 40 km in the Rappahannock River there are 715 acres of public grounds that are currently or potentially capable of producing oysters. This figure is only 8% of the total potentially productive public grounds in the Rappahannock River. The results from the simulation model were evaluated to determine what amount could be produced from 715 acres at the 40-50 km locations. If a 15-ppt mortality threshold is assumed, the average harvest:seed ratio for these locations is 0.84. For the salinities evaluated, a 1.5-inch seed oyster reaches market size in an average of less than three years at this location. If a one-year fallow period following harvest is included to provide for dermo control (Andrews and Burreson, 1987), then four years are required per crop and one fourth of the 715 acres could be harvested per year. Assuming 900 bushels of seed are planted per acre[20] and a 0.84 harvest:seed ratio, average production per year from these public grounds would be 135,135 Virginia bu. This production is equal to 60% of the 224,000 bushel average production from all grounds on the Rappahannock River from 1976-1985. Only 470 acres of private grounds production above 40 km would need to be included to produce the 1976-1985 average production in the whole river. This analysis is not meant to imply that public grounds should be turned over to private planters. The analysis does suggest that for public grounds in the Rappahannock River, intensive planting of a small number of upriver acres could very nearly maintain current production levels even in the face of MSX risk. This planting could be carried out by the state through its repletion program.[21]

The evaluation of research strategies indicates that research strategies targeted at lowering seed harvest costs, increasing setting rates on public seed beds, and defining more precisely the relationship between salinity and MSX disease mortality are likely to have high benefits. However, if this research is successful, other policies will also be necessary to insure that the research benefits are fully realized.

Section 5.3: Other Strategies to Encourage Private Oyster Planting

Public Seed Bed Management

As described previously, research on seed harvest techniques on public seed beds is likely to have a high payoff. If research indicates that such harvest techniques are economical, portions of the public beds where they are likely to be effective should be identified. Existing regulations prohibiting the use of such techniques in these areas should be removed. Actual implementation of the practices could be handled in any one of several ways. One alternative would be for the VMRC to carry out the mechanized harvest and sell the seed to private planters. A second alternative would be to lease the grounds to individuals who would harvest and sell the seed to planters.[22] For example, the state currently has established several hundred acres of seedbeds in the Piankatank and Great Wicomico Rivers to be dredged to provide seed for its repletion program (Barth, 1990). These beds could also be opened to provide seed for sale to private planters.

As was noted earlier, there is likely to be opposition to mechanized harvest from public watermen who currently harvest seed from these beds using hand tongs. Many of these watermen also harvest market oysters from the public grounds and, hence, benefit from the state's oyster repletion activities on public grounds (Shabman and Thunberg, 1988). The state is currently using mechanized harvest to provide seed for public grounds repletion. Thus, research and policies to further encourage mechanized seed harvest will make repletion programs more effective and, also provide benefits for public watermen. Education of watermen is needed to explain the potential benefits of more efficient seed production.

Transplanting Oysters

Results discussed previously indicated that transplanting MSX-infected oysters to upriver locations might be economical in areas susceptible to MSX mortality if seed counts per bushel were increased. However, upriver locations would have to be held in reserve for transplanting. Although most private grounds are now barren, they are under lease. Efforts to require use of oyster leases by leaseholders are being made by the state. As discussed earlier, proof of "reasonable" use will be required in order for a current leaseholder to have the lease renewed after 1990 (Code of Virginia, 28.1-109). How this law will be initiated by the state or implemented is yet to be determined. If transplanting were to become a viable option, would holding upriver grounds in reserve in order to have a location to use for transplanting constitute a reasonable use? This issue will require further investigation.

Access to Grounds

The results from the bioeconomic model showed that some planting locations are more profitable than others. If seed prices can be lowered and better information provided on areas susceptible to MSX mortality, competition for the most desirable locations could increase. The question then arises as to how access to grounds that are available for lease should be allocated. One method would be through competitive bidding. The most capable planters will realize the highest return from planting a given location and, therefore, would be able to bid the highest for the right to use it. Competitive bidding would encourage allocation of the most productive grounds to those who can make the best use of them.

Leaseholder Education

Results from the mail survey showed that the level of understanding among many leaseholders about private planting is limited. Many leaseholders do not currently plant their grounds. Many leaseholders had never sought or received advice from the Virginia Marine Advisory Service, despite its long record of offering such advice. Yet those planters who had contacted the Service for information on oyster production were more knowledgeable about oyster production than those who had not. Thus, efforts to increase returns to private planting through research must be complemented with education of planters and potential planters to make them aware of new opportunities as well as problems involved in oyster production.

Section 6.0: Summary and Conclusions

Virginia oyster production is declining primarily because of reduction in private harvests. The state has a goal of increasing private oyster production. If private production is to be increased, policies must be instituted to deal with the constraints facing private production. As a result, the state requires a better understanding of the factors that have contributed to the decline of private planting.

The oyster disease MSX has received much of the blame for reduced profitability of private planting. However, economic factors, particularly the rising real cost of oyster seed relative to market prices, are also an important reason for declining profits. The objectives of this study were to evaluate economic and biological factors affecting private planting in order to identify the reasons for reduced private harvests. The results of the analysis were used as a basis for making policy recommendations for restoring private production. The analysis of private planting was carried out using personal interviews with private planters and oyster biologists, and mail interviews with leaseholders, and by developing a bioeconomic simulation model for analyzing private oyster production.

Respondents to the mail survey viewed disease, pollution, and the cost and availability of seed as factors limiting the profitability of planting. MSX is viewed by both planters and nonplanters as being the most important barrier to profitability from commercial planting. Most respondents also felt that the risk of loss from MSX was related to the salinity of planted grounds. These responses may suggest recognition that choice of planting location is important to determining losses that will be suffered from MSX. However, most respondents did not recognize that faster growth could be achieved in areas of higher salinity, thus implying that they did not recognize the possible tradeoffs between risks and returns in choosing higher salinity locations for planting. The analysis with the bioeconomic model makes clear that by its effects on salinity levels the choice of planting location affects risks and returns from oyster production. Research is needed to better specify the salinity threshold at which mortality from MSX occurs. The research results could then be used to advise planters as to the locations where returns from planting are most favorable.

Respondents to the mail survey were also concerned with the effects of Dermo disease on profitability. Most respondents did not feel that proper management of grounds would control losses to Dermo, as oyster biologists suggest (Andrews and Burreson, 1987). This finding suggests that additional education of planters may be needed to demonstrate management techniques that can be used for controlling Dermo.

Respondents also viewed increasing seed prices and potential lack of availability of seed as constraints to profitability. These concerns were generally not as strong as were concerns with disease. However, analysis conducted with the bioeconomic model suggests that increasing real seed prices are a greater constraint to planting profitability than is disease. The analysis showed that increasing real seed costs over the past 30 years led to greatly reduced profitability and increasing relative riskiness of private planting. These results were obtained with MSX risk held constant. This finding suggests the need for research to increase the efficiency and lower the costs of seed production. Seed cost reduction is most likely to be accomplished by increasing the productivity of the public seed beds and reducing the cost of public seed harvest through increased mechanization. Research on hatchery production of seed is likely to be less effective in reducing seed prices. If research indicates that mechanized harvest is an effective strategy, then steps will have to be taken to encourage such practices on those portions of the seed beds where they are likely to be effective. Also, the research must be followed with education of planters and potential planters as to the increased opportunities in private planting due to lower seed prices.

Most leaseholders responding to the mail survey did not agree that planting would increase if public grounds were made available for private lease. This finding suggests that most leaseholders do not view the availability of grounds as a significant constraint to planting oysters. Because the salinity threshold at which mortality to MSX occurs is uncertain, it was not possible to evaluate this response with the model. If the salinity threshold at which MSX mortality occurs is very low, it may be that only limited grounds are available where salinities remain below the threshold. In that case, development of MSX- resistant oysters would have a high potential payoff in that it would eliminate a grounds constraint. However, if the threshold salinity is higher, then availability of grounds is less likely to be a constraint to profitable planting. In that case, research that lowers the price of seed and research showing which grounds are most profitable for planting would be more important.

Research results indicated that grounds differed in potential productivity depending on location. The most profitable locations were those where salinity levels tended to remain below the mortality threshold for MSX but were high enough to promote rapid growth of oysters. If the profitability of private planting can be raised by reducing seed prices and if research and extension efforts are successful in showing planters the most productive locations for planting oysters, then competition for the best locations will increase. Allocating leases to grounds via competitive bids would be an effective way of encouraging the best use of these grounds. Because the most productive planters would be able to bid the highest for such grounds, they would be most likely to obtain access.

Returns from the mail interviews showed that most leaseholders who responded do not currently plant their leases. Results from the simulation study suggest that the profitability of planting oysters must be increased if more leaseholders are to be induced to plant oysters. Profitability is likely to be increased by research on ways to make oyster planting more productive and through extension of the research findings to both planters and potential planters.

Footnotes

[1]Unless otherwise stated, percentages are calculated as a percent of the number of respondents (regular leaseholders) who answered the question.

[2]There are some exceptions, such as if the Virginia Marine Resources Commission finds that there was good cause for failure to produce or plant oysters at a location.

[3]Although the responses in the "other" category varied considerably, most of the responses implied that these respondents did not intend to plant seed on their leases in the future.

[4]The Virginia Marine Resources Commission has not advocated that any Baylor grounds be turned over to private use because of concern that public opposition would outweigh potential benefits (Barth, 1990).

[5]An alternative to simulation would have been the use of econometric techniques (March, 1986; Strand and Lipton, 1986). However, the econometric approach was handicapped by the limited availability of data. The simulation approach was chosen because it allowed biological relationships developed in other studies to be integrated into a model that could be used to study the importance of disease and economic factors to profitability of oyster planting.

[6]Planters noted that costs, particularly for hand tong harvest, increase when oysters are less dense on the bottoms. However, with lower density, planters are more likely to use a mechanical dredge for harvest, which lowers costs compared with hand tong harvest. In this analysis, per-bushel harvest cost is assumed to be unaffected by the harvest density.

[7]Most private grounds in the river are currently barren. Consequently, the planter whose expectations as to salinity level at a given location change is more likely to vary locations than to vary the amount of seed planted at a given location. Thus, the number of bushels of seed planted was assumed to be constant at all locations evaluated.

[8]It is recognized that after-tax returns may be more relevant to the planter's objectives, but the analysis was conducted on a before-tax basis because of the unavailability of data on planters' marginal income tax rates.

[9]The advantage of waiting is that the monthly price may be higher. Monthly prices equal the seasonal average price plus or minus a monthly adjustment obtained by taking the average deviation of each monthly price from the seasonal average price for the years 1981-1987. MSX disease loss and monthly weight gains from delaying harvest were not considered in this decision rule because these values are unknown at the time the harvest decision rule is made. The development of optimal harvest rules under uncertainty was beyond the scope of this study.

[10]The entire cycle may last longer than 42 years; for example, if a crop is planted in year 41 and requires three years to mature, the cycle would be 44 years long. The added returns from a one or two-year increase in the production cycle would be quite small because they are discounted over 42 years.

[11]Because month varies from 1 to 12, when j equals 1 (January), j - 1 equals 12 (December).

[12]Counts from these samples are indicative of the productivity of the seed bed but are not directly comparable to planter estimates of seed count. Blank shells and debris are not culled from samples but are, at least partially, culled from seed sold to planters (Haven, 1988).

[13]This comparison does not consider that average seed size was also larger in the 1980s, as indicated in Table 8, meaning that time required from planting to harvest was also reduced. However, the analysis of trends in seed costs reported in the next section does take changes in seed size into account.

[14]The possibility of transplanting diseased oysters to an area of lower salinity was not considered in initial model runs because it is not currently practiced by planters. This consideration was examined and is reported later in this section.

[15]The effects of the threshold salinity on trends in risks and returns were evaluated by varying the threshold salinity from 18 to 15 ppt. The lower threshold caused expected returns to fall at most locations. However, lowering the mortality threshold did not affect the general conclusions about trends in risks and returns to private oyster culture.

[16]These ratios were developed with the growth model described earlier and take into consideration the larger seed size in the 1980s compared with the 1960s.

[17]The model is run using parameters for the 1980s from Table 8.

[18]Better methods of diagnosis might also be developed to determine if seed are infected by MSX. However, MSX infection is transmitted by an undetermined host, and infection and mortality are primarily determined by salinity at the grounds rather than presence of infection within the seed.

[19]The possibility that increasing or decreasing the interest rate might significantly increase the advantage of MSX-resistant seed was evaluated. However, the required reductions in seed price needed to match the benefits from MSX resistance were insensitive to variations in the interest rate.

[20]Seeding rates for James River seed typically vary from 500 to 1,000 bushels per acre (Haven and Whitcomb, 1986). Interviews with Rappahannock River planters indicated that a 900-bushel per acre rate would be appropriate for a 600-seed per bushel count.

[21]The repletion program is run by the VMRC and is intended to restore public oyster beds by planting oyster seed and shell.

[22]In this case it would be important that the leases be long enough in duration so that the leaseholder would have the incentive to maintain the productivity of the seed bed.

Appendix A: Mail Survey of Leaseholders

This appendix contains the cover letter sent with each survey, the reminder letter sent to encourage additional responses, and a copy of the survey with the summarized responses from the 248 regular leaseholders. Individual responses to question 12 of the survey are also shown.

January 3, 1989

Dear

The dramatic decline of the Virginia oyster industry has been widely publicized in the media. The fact that the biggest loser in this decline has been the private oyster planter is not as commonly recognized. Indeed, many leaseholders no longer plant their leases.

The enclosed survey, which is being administered by researchers at Virginia Tech, offers you, the private leaseholder, the opportunity to express your views and concerns on the future of the oyster industry in the Commonwealth. Even if you are not an active planter, we are asking you to respond. In this way our results will be a more valid representation of all leaseholders. Please return the survey in the prepaid envelope after you have filled it out. If you no longer own a lease, please check the box on the front of the survey indicating this and return the unanswered survey in the pre-paid envelope.

Each survey is numbered for our record keeping purposes only. Individual responses will **not** be made available to anyone. To preserve confidentiality, **only** summaries of the responses will be provided to state and federal management agencies. If you wish to receive a summary of the final survey results, please check the box on the front of the survey form. We thank you for taking a few minutes to fill out the survey in order to express your views on this important subject.

Sincerely,

Darrell Bosch
Assistant Professor

Leonard Shabman
Professor

January 31, 1989

Dear

About three weeks ago, we sent you a survey on the future of Virginia's oyster industry. As of today, we have not yet received your completed questionnaire. We are writing to you again because your response is important to us as we evaluate future problems and opportunities faced by private oyster grounds leaseholders. Although the decline of oyster industry has been well recognized, less attention has been given to the problems faced by private leaseholders. Your response to the survey can make a difference.

Even if you are not an active planter, we are asking you to respond so that our results will be more representative of all leaseholders. If you no longer own a lease, please check the box on the front of the survey indicating this and return the unanswered survey in the pre-paid envelope.

We assure complete confidentiality. The survey is numbered for our record keeping purposes only. Individual responses will not be made available to anyone. Only summaries of the responses will be provided to state and federal management agencies. If you wish to receive a summary of the final survey results, please check the box on the front of the survey form.

If your survey has been misplaced, a replacement copy is enclosed. If you have already completed the survey and returned it, please accept our thanks. If not, we would appreciate your returning it to us today. Again, thank you for your time and assistance. If you have questions about the study or the questionnaire, please feel free to call Darrell Bosch at (703) 231-5447.

Sincerely,

Darrell Bosch
Assistant Professor

Leonard Shabman
Professor

The Future of Virginia's Oyster Industry
A Survey of Private Oyster Grounds Leaseholders

Summary of responses from 248 surveys returned by regular leaseholders. Entries reported are the percent of the respondents who answered the question. Percentages may not sum to 100 because of rounding.

☐ I would like a summary of the survey results sent to me.

☐ The survey does not apply to me because I no longer own a lease.

Department of Agricultural Economics
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

FIRST WE WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT YOUR OYSTERING AND OTHER FISHING ACTIVITIES.

1. Have you ever worked for another oyster planter (planting, tonging, etc.)?

   35 Yes 65 No

2. Have you ever harvested oysters from public grounds?

   48 Yes 52 No

3. Have you ever planted oyster seed or shell on your or someone else's grounds?

   69 Yes 31 No

4. Have you ever harvested crabs for sale?

   43 Yes 57 No

5. Have you ever harvested finfish for sale?

   32 Yes 68 No

NOW WE WANT TO ASK YOU SOME QUESTIONS ABOUT OYSTER PRODUCTION AND PROBLEMS FACING OYSTER PLANTERS.

6. Many people think the oyster industry faces an uncertain future. We would like your opinions about the situation that the oyster industry faces in the next five years or so. Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree 4 (%)	3 (%)	2 (%)	Strongly Disagree 1 (%)	Don't Know 0 (%)
The price of oyster seed is making planting unprofitable.	24	13	14	18	31
Low market prices for oysters are making planting unprofitable.	4	5	17	54	21
Lack of seed limits private planting.	28	15	18	10	30
A shortage of harvest labor limits planting.	7	9	19	39	26
Oyster planting is limited because it is difficult to borrow the capital required.	17	8	14	25	36
Competition from other oyster-producing regions is making planting unprofitable.	8	10	16	40	27
Planting is limited because it is hard to find a place to sell the harvested oysters.	4	1	5	73	17
Planting is limited because of problems with people stealing oysters from planted grounds.	21	14	17	28	22
Private oyster planting would increase if some designated part of the public grounds were leased to private planters.	13	8	10	39	31

7. Oyster diseases and growth rates play an important role in determining the planter's profits. Please indicate whether you agree or disagree with the following statements. You may also indicate you don't know.

	Yes	No	Don't Know
	2 (%)	1 (%)	0 (%)
MSX disease is more likely to occur if the salinity of the water is higher.	67	3	30
Dermo disease can be avoided by proper management of oyster grounds.	9	36	56
MSX disease is more of a problem during drought years.	75	2	24
If the water salinity increases, oysters will grow faster.	22	25	53

NOW WE WOULD LIKE TO ASK YOU SOME QUESTIONS ABOUT THE GROUNDS THAT YOU LEASE

8. How would you evaluate the production potential **of your leased grounds** over the next five years or so? Please indicate how strongly you agree or disagree with the following statements.

	Strongly Agree 4 (%)	3 (%)	2 (%)	Strongly Disagree 1 (%)	Don't Know 0 (%)
Losses to rays make planting risky on my grounds.	20	9	20	24	28
Losses caused by MSX make planting risky on my grounds.	56	13	9	5	18
Losses caused by Dermo make planting risky on my grounds.	43	16	8	3	30
Losses caused by water pollution make planting risky on my grounds.	29	12	15	23	21
Shelling costs are too high for profitable oyster production on my grounds.	17	12	22	24	25
The water is too deep at my grounds for profitable oyster production.	2	0	6	82	10
The water is too shallow at my grounds for profitable oyster production.	7	4	14	65	11
Oysters don't grow fast enough for profitable production on my grounds.	8	7	16	52	18

9. Virginia law requires a leaseholder to demonstrate some level of production in order to be able to renew an oyster grounds lease. Specifically the code (Section 28.1-109) states:

"Upon expiration of the initial or any subsequent term of the assignment, the Commission shall, on application of the holder, renew the assignment for an additional term of ten years. The Commission shall not renew or extend an assignment where there has been neither significant production of shellfish nor reasonable plantings of shellfish or cultch during any portion of the ten-year period immediately prior to the application for renewal, unless the Commission finds that there was good cause for the failure to produce or plant shellfish or cultch or finds that the assignment is directly related to and beneficial to the production of oyster-planting grounds immediately adjacent to the assignment."

How will this law affect your decisions on the grounds you lease? Check the item that best describes your situation.

_47_ The law does not affect me because I will produce oysters on my grounds as long as production is feasible even if the law did not require it.

_11_ Because of the law, I will produce oysters on my grounds in order to renew my lease.

_4_ I will sell the lease to my grounds.

_7_ I will rent my grounds to another planter.

_1_ I will forfeit my lease back to the state.

_17_ Don't know.

_13_ Other (please explain)____________________________________

10. Answer this question **only** if you are currently planting oysters on your grounds. The following list shows some possible reasons why oyster planting may be less profitable at your grounds in the future. How would you rank these reasons in terms of their importance? (Put the number of the item on the appropriate line.)

Most* Important	2nd Most Important	3rd Most Important	
62	13	4	Losses caused by MSX
8	22	16	Losses caused by water pollution
4	14	11	Destruction of the grounds by rays
0	1	2	Lack of harvest labor
10	6	18	Lack of seed
0	1	0	Low market prices
4	6	20	High priced seed
11	33	21	Losses caused by dermo
0	4	9	Lack of borrowed capital
0	0	0	Lack of a place to sell the oysters

*Number in each column indicates the % of those answering the question who gave the indicated reason as the first, second, or third most important reason for reduced future profits.

11. Answer this question only if you are **not** currently planting oysters on your grounds. The following list shows some possible reasons why you chose not to plant oysters on your grounds. How would you rank these reasons in terms of their importance? (Put the number of the item on the appropriate line.)

Most Important	2nd Most Important	3rd Most Important	
56	16	6	Losses caused by MSX
17	16	16	Losses caused by water pollution
3	6	16	Destruction of the grounds by rays
1	2	3	Lack of harvest labor
4	6	7	Lack of seed
0	1	2	Low market prices
3	7	10	High priced seed
3	31	16	Losses caused by dermo
1	2	8	Lack of borrowed capital
1	0	0	Lack of a place to sell the oysters
6	7	4	I don't have time to plant oysters
7	6	10	I don't know enough about oyster planting

12. Please list in the following space any ideas you have as to what needs to be done to make oyster planting more profitable.

FINALLY WE WANT TO ASK SOME QUESTIONS ABOUT YOU.

13. Have you ever sought or received advice on oyster planting from the Marine Advisory Service at VIMS? (Entries indicate percentage responses)

22	Yes	78	No

14. What is your age?

-	19 - 24 years	12	35 - 44 years	26	55 - 64 years
2	25 - 34 years	22	45 - 54 years	38	65 years or older

15. What is the highest level of education you have completed?

11	8th grade	24	Some college
10	Some high school	30	Completed college
25	Graduated from high school		

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Virginia's Agricultural Experiment Stations

1—Blacksburg
Virginia Tech, Main Station
Dairy, Poultry, and all other topics

2—Steeles Tavern
Shenandoah Valley Agricultural Experiment Station
Beef, Forages, Fruit, Insect and Pest Control, Sheep

3—Orange
Northern Piedmont Agricultural Experiment Station
Alfalfa, Corn, Crops, Small Grains

4—Winchester
Winchester Agricultural Experiment Station
Fruit, Insect and Pest Control

5—Middleburg
Middleburg Agricultural Experiment Station
Beef, Forages

6—Warsaw
Eastern Virginia Agricultural Experiment Station
Field Crops, Insect and Pest Control

7—Holland Station, Suffolk
Tidewater Agricultural Experiment Station
Corn, Peanuts, Pest Control, Small Grains, Soybeans, Swine

8—Blackstone
Southern Piedmont Agricultural Experiment Station
Forages, Horticulture Crops, Small Grains, Tobacco, Turfgrass

9—Critz
Reynolds Homestead Agricultural Experiment Station
Aquaculture, Forestry, Wildlife

10—Glade Spring
Southwest Virginia Agricultural
Experiment Station
Beef, Burley Tobacco, Sheep

11—Hampton
Virginia Seafood Agricultural Experiment Station
Seafood

12—Virginia Beach
Hampton Roads Agricultural Experiment Station
Ornamentals, Vegetables, Insect and Pest Control

13—Painter
Eastern Shore Agricultural Experiment Station
Fruit, Field Crops, Herbs, Insect and Pest Control, Vegetables