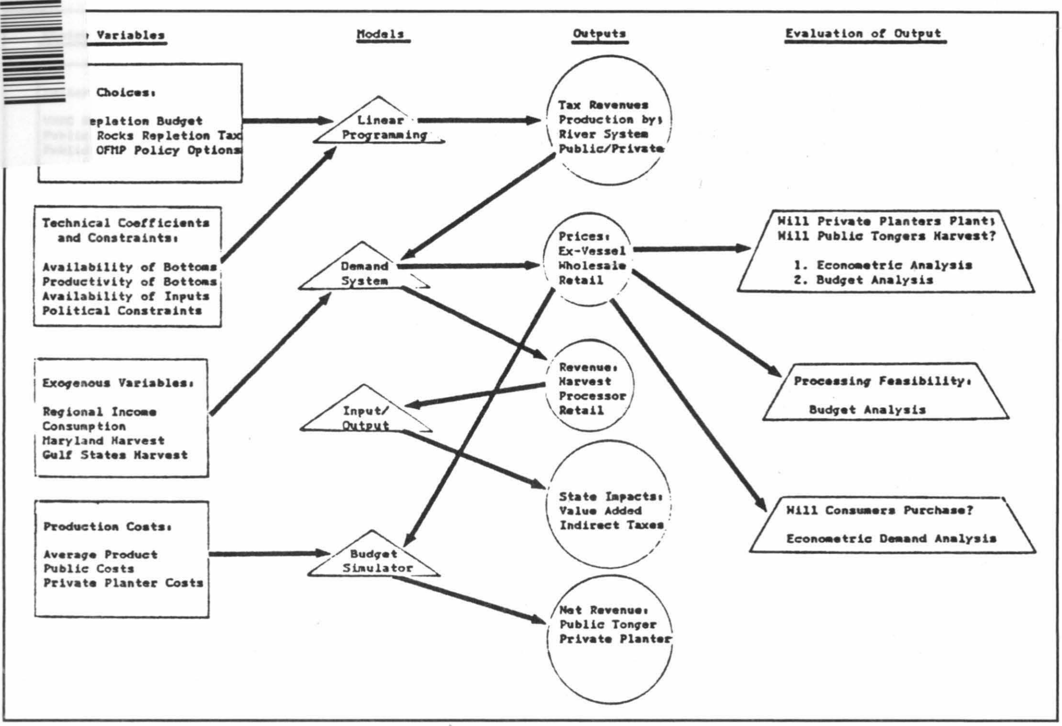
...ultural Experiment Station
...chnic Institute and State University

Bulletin 88-4
VSG-88-03

An Evaluation of Alternative Strategies for Virginia Oyster Grounds Management: Economic Considerations in Policy Design

Leonard Shabman and Eric Thunberg



James R. Nichols, Dean and Director
College of Agriculture and Life Sciences
Virginia Agricultural Experiment Station
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0402

The Virginia Agricultural and Mechanical College came into being in 1872 upon acceptance by the Commonwealth of the provisions of the Morrill Act of 1862 "to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life." Research and investigations were first authorized at Virginia's land-grant college when the Virginia Agricultural Experiment Station was established by the Virginia General Assembly in 1886.

The Virginia Agricultural Experiment Station received its first allotment upon passage of the Hatch Act by the United States Congress in 1887. Other related Acts followed, and all were consolidated in 1955 under the Amended Hatch Act which states "It shall be the object and duty of the State agricultural experiment stations . . . to conduct original and other researches, investigations and experiments bearing directly on and contributing to the establishment and maintenance of a permanent and effective agricultural industry of the United States, including the researches basic to the problems of agriculture and its broadest aspects and such investigations as have for their purpose the development and improvement of the rural home and rural life and the maximum contributions by agriculture to the welfare of the consumer . . . "

In 1962, Congress passed the McIntire-Stennis Cooperative Forestry Research Act to encourage and assist the states in carrying on a program of forestry research, including reforestation, land management, watershed management, rangeland management, wildlife habitat improvement, outdoor recreation, harvesting and marketing of forest products, and "such other studies as may be necessary to obtain the fullest and most effective use of forest resources."

In 1966, the Virginia General Assembly "established within the Virginia Polytechnic Institute a division to be known as the Research Division . . . which shall encompass the now existing Virginia Agricultural Experiment Station . . . "

AN EVALUATION OF ALTERNATIVE STRATEGIES FOR VIRGINIA OYSTER GROUNDS MANAGEMENT: ECONOMIC CONSIDERATIONS IN POLICY DESIGN

Leonard Shabman
Eric Thunberg

Department of Agricultural Economics

A Virginia Sea Grant Publication
Publication No. VSG-88-03

Bulletin 88-4
Virginia Agricultural Experiment Station
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

August 1988

This work is a result of research sponsored in part by the National Sea Grant College program of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce under Grant No. NA86AA-D-SG042 to the Virginia Marine Science Consortium and the Virginia Sea Grant College Program. The U.S. Government is aurhorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

Table of Contents

Page

Preface ix

List of Tables v

List of Figures vii

Section

Introduction 1

Section 1: Review of Oyster Grounds Law and Policy 2
- Trends in Virginia Oyster Production 2
- Virginia's Oyster Grounds Management Approach 3

Section 2: The Oyster Industry Today: Policy Alternatives 4
- The OFMP Planning Process 4
- OFMP Goals and Objectives 4

Section 3: Management Alternatives 6
- Regulatory Measures 6
- Public Grounds Repletion Measures 7

Section 4: Overview of Oyster Fishery Economic Models 7
- The Linear Programming Model 8
- The Econometric Demand System 8
- The Budget Simulator 9
- The Input/Output Model 9

Section 5: An Analytical Framework for Policy Evaluation 10
- Policy Variables 10
- Framework Structure 11
- The Policy Evaluation Procedure 11

Section 6: Policy Simulations: Results 13
- Conditions Without a Management Plan 14
- The Baseline Condition 17
- A Seed Transplant Policy 17
- A Seed Transplant and Seed Dredge Policy 19
  - Seed Dredging All Areas 19
  - Dredge or Tong Seed 22
  - Seed Dredging in Restricted Areas Only 22
- Market Oyster Dredging Policy 25
  - Market Oyster Dredging-Only 25
  - Dredging Market Oysters in Restricted Areas 25
  - Combinations of All Strategies 27

Section 7: Discussion of Results and Recommendations 32
- Competitive Production Cost 34
- Repletion Budget 34
- Income and Access to Baylor Grounds 35
- Shell Requirements 37

Recommendations and Discussion 37

Appendix A. The Linear Programming Model 43

Part 1: Technical Structure 45
Introduction 46
The Linear Programming Model 46
The Objective Function 47
Model Activities 47
Primary Activities 48
Secondary Activities 52
Tax Collection and Repletion Fund Transfer 54
Constraints 55
The Computer Model 55

Part 2: Estimation of Technical Coefficients 65
Introduction 66
Objective Function Coefficients 66
Public Grounds Repletion Costs 66
Private Grounds Production Costs 67
Oyster Harvesting Costs 69
Estimation of Constraint Coefficients 71
Estimation of Matrix Elements 72

Appendix B. Demand for Chesapeake Bay Oysters 77
General Background 78
Chesapeake Bay Oyster Demand 79

Appendix C. The Budget Simulator 85
Budget Format 86

Appendix D. Contribution of the Oyster Industry to the Virginia Economy and Tax Base 93
Introduction 94
Measuring the Regional Economic Impact of the Oyster Industry 94
Virginia's Commercial Oyster Industry 96
The Multiplier Effects of Virginia's Oyster Industry 96
Estimated Impacts of the Oyster Industry 97
Future Research Needs 98
Indirect Tax Revenue from the Oyster Industry 98

References 103

List of Tables

Table		Page
Table 1:	Summary of Policies Included in Policy Scenarios	15
Table 2:	Pre-OFMP Conditions	16
Table 3:	Scenario 2: The Baseline Condition An Increased Repletion Budget With No Change in Repletion Strategy	18
Table 4:	Scenario 3: A Seed Transplant Policy	20
Table 5:	Scenario 4: Seed Transplant and Seed Dredge All Seed Beds	21
Table 6:	Scenario 5: Seed Transplant and Seed Dredge or Tong	23
Table 7:	Scenario 6: Seed Transplant and Dredge Seed Except in the James River	24
Table 8:	Scenario 7: Seed Transplant and Dredge All Market Oysters	26
Table 9:	Scenario 8: Seed Transplant and Harvest Market Market Oysters by Dredge or Tong	28
Table 10:	Scenario 9: Seed Transplant, Tong or Dredge Market Oysters and Dredge All Seed	29
Table 11:	Scenario 10: Seed Transplant, Dredge or Tong Market Oysters and Dredge or Tong Seed	30
Table 12:	Scenario 11: Seed Transplant, Dredge or Tong Market Oysters and Dredge Seed Except in the James	31
Table 13:	Comparison of Policy Scenarios to the Baseline Condition	33
Table 14:	Shell Requirements and Labor Requirements	36
Table 15:	Summary of Annual Activity Levels: Baseline Compared to Scenario 11	38
Table A.1:	Description of Model River Systems	48
Table A.2:	Feasible Shell-Harvest River Systems	51
Table A.3:	Public and Private Growing Areas	52
Table A.4:	Summary of Primary Activities	53
Table A.5:	Public Grounds Seed Areas	55
Table A.6:	MSX Compatibility by Seed Origin and Receiving System	57
Table A.7:	River System Compatibility by MSX Type	58
Table A.8:	Tableau Key	62

Table A.9: Annual Harvest Cost Budget 70

Table B.1: Demand Estimation: Chesapeake Bay Oyster Industry 83

Table B.2: Analytically Derived Reduced Form Equations for Chesapeake Bay Oyster Demand 84

Table C.1: Budget Spreadsheet Format for a Representative Private Grounds Planter 87

Table C.2: Per Acre Returns to Fixed Costs and Management for a Representative Private Planter 88

Table C.3: Budget Spreadsheet Format for a Representative Public Grounds Hand Tonger 89

Table C.4: Annual Returns to Fixed Costs and Management for a Representative Public Grounds Hand Tonger 90

Table C.5: Spreadsheet Format for a Public Grounds Tonger 91

Table C.6: Annual Returns to Fixed Costs and Operator Labor for a Representative Public Grounds Dredge Harvester 92

Table D.1: Multipliers for the Virginia Seafood Industry from the Virginia Input-Output Model 99

Table D.2: Example of Calculation of Output and Value-Added Effects 100

Table D.3: Economic Impact of the Oyster Industry 101

Table D.4: Virginia State Tax Revenues as a Percent of Gross State Product 102

List of Figures

Figure		Page
Figure 1:	Policy Evaluation Flow Diagram	12
Figure A.1:	Model River Systems	49
Figure A.2:	Diagram of Model Activities	50
Figure A.3:	Cultural Technique Feasibility	56
Figure A.4:	Model Tableau	59
Figure A.5:	Fund Transfer Submatrix	61
Figure D.1:	Product Flows in the Virginia Seafood Industry	97

Preface

The Commonwealth of Virginia's concern over the economic state of its oyster industry has resulted in an active program to define new management goals and strategies. Economic analysis of alternative strategies has been conducted at Virginia Tech over the past few years. This report, a synthesis of that research work, was written to provide assistance to the Virginia Marine Resources Commission in its continuing effort to develop an oyster fishery management plan. The analysis included in this report draws heavily on a Masters thesis project completed by Eric Thunberg. That work received financial support from the Virginia Sea Grant College Program, through the Virginia Graduate Marine Sciences Consortium. A second work product included in Appendix B of this report was completed by Oral Capps and Leonard Shabman as a part of that same Sea Grant-supported effort.

The integration of these models, the improvement of their data base and the addition of auxiliary models was completed with the support of funds from the NOAA 309 program administered through the Virginia Council on the Environment. The development of this report would not have been possible without that support.

The development of this report has benefited from extensive discussions with the VMRC staff. Their insights on both the technical data in the linear programming model and the general issues facing the Commonwealth as it develops the oyster management plan have been invaluable.

The authors acknowledge the contribution made to this report by reviewers, Dr. Darrell Bosch, Dr. Charles Coale, Dr. George Santopietro and Eric Barth. Their comments and suggestions proved invaluable for its completion.

An Evaluation of Alternative Strategies for Virginia Oyster Grounds Management: Economic Considerations in Policy Design

Leonard Shabman and Eric Thunberg

Introduction

Throughout its history the oyster fishery has played an important role in Virginia's coastal economy. Accounting for fifteen to twenty percent of the total value of all commercial species landed in Virginia, the oyster fishery is a source of income and employment for thousands of Tidewater residents (JLARC, 1977). It is because of its importance to the Tidewater region that the oyster industry has been a subject of law and public policy since colonial times. (Santopietro, 1986).

Once the single largest producer of oysters in the United States, the Virginia oyster industry has been in a steady decline since the early 1960s. Public and private concern over the industry's decline prompted the State's legislature to review the condition of the oyster fishery and the State's role in its management. In response to the findings the 1984 legislature directed the Virginia Marine Resources Commission (VMRC) to develop and implement an oyster fishery management plan (OFMP). The State set the plan's goal to maximize the biological, economic, and social benefits from the harvest and utilization of market oysters. To achieve this end, the VMRC can employ management alternatives that include harvest season, harvest gear, and entry regulations in combination with alternative public investment strategies (shelling and oyster seed transplanting) to enhance harvestable populations. Any alternative strategy would have a different impact on the cost of producing and harvesting oysters in the State and upon the VMRC budget. The task before the VMRC is to select a mix of policies that (1) satisfies the production goals of the OFMP, (2) remains within the VMRC budget, and (3) is acceptable to the State's harvesters and processors. Balancing these three objectives is the management challenge.

Addressing this management challenge, this report provides a summary of a series of research projects conducted at Virginia Tech in the Department of Agricultural Economics under grants from the National Oceanic and Atmospheric Administration (NOAA), VMRC, and Sea Grant. While each project had an independent scope and purpose, the body of empirically developed models may be used in an integrative fashion to evaluate the VMRC's management alternatives. This integrative work was the product of special funding provided through the NOAA Section 309 program.

The objective of this report is to present the analytical framework that has been developed to evaluate the economic impacts of oyster grounds policy alternatives and to draw implications for policy design based on management strategies identified in the September 1986 draft overview of the OFMP. This report is organized into seven sections. First, an overview of the oyster industry and oyster management policies is presented. The second section discusses the current state of the oyster industry and the goals and objectives of the fishery management plan. Section three describes the management alternatives available to the VMRC. The fourth section provides an overview of oyster fishery economic research and describes the economic models that are used to evaluate the VMRC's management options. Section five presents an analytical framework for evaluating the effectiveness of alternative management strategies. Section six identifies the management strategies to be evaluated and presents the results of the analysis. The final section draws conclusions and recommendations for oyster grounds policy design.

Section 1.0: Review of Virginia Oyster Grounds Law and Policy

The Virginia oyster, *Crassostrea virginica*, is a sessile mollusk attaching itself to any firm clean substrate. Oysters may be found in intertidal zones and waters up to and sometimes exceeding 25 feet in depth. A filter feeder, the oyster subsists on nutrients extracted from the water column by passing water over its gills. The oyster's ability to select its food and extrude unwanted materials allows it to survive in waters carrying high silt and turbidity loads characteristic of estuarine environments. Reproduction is triggered by temperature (Kennedy and Breisch, 1981). In Virginia spawning begins in early July and continues into September as long as Bay temperatures do not fall below 20 degrees Celsius (Merritt, 1977). Larval oysters spend their first few weeks in a free-swimming state until they settle to the bottom and attach themselves, whereupon they are termed spat. It is at this point that the availability of a hard surface is paramount. The productivity of a river system can be enhanced by placing oyster shells, the preferred material, on the growing bottom just prior to the spawning period.

The oyster survives best in estuarine conditions where salinities range between 5 and 35 parts per thousand (ppt) (Haven et al., 1981a). Oyster growth is most rapid in salinities exceeding 15 ppt. Unfortunately, salinities of this level are favored by the oyster's principal enemies: the diseases MSX, SSO, and DERMO and the oyster drill (a snail-like organism). Mortalities due to these two enemies are particularly high among spat and yearling (known as seed) oysters. In waters below 15 ppt. in salinity, survival of young oysters is greatly enhanced due to lowered mortality rates; however, growth rates are slow as salinities decrease, and oyster growth can be stunted due to overcrowding. When harvested and transported to a different river system the oyster resumes growing and will reach the 3-inch legal size quickly. The interesting result is that the oyster grounds in Virginia can be divided into two distinct types, those that produce large amounts of seed and undersized oysters and those that are productive of market oysters. Moreover, the location of these grounds is well known and has changed little over time, enabling oyster biologists to identify "best" management strategies for oyster production by river system (Haven et al., 1981b).

Section 1.1: Trends in Virginia Oyster Production

By today's standards, market oyster production in Virginia at the turn of this century was large, averaging over five million bushels per year over the period 1890-1925 (Haven et al., 1981). Although data are sketchy, sufficient evidence exists to suggest that oyster production prior to this time was even greater. Due to such heavy exploitation of Virginia's oyster resources, biologists noted as early as 1881 that the natural oyster rocks were significantly depleted (Haven et al., 1981). By 1930 total oyster production had dipped to 1,686,914 bushels. From 1930 to 1960 harvests were relatively stable, ranging between 1.5 and 3.5 million bushels, but never approached production levels experienced prior to 1930. Over the last twenty-five years a dramatic decline in oyster production has occurred following the appearance of MSX disease in 1960. MSX, an oyster disease active in high salinity waters, had a devastating effect on privately leased growing bottoms. Additionally, worsening economic conditions throughout the 1970s in combination with the appearance of MSX forced the abandonment of Virginia's most productive private oyster beds. Public grounds harvests were also adversely affected by MSX and Hurricane Agnes in 1972. The latter event devastated brood stock in many of the lower salinity portions of the Bay, fundamentally altering the level and distribution of setting in the affected river systems.

Section 1.2: Virginia's Oyster Grounds Management Approach

As a matter of policy, Virginia maintains a dual approach to oyster grounds management. Such an approach was initiated upon the completion, in 1896, of a survey of the State's natural oyster bottoms. The survey, known as the Baylor Survey, delineated naturally productive oyster rocks on the basis of the presence of live oysters or oyster shell. Bottoms identified as being naturally productive were designated as Public grounds, as stated in Article XI of the Constitution of Virginia:

> The natural oyster beds, rocks and shoals in the waters of this State shall not be leased, rented or sold, but shall be held in trust for the benefit of the people of this State.....

Bottoms not so designated were made available to private individuals for the express purpose of oyster culture. The practical importance of the Baylor Survey was to establish the limits of the natural oyster resources and the State's stewardship over them.

Prior to the Baylor Survey all harvesters were subject to several legal measures regulating the taking of oysters. These measures included gear, entry (residency, licensing, and season restrictions), and harvestable size regulations, required the culling of live oysters from shell at the time of harvest, and restricted the removal of oyster shells for road paving and the manufacture of lime (Santopietro, 1986). It is important to note that by 1900 all of the above harvest restrictions were implemented and that the same regulations exist today in very much the same form. The harvest laws apply only to watermen, as the Chesapeake Bay harvesters are called, working the public grounds. The production and harvest of oysters on leased grounds are not subject to the above regulations.

An additional measure employed by the State is the Oyster Repletion Program (ORP). Through the application of aquacultural techniques, the objective of the ORP is to influence the supply of seed and market oysters available for harvest. This objective is accomplished by planting shell on public seed beds and growing areas or transplanting seed to areas better suited for growth. From its authorization in 1928 to 1960, however, it is doubtful that the ORP had any effect on harvestable populations as repletion effort varied greatly and little attention was paid to biologically optimal timing or placement of shell (Haven et al., 1981). It was not until after the appearance of MSX that repletion effort was undertaken in earnest, and greater care was taken to insure that shells were placed on bottoms most likely to receive a set of larval oysters.

Since 1960, the ORP has functioned as a disaster relief program and as an on-going oyster bed replenishment program (Baker et al., 1977). In any given repletion season both functions are served, as some repletion effort may be targeted for river systems experiencing natural disaster (such as freshwater kill due to heavy rains), while the remainder of the ORP budget may be used in replenishment of oyster bed substrate depleted during normal harvesting. The Virginia Marine Resources Commission's success in administering the ORP to achieve its objectives is difficult to assess due to data deficiencies. Studies in 1977 and 1983, however, concluded that the ORP's impact was positive (JLARC, 1977; JLARC, 1983). In spite of a positive assessment of the ORP's success both studies pointed out deficiencies in the ORP and the State's management of public oyster grounds.

The 1977 JLARC report documented the decline of the oyster industry and cited the need to consider policy alternatives to enhance production. The authors concluded that production increases would be feasible, but that an expanded state role for management of the oyster grounds would be required. The 1983 JLARC study examined several alternative management strategies and simulated their impacts on oyster production through 1990. The authors found that unless current approaches to oyster grounds management were changed the industry would continue its current decline. They further concluded that even if existing harvest or leasing regulations were changed, only small increases in oyster production could be achieved unless current repletion strategies were also changed. This finding reveals the interdependence of legal and repletion strategies in oyster grounds management. The authors recommended that: 1) the state modify existing approaches to oyster grounds management, 2) the state incorporate the use of economic modeling as a fisheries management tool to assess the impact of alternative strategies, and 3) the state implement an oyster fishery management plan that employs the most effective harvest and repletion strategies subject to technical, economic, and political feasibility. In response to these recommendations the 1984 General Assembly mandated that VMRC develop and implement such an oyster management plan.

Section 2.0: The Oyster Industry Today: Policy Alternatives

The State legislature mandate to VMRC was to develop and implement an OFMP and set as its goal to maximize the biological, economic, and social benefit from the harvest and utilization of the State's oyster resources. The legislature declined, however, to make any recommendations or provisions as to how this was to be done. In 1985, the VMRC began to take steps toward development of an OFMP.

Section 2.1: The OFMP Planning Process

The development of the OFMP has taken place in four phases. In the first phase a Fisheries Management Advisory Council (FMAC) was formed with members appointed by the commissioner of VMRC. The advisory committee is made up of private citizens active in and knowledgeable about the seafood industry. The Commissioner also appointed scientific advisors including economists, biologists, and management specialists to assist the committee. While VMRC has the ultimate responsibility for the plan, the purpose of the FMAC is to provide recommendations and citizen expertise to VMRC with regard to OFMP provisions, goals, and strategies.

The second phase in the plan's development was for the FMAC and VMRC to meet and discuss in a broad sense what the objectives of the plan should be. Following this, VMRC staff drafted a management plan with stated goals, objectives and proposed management options to meet the plan's goals. The third phase in the OFMP development process took place over the next several months as FMAC and VMRC met, discussed, and revised the proposed management plan. Currently the OFMP is in its fourth phase, that of evaluating the impact of alternative policies and choosing the mix of regulatory and repletion strategies that most effectively meet the OFMP goals and objectives. The final phase in the OFMP process will be the implementation of the plan.

Section 2.2: OFMP Goals and Objectives

Selection of the "best" mix of management alternatives requires that some standards or criteria be set against which each management strategy may be measured or compared. In this case the appropriate standards should be consistent with the stated goals of the OFMP and current legislative and executive concerns.

The stated goal and objectives of the OFMP are as follows:

Goal: To achieve and maintain a level of Virginia's Public and Private ground oyster stock to generate the greatest possible biological, sociological, and economic benefits from their harvest and utilization.

Objectives:

1. By 1993, increase public grounds production to at least 700,000 bushels (20% above the ten-year average). To the extent possible, reduce annual fluctuations in public production.

2. Assist private oyster producers to ensure an increase in private grounds production to 700,000 bushels (the approximate 20-year average) by 1995.

3. Ensure the collection of biological, sociological, and economic data as well as fisheries statistics to monitor and evaluate the effectiveness of management measures.

4. Implement the Marine Resource Commission's regulatory authority to impose effective and timely management measures.

5. Support water and habitat quality standards necessary for natural production. Encourage reclamation, where practical, of condemned oyster grounds through VMRC cooperation with the State Water Control Board and other State agencies. (Source: VMRC, 1986, p. 17-18)*

In addition, concerns have been expressed by the legislative and executive branches of State government (JLARC, 1983) that:

1. The goals and objectives of the OFMP should be achievable without undue increases in State funding requirements.

2. The repletion program should be self financing with no unwarranted State subsidy to private planters or Baylor grounds harvesters.

The objectives and concerns listed above, while not amenable to analysis as stated, form the basis of a framework within which specific performance criteria may be set for evaluation of alternative management policies.

To cast the above objectives and concerns into a framework that is amenable to analysis, it is necessary to establish a conceptual analytical approach. First, it must be recognized that it may not be possible to maximize two or more policy goals simultaneously. The simultaneous maximization of biological, sociological, and economic benefits of the oyster resource, therefore, is not an operational policy goal. Instead, it is necessary to identify a single policy goal while setting minimum satisfactory attainment levels for the remaining goals.

Given that the impetus behind the OFMP mandate was declining oyster production, it is logical that increased oyster production be selected as the primary policy goal. The remaining objectives and legislative concerns then become constraints or conditions under which increased oyster production is to be achieved. Within this context the policy goal of the OFMP can be restated in the following general way:

The State should seek to implement management strategies to increase oyster harvests above their currently depressed levels, subject to the following conditions:

- Total production should be divided between public and private grounds conditional on the maintenance of a minimum level of public grounds harvest.

- The production goal should be attained in the least costly manner possible, recognizing the increasingly competitive national oyster market.

*The dates indicated in the 1986 draft OFMP may be subject to change.

- Repletion program expenditures should stay within a predetermined annual repletion budget.
- The repletion program should be self sufficient, with no unwarranted state subsidy to private planters or Baylor grounds harvesters.
- Regulatory measures should assure continued access to the Baylor grounds for those watermen who wish to earn income from oystering.

Stated in this manner a single policy goal is identified and the conditions under which every alternative management strategy is to meet that goal are clearly defined. These policy constraints derive from the goals and objectives of the OFMP and from the legislative concerns listed previously*.

Section 3.0: Management Alternatives

The preceding discussion pointed out the specific goal and policy constraints that are implied by the broadly stated OFMP goal. Of the many management options available to VMRC, it is unlikely that any single policy will be capable of satisfying all the management conditions set for the OFMP. Rather, it is likely that a mix of regulatory and management strategies will be required to attain OFMP goals at levels considered satisfactory by VMRC managers and industry representatives alike.

Section 3.1: Regulatory Measures

The policy alternatives from which VMRC may choose are either regulatory in nature or involve direct public investment in the oyster fishery. VMRC's regulatory options fall into three broad categories: market oyster harvest regulations, bottoms designation, and seed oyster harvest regulations. Market oyster harvest regulations include: minimum size, open season, gear, quotas, and restricted entry. These proposed regulations are not in themselves a departure from traditional approaches to regulating the harvest of oysters in Virginia. The proposed means of administering these regulations, however, represents a significant change in oyster grounds management policy. In order to allow for increased management flexibility, the 1985 Legislature granted VMRC the regulatory authority to implement all harvest-related restrictions as they deemed appropriate. Prior to this action all harvest regulations were legislatively set, limiting VMRC's ability to respond quickly to changes in environmental considerations. Today, rather than representing limits or legal confines within which VMRC must work, the setting of harvest regulations is an important management tool to be molded and used as management circumstances dictate.

The purpose of bottoms designation policies is to increase the quantity of harvestable acreage for public hand tongers and to increase the number of acres of growing bottom that are available for lease by private individuals. OFMP provisions propose to increase harvestable acreage by opening formerly condemned public oyster beds. In the event of shellfish contamination the Bureau of Shellfish Sanitation will close the affected bottoms to all harvesting. VMRC proposals include reviews of condemned oyster grounds to assess the possibility of reopening condemned oyster grounds that are no longer contaminated. Policies aimed at increasing leasable acreage include the opening of nonproductive public grounds for lease and requiring proof of active cultivation on oyster grounds currently under lease. The former policy would

*Note, however, that the OFMP objectives 3, 4 and 5 are excluded. Objectives 3, 4 and 5 are administrative in nature and are assumed to be carried out in addition to the specific management strategies that are implemented to meet the oyster production goal.

represent a radical departure from traditional approaches to oyster grounds management and would face considerable opposition (Santopietro, 1986). Proposed proof of use policies would prohibit the nonproductive holding of leases, thereby, forcing the choice between either production or abandonment. The latter choice, it is believed, will increase the number of oyster grounds available to individuals who are willing to plant seed oysters.

Although, in principle and application, seed oyster harvest regulations are similar to market oyster harvest regulations, they serve at least one distinctly different purpose. The purpose of proposed seed harvest regulations is to reduce the cost of harvesting seed. The seed harvest regulations are designed to reduce ORP costs and lowered seed costs might attract increased investment in private oyster grounds production. The most important seed oyster harvest policy considered for the OFMP is permitting the use of a dredge on specifically designated seed beds. Currently, the only harvest gear permitted on public grounds seed beds is the hand tong. Permitting the more labor-efficient dredge would substantially reduce seed harvest costs and seed prices.

Section 3.2: Public Grounds Repletion Measures

In addition to regulatory policy measures, VMRC is also authorized to oversee direct public investment in the oyster fishery, i.e. the oyster repletion program. Although, management policy toward administration and the basic aquacultural techniques used in the program are unchanged, OFMP provisions represent significant changes in VMRC's approach to public grounds repletion. The important change in oyster grounds repletion policy called for in the OFMP is the evaluation of alternative repletion techniques to identify the most cost-effective mix of repletion activities. To make such an evaluation possible, increased use of economic and biological analysis is called upon, and to support these efforts OFMP provisions emphasize the need for improved and expanded data collection. It is in these three provisions that the proposed management plan marks a change in ORP policy. For the first time the utility of a formal analysis of the repletion program has been recognized.

Section 4.0: Overview of Oyster Fishery Economic Models

Beginning in January 1980 and continuing through December 1985, the Virginia Sea Grant consortium supported a broadly scoped fishery economic studies program, focused upon the Chesapeake Bay fisheries. The first project lasted three years and was entitled "Alternative Future Directions for Virginia's In-Shore Fishery." One product of this effort was the econometric model results used to develop the oyster management planning recommendations of the 1983 JLARC study. Following from this study a second project, more clearly focused upon the oyster fishery, was funded by Sea Grant. The study, "Evaluation of Public Policy Options for Increasing Virginia Commercial Oyster Harvest," was the basis for the development of the models described in Sections 4.1 - 4.4. By 1985, when the OFMP planning process was initiated, these various economic models were, in large part, developed. Given the OFMP mandate to consider economic factors in the plan evaluation process, the potential for use of these models in the OFMP process seemed to be significant. However, a realistic appraisal of their usefulness identified three potential problems.

First, some aspects of the modeling had not yet been reviewed by oyster management specialists. Second, some of the model data bases could be made more current. Third, the separate models had not been integrated into a complete analytical system. Therefore, during late-1985 and 1986 actions were taken to address each of these three concerns. Financial support for this effort was provided by VMRC and by the Virginia Council on the Environment through the NOAA Section 309 program. The structure and functioning of the analytical system developed under this funding is described in Section 5. The separate models (a linear programming model, an econometric demand system, a budget simulator, and an input/output model) that comprise the system are briefly described below. A detailed treatment of each of the models can be found in the technical appendices included in this report.

Section 4.1: The Linear Programming Model

The first model used in policy evaluation is a Linear Programming (LP) model. LP models, a subset of all mathematical programming models, describe an economic system in terms of linear equations. The economic, biological, and political relationships contained within the model's technical structure are assumed to be linear. LP is a mathematical technique that optimizes an objective function subject to limits of resource availability and technical feasibility. Specifically, the LP model described here minimizes the public-plus-private cost of producing and harvesting a prespecified level of market oysters (Thunberg, 1985). Framed in this way the policy goal of the OFMP is captured through the preset harvest level, and the policy constraint that the goal be attained in the least costly manner is also incorporated. The model captures the remaining policy considerations by placing restrictions on the model's ability to achieve the production goal. In a LP context these restrictions take the form of constraints on the model's ability to select specific management strategies or by placing limits on the availability of resources that are needed in order to achieve the management goal. For example, the requirement that the repletion program stay within a specified annual budget is modeled by placing a limit on the availability of repletion funds either for a repletion season or for a specified time period. For a complete description of the model's activities, and constraints see Appendix A, Part 1.

The technical information incorporated into the LP model is reflective of specified legal and repletion policies existing as of 1983. The technical information was initially developed under a Sea Grant-funded project. Revisions to the model were made through consultations with VMRC management personnel under the Section 309 funding. A detailed discussion of the technical information included in the model can be found in Appendix A, Part 2. Proposed management strategies are evaluated by altering the model's technical information to reflect the changed management environment. For example, a regulatory change permitting the use of a new harvest gear would alter the cost of harvesting oysters. To examine the economic impacts of such a management policy, the analyst must identify the magnitude of the change in harvest cost and then adjust the model to reflect the new information. Solving the model yields an estimate of the cost and repletion funding savings or increases associated with the new gear regulation. In addition to repletion and cost information the model's output determines tax collections and production levels by river system on public and private grounds. The LP model, therefore, provides quantitative estimates of the mix of market oyster production between public and private grounds, the total cost of achieving the harvest goal, the total amount of repletion funding required to achieve the goal, and the amount of tax that is collected to offset the repletion program costs.

Section 4.2: The Econometric Demand System

Using the production levels determined by the LP model associated with a policy change, oyster ex-vessel, wholesale, and retail prices can be predicted using a system of demand equations. The demand system expresses oyster prices at each level of the marketing chain as a function of Chesapeake Bay and Gulf State harvest, U. S. consumption of oysters, population, income, time trends, and an index of intermediated goods and services. Price changes, therefore, can not only be forecast for changes in Virginia production but for changes in other factors affecting price as well.

The demand model is estimated as a system using multiple regression techniques. The resulting individual parameter estimates are interpreted as being the change in the dependent variable associated with a one-unit change in any one independent variable, holding all other independent variables constant. Since changes in Virginia management policies have an impact only on Virginia production, prices can be forecast by multiplying the Virginia production regression coefficient by the new level of oyster harvest while maintaining all other independent variables at their specified levels. In this manner oyster ex-vessel, wholesale, and retail prices are estimated. For a detailed description of this demand model see Appendix B. The new price estimates can then be applied to the production levels determined in the LP solution to compute harvester, processor, and retailer total revenues. While most policy changes will likely have some effect on oyster prices and, therefore, on industry total revenues, in order to determine whether or not industry participants have been made better off by a policy change, it is necessary to examine net revenue effects.

Section 4.3: The Budget Simulator

The third model used in the analytical framework, a budget simulator, is used to evaluate changes in net revenue due to a policy change. The budget simulator estimates changes in net revenues for a typical public grounds harvester and private planter, given specified relationships for each budget item. Changes in net revenues are assessed by determining the impact of a proposed policy on particular budget items. For example, private planter net revenue changes associated with policies resulting in lowered seed prices would be attained by adjusting the seed price coefficient in the budget simulator. Lowered seed prices would likely result in increased production and lowered oyster prices. Adjusting the private planter's budget to account for the input and output price changes yields an estimate of net revenues for the private planter attributable to the proposed policy. Comparing the new level of net revenue to net revenues that would have existed without the policy change provides the opportunity to determine whether or not industry participants are made worse off or better off because of the policy change. A description of the budget model can be found in Appendix C.

Section 4.4: The Input/Output Model

The preceding effects, production, cost, repletion funding, price, total, and net revenue effects relate specifically to the oyster industry alone. Recognizing that linkages between the oyster industry and other sectors of the Virginia economy exist, it is important to consider how management changes within the oyster-producing sector affect the Virginia economy as a whole. These state-wide effects can be evaluated through the use of multipliers generated with an Input/Output (I/O) model.

An I/O model describes the interdependencies that exist between different sectors of an economy in terms of the purchases that are made by each industry from all other industries. Oyster harvesters purchase fuel and materials from several other economic sectors. These purchases in turn become income to the sellers of the materials, income which may be spent on purchases of seafood products or numerous other products produced in other sectors. The total amount of economic activity in an economy induced by an initial transaction in a single sector is termed a multiplier effect and can be computed for each economic sector. Multipliers for the seafood industry are available from a Virginia Input/Output model (Regional Science Research Institute, 1982). Using these multipliers, it is possible to estimate changes in value-added and additions to net State income. A second adjustment allows computation of indirect tax revenues. Changes in value-added and indirect tax revenues indicate state-wide net (gross sales less production costs) changes in economic activity due to a management change in the oyster industry alone. Indirect tax revenues are useful in assessing whether or not the repletion program can be made self-financing. For example, a change in management strategy may result in increased direct oyster taxes but may still not recover all costs of the repletion program. The collection of indirect tax revenues (tax revenues generated in sectors other than the seafood sector) may be sufficient to recover the remaining repletion budget deficit. For a discussion of this modeling work see Appendix D.

Section 5.0: An Analytical Framework for Policy Evaluation

The policy goal and constraints for the OFMP were stated in Section 2, and the management alternatives available to VMRC to achieve that goal were discussed in Section 3. In the absence of any policy constraints a variety of management strategies would likely be capable of satisfying the OFMP policy goal. However, several policy constraints do exist, and selection of any given management alternative would have different implications for the degree to which these constraints are met. The "best" choice of specific policies and combinations of policies requires, therefore, that VMRC be able to quantify the degree to which proposed management strategies can satisfy the goal and policy constraints set for the OFMP. In addition, informed selection of policy alternatives requires that potential policy conflicts be identified. In this section, an integrative analytical framework based on the economic modeling described previously will be presented that is capable of accomplishing this task. First, however, what is meant by an integrative approach?

The analytical framework is integrative in two senses. First, economic modeling often incorporates biological and political information in addition to economic considerations. The economic models described in Section 4 are integrative because they treat the oyster industry as a system in which limits to biological feasibility and political acceptability are built into the models' structures. Secondly, the analytical framework is itself integrative in that individual models interface with each other as output from one model is used as input to other models. The analytical framework is integrative, therefore, with respect to the technical information incorporated into the system and with respect to the economic models themselves.

The analytical framework employs the four economic models described in Section 4 to estimate the economic impact of a given management policy or mix of policies. The aim of the framework is to obtain quantitative estimates of changes in selected policy variables due to a change in management strategy. Given these, the ability of each policy or policy mix to meet the goal and various constraints of the OFMP can be assessed and policy conflicts may be identified. Relative performance for different management strategies can be evaluated and compared, enabling VMRC to identify the most effective mix of management strategies for the OFMP. The policy variables of interest are identified below.

Section 5.1: Policy Variables

The goal of the OFMP is to increase the production of market oysters. The first policy variable of interest is, therefore, the total state harvest resulting from any given management strategy. The policy constraints of the OFMP require estimates of several more variables. First, the distribution of harvest between public and private grounds must be estimated. Second, in order to satisfy the condition that the harvest goal be attained in the least costly manner possible, the total cost of achieving the harvest goal must be estimated. Third, to determine whether, under any given management strategy, the repletion program can be self financing, the ORP funding requirements and the level of direct and indirect tax collections must be estimated. Fourth, the income effects of increasing harvest and changing management policies require that oyster prices at the ex-vessel, wholesale, and retail levels be estimated. These prices can then be used to estimate changes in industry gross revenues at the harvest, wholesale, and retail levels and to evaluate changes in net revenues for individual Baylor grounds tongers and private planters. The last policy variable of interest is the total impact on the Virginia economy associated with increased market oyster production.

Section 5.2: Framework Structure

The structure and flow of the analytical framework is depicted in Figure 1. The policy variables that are being evaluated are shown within the circles of Figure 1. The models used to estimate the impact on the policy variables due to a policy change are represented by triangles. The policy analysis is initiated by specifying values for the choice variables listed in the rectangles of Figure 1.

The choice variables represent either policy choices or exogenous factors. The allowable limit on repletion spending or the level of the repletion tax, for example, set the conditions under which each management option is to be evaluated. The availability of productive oyster beds or the level of U. S. consumption of oysters represent limits of physical resource availability or factors that are unaffected by the particular management strategy under scrutiny.

Both aspects of the integrative nature of the analytical framework can readily be seen in Figure 1. Political and biological considerations are incorporated as choice variables that place explicit restrictions on the linear programming model that are then carried implicitly through to the demand system and the budget simulator. For example, political considerations may require that minimum historical repletion patterns be maintained. These requirements place restrictions on the LP model that affect the model's results and are implicitly carried through the entire analytical system. The relationships between the models of the system are indicated by the direction of the arrows. For example, output from the linear programming model is imposed on the demand system. Likewise, the demand system output is imposed on the Input/Output model and the Budget model. A final dimension included in the analytical framework is the qualitative evaluation of specific components of the output to determine the feasibility of the production levels determined in the policy analysis. For example, prices may fall below that required for private planters or public harvesters to operate profitably. Similarly, production levels may exceed available processing capacity. In either case, the analytical framework suggests the need to go beyond the quantitative results of the models to offer a qualitative interpretation of the results before drawing management implications.

Section 5.3: The Policy Evaluation Procedure

The policy analysis begins by setting the conditions under which the policy is to be evaluated. Specifically, the policy goals and restrictions under which the management policy is to be evaluated must be set. The policy goal set for the OFMP is to increase total State harvest to an annual level of 1,400,000 bushels for a period of ten years. This total harvest is to be allocated among public and private grounds in the following manner: public grounds harvest must be at least 700,000 bushels annually while private grounds production may not be greater than 700,000 bushels each year. The rationale for these restrictions is as follows. First, it is assumed that private grounds production would not increase substantially without an increased commitment from the State to promote policies that would increase private incentives to produce market oysters. Second, any such commitment would involve a redistribution of State funds to activities benefiting private planters that would otherwise have been spent on public grounds

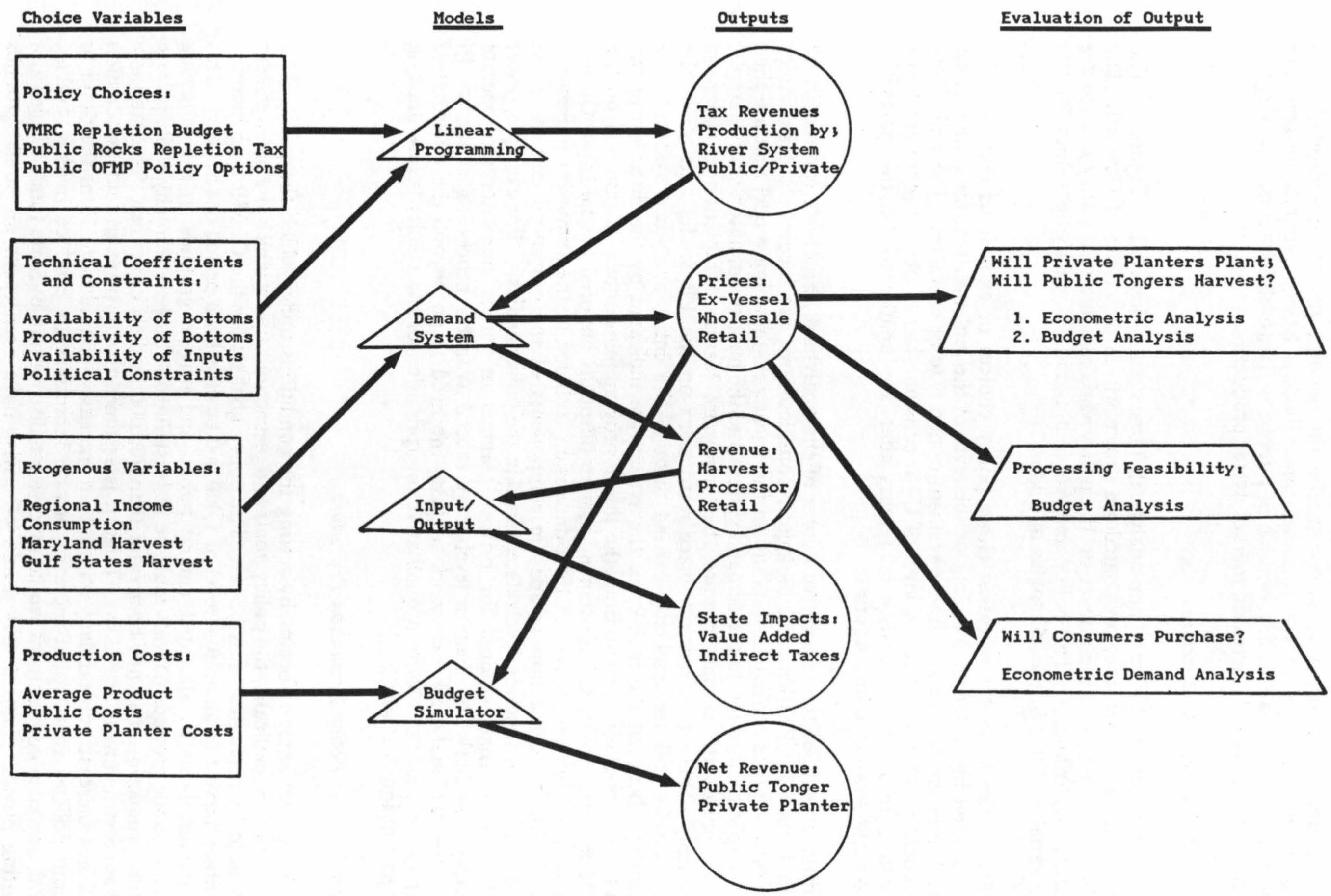


Figure 1: Policy Evaluation Flow Diagram

repletion. Constraining private grounds production to no more than 700,000 bushels per annum implicitly limits the amount of State resources that can be spent to improve private grounds production and insures that any increased State management efforts will not unduly benefit private planters at the expense of the public grounds harvester.

In addition to the restrictions placed on oyster grounds production, two conditions are placed on the oyster repletion program. First, river systems that have historically been shelled are required to continue to receive a minimum annual level of repletion effort. This requirement acknowledges political pressures that may exist to maintain repletion activities in river systems that have historically received attention and insures that at least some repletion effort be expended throughout the Virginia portion of the Chesapeake Bay. The second condition set for the repletion program is that repletion funding is set at no more than $12,500,000 for the entire ten-year planning period, to be allocated on an annual basis as repletion conditions require. While this condition may be somewhat unrealistic in view of the budget appropriations process, it does permit the flexibility to allocate the repletion budget in the most cost-effective way while remaining within a prespecified total spending limit.

Procedurally, any particular management strategy can be evaluated, subject to the above conditions, in the following manner. The values for the choice variables are selected and incorporated into the technical information of each affected economic model. For example, a seed dredging policy would alter the price paid for seed. Since output is constrained, the demand model and the I/O model would not be affected by this policy change, but the coefficients of the LP model and the budget simulator would have to be adjusted to reflect the new policy. The policy analysis begins by using the linear programming model to evaluate the least-cost mix of production activities that are required to meet the goal, subject to the specified constraints. The results of the linear program determine total production between public and private grounds, the total cost of achieving the harvest goal, total repletion program costs, and total repletion tax collections. As indicated in Figure 1, the total production figure is then incorporated into the demand system to estimate ex-vessel, wholesale and retail prices. Given these, gross revenues at each level of the industry can be computed. Applying the multipliers from the I/O model to the gross revenue figures results in an estimate of the net value of increased State-wide economic activity and the level of indirect taxes induced by the increased level of market oyster harvest. Imposing on the budget simulator the estimated prices and any changes in production costs associated with a specific management policy results in estimated annual net revenues for a representative public grounds harvester and net returns per acre for a representative private planter.

The final phase in the policy analysis is a qualitative analysis phase. In this step the results of the policy simulation are examined to determine whether or not they seem reasonable in terms of the likely demand for increased oyster production, and the likelihood that sufficient labor will exist to harvest the increase in oyster production. The following section provides the results of policy simulations based on this analytical framework for the management alternatives discussed in Section 3.

Section 6.0: Policy Simulations: Results

In this section the results of eleven possible policy scenarios are presented, based upon the consideration of the policies and combinations of policies that were discussed in Section 3. Table 1 provides a tabular summary of these policies. The column headings of Table 1 indicate the various policies that are available for consideration. The row labels indicate the different policy scenarios that were evaluated. The cell entries in Table 1 indicate the scenario and policy alternatives that are evaluated in that scenario. If an "X" appears in any row then the corresponding management policy, as indicated by the column heading, is incorporated into that particular analysis. For example, Scenario 6 evaluates a management strategy that: i) limits repletion spending to a maximum of $12,500,000, ii) uses a repletion strategy that includes shelling oyster grounds and transplanting seed, iii) permits the taking of market oysters with hand tongs only, and iv) permits the harvest of seed on all seed beds and the harvest of seed with a dredge on all seed beds except those in the James River. For each scenario the basic conditions as discussed in Section 5.3 were set. In addition to these, it is assumed that the management area concept as described in the September Draft Summary of the OFMP is adopted for the entire Virginia portion of the Bay and its tributaries (VMRC, 1986). Given these initial conditions, the economic impacts of each of the policy scenarios were evaluated, the descriptions and results of which are presented below.

Section 6.1: Scenario 1--Conditions Without a Management Plan

In this scenario the production, price and cost conditions that existed before the OFMP mandate were simulated. The average 1983, 1984, and 1985 production, repletion budget, and tax collections were used to establish the pre-OFMP conditions. The results of this scenario are presented in Table 2.

These results do not replicate the pre-OFMP conditions in a specific year but represent a composite for 1983-1984-1985. The results can provide useful information for comparison with the alternative management strategies incorporated in the OFMP and are reported as if the condition were to be maintained for a ten-year period. Under the pre-OFMP conditions total harvest was 6,419,720 bushels, 3,418,700 and 3,001,030 bushels harvested from public and private ground respectively. The predicted prices associated with this harvest were $0.937, $1.307, and $2.151 per pound of meat at ex-vessel, wholesale, and retail respectively.* The repletion program spent $8,282,570, and tax revenues from the public grounds oyster repletion tax were $4,181,250, leaving a budget deficit o $4,101,320.** The dollar value of the State-wide addition to net income (value added) associated with the oyster fishery under pre-OFMP conditions was estimated to be $23,596,717. Indirect tax revenues were estimated to be 11.75% of value added or $2,772.613. Under pre-OFMP conditions, therefore, all but $758,750 of repletion program expenditures were recovered either through direct or indirect sources.

Gross revenues at each level of the oyster industry were estimated to be $28,085,310, $39,715,650, and $64,460,880 for harvesters, processors, and retailers, respectively. Net returns to fixed costs and the waterman working the public grounds were estimated to be $1,252.69 per year. Private planters holding high productivity beds (1,500 bushels per acre) were estimated to net $1,502.87 per acre per year while planters holding moderate productivity grounds (1,125 bushels per acre) earned $489.93 per acre per year, and planters on low yielding grounds (750 bushels per acre) were estimated to lose $523.00 per acre per year.

The scenario described above typifies what the condition of the oyster industry might be in the absence of a fishery management plan or any of the policy changes such a plan might entail. The remaining scenarios assume the existence of an oyster fishery management plan but in each case a different set of management provisions incorporated in the plan is evaluated.

---

*A conversion rate of 4.6684 pounds of meats per bushel was used to convert bushels of oysters harvested to meat yields. This conversion rate represents a weighted average based on reported conversion rates in the Fisheries Statistics of the United States (FSUS) and harvest levels reported in VMRC Annual Reports for the years 1960 to 1977 (FSUS, 1977; VMRC Annual Report, 1982).

**All dollar figures are reported in 1983 dollars.

Table 1
Summary of Policy Choices Included in Policy Simulations

Scenario	Repletion Budget $12,500,000	Repletion by Planted Shell	Repletion by Transplanted Seed	Tong Market Oysters	Dredge Market Oysters	Tong* Seed Oysters	Dredge* Seed Oysters	Tong Seed in James R.	Dredge Seed in James R.
Scenario 1	NA	X		X		X		X	
Scenario 2	NA	X		X		X		X	
Scenario 3	X	X	X	X		X		X	
Scenario 4	X	X	X	X			X		X
Scenario 5	X	X	X	X		X	X	X	X
Scenario 6	X	X	X	X		X		X	
Scenario 7	X	X	X		X	X		X	
Scenario 8	X	X	X	X	X	X		X	
Scenario 9	X	X	X	X	X		X		X
Scenario 10	X	X	X	X	X	X	X	X	X
Scenario 11	X	X	X	X	X	X		X	

An X indicates that the policy in the column heading is included in the indicated scenario.

*All river systems except the James River.

Table 2: Scenario 1: Pre-OFMP Conditions

Total Harvest (Bushels)	6,419,720
Public Harvest	3,418,700
Private Harvest	3,001,030
Repletion Budget ($)	8,282,570
Tax Collections ($)	4,181,250
Budget Deficit ($)	4,101,320
Prices ($/Pound)	
Ex-Vessel	0.93712
Wholesale	1.30717
Retail	2.15086
Total Revenues ($)	
Harvester	28,085,318
Processor	39,175,650
Retailer	64,460,888
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre/year)	-523.00
1125 (bushels/acre/year)	489.93
1500 (bushels/acre/year)	1502.87
Hand-Tonger	1252.69
Dredger	NA
Value Added	23,596,717
Indirect Tax Revenues	27,726,134

Section 6.2: Scenario 2--The Baseline Condition

In this scenario the effect of increasing the repletion program budget without any other changes in management strategy is evaluated. Therefore, the repletion program uses a shelling-only strategy. This scenario will be used as a baseline condition because it considers no management changes other than an increase in repletion program expenditures. Indeed, the decision to increase repletion spending has been made. The management options considered in the remainder of this section can be compared with this baseline.

Initially a total repletion budget of $12,500,000 was given to the model to be allocated across the ten-year planning period considered in the analysis. The annual harvest goal of 1,400,000 bushels, however, could not be attained at this repletion program funding level. The repletion budget was then increased and the models were run. The results of the analysis are presented in Table 3.

Under a repletion strategy that relies on a shelling program alone the annual harvest goal of 1,400,000 bushels is feasible <u>only</u> if repletion program expenditures are $13,836,105 over the ten-year planning horizon. Total harvest is 13,748,040 bushels with 8,143,138 and 5,604,402 coming from public and private grounds, respectively. The total cost of achieving this level of production is $47,268,580. The total cost is split between public and private grounds in the amounts of $28,756,978 and $18,511,602, respectively. The predicted prices associated with the annual 1,400,000 bushel harvest goal are $0.85889, $1.23894, and $2.10822 per pound at ex-vessel, wholesale, and retail respectively. These prices are below those that exist in the pre-OFMP situation of Scenario 1. Total revenues over the ten-year period for harvesters, processors and retailers are estimated to be, respectively, $55,124,719.60, $79,516,841.60, and $135,308,405.50, an increase over pre-OFMP conditions. Annual returns to fixed costs and management for a representative public grounds hand tonger are estimated to be $3,736.84, over two times the pre-OFMP figure. This figure is based on the assumption that the increased harvest goal will, on average, double the productivity of the oyster grounds and, therefore, double the productivity of the average hand tonger. The change in productivity more than offsets the reduction in prices, resulting in a net increase in returns to public harvesters. Net returns for private planters are lower under this scenario, versus the pre-OFMP condition, because increased harvests result in lower prices received and there are no offsetting cost savings realized by private planters. Planters on high productivity grounds are estimated to receive net revenues of $964.03 per acre per year while moderate productivity grounds are estimated to yield a net return of $85.80 per acre per year. Low productivity grounds yield an annual loss of $792.42 per acre. Over the ten-year planning period the increased harvest goal is estimated to result in an increase in State-wide net income of $47,729,529 and indirect tax collections of $5,608,219.70. These indirect tax collections represent nearly 60% of the repletion budget deficit of 9.5 million dollars.

Section 6.3: Scenario 3--A Seed Transplant Policy

The previous scenario assumed that the only repletion activity was the shelling of public rocks to produce market oysters. This scenario permits the transplanting of seed subject to the requirement that minimum historical shelling levels are maintained. This constraint was incorporated in response to VMRC concerns expressed in 1983 that, given the fact that repletion activities were highly visible, considerable opposition would be mounted against attempts to curtail repletion efforts in areas that had previously received attention. Once these minimum repletion requirements are met the choice of transplanting seed or planting shell is based on the relative cost-effectiveness of each

Table 3: Scenario 2: The Baseline Condition An Increased Repletion Budget With No Change in Repletion Strategy

Total Harvest (Bushels)	13,748,040.0
Public Harvest	8,143,138.0
Private Harvest	5,604,402.0
Total Cost ($)	
Public	28,756,978.0
Private	18,511,602.0
Total	47,268,580.0
Average Cost ($/bushel)	
Total	3.4382
Public	3.5314
Private	3.3030
Repletion Budget ($)	13,836,105.0
Tax Collections ($)	4,370,228.0
Budget Deficit ($)	9,465,877.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.6
Processor	79,516,841.6
Retailer	135,308,405.5
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-792.42
1125 (bushels/acre)	85.80
1500 (bushels/acre)	964.03
Hand-Tonger	3736.84
Dredger	NA
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

activity. The repletion budget is set at a maximum of $12,500,000 to be allocated over the ten-year planning period. The results of this scenario are presented in Table 4.

The total harvest of market oysters is the same as that under a shelling-only repletion strategy. Due to the increased productivity of the transplanted seed, the distribution of production between public and private grounds changes because under a seed-transplant strategy the public grounds become more competitive with private grounds on a cost-effectiveness basis. Under this strategy public grounds production increases to 9,248,037 bushels while private grounds production decreases to 4,500,003 bushels. The seed-transplant option also allows the harvest goal to be attained within the limits of the repletion budget on expenditures of $12,050,558. With a budget deficit of $7,140,125, the repletion program deficit amounts to $1,531,906 when indirect tax collections are considered. Additionally the total public plus private cost of producing the harvest goal declines to $42,929,639. The total private grounds cost falls to $14,132,969 while public grounds costs rise slightly to $28,796,670 as compared to the baseline condition. The drop in private grounds costs and rise in private grounds costs are attributable to the change in the distribution of production on public and private grounds that takes place under this scenario.

The production goal is the same as that in the baseline condition. Since this is the case, the predicted prices, total revenue figures, hand tonger net revenue, value added, and indirect tax revenues remain the same for this scenario and will be the same for all the other scenarios considered below. For this scenario net revenues for private planters are also the same as the baseline condition because a seed transplant strategy does not affect the cost or price conditions faced by private planters.

Section 6.4.0: A Seed Transplant and Seed Dredge Policy

A policy that permits the dredging of seed is expected to result in lowered seed prices resulting in increased private planting and possibly lowering repletion program costs as well. In the recent past all seed dredging policies had been vigorously opposed by watermen and viewed with skepticism by VMRC managers as well. Recent survey work demonstrates, however, that opposition to seed dredging may be weakening among watermen (Santopietro, 1986). Additionally, in public hearings held in the fall of 1986 watermen expressed little opposition to the principle of seed dredging under certain conditions. Several biological and political concerns have been expressed by both management and watermen groups, therefore, three alternative seed dredging policies are evaluated.

Section 6.4.1: Scenario 4--Seed Dredging All Areas

In this scenario the only method considered for harvesting seed is dredging. Under such a policy it is assumed that a seed bed, once harvested, would have to be reshelled before it could be expected to be productive again. This assumption was incorporated into the technical structure of the linear programming model. In addition to this assumption, it was also assumed that a bushel of dredge seed would be less productive than a bushel of tonged seed.* Specifically, it was assumed that it would require two bushels of dredged seed to match the productivity of a single bushel of tonged seed. The harvest cost per bushel for dredged seed was set at $1.00 per bushel (twice that paid by the Potomac River Fisheries Commission in 1984). The results of the policy simulation including seed-transplant activities, and setting the repletion budget at $12,500,000, are presented in Table 5.

---

*The rationale for this assumption will be discussed later.

Table 4: Scenario 3: A Seed Transplant Policy

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,248,037.0
Private Harvest	4,500,003.0
Total Cost ($)	
Public	28,796,670.0
Private	14,132,969.0
Total	42,929,639.0
Average Cost ($/bushel)	
Total	3.1226
Public	3.1138
Private	3.1406
Repletion Budget ($)	12,050,558.0
Tax Collections ($)	4,910,432.0
Budget Deficit ($)	7,140,125.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-792.42
1125 (bushels/acre)	85.80
1500 (bushels/acre)	964.03
Hand-Tonger	3736.84
Dredger	NA
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

Table 5: Scenario 4: Seed Transplant and Seed Dredge All Seed Beds

Total Harvest (Bushels)	13,748,040.0
Public Harvest	8,970,328.0
Private Harvest	4,777,712.0
Total Cost ($)	
Public	29,095,960.0
Private	14,894,132.0
Total	43,990,092.0
Average Cost ($/bushel)	
Total	3.1997
Public	3.2435
Private	3.1174
Repletion Budget ($)	12,500,000.0
Tax Collections ($)	5,049,821.0
Budget Deficit ($)	7,450,179.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-507.42
1125 (bushels/acre)	663.55
1500 (bushels/acre)	1249.03
Hand-Tonger	3736.84
Dredger	NA
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

Under a seed dredge-only policy the total cost of achieving the harvest goal is $43,990,092. The total private cost increases slightly over that in Scenario 3 to $14,894,132 but so too does total private grounds production at 4,777,712 bushels. The increase in private grounds production compared to Scenario 3 occurs because the reduced cost of seed makes some private grounds relatively more cost-effective to the next best public grounds production alternative. Note, however, the public grounds cost is greater in this scenario than under any previous one because of the assumed need to completely reshell the public grounds seed beds after each harvest. This fact is also reflected in repletion program expenditures of $12,500,000 required to meet the harvest goal.

Private planters are made better off with a seed dredge policy because their production costs are reduced. The lower production costs are reflected in increased annual per acre returns of $1,249.03, $663.55, and $-507.42 for high, moderate, and low productivity beds, respectively. All other economic impacts, prices, total revenues, tonger net revenue, value added, and indirect tax revenues remain unchanged.

Section 6.4.2: Scenario 5: Dredge or Tong Seed

Recognizing that repeated shelling for seed may be more costly than necessary, this scenario permits the choice between dredging or tonging seed on a cost-effectiveness basis. The linear programming model was adjusted to allow either seed dredging (under the conditions described above) or tonging. Areas that should be dredged and areas that should be tonged are determined from the results of the linear program. In principle, the linear program makes this determination by comparing the cost per bushel of seed produced for all the public grounds seed beds for dredged seed and tonged seed. The model then selects the lowest cost combination of harvest gear and river system in which to produce seed, subject to limits of technical feasibility and resource availability. All other policy conditions remain the same as that for Scenario 4. The results of the analysis are presented in Table 6.

Permitting the choice between dredging or tonging seed reduces the repletion cost of attaining the harvest goal. The repletion budget deficit is likewise reduced and, when indirect tax revenues are considered the repletion program is nearly self-financing, with a modest budget deficit of $271,035. The total public costs are reduced as compared to Scenario 4 even though the distribution of public and private grounds production favors increased public grounds production. All other factors prices, revenues, etc. are the same as they were in Scenario 4 and the baseline condition.

Section 6.4.3: Scenario 6--Seed Dredging in Restricted Areas Only

The opinions expressed at the Fall of 1986 public hearings reflected the view that the establishment, by VMRC, of seed-dredging areas in the Piankatank and Great Wicomico would be acceptable to the watermen whereas similar areas in the James would be strongly opposed. This view has its origin in the fact that prior to VMRC's shelling efforts in the Piankatank and Great Wicomico neither of these river systems had been productive of seed. Since the VMRC was the agency to initiate the shelling, watermen view the VMRC as having property rights to the seed resources that were developed there. To reflect this policy environment, this scenario permits the dredging of seed only in the Piankatank and Great Wicomico rivers while allowing seed to be hand tonged in all river systems. Seed transplanting is still considered, and the repletion budget remains at $12,500,000. The results of this scenario are presented in Table 7.

Under a restricted-area seed-dredging policy the distribution of production between public and private areas is the same as it was under Scenario 5. This result indicates that

Table 6: Scenario 5: Seed Transplant and Seed Dredge or Tong

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,248,036.0
Private Harvest	4,500,004.0
Total Cost ($)	
Public	28,216,013.0
Private	13,473,271.0
Total	41,689,284.0
Average Cost ($/bushel)	
Total	3.0323
Public	3.0510
Private	2.9940
Repletion Budget ($)	11,057,677.0
Tax Collections ($)	5,178,423.0
Budget Deficit ($)	5,879,254.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-507.42
1125 (bushels/acre)	663.55
1500 (bushels/acre)	1249.03
Hand-Tonger	3736.84
Dredger	NA
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

Table 7: Scenario 6: Seed Transplant and Dredge Seed Except in the James River

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,248,045.0
Private Harvest	4,499,995.0
Total Cost ($)	
Public	28,317,594.0
Private	13,514,179.0
Total	41,831,773.0
Average Cost ($/bushel)	
Total	3.0427
Public	3.0620
Private	3.0031
Repletion Budget ($)	11,526,678.0
Tax Collections ($)	5,161,741.0
Budget Deficit ($)	6,364,937.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-507.42
1125 (bushels/acre)	663.55
1500 (bushels/acre)	1249.03
Hand-Tonger	3736.84
Dredger	NA
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

limiting the areas in which seed oysters may be dredged does not alter the relative cost-effectiveness of public as opposed to private grounds production. Limiting seed dredging does, however, increase the cost of attaining the harvest goal slightly to $41,831,773 as compared to Scenario 5. The repletion cost associated with restricting seed dredging is also increased over the unrestricted case. Additionally, under this scenario public rocks oyster repletion tax collections decrease compared to Scenario 5 and, when combined with indirect tax collections, a budget deficit of $756,718 results. Like the previous two scenarios prices, revenues, net returns, value added, and indirect tax revenues are unaffected by the particular form of the seed dredging policy adopted.

Section 6.5.0: Market Oyster Dredging Policy

The management area concept includes the possibility that market oysters areas may be identified and dredging of market oysters could be permitted in specific portions of river systems on a permanent basis or in response to changing resource abundance. Existing policy does permit the dredging of market oysters on a limited basis in carefully designated regions of the Bay. The following analysis examines two different management approaches to a market oyster-dredging policy. In each case the dredging of seed is not permitted, but seed transplanting is allowed, and the repletion budget is set at $12,500,000 for the ten-year planning period. It is assumed in each case that if a market oyster bed is harvested by dredging it will not become productive again until it is reshelled or reseeded. The cost per bushel of harvesting market oysters by dredging was estimated, using the budget analysis, to be $1.60. For each scenario the linear programming model was adjusted to reflect these changes.

Section 6.5.1: Scenario 7, Market Oyster Dredging-Only

The first market oyster dredging policy to be examined is one that would permit the dredging of market oysters on all oyster rocks in the State. The results of this scenario are presented in Table 8.

Under this scenario it is assumed that all market oysters harvested on public grounds will be harvested with a dredge. Permitting the taking of oysters with a dredge results in a greater share of total production going to the public grounds than under the baseline condition. The allocation of production is, however, identical to that determined in Scenario 3, the seed-transplant policy. The total public grounds cost of achieving the harvest goal decreases to $26,852,969 largely due to the decreased cost of harvesting the market oysters. The repletion budget, however, is nearly exhausted because of the increased repletion effort required to maintain the productivity of the public oyster rocks. Prices, total revenues, net returns to private planting, value added, and indirect tax revenues are the same as they were for the baseline condition. Since it is assumed that all harvest will be done with a dredge, net returns to hand tongers are excluded from consideration. Instead, using the budget simulator net returns to fixed costs and the operator of a dredge boat are estimated to be $21,309.52 per year. Private planter net revenues are the same as they were in the baseline condition because the dredging of seed is not permitted in this scenario.

Section 6.5.2: Scenario 8, Dredging Market Oysters in Restricted Areas

It is doubtful that pursuit of an unrestricted dredging policy to harvest market oysters would be politically acceptable or biologically responsible. A more sound approach may be to permit the dredging of oysters in limited areas of stock abundance or in areas where the sustainability of natural production is questionable. Scenario 8 evaluates the potential impacts of implementing a limited area market oyster dredging policy. The location and acreages of market oyster dredging areas and tong areas were

Table 8: Scenario 7: Seed Transplant and Dredge All Market Oysters

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,248,043.0
Private Harvest	4,499,997.0
Total Cost ($)	
Public	26,852,969.0
Private	14,077,380.0
Total 40,930,349.0	
Average Cost ($/bushel)	
Total	2.9771
Public	2.9036
Private	3.1283
Repletion Budget ($)	12,467,420.0
Tax Collections ($)	5,029,292.0
Budget Deficit ($)	7,398,128.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-792.42
1125 (bushels/acre)	85.80
1500 (bushels/acre)	964.03
Hand-Tonger	NA
Dredger	21,309.52
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

determined by using the results of the linear programming model. As described earlier, the linear program selected the dredge and tong areas by selecting the least costly combination of river system and harvest gear to produce market oysters. Table 9 presents the results of the analysis for this scenario.

Establishing market oyster dredge areas results in a higher portion of total harvest going to the public as compared to the baseline condition or any other scenarios examined previously. At $39,990,807 the total cost of attaining the market oyster production goal is lower than that of any scenario evaluated previously. The reason for this result is that the majority of the public grounds production is attributable to the transplanting of seed. It was assumed, upon the recommendation of VMRC repletion officers, that only those areas that did not receive a natural set would be candidates to receive transplanted seed. This condition is precisely that which would make a particular market oyster bed a suitable area for dredging. Since the majority of the public grounds harvest comes from these dredged areas, the total cost of achieving the harvest goal is lower than it would be otherwise.

Permitting the dredging of market oysters in limited areas makes those areas cost-effective relative to comparable private grounds. This result can be seen as the public grounds production in this scenario is greater than that in the baseline condition or any other scenario previously examined. In this scenario public grounds production in which oysters were harvested with a dredge were selected over alternative private grounds because the harvest cost reduction afforded by the dredge policy made these grounds more cost-effective than would be the case if they were tonged. The repletion budget required to meet this public grounds production level falls within the prespecified spending limit of $12,500,000 but exceeds the amount at which the repletion program could be made self financing through direct and indirect revenue sources. Since total public plus private grounds production is equivalent to that in the baseline condition, prices, revenues, private planter net revenues, value added, and indirect taxes are the same as estimated for the baseline condition. Net returns to fixed costs and management for a representative dredger are the same as they were in Scenario 7. The cost and price conditions faced by public grounds hand tongers have not changed and, therefore, estimated net returns for an average hand tonger working in a dredge-restricted area, are equivalent to those in the baseline condition.

Section 6.6: Combinations of All Strategies

The remaining policy simulations represent three different combinations of all the individual policies examined above. The first combination, Scenario 9, permits the transplanting of seed, the dredging of market oysters in limited areas, and the dredging of seed oysters in all seed areas. The second policy combination, Scenario 10, is equivalent to the first with the exception that seed dredging is permitted in limited areas only as determined by the results of the linear programming model. The last policy combination, Scenario 11, is the same as the second except that seed dredging is not permitted in the James river. The results of these respective policy combinations are presented in Tables 10, 11 and 12.

Under all three policy combinations total State harvest is the same and, therefore, prices, revenues, value added, indirect tax revenues, and net returns for public grounds harvesters are the same for each scenario. Private planter net returns are the same for all three scenarios as well, but net revenues are higher than in the baseline condition because of the availability of dredged seed. In scenario 9, where all seed oysters are harvested with a dredge, total costs and repletion costs are higher than when only limited dredging is allowed. Scenarios 10 and 11 attain very similar results with respect to the allocation of production between public and private grounds, the total public and private

Table 9: Scenario 8: Seed Transplant and Harvest Market Oysters By Dredge or Tong

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,646,834.0
Private Harvest	4,101,206.0
Total Cost ($)	
Public	27,146,840.0
Private	12,843,967.0
Total 39,990,807.0	
Average Cost ($/bushel)	
Total	2.9088
Public	2.8140
Private	3.1317
Repletion Budget ($)	12,299,954.0
Tax Collections ($)	5,248,199.0
Budget Deficit ($)	7,051,755.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-792.42
1125 (bushels/acre)	85.80
1500 (bushels/acre)	964.03
Hand-Tonger	3,736.84
Dredger	21,309.52
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

Table 10: Scenario 9: Seed Transplant, Tong or Dredge Market Oysters And Dredge All Seed

Total Harvest (Bushels)	13,748,040.0
Public Harvest	8,926,984.0
Private Harvest	4,821,056.0
Total Cost ($)	
Public	28,983,169.0
Private	15,035,181.0
Total	44,018,350.0
Average Cost ($/bushel)	
Total	3.2017
Public	3.2466
Private 3.1186	
Repletion Budget ($)	12,500,000.0
Tax Collections ($)	5,345,782.0
Budget Deficit ($)	7,154,218.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-507.42
1125 (bushels/acre)	663.55
1500 (bushels/acre)	1249.03
Hand-Tonger	3,736.84
Dredger	21,309.52
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

Table 11: Scenario 10: Seed Transplant, Dredge or Tong Market Oysters and Dredge or Tong Seed

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,248,044.0
Private Harvest	4,499,996.0
Total Cost ($)	
Public	28,216,012.0
Private	13,473,271.0
Total	41,689,283.0
Average Cost ($/bushel)	
Total	3.0323
Public	3.0510
Private	2.9940
Repletion Budget ($)	11,410,809.0
Tax Collections ($)	5,350,003.0
Budget Deficit ($)	6,060,806.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-507.42
1125 (bushels/acre)	663.55
1500 (bushels/acre)	1249.03
Hand-Tonger	3,736.84
Dredger	21,309.52
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

Table 12: Scenario 11: Seed Transplant, Dredge or Tong Market Oysters and Dredge Seed Except in The James

Total Harvest (Bushels)	13,748,040.0
Public Harvest	9,248,036.0
Private Harvest	4,500,004.0
Total Cost ($)	
Public	28,347,624.0
Private	13,502,133.0
Total	41,849,757.0
Average Cost ($/bushel)	
Total	3.0440
Public	3.0652
Private	3.0004
Repletion Budget ($)	11,563,183.0
Tax Collections ($)	5,282,057.0
Budget Deficit ($)	6,281,126.0
Prices ($/Pound)	
Ex-Vessel	0.85889
Wholesale	1.23894
Retail	2.10822
Total Revenues ($)	
Harvester	55,124,719.64
Processor	79,516,841.68
Retailer	135,308,405.56
Net Revenues ($/Year)	
Private Planter	
750 (bushels/acre)	-507.42
1125 (bushels/acre)	663.55
1500 (bushels/acre)	1249.03
Hand-Tonger	3,736.84
Dredger	21,309.52
Value Added	47,729,529.00
Indirect Tax Revenues	5,608,219.70

costs of attaining their respective harvest levels, and the repletion funding required to meet the harvest goal. Direct tax revenues are slightly higher, however, in Scenario 10, making it, of the three policy combinations, the one that comes closest to resulting in a self-financing oyster repletion program.

Section 7.0: Discussion of Results and Recommendations

This section will compare the results of the alternative model simulations. The comparisons will be to the pre-OFMP condition (Scenario 1) and the baseline condition (Scenario 2). Recall that the baseline condition begins with a recognition that the state is committed to an expanded repletion program and to increasing oyster harvests as a result. The challenge to VMRC is to utilize this increased budget authority to meet the goals of the stated management plan. In Section 2.2 the goal statement was summarized as follows:

The State should seek to implement management strategies to increase oyster harvests above their currently depressed levels, subject to the following conditions:

- *Total production should be divided between public and private grounds conditional on the maintenance of a minimum level of public grounds harvest.*
- *The production goal should be attained in the least costly manner possible, recognizing the increasingly competitive national oyster market.*
- *Repletion program expenditures should stay within a predetermined annual repletion budget.*
- *The repletion program should be self sufficient, with no unwarranted state subsidy to private planters or Baylor grounds harvesters.*
- *Regulatory measures should assure continued access to the naturally productive Baylor grounds for those watermen who wish to earn income from oystering.*

The results of the model analysis give insights into the management approaches needed to assure attainment of these goals. The discussion which follows will draw upon the results reported in Section 6 and Table 13, which is a summary of certain results from Section 6.

The modeling results suggest that a 1.4 million production target is achievable. However, this target can not be achieved within the expected $12.5 million ten-year repletion budget if the only repletion strategy is shelling for market oysters. The management strategies which include at least some seed transplanting will permit the production goal to be attained within allowed repletion program spending limits.

Compared with pre-OFMP conditions, any management strategy will result in reduced oyster prices but increased gross revenue, state economic activity of over $47 million for the ten-year period, and indirect tax revenues on this economic activity of $5.6 million for the period because of increased harvests. For the individual hand tonger the scenarios all promise increased income from oystering compared with the pre-OFMP condition. This increase occurs despite the price-depressing effect of increased production. For the private planters some scenarios make them worse off financially, compared with pre-OFMP conditions. This occurs in those cases where the OFMP induces a price-depressing production increase, but does not offer offsetting reductions in private planting costs through seed price reductions. Thus, although the model suggests that the production goal might be achieved for any scenario and that a mix of private and public production is possible, the economic feasibility of private oyster planting is reduced from pre-OFMP conditions in some cases. Specifically, Table 13

Table 13: Comparison of Policy Scenarios to the Baseline Condition

Scenarios	Average Total Cost per Bushel	Repletion Budget	Budget Deficit W/O Indirect Taxes	Budget Deficit W/ Indirect Taxes	Subsidy Rate	Public Grounds Net Revenues Tonger	Public Grounds Net Revenues Dredge	Private Planter Net Revenues (1125 Bushels/Acre)
Scenario 1	NA	8,282,570	4,101,320	1,328,707	.207	1,252.69	NA	489.93
Baseline (Scenario 2)	3.4382	13,836,105	9,465,229	3,857,080	.281	3,736.84	NA	85.80
Scenario 3	3.1226	12,050,558	7,140,125	1,531,906	.111	3,736.84	NA	85.80
Scenario 4	3.1997	12,500,000	7,450,179	1,841,960	.134	3,736.84	NA	663.55
Scenario 5	3.0323	11,057,677	5,879,254	271,035	.020	3,736.84	NA	663.55
Scenario 6	3.0427	11,526,678	6,364,937	756,718	.055	3,736.84	NA	663.55
Scenario 7	2.9771	12,467,420	7,398,127	1,798,908	.131	NA	21,309	85.80
Scenario 8	2.9088	12,299,954	7,051,755	1,443,536	.105	3,736.84	21,309	85.80
Scenario 9	3.0880	12,500,000	7,154,218	1,545,999	.112	3,736.84	21,309	663.55
Scenario 10	2.9055	11,410,809	6,060,806	452,587	.033	3,736.84	21,309	663.55
Scenario 11	2.8653	11,563,183	6,281,126	672,907	.049	3,736.84	21,309	663.55

NA = not applicable

shows $85 per acre per year net returns for the baseline condition (Scenario 2) and Scenarios 3, 7 and 8. Pre-OFMP returns for a planter harvesting 1125 bushels per acre were estimated at $490 per year. With the economic conditions existing in the oyster industry at this time, it seems likely that reductions in returns to private oyster culture will discourage industry entrants and lead to the exit of existing growers. Therefore, without further analysis it appears that these management approaches would not achieve the OFMP total production goal, because of the adverse effect on the economics of private planting. The common characteristic of all these scenarios is that they rely only upon tong harvest of seed. Only by dredge harvest, recognizing that dredge seed is assumed to be lower in productivity per bushel and will require more frequent seed bed shelling, does the production goal appear achievable. Note that dredge harvest need not be in the James River (Table 1). Further discussion of these points is included in sections below. However, the first management implication is clear.

Implication 1: The OFMP must adopt policies which lower seed prices to private planters by permitting dredge harvest of seed. The OFMP will directly affect the economic feasibility of private planting by lowering market oyster prices and can only be offset by policies to lower seed prices.

Section 7.1: Competitive Production Cost

The national market for oyster production is becoming increasingly competitive. Production from the Pacific Coast is now being added to South Atlantic production as a competitor to Chesapeake Bay oysters. One important aspect of a competitive advantage will be oyster prices which will in turn depend on cost of production. Therefore, the need to attain production targets at lowest cost is understandable. The least cost strategy, according to Table 13, is scenario 11. Scenarios 7 and 8 run a close third and fourth behind Scenarios 11 and 10. Scenarios 7 and 8, however, result in substantially lowered returns to private planting (as compared to pre-OFMP conditions) and would, as noted earlier, be likely to discourage private oyster planting. Thus, scenarios 7 and 8 are acceptable only if the public grounds are increasingly the focus of the OFMP and the private planters are allowed to exit from the industry. The latter is not consistent with the policy statement. Scenarios 4, 5, 6, 9, 10 and 11 all are cost-minimizing strategies which raise private planter's returns over the pre-OFMP condition. These scenarios all have the common characteristic of allowing seed dredging. Thus a second management implication is obtained:

Implication 2: The national competitiveness of the Virginia oyster industry will be enhanced if seed dredging is allowed and if seed transplanting is the basis for the repletion program for the public grounds.

Section 7.2: Repletion Budget

The ORP represents public subsidy to the oyster industry. However, in view of repletion tax collections and indirect tax revenues the entire magnitude of the subsidy should be evaluated in terms of the amount of repletion expenditures not recovered through tax collections. The effective subsidy to the industry can be measured by the amount of the budget deficit after all direct and indirect taxes have been considered. The budget deficits that would result from each policy scenario are displayed in column 4 of Table 13. An effective subsidy rate (the ratio, budget deficit:total harvest) is also computed for each scenario and reported in column 5 of Table 13.

There is no scenario that results in a zero deficit in the repletion budget without consideration of indirect tax revenues. However, Scenarios 5, 6, 10 and 11 result in modest repletion budget deficits if indirect tax revenues are considered. The characteristic that all these scenarios have in common is that they all include seed dredging. Given the imprecision of the indirect tax revenue estimates, it appears that Scenarios 5, 6, 10 and 11 all permit near-full recovery of relatively low repletion spending from direct and indirect taxes. However, a shelling-only repletion strategy (the baseline condition) will result in substantial deficits.

Implication 3: Self sufficiency of the repletion budget is possible, if indirect tax revenues are considered and dredge seed harvest and seed transplant are part of the OFMP repletion strategy.

Section 7.3: Income and Access to Baylor Grounds

It was noted in Section 7.0 that hand tong labor realizes an increase in net income in Scenario 2-11 due to the increased productivity of the Baylor grounds. Table 13 shows the increase to be $3,736 per year to operator labor and the boat. Additionally, in the instances where Baylor grounds dredging is allowed, harvesters are estimated to earn an annual net return of $21,309 to the dredge operator and boat. Of course the boat costs would be higher for the dredge operator so the difference in returns between hand tong and dredge effort is less than suggested by these figures.

If the OFMP is to succeed, it is necessary to evaluate these net returns figures to determine whether they are sufficient to attract a sufficient labor force to harvest the production goal. Consider that for the Pre-OFMP condition public grounds harvest was 341,780 bushels. Assuming that an average hand-tonger fishes 75 days each year and harvests 10 bushels per day (as assumed in the cost budgets), it would take 331.42 full time equivalent (FTE) tongers to harvest the 341,780 bushels. The first two columns of Table 14 show the number of full time hand tongers and dredgers that would be required to harvest market and seed oysters for each scenario. These figures were computed assuming that due to the OFMP production targets the average hand tonger would harvest 20 bushels per day while still fishing for 75 days and the average dredger would fish for 75 days per year and harvest 160 bushels of market oysters per day. Note that only in Scenario 7 (where all market oysters are harvested by dredge) does the annual hand tong labor required for the production goal fall below that of the pre-OFMP condition. All other scenarios, including Scenario 11 where the dredging of seed and market oysters is permitted, result in greater hand tong labor demand than the pre-OFMP condition. These findings indicate that, with the exception of Scenario 7, permitting managed dredging will not adversely affect the existing tong labor force either in terms of income opportunities or access to the Baylor grounds. Indeed in each case an increase in the tong labor force is called for.

The issue that must be confronted is whether or not the hand tong labor force required in each scenario would, in fact, be allocated into the tong fishery. Although the number of watermen willing to offer their labor to the existing tong labor force is difficult to predict, the survey findings of Santopietro (1986) do provide some insights into this question. First, while more than 60% of the watermen surveyed held a tong license, only 10% of their income came from harvesting oysters. Second, the average age of a hand tong license holder is increasing over time. These findings suggest that holders of hand tong licenses are primarily engaged in activities other than oystering and that there is little recruitment of tong labor to the fishery. Furthermore, opportunity costs of labor and changing seashore community structure suggest that few new persons will enter the hand tong fishery given the modest increase in returns for hand tong market oyster harvesters. Therefore, if only tong harvest is allowed, it seems unlikely that the additional numbers required to harvest the 1,400,000 bushel goal (a harvest goal in excess of twice that in the baseline condition) will be found if only hand tong harvest is allowed.

Table 14: Shell Requirements and Labor Requirements

Scenario	Annual Public Tong Harvesters (full time)	Annual Public Dredge Harvesters (full time)	Tonged Seed Oysters (bushels)	Dredged Seed Oysters (bushels)	Tonged Public Market Oysters (bushels)	Public Dredged Market Oysters (bushels)	Private Market Oyster (bushels)	Shells Planted (bushels)
1	331.42	NA	NA	NA	3,418,700	0.0	3,001,030	16,611,940
2	642.43	25.01	2,986,596	0.0	8,143,130	0.0	5,604,902	36,338,287
3	712.01	46.71	2,864,140	0.0	9,248,030	0.0	4,500,003	21,057,255
4	616.54	37.50	0.0	5,646,569	8,970,320	0.0	4,777,712	22,399,938
5	684.35	63.34	2,304,281	3,509,766	9,248,030	0.0	4,500,004	16,951,666
6	706.18	52.12	2,689,511	2,687,674	9,248,040	0.0	4.499,995	15,426,108
7	148.42	48.70	4,452,706	0.0	0.0	9,248,043	4,499,997	13,770,270
8	492.11	114.57	4,247,813	0.0	5,257,734	4,389,099	4,101,206	13,379,659
9	350.62	70.75	0.0	8,641,326	5,259,293	3,703,999	4,784,742	22,353,055
10	414.04	87.10	1,848,154	4,131,721	5,286,534	4,217,498	4,244,010	17,475,537
11	439.41	82.10	2,702,734	2,688,914	5,239,784	4,246,099	4,262,157	15,430,812

NA = not applicable

Alternatively, if some dredge harvest were permitted, the increase in hand tong labor required to harvest the production goal would be reduced. For example, in the baseline condition it would require a near doubling over pre-OFMP levels of the number of hand tongers needed to harvest the public grounds production that would occur under the management plan. It is only when managed dredging of market oysters is considered that the numbers of hand tongers required to harvest the public grounds production seem feasible given the potential for little new entry into the tong labor force, due to the modest increase in returns to hand tongers. Note that the scenarios that include managed dredging of the public grounds (7, 8, 9, 10 and 11), with the exception of Scenario 7, compare favorably with the number of hand tongers in the pre-OFMP scenario (Scenario 1), suggesting that few persons would be replaced with a dredge policy. As oyster production grows, increased use of dredge harvest could be permitted. Indeed, it seems that without dredge harvest of market oysters the production goal cannot be met.

Implication 4: It is possible to meet production goals, maintain access to Baylors, and assure adequate income to harvesters only by permitting a mixed strategy of hand tong and managed dredge harvest of market oysters on the Baylor grounds.

Section 7.4: Shell Requirements

Given the relative difficulty VMRC has had with obtaining sufficient shell supplies for its current repletion activities, it is important to assess the shell requirements for each scenario. Table 14 lists the amount of shell that would be required in order to meet the harvest goal. In the pre-OFMP condition (Scenario 1) 1,661,194 bushels of oyster shell were planted. On a ten-year basis this level of shelling would amount to 16,611,940 bushels. If pre-OFMP repletion strategies are maintained (Scenario 2) a shelling-only strategy would require 36,338,287 bushels of oyster shell over the ten-year period, more than double the pre-OFMP amount. It seems unlikely that such a shelling level can be sustained given limited access to house shell and uncertain quantities of reef shell. Only Scenarios 5, 6, 7, 8, 10 and 11 call for shell quantities that are reasonably close to those used in the pre-OFMP condition. At a minimum each of these scenarios calls for a repletion program heavily oriented toward the transplanting of seed.

Implication 5: Given the limited availability of house shell and uncertain supplies of reef shell, only a repletion strategy that, at a minimum, emphasizes transplanting seed will be capable of meeting and sustaining the production goal set for the OFMP.

Section 7.5: Recommendations and Discussion

Only Scenarios 10 and 11 are capable of meeting the multiplicity of goals set for the OFMP. The management characteristics associated with these scenarios are that all repletion strategies and all harvest strategies are possible. Because of the political sensitivity of the issue of seed dredging in the James, Scenario 11, which does not permit dredging the James River seed beds, would be favored. Table 15 provides a summary comparison of activity levels for selected policy variables for the baseline condition as compared to Scenario 11.

The general outline of a management plan following Scenario 11 and drawing upon the results of the model can be described. First, in 11 the repletion program concentrates its activities on shelling for a set in good seed areas and then harvesting seed by dredge in all areas except the James for grow-out in other areas. Associated with this strategy is the fact that seed prices would be lowered, encouraging more private planting. Seed areas that might be considered are the Piankatank and Great Wicomico Rivers. Once

Table 15
Summary of Annual Acivity Levels: Baseline Compared to Scenario 11

	Year 1	Year 2	Year 3	Year 4	Year 5
Public Grounds Cost ($1000)					
Baseline	4289	1355	1374	1990	4282
Scenario 11	1499	1729	2297	2089	2438
Private Grounds Cost ($1000)					
Baseline	0	1183	1225	2388	2384
Scenario 11	0	1086	431	1823	1451
Repletion Cost ($1000)					
Baseline	3516	582	601	575	2867
Scenario 11	1022	1250	1250	1250	1250
Tax Collections ($1000)					
Baseline	191	228	230	390	390
Scenario 11	192	241	240	398	603
House Shell ($1000 bu)					
Baseline	8854	472	526	453	7000
Scenario 11	849	286	286	286	681
Reef Shell (1000 bu)					
Baseline	914	914	914	914	914
Scenario 11	914	914	923	914	914
Public Harvest (1000 bu)					
Baseline	383	383	383	700	700
Scenario 11	383	383	383	702	1113
Private Harvest (bu)					
Baseline	0	0	0	700	700
Scenario 11	0	0	0	698	287
Leased Acres					
Baseline	0	493	510	530	528
Scenario 11	0	465	191	304	422
Repleted Acres (Shelled)					
Baseline	1264	244	235	234	888
Scenario 11	297	217	217	217	273
Repleted Acres (Tranplants)					
Baseline	0	0	0	0	0
Scenario 11	113	225	523	375	225
Acres Tonged (Market)					
Baseline	1264	244	234	234	888
Scenario 11	217	217	217	217	217
Acres Dredged (Market)					
Baseline	0	0	0	0	0
Scenario 11	113	225	523	375	225
Acres Tonged (Seed)					
Baseline	35	35	35	35	35
Scenario 11	115	35	36	35	91
Acres Dredged (Seed)					
Baseline	0	0	0	0	0
Scenario 11	0	0	0	0	0

*Note that some of the totals do not exactly match those reported previously. Results reported previously included some production and, therefore, costs that occur beyond the ten-year planning period but are attributable to activities conducted during the planning period. The summary presented above includes only the ten-year totals.

Table 15 (Continued)
Summary of Annual Acivity Levels: Baseline Compared to Scenario 11

	Year 6	Year 7	Year 8	Year 9	Year 10	TOTAL
Public Grounds Cost ($1000)						
Baseline	5045	1932	1932	2508	2398	27106
Scenario 11	3599	2988	2381	3431	3191	25644
Private Grounds Cost ($1000)						
Baseline	2258	1782	1973	1496	1872	16561
Scenario 11	1103	1686	1383	1365	1455	11783
Repletion Cost ($1000)						
Baseline	3629	517	517	517	517	13836
Scenario 11	1250	1250	956	1250	1250	11978
Tax Collections ($1000)						
Baseline	386	371	377	518	500	3580
Scenario 11	518	430	623	528	431	4203
House Shell ($1000 bu)						
Baseline	6867	286	286	286	286	25317
Scenario 11	445	286	178	526	178	4002
Reef Shell (1000 bu)						
Baseline	2795	914	914	914	914	11022
Scenario 11	914	914	1022	1022	1022	9473
Public Harvest (1000 bu)						
Baseline	700	700	700	984	930	6562
Scenario 11	943	767	1154	962	767	7556
Private Harvest (bu)						
Baseline	700	700	700	416	470	4386
Scenario 110	457	633	246	438	633	3392
Leased Acres						
Baseline	475	277	355	346	467	3981
Scenario 11	164	291	422	285	186	2730
Repleted Acres (Shelled)						
Baseline	1209	217	217	217	217	4942
Scenario 11	217	239	217	217	217	2328
Repleted Acres (Tranplants)						
Baseline	0	0	0	0	0	0
Scenario 11	523	375	225	383	408	3375
Acres Tonged (Market)						
Baseline	1209	217	217	217	217	4941
Scenario 11	217	217	217	217	217	2170
Acres Dredged (Market)						
Baseline	0	0	0	0	0	0
Scenario 11	523	375	225	383	408	3375
Acres Tonged (Seed)						
Baseline	35	35	35	35	45	360
Scenario 11	57	35	35	35	45	519
Acres Dredged (Seed)						
Baseline	0	0	0	0	0	0
Scenario 11	0	0	0	50	0	50

*Note that some of the totals do not exactly match those reported previously. Results reported previously included some production and, therefore, costs that occur beyond the ten-year planning period but are attributable to activities conducted during the planning period. The summary presented above includes only the ten-year totals.

transplanted, market oyster harvest would be by dredge. Tong harvest would be reserved for those areas that are shelled to receive a natural set for market oyster production.

The harvest of seed and market oysters would likely require regulation of access to the managed dredge sites. It is recognized that the assignment of dredge rights would be politically sensitive and would require careful study to allocate rights in an equitable manner. One possible means of limiting numbers could include giving dredging rights to holders of hand tong licenses who would then dredge or sell their right to others who wish to dredge. Other possibilities would need to be explored.

This management strategy is realistic in that it results in a technically attainable goal and is consistent with the economic realities that can keep the Virginia harvest sector and private planter competitive with other oyster-producing regions. In this regard, it is important to note that the final model structure has been formed to favor tong harvest of seed and market oysters. As a result the fact that dredge activity is at all suggested is that much more significant, particularly with regard to seed. The primary examples of the intentional bias toward tong harvest are the following:

1. Seed bed shelling requirements: For tong harvest, shelling is assumed to be required only once every four years. Setting success declines only 10% per year between shelling. For dredge harvest, shelling is assumed to be required every year. Setting success goes to zero if not reshelled.

2. Productivity of Seed: Tong seed is assumed to be twice as productive of market oysters as is dredge seed. In other words, spat count per bushel is one half that of tong seed.

Logic suggests that these are extreme assumptions. To illustrate, if it is the case that shelling for dredging occurred every four years and if it is assumed that productivity declined 50% (as distinct from the extreme model assumption of the need to reshell yearly) the model would always choose dredge over tong harvest. Thus, even this radical decline in setting rates (50%) on dredged beds relative to the tonged beds (10%) still favors dredging.

The productivity of seed also was biased toward tonging. To ilustrate, assume a spat count of 600-800 per bushel for hand tong seed. The model assumes a spat count of 300-400 for dredge seed. However, the Potomac River Fisheries Commission has permitted the dredge harvest of seed for a number of years. Their spat counts per bushel were 477, 514, and 503 for 1982, 1983, and 1984 respectively.

Taken together, modest, and probably defensible, adjustments to seed bed shelling requirements and seed productivity for tong vs. dredge harvest would tilt the model solution entirely toward dredge harvest of seed. The effects would be to (1) reduce average costs below those shown in Table 13, (2) reduce the repletion budget and repletion budget deficits shown in Table 13, (3) enhance the access to and income potential from the Baylor grounds and (4) enhance the returns to private planting shown in Table 13.

The results of the models developed for this work can only be a guide to change. Any change which is instituted will come slowly and must be carefully monitored. However, change is needed if there are to be increased oyster production, a labor force that is willing to harvest the oysters, and a private sector that is willing to invest in oyster planting. In summary, the needed changes are:

(1) A repletion program emphasis on seed transplant.

(2) A program for managed dredging of seed and market oysters.

The alternative is the continued decline of the industry as labor and capital resources leave the sector and as other areas capture Virginia's oyster market.

Appendix A

The Linear Programming Model

Appendix A

The Linear Programming Model

Appendix A is reported in two parts. Part one provides a technical description of a linear programming model that was developed under Sea Grant funding. Part two presents a discussion of the technical information incorporated into the models described in Part 1. For more information, a complete description of all aspects of the model, a Master's thesis entitled, "A Decision Model to Evaluate the Cost-Effectiveness of Alternative Oyster Grounds Management Strategies" (Thunberg, 1985) should be consulted.

Appendix A, Part 1

The Linear Programming Model: Technical Structure

Appendix A, Part 1

The Linear Programming Model: Technical Structure

Section 1.0: Introduction

The Virginia Marine Resources Commission (VMRC) is responsible for the management of all oyster bottoms within the State's domain. VMRC is charged with the administration of the Oyster Repletion Program (ORP) and the formulation and enforcement of policies and regulations governing the production and harvest of oysters on public and private oyster beds. In attempting to achieve repletion and total State market oyster production goals, VMRC must allocate limited resources over time among alternative aquacultural practices and river systems. In addition, VMRC must evaluate and recommend regulations on harvest of seed and market oysters.

These resource allocation and policy decisions should provide for the attainment of oyster production goals at minimum cost to public and private interests over time. VMRC's repletion activities and policies affect both public and private costs of producing market oysters. VMRC, therefore, should concern itself not only with the costs of administering and conducting its activities, but also how its actions affect the cost to private individuals harvesting oysters on public grounds or producing market oysters on leased bottoms. The decision problem faced by VMRC is one of minimizing costs over time, subject to limits of resource availability, market oyster production potential, and the range of policy options available. Linear Programming (LP) is a mathématical optimization technique that can be used to determine an optimal solution to this decision problem.

A multi-period LP model permits the simultaneous consideration of many different repletion and policy alternatives while recognizing that VMRC's decisions take place over time. In addition to being an optimization technique, LP provides useful information pertaining to shadow prices for included constraints, and the sensitivity of the model's solution with respect to changes in objective function or constraint coefficients.

Within a linear programming framework, VMRC's management problem may be stated in the following way. The VMRC has limited funds for repletion purposes, ie. planting shell or seed. VMRC may also choose to substitute repletion activities with policy changes designed to increase market oyster harvest, such as permitting dredging of seed or leasing of unproductive Baylor grounds. By allocating its funds and implementing alternative policies, VMRC can provide many combinations of aquacultural practices and policies to achieve a given market-oyster harvest goal. These combinations form the activities of an LP model. Knowing how much each activity contributes to the harvest goal, and recognizing its limited resources, the Commission must determine the unique mix of activities required to meet a harvest goal at minimum cost over its planning horizon.

Section 2.0: The Linear Programming Model

The linear programming model described below is the model which has been formulated to analyze VMRC's decision problem. The model considers the production of market oysters from public and private grounds over a period of ten years. All model activities are assumed to be initiated at the beginning of the year in which they occur.

The ten-year planning horizon may be thought of as consisting of two distinct parts. The model is formulated as if no repletion program existed prior to the first year of the model's planning period. The first part of the planning horizon, therefore, is an interim period over which no market oyster harvest goal is set. This interim period is necessary because oysters take, on average, 2-5 years to reach the three inch minimum legal harvestable size (Haven et al. 1981a). A lag, therefore, exists between the time production activities are initiated and the time market oysters become available for harvest. The length of the lag depends on whether seed (2-3 year lag) or shell (3-5 year lag) is planted and the growth potential of the receiving system. The second part of the planning horizon is the period of years over which a specified market-oyster harvest goal may be set.

In the model all public and private oyster bottoms in Virginia have been disaggregated into the 13 river systems listed in Table A.1.

The indicated number for each river system corresponds to the system location depicted in Figure A.1*. The Potomac river is managed jointly by Maryland and Virginia and is not considered in the model. Separate river systems were identified using two criteria; i) geographic location and ii) similarities in environmental characteristics important for oyster growth.

Section 2.1: The Objective Function

The objective of the linear programming model is to minimize the present value of public plus private costs of producing a prespecified level of market oyster harvest over the ten year planning horizon. The public costs included in the model are expenditures for contracted services incurred by VMRC as it carries out its repletion program. Private costs considered in the model are all costs incurred by private planters in the production and harvesting of market oysters and the cost of harvesting market oysters to watermen working the public grounds. It is often assumed that the public sector has a longer-term investment horizon relative to the private sector. Given this assumption, an interest rate of 4.51 percent was used to discount public costs to the end of the first period. This public rate reflects the 1983 quarterly average interest rate offered on long-term state and local government securities (Federal Reserve Bulletin 1984) adjusted by a 5 percent inflation rate. Private costs were discounted by an interest rate of 6.0 percent. The private rate is equivalent to the 1983 prime rate on short term business loans adjusted by a 5 percent inflation rate. The short term private interest rate was used because it is assumed that such loans would be used to cover operating expenses incurred between harvest periods.

Section 2.2: Model Activities

There are two general types of activities considered in the model. Activities that result in market oyster production, hereafter referred to as primary activities, are represented in Figure A.2 by the rectangular boxes. The primary activities of Figure A.2 are the final products of the production process depicted by a flow chart for each activity. Activities which do not directly result in the production of market oysters are represented by the circles in Figure A.2.

---

*Originally only ten river systems were identified for modeling. Upon the recommendation of VIMS oyster biologists, the James and York rivers were split into two regions each, the Rappahannock was split into upper, mid- and lower sections and the Corrotoman river was incorporated into the Lower Rappahannock, forming the 13 river systems listed in Table A.1.

	Table A.1: Description of Model River Systems	
1	Upper James	above James River Bridge
2	Lower James	below James River Bridge
3	Upper York	
4	Lower York	
5	Mobjack Bay	including North, East, Ware and Severn Rivers
6	Piankatank	
7	Upper Rappahannock	
8	Mid-Rappahannock	
9	Lower Rappahannock	including the Corrotoman to Windmill Point
10	Great Wicomico	
11	Upper Management Area	Windmill Point to Smith Point
12	Pocomoke and Tangier	including Baylor bottoms on the Bayside of Eastern Shore
13	Eastern Shore Seaside	

Section 2.2.1 Primary Activities

The four primary activities are based on current harvest regulations and aquacultural practices used in the Chesaspeaske Bay by public and private culturists. Each of these activities is uniquely defined by aquacultural technique, harvest technology, bottom ownership and production period.

The first primary activity is a shell-to-harvest activity where fresh or dredged oyster shells are planted on Baylor bottoms by VMRC to receive a set. The resulting young oysters are left to grow to a harvestable size. This aquacultural technique has for many years been the most important part of VMRC's repletion strategy. For this reason and because setting rates on private grounds are usually insufficient to make shell-to-harvest economically feasible, the model includes only the Baylor bottoms as candidates for oyster production using this technique. Setting rates vary from river system to river system. A shell-harvest activity is included in the model for only those river systems (listed in Table A.2), determined by a literature survey and consultation with oyster management professionals, with sufficient setting rates to make shell-to-harvest a feasible oyster production activity.

The shell-to-harvest activity is carried out on Baylor grounds. Harvesting, therefore, is done by hand tongers. A four-year growing period is assumed to be

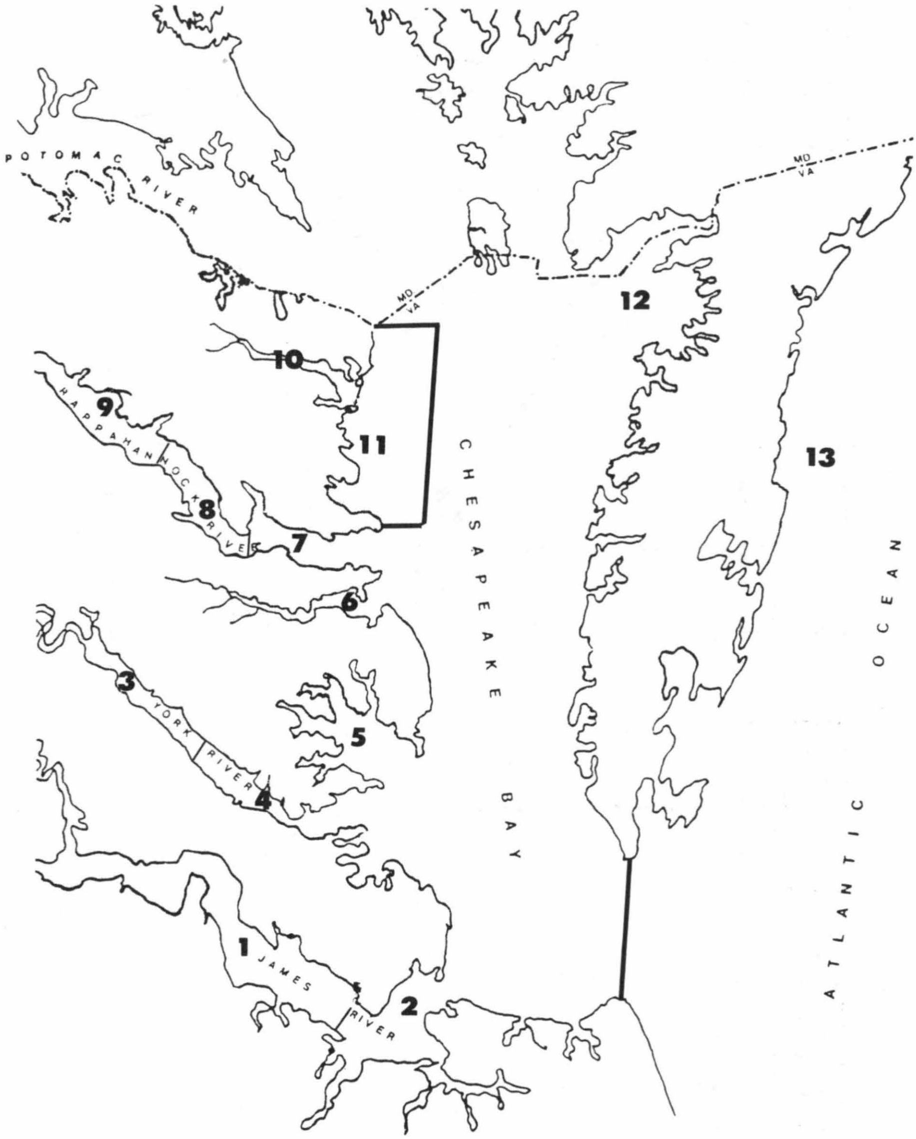


Figure A.1: Model River Systems

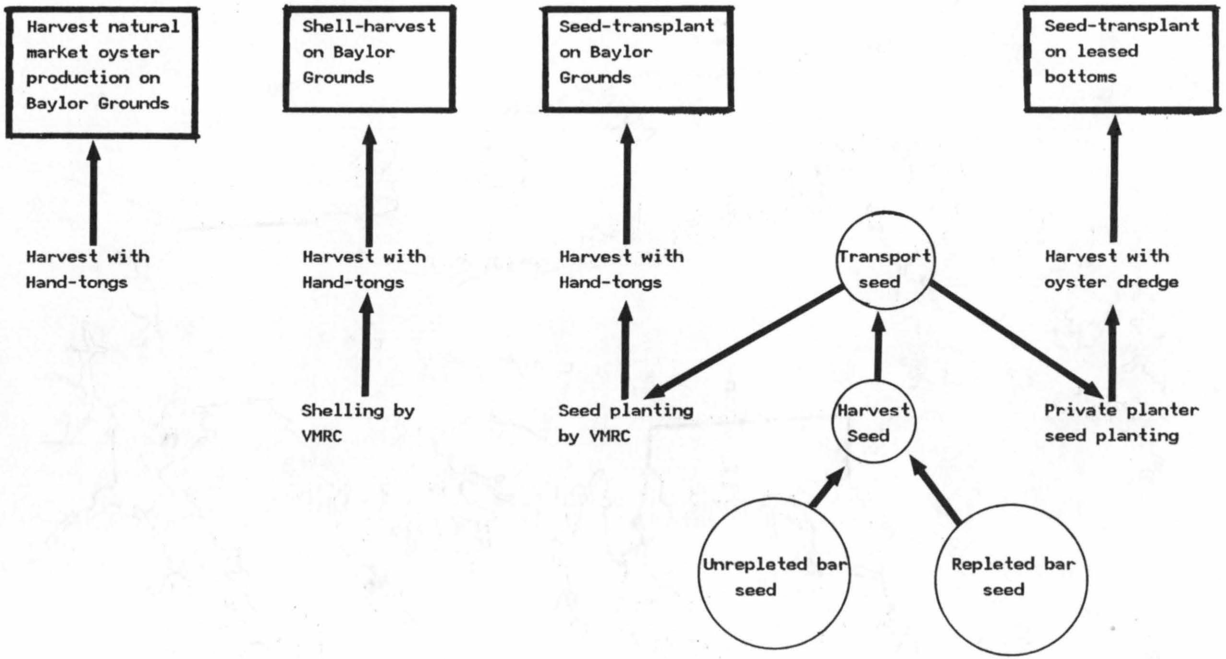


Figure A.2: Diagram of Model Activities

Table A.2: Feasible Shell-Harvest River Systems
Great Wicomico
Mid-Rappahannock
Lower Rappahannock
Mobjack Bay
Seaside Eastern Shore
Piankatank
Upper Management Area
Pocomoke and Tangier

required from the time the shelling is initiated to the time the first harvestable oyster is taken. Upon consultation with VMRC repletion personnel it was further assumed that the shelled oyster bed will remain productive, but at a declining rate, for four years after the first oyster is harvested. A annual decline in productivity of ten percent of the previous years standing crop was assumed.

The second and third primary activities are seed transplant-to-harvest activities. This activity involves harvesting seed from seed areas and transplanting the seed to grow-out areas on Baylor grounds or to growing areas on leased bottoms. Where setting rates are considered sufficient to support self-sustaining oyster populations on public grounds, and where losses to diseases and predators to non-indigenous seed, seed transplant-to-harvest activities were eliminated from model consideration. Public grow-out areas and leased growing areas are listed in Table A.3.

The cultural technique for transpant-to-harvest activities is the same whether seed is planted on public or private grounds. The distinction between primary activity number two (seed transplanted onto Baylor grounds by VMRC) and primary activity number three (seed transplanted by private individuals on leased bottoms) is one of harvest technology. All harvesting on Baylor grounds is assumed to be done with hand tongs, while all harvesting on leased bottoms is assumed to be done with an oyster dredge. The production period for both public and private seed-transplant activities is three years, where seed oysters are planted at the beginning of the first year of the production period and are harvested at the end of the third year of the production period. The only exception is seed transplanted on the Eastern Shore Seaside. Seed transplanted to these leased bottoms grow very rapidly and losses to disease and predation are heavy if the oysters are left on the bottom for more than eighteen months. A two-year production period is assumed for leased bottoms in this region. According to VMRC repletion officers, seed would only be transplanted to areas that do not receive a natural set. It is assumed, therefore, that the oyster bed will remain productive for only one season.

Not all market-oyster harvest results from man-induced production. A fourth primary activity, included in the model, permits the harvest of market oysters from naturally occurring stocks. Natural production is simply defined as any production of market oysters that is not directly the intentional result of Man's repletion or cultural activities. The Baylor grounds were established on the basis of natural productivity. It is assumed, therefore, that all market oyster harvest of natural production takes place on the public oyster beds. No attempt is made to determine the natural productivity of each river system. For the model's purpose, therefore, a given level of annual Bay-wide natural market oyster production is assumed. This yearly production is harvested by the end of each year of the planning horizon. Table A.4 provides a summary of all the

Table A.3: Public and Private Growing Areas

Baylor Grounds	Private Grounds
Great Wicomico	Upper Management Area
Upper Rappahannock	Great Wicomico
Mid-Rappahannock	Upper Rappahannock
Upper York	Mid-Rappahannock
Lower York	Lower Rappahannock
Upper Management Area	Mobjack Bay
Piankatank	Upper York
	Lower York
	Upper York
	Upper James
	Lower James
	Pocomoke and Tangier
	Seaside Eastern Shore

primary activities by cultural technique, harvest gear, bottom ownership, and production period.

Section 2.2.2: Secondary Activities

Secondary activities do not directly result in market oyster production. The secondary activities are, instead, support activities providing the means through which i) seed is brought into the market oyster production process and ii) funds are made available to carry out VMRC's repletion program. Included in the model are four seed-related secondary activities and two repletion fund-related activities.

The model permits the harvest of seed from the Baylor grounds on unrepleted and repleted bars. Although some seed is produced by private planters, the majority of seed comes from public seed beds. For this reason private seed production is not considered in the model. Seed from unrepleted bars represents a stock which may be exploited. A given level of annual natural recruitment is assumed for modeling purposes. If in any year this annual stock is exhausted and more seed oysters are demanded, then the model permits seed to be produced by including a set of seed production activities. Unlike seed from unrepleted bars which can enter the market oyster production process as soon as

Table A.4: Summary of Primary Activities

	Cultural Technique	Harvest Gear	Bottom Ownership	Production Period*
Shell-Harvest	Plant shell on Baylor Bottoms to receive a set and grow-out to a harvestable size.	Hand-tongs	Public	4 Years
Public Seed-Transplant-Harvest	Transplant seed on Baylor bottoms and allow grow-out to a harvestable size	Hand-tongs	Public	3 Years
Private Seed-Transplant-Harvest	Transplant seed on leased grounds and allow grow-out to a harvestable size	Oyster Dredge	Private	3 Years**
Natural Production	________	Hand-tongs	Public	--------

* The production period includes harvesting the oysters.

** Except for Eastern Shore Seaside where growth is rapid and losses to predation are heavy if seed is left on the bottom for more than 18 months.

it is required, seed from repleted bars must first be produced by shelling Baylor bottoms to catch a strike. River systems identified as seed areas are listed in Table A.5.

Once set, the immature oysters grow rapidly enough to be harvested by fall of the year they were spawned. All activities are assumed to take place at the beginning of any given period. A one-year growing cycle for seed production is assumed even though it may well be the case that the seed oysters will be harvestable before the year is up. Like the market-oyster shelling activities, a seed bed is assumed to remain productive at a ten percent declining rate for four years after the first seed oyster is harvested. Also included in the model is a seed harvest activity from unrepleted bars for each of the seed transplant-to-harvest activities. Figure A.3 provides a pictorial summary of Tables A.2, A.3 and A.5. Cultural techniques determined to be feasible are indicated for each river system.

The harvest of repleted-bar seed and the transport of seed from its origin to the planting site remain to be discussed. Both of these activities will only enter the model solution if seed production enters first. Seed that is produced must be harvested. Current regulations permit the harvest of seed only with hand tongs. A separate seed harvest activity is included for each seed production activity to maintain continuity in the seed-to-market oyster production process. Separate activities are not required, but their absence could mask differing harvest technologies or regulations associated with the harvest of seed in one area versus another.

A set of seed transport activities is incorporated into the model for two reasons: i) to define the unique cost of transporting seed from one region to another, and ii) to prohibit the transport of seed from a given seed area to an MSX-incompatible receiving system (as shown in Table A.6). A seed transport activity is included to move seed from each seed-producing area (from Table A.5) to each grow-out area (Table A.3), conditional on MSX compatibility.

Seed resistance to MSX is assumed to improve the higher the disease incidence in the system of seed origin. Seed that originates in a system of relatively low MSX incidence, however, has very little resistance to the disease and will likely perish before reaching a harvestable size. The MSX categories defined in 1968 and reported in Haven et al. (1981a), are used to determine MSX compatibility. It is assumed that seed originating in a Type I MSX area can be transplanted to any river system of Type I or higher. Similarly, seed originating in a Type II river system may only be transplanted to Type II or higher river systems and so on as depicted in Table A.7.

Table A.6 is a matrix of seed and grow-out area compatibilities by river system of origin and receiving system. MSX compatibility is assumed to be the same on public and private grounds. Over 70% of the seed transplanted to leased bottoms in 1981 came from the James river seed beds (VMRC Annual Reports 1982). For this reason, only James river seed is allowed to go to all leased bottoms.

Section 2.2.3: Tax Collection and Repletion Fund Transfer

The final secondary activities are: i) oyster repletion tax collection, and ii) repletion fund transfer from one year to another. One source of repletion funds is the Public Rocks Oyster Repletion Tax. The repletion tax is levied on all seed and market oysters harvested on the Baylor grounds. Any harvest of oysters on public grounds, therefore, generates revenue which goes into the State's repletion program budget. The model is designed so that whenever a market oyster harvest or production activity (all production

Table A.5: Public Grounds Seed Areas

Upper James
Lower James
Mobjack Bay
Lower Rappahannock
Piankatank
Great Wicomico

is assumed harvested) or a seed harvest activity is initiated a tax collection activity is initiated, in the year the oysters are harvested.

It is possible that ORP budgetary requirements will differ from year to year depending on the mix of repletion activities undertaken by VMRC. One would expect, therefore, years of funding shortages and years of funding surpluses. The model permits the transfer of funds from years of budgetary surplus to years of budgetary shortage.

Section 3.0: Constraints

In the linear programming model, maximum constraints are placed on the availability of private and public oyster bottoms, the ORP budget, and the natural production of seed and market oysters on the Baylor grounds.

In addition to these resource availability constraints, there is a set of transfer rows which force an activity or sequence of activities into the solution whenever a primary activity requires an auxiliary secondary activity. If, for example, a seed-transplant activity enters the basis and natural seed availability is exhausted, the transfer rows force the following sequence of secondary activities into the basis: seed production, seed harvest, and seed transport. Another set of transfer rows initiates a tax collection activity any time seed or market oysters are harvested on public grounds. Also included in the model is a set of transfers which effect the transfer of ORP funds from one year to another.

The final set of constraints is the setting of the harvest goal. The harvest goal is constrained with equality for each of the ten years of the planning horizon.

Section 4.0: The Computer Model

The linear programming model just described is now presented in tableau form in Figure A.4. The columns of the tableau represent the alternative activities which may be chosen to achieve the prespecified level of market oyster harvest.

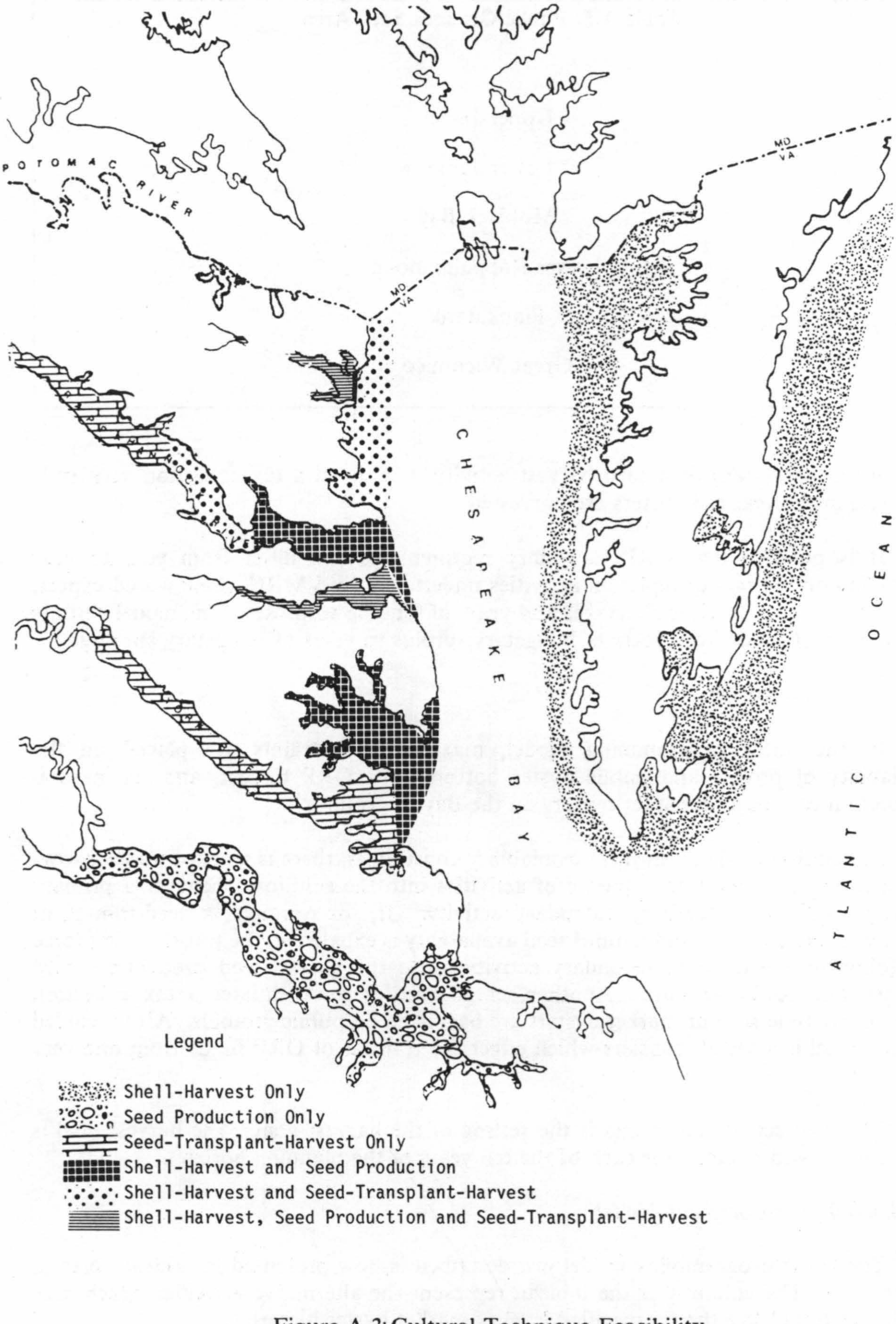


Figure A.3: Cultural Technique Feasibility

Table A.6: MSX Compatibility by Seed Origin and Receiving System

	Upper York	Lower York	Mobjack Bay	Pianka-tank	Upper Rapp.	Lower Rapp.	Mid-Rapp.	Great Wicom.	Upper Mgt. Area	Pocomoke &Tangier	Upper James	Lower James
Upper James	C				C	C	C	C	C		C	
Lower James	C	C			C	C	C	C	C		C	C
Lower Rapp.	C				C	C	C	C	C		C	C
Piankatank	C			C	C	C	C	C	C		C	C
Great Wicom.	C				C	C	C	C	C		C	C
Mobjack Bay	C	C	C	C	C	C	C	C	C	C	C	C

Source: Haven et. al. (1981)
A "C" indicates MSX compatibility.

Table A.7: River System Compatibility by MSX Type

		MSX Type of Receiving River System			
		I	II	III	IV
MSX Type of Seed Origin	I	C	C	C	C
	II		C	C	C
	III			C	C
	IV				C

This table shows the MSX Type relationship between system of seed origin and the receiving river system. A "C" indicates compatible MSX types.

	$SHFF_{rt}$	$SHFD_{rt}$	$SHSF_{rt}$	$SHSD_{rt}$	TSF_{rt}	$TSSF_{rt}$	$TSSD_{rt}$	TSL_{rt}	$PSFF_{rt}$	$PSFD_{rt}$
RBF_t	1	1			1				1	1
RBS_t			1	1		1	1			
RL_t								1		
FRS_t	F		F			F			F	
DRS_t		D		D			D			D
$NSPC_t$										
$NMOP_t$										
BT_t	B	B	B	B	B	B	B		B	B
$GOAL_t$	G	G	G	G	G	G	G	G		
TR_t	-T	-T	-T	-T	-T	-T	-T			
TST_{rt}					SR	SR	SR			
$TSTL_{rt}$								SRL		
TSH_{rt}										
THT_{rt}									-SP	-SP
COST	$\frac{C_{SHFF_{rt}}}{(1+i)^n}$	$\frac{C_{SHFD_{rt}}}{(1+i)^n}$	$\frac{C_{SHSF_{rt}}}{(1+i)^n}$	$\frac{C_{SHSD_{rt}}}{(1+i)^n}$	$\frac{C_{TSF_{rt}}}{(1+i)^n}$	$\frac{C_{TSSF_{rt}}}{(1+i)^n}$	$\frac{C_{TSSD_{rt}}}{(1+i)^n}$	$\frac{C_{TSL_{rt}}}{(1+i)^n}$	$\frac{C_{PSFF_{rt}}}{(1+i)^n}$	$\frac{C_{PSFD_{rt}}}{(1+i)^n}$

Figure A.4: Model Tableau

	$PSSF_{rt}$	$PSSD_{rt}$	$HARS_{rt}$	$STOR_{rt}$	$STORL_t$	$HNSP_t$	$HNMOP_t$	$TAXC_t$	$TFUND_t$	RHS
RBF_t										$\leq RBF^*$
RBS_t	1	1								$\leq RBS^*$
RL_t										$\leq RL^*$
FRS_t	F									≥ 0
DRS_t		D								≥ 0
$NSPC_t$						1				
$NMOP_t$							1			
BT_t	B	B						-1	1	$\leq RB^*$
$GOAL_t$							G			$= G^*$
TR_t			-T			-T	-T	1		$= 0$
TST_{rt}				-1		-1				$= 0$
$TSTL_{rt}$					-1	-1				$= 0$
TSH_{rt}			-1	1	1					$= 0$
THT_{rt}	-SP	-SP	1							
COST	$\frac{C_{PSSF_{rt}}}{(1+i)^n}$	$\frac{C_{PSSD_{rt}}}{(1+i)^n}$			$\frac{C_{STORL_t}}{(1+i)^n}$	$\frac{C_{HNSP_t}}{(1+i)^n}$	$\frac{C_{HMNOP_t}}{(1+i)^n}$			

Figure A.4: Model Tableau (Continued)

The objective function for the model is described in the "COST" row. Included in this row are the public plus private costs of initiating a public grounds repletion and harvest activity or a private bottoms market-oyster production and harvest activity. The coefficients in the objective function row represent the total cost of undertaking a single unit of a given activity discounted to the first year of the ten-year planning period.

The bottom acreage, shell, seed, and budget requirements for each activity are included in the rows section. Also included in this section are tax revenues generated by each activity, the quantity of seed resulting from a given seed production activity, and the bushels of harvested market oysters generated by each primary activity.

Maximum levels of private and public acreage are listed under the column labeled "RHS." Limitations on repletion funds, and natural seed and market oyster harvest, are also listed in this column. The budget for any given year can also be increased by transferring unused funds from one year to be used in another. This particular activity is represented in Figure A.5.

In this submatrix the budget for the year receiving the fund transfer is increased while the budget year from which the funds are taken is decreased by the amount of the transfer. This is indicated by a -1 in each "BT" row of any year (j) receiving a transfer and a 1 in the "BT" row of the year (i) making the transfer. It is only possible to transfer funds forward in the planning period. A fund transfer activity, therefore, is included for all years i and j such that j > i. Also included in the RHS section is the prespecified level of market oysters, as indicated by the row labeled "GOAL."

The technical coefficients for the model define the relationship between a given activity and a given constraint. The coefficients denoted by the letter "F" in Figure A.4, for example, define the quantity of fresh shell required in order to undertake a particular shell-to-harvest activity. The estimation of these technical relationships will be discussed in detail in Part 2 of this appendix.

The input data analyzed by the linear programming model is represented by generalized notation in the matrix tableau. Table A.8 explains the notation used.

Figure A.5: Fund Transfer Submatrix

	TFUND12	TFUND13	TFUND14	TFUND15.....TFUNDij		RHS
BT1|	1	1	1	1		< RB*
BT2|	-1					< RB*
BT3|		-1				< RB*
BT4|			-1			< RB*
BT5|				-1		< RB*
BTi|					1	< RB*
BTj|					-1	< RB*

* Note that the submatrix presented here includes only the first four years of the planning period. The sub-matrix continues in a similar manner for the remaining years of the planning period.

Table A.8
Tableau Key

Subscripts and Superscripts

t = time period; t = 1-10

r = river system; r = the river systems listed in Table A.1

i = the discount rate. An interest rate of 4.51 percent was utilized to discount the future cost of public expenditures for oyster bed repletion. Private grounds production expenditures are discounted by an interest rate of 6 percent.

n = the number of years over which discounting occurs.

Coefficients

C = the cost in current dollars of undertaking any secondary or primary activity.

F = the number of bushels of house shell required by an activity.

D = the number of bushels of reef shell required by an activity.

B = the amount of public expenditures required to initiate one unit of any public repletion program activity.

G = the contribution toward satisfying the harvest goal made by a unit of any given primary activity.

T = the tax revenue generated by a unit of seed or market oyster production on Baylor grounds.

SR = the number of bushels of seed required by a public seed-transplant activity.

SRL = the number of bushels of seed planted on private grounds.

SP = the bushels of seed produced on public grounds from a unit of a seed production activity.

RBF* = the maximum acreage of firm public bottoms in a given river.

RBS* = the maximum acreage of soft public bottoms in a given river.

RL* = the maximum leased acreage in a given river.

RB* = the maximum amount of repletion funds available in any given year.

G* = the market oyster harvest goal.

Columns

SHFF = a shell-harvest activity using fresh shell on firm Baylor grounds. Rivers included in this activity and the next three activities are listed in Table A.2

SHFD = a shell-harvest activity using dredge shell on firm Baylor bottoms.

SHSF = a shell-harvest activity using fresh shell on soft Baylor bottoms.

SHSD = a shell-harvest activity using dredge shell on soft Baylor bottoms.

TSF = transplanting seed to grow-out areas on firm Baylor grounds. River systems included in this and the next two activities are listed in Table A.3.

TSSF = transplanting seed to grow-out areas on soft Baylor bottoms where shelling with fresh shell used.

TSSD = transplanting seed to grow-out areas on soft Baylor bottoms where shelling with dredge shell is used.

TSL = transplanting seed on private grounds; river systems included in this activity are listed in Table A.3.

PSFF = shelling firm Baylor grounds with fresh shell to produce seed; river systems included in this and the next three activities are listed in Table A.5.

PSFD = shelling firm Baylor grounds with dredge shell to produce seed.

PSSF = shelling soft Baylor grounds with fresh shell to produce seed.

PSSD = shelling soft Baylor grounds with dredge shell to produce seed.

HARS = harvest seed produced by the previous activities.

STOR = transport the harvested seed (from the HARS activity) to a receiving system on Baylor bottoms.

STORL = transport the harvested seed (from the HARS activity) to leased bottoms.

HNSP = harvest natural seed production.

HNMOP = harvest naturally occurring market oysters.

TAXC = tax collection.

TFUND = transfer funds from one year to another.

Rows

RBF = firm Baylor grounds.

RBS = soft Baylor grounds.

RL = leased bottoms.

FRS = fresh shell.

DRS = dredge shell.

NSPC = natural seed production.

NMOP = natural market oyster production.

BT = VMRC's repletion budget.

GOAL = the prespecified level of market oyster harvest.

TR = tax revenue.

TST = transfer transported seed to a public seed-transplant activity

TSTL = transfer transported seed to a private seed-transplant activity.

TSH = transfer harvested seed to a seed transport activity.

THT = transfer produced seed from repleted bars to a seed harvest activity.

Appendix A, Part 2

The Linear Programming Model: Estimation of Technical Coefficients

Appendix A, Part 2

The Linear Programming Model: Estimation of Technical Coefficients

Section 1.0: Introduction

The decision model developed in Part 1 permits an evaluation of the alternative oyster grounds management options available to VMRC. Underlying each management option is the assumption that the effects of implementing a given policy or repletion option are known. It is assumed, for example, that VMRC knows exactly how many bushels of market oysters will be produced when it plants seed in any given river system. However, the information base upon which management decisions are formed is imperfect. An inadequate data base, the absence of an efficient means of collecting and processing fisheries management information, and the lack of economic and biological modeling contribute toward management uncertainty. The purpose of this chapter is to provide a detailed treatment of how the technical coefficients required for the model developed in Part 1 were estimated. Data requirements for objective function constraints and activities are discussed separately. Included in each section is a list of data sources used and a treatment of the informational or data problems associated with each coefficient type.

Section 2.0: Objective Function Coefficients

The objective function coefficients indicate the total public plus private cost of undertaking a given primary or secondary activity. These cost coefficients may be broken down into three general categories; public grounds repletion costs, private grounds production costs, and private harvest costs.

Section 2.1: Public Grounds Repletion Costs

All activities that take place on public oyster rocks have associated with them a repletion cost and a private harvester cost. Together these costs make up the total cost of undertaking any public grounds activity. The private harvester costs, however, will be discussed later as estimation of these coefficients merits separate consideration.

VMRC contracts the services of private watermen to carry out its repletion program. Estimation of these cost coefficients under current repletion program policies is an easy task as the per-bushel costs for contractual services are readily available from VMRC Annual Reports. To put these costs on a per-acre basis, it is necessary to multiply the per-bushel cost of seed or shell planted by the quantity planted per acre. The public grounds shell planting costs are computed as follows:

$$\text{Repletion Cost/Acre}_i = (\text{\$/bushel shell}_j) \times (\text{bushels planted}_{i,k})$$

where: i = river system
j = shell type (fresh or dredge shell)
k = bottom type*

---

*Two classes of bottom are considered in the model, firm and soft bottom. Bottoms in which grab samples contain at least 50% shell or shell fragments in volume are defined as being firm (Haven et al. 1981a). Firm bottoms require planting of 7,000 bushels of shell per acre to make them suitable for oyster culture. All other bottoms are classed as soft and require 10,000 bushels of shell per acre to make oyster culture possible.

Public shelling costs, therefore, depend on the river system shelled, the shell type, and the quality of the growing bottom. Public grounds seed-transplanting costs may be calculated in similar fashion by the following formula:

Seed Planting Cost/acre$_i$ = (\$/bushel for seed$_h$) x (bushels planted**)

where: i = receiving river system
h = system of seed origin

Using these formulae, the repletion cost of any specific public grounds repletion-harvest activity can be determined. The objective function coefficient for any of these activities is simply the sum of the repletion cost and the cost of harvesting the resulting oysters.

The repletion costs are reported in tables from 1983 VMRC repletion cost data sheets (unpublished VMRC records). These recorded costs include the cost per bushel of acquiring, transporting, and planting shell or seed by shell type, seed, and river system. Unfortunately these costs are not broken down into their individual components.

The inability to consider purchasing, transportation, and planting costs separately masks the fact that each repletion activity is itself a process composed of several subactivities. Redefined in this way it can be seen that there exist alternative shell or seed sources and their associated transportation costs, transportation technologies, and shell or seed planting technologies. If it were possible to examine each of these costs separately, it would enable the introduction of a greater level of detail into the model. The model would be able to determine not only the shell type to plant, where to plant it, and how much to plant, it would also determine the least costly way of purchasing, transporting and planting the shell.

Section 2.2: Private Grounds Production Costs

Before describing how the private planter production costs were estimated, it is first necessary to discuss the assumptions that were required to motivate private grounds market-oyster production. It is assumed that private planters seek to maximize profit. In so doing, leaseholders minimize their costs by selecting the most cost-effective combination of activities required to produce market oysters. Recall that the model developed in Part 1 does not necessarily require that private grounds market-oyster production be profitable. Economic theory of the firm, however, predicts that the individual will produce a positive amount of output only if at least all operating costs are recovered in the short run and at least all fixed plus operating costs are recovered in the long run. Given that the model considers a ten-year planning period for public and private decisions, it is assumed that no private grounds production will occur unless long run economic returns to private grounds market-oyster production is greater than or equal to zero. In order to guarantee that private grounds market-oyster production is positive, the assumption is made that the price of market oysters is always at least as great as the unit cost of producing market oysters. Similarly, for private watermen working the public grounds, it is assumed that the price of market oysters is always sufficient to cover all harvest costs incurred by the harvester. The costs associated with

**VMRC personnel recommend planting between 550 and 750 bushels of seed per acre, depending on the size and the spat count (number of spat per bushel) of the seed. An average of 650 bushels per acre was chosen for the model to allow for this variation in seed quality.

private grounds market-oyster production are now discussed. As previously stated, harvester costs will be presented in a later section.

The costs associated with private grounds oyster production, considered in the objective function, consist of the cost of acquiring, transporting, and planting seed along with the cost of harvesting the market oysters. The model considers production of market oysters in a two step process by including two separate activities, one for purchasing and transporting seed oysters, and another for planting seed and harvesting market oysters.

Each seed purchase and transport activity defines a unique combination of the river system from which seed is transported and the receiving river system. The objective function coefficient for each activity is determined by the price of the seed plus the cost of transporting the seed. These coefficients are estimated by determining the price of seed in each seed-producing river system and the transportation cost of bringing the seed to the planting site. VMRC seed and market-oyster production and price data were used to determine the price of seed in seed-producing river systems. Little information, however, is available to estimate the cost of transporting seed. According to records of a Rappahannock river planter obtained by Haven et al. (1981a), transportation costs ranged between 25 and 50 cents per bushel. Unfortunately no insight is offered as to the distances corresponding to these costs.

In order to establish a relationship between transportation costs and distance, the 25 to 50 cent cost interval is assumed to provide upper and lower bounds to per bushel transportation costs. The purpose here is to provide a means of assigning transport costs based on relative distance between seed origins and receiving systems. In this respect the 25 to 50 cent interval is being used as an indexing mechanism. Using five cent increments, relative transportation costs were assigned to each seed purchase and transport activity. These assignments are made on the basis of the geographical location of a receiving system relative to how far away it is from a specific seed origin when compared to the closeness of other potential receiving river systems competing for seed from the same source. For example, the cost assigned to transporting seed from the James to the Rappahannock is \$.40. The cost of transporting seed assigned to the York from the James is \$.25. Here shipping seed from the James to the York is less costly than shipping seed from the James simply because the York is closer to the seed source. The opposite is true when shipping seed from the Great Wicomico to the Rappahannock and the York (\$.30 and \$.45 respectively).

The transport costs are not inflated because they are based only on relative distance between any two river systems and not on actual shipping cost data. If these shipping costs were inflated, only the magnitude of the cost would change. The relative difference in transport cost between any two river systems as compared to any other two river systems, however, would remain unaltered. The objective function coefficient for each seed purchase-to-transport activity is left on a per-bushel basis and may be calculated with the following formula:

Purchase-to-Transport Cost/bu_i = $SeedPrice_j$ + transport cost from $system_j$ to $system_i$

where: i = receiving system
j = seed origin.

The second step in the production process is the seed-planting and market-oyster-harvesting activity. Once again a discussion of harvesting costs will be put aside momentarily. Seed-planting costs simply involve the costs of putting the seed on leased growing bottoms. For simplicity it is assumed that a uniform planting technology is employed by all private planters. Seed planting costs can then be assumed to be the same across all private planters and river systems. Seed planting costs are reported by Haven et al. (1981a) as being $.30/bu (1975 dollars). When inflated to 1983 dollars (using the CPI), and multiplied by a fixed per-acre planting rate, the cost of planting seed on any one acre of leased bottom is $412.50*.

The objective function coefficient for a one-acre unit of any private seed-transplant-harvest activity is the sum of the seed-planting cost and the cost of harvesting the resulting market oysters. The following formula can be used to determine the objective function coefficient for each private seed-transplant-harvest activity:

Seed-Transplant-Harvest Cost/acre$_i$ = Seed Planting Cost/acre + (Harvest cost/bu.) x (bushels harvested$_i$).**

where: i = river system

Estimation of private production costs is made difficult by the lack of published information on what these costs are. The records of the Rappahannock grower mentioned previously constitute the only source of published quantitative data which was made available. While these records are better than none at all, they do not represent a sample of the cost conditions faced by other planters in the Rappahannock or any other river system. The lack of published information on private leaseholders' oyster production techniques also presents a problem in that there is no way to ensure that all relevant cost information has been included in the production cost estimates incorporated in the model. For example, during the normal production process some amount of shell is lost due to siltation or removal during harvesting. Substrate maintenance costs are, therefore, likely to be incurred. It was not possible to determine under the current information base what these costs might be. A better information base would permit more accurate and reliable estimation of private market-oyster production costs.

Section 2.3: Oyster Harvesting Costs

The harvest of market oysters takes place on both public and private grounds. It is assumed that only hand tongs are used on public grounds and all private planters use an oyster dredge. It is necessary, therefore, to estimate a cost coefficient for each gear type. Both hand tong and dredge harvest costs were estimated by creating a budget that was estimated on an annual cost-per-harvest-season basis. Items included in each budget are vessel and gear maintenance, fuel, wages, food, and amortized vessel and gear principal plus interest costs.

---

*According to Haven et al. (1981a), planting rates on private grounds range between 500 and 1,000 bushels per acre. Planting rates chosen by private planters depend on seed size and the firmness of the growing bottoms. Bottom type for all leased bottoms is assumed to be the same across all planters and river systems. An average planting rate of 750 bushels per acre was chosen for the model to account for varying seed size and to reflect a bottom quality which is assumed to be representative of most leased acreage.

**Note that the seed planting cost per acre has already been assumed constant. It will be shown later that per-bushel harvest cost is also assumed constant. The value of this coefficient varies, therefore, only with the number of bushels of market oysters harvested from a given acre of leased bottom in a given river system.

Table A.9: Annual Harvest Cost Budget	
Variable Costs	
Vessel Maintenance	_____
Gear Maintenance	_____
Fuel	_____
Wages	_____
Food	_____
Total Variable Costs	_____
Fixed Costs	
Vessel Principal	_____
Gear Principal	_____
Interest Payment	_____
Total Fixed Cost	_____
Total Cost	_____

Table A.9 presents the format that was used to form each budget. The per bushel harvest cost for each gear type was estimated by dividing total annual harvest cost by average annual landings for a representative harvester. This coefficient is assumed to be constant for all harvesters. It is now possible to substitute this per-bushel harvest cost coefficient into the following formula to obtain the objective function coefficient for each activity previously discussed in this section.

$$\text{Objective Function Value}_{i,k} = \$/\text{activity unit}_i + (\text{harvest cost/bu}_j) \times (\text{bushels harvested}_{i,k})$$

where: i = activity type
j = gear type
k = river system

The principal source of data for compiling the harvest budgets is the Chesapeake Bay Harbors Study (1961). This study, conducted by the Corps of Engineers in 1961, surveyed watermen to determine various harvest-related expenditures. While the study does not construct budgets for different gear types, it does provide insight into the cost items associated with harvesting oysters for several gear types and vessel sizes. Also included in the survey is information relating to hours and days worked per year and average daily catches. The more recent work by Haven et al. (1981a), The Oyster Industry of Virginia: Its Status, Problems and Promise, was also used to confirm and supplement the findings reported in the the Corps study.

Even with these sources, one basic difficulty arises. While technical information on vessel, gear, fuel, and labor costs is not difficult to obtain, information on average daily catch by gear type remains elusive. The problem arises because daily catches vary depending on where oysters are being harvested, how many men are in the boat, and the skill of the harvester himself. The most complete information, in the Corps study, reports a range of 20-300 bushels per day for a medium dredge and 5-100 bushels per day for hand tongers. These ranges apply to the entire survey area, which includes only the Southern half of the Virginia portion of the Chesapeake Bay. More reliable harvest cost coefficients would necessitate a new survey or improved methods of catch reporting to obtain a better understanding of what average daily catches might be by region and gear type.

Section 3.0: Estimation of Constraint Coefficients

This section discusses only estimation of the coefficients which determine the bounds or Right-Hand Side (RHS) for each constraint. All other coefficients found in the constraint rows will be discussed in the Activities Coefficients section of this appendix.

From the model tableau (Figure A.4) it can be seen that the first three constraints are oyster grounds acreage constraints. The RHS for the constraints RBF and RBS define the total quantity of firm and soft bottomed Baylor grounds, respectively, in any given river system. The RHS coefficient for RL defines the total available acreage of leased bottoms in any given river system. In the most recent survey of the Baylor grounds VIMS scientists classified each discrete oyster-growing area by size and bottom type. This information is recorded and reported in The Present and Potential Productivity of the Baylor Grounds in Virginia (Haven et al. 1981b). Total availability of public grounds by bottom type and river system was determined by summing the acreage of each discrete area classified as being at least ten acres in size. The ten-acre cut-off was used because it is the minimum discrete acreage that VMRC repletion officers considered feasible to replete. Acreage of privately held oyster grounds by size of holding is published in The Oyster Industry of Virginia: Its Status, Problems Promise (Haven et al. 1981a). The total lease acreage was estimated by determining the amount of privately held bottoms in each river system held in units of twenty acres or more. Any acreage held in units less than twenty acres is either riparian or considered too small to be commercially productive and was, therefore, not included in the leased bottom totals.

Following the acreage constraints are two constraints, one for each of the two different shell types used by VMRC in its repletion program. An inspection of the RHS coefficients shown in Figure A.4 for each of these constraints (FRS and DRS) reveals that they have no upper limit. The reason is a lack of information in regard to the limits of availability of either reef or fresh shell. There is no way to tell whether VMRC uses reef shell instead of fresh shell or vice versa because one is in short supply relative to another. Alternatively, there may other reasons for choosing one shell type over the other. In some studies, for example, reef shell has been found to be slightly more efficient in catching spat than fresh shell (Campbell and Forste, 1978). The lack of an upper bound avoids this measurement problem as the quantity of either type of shell used becomes an output of the model solution.

The constraints NSPC and NMDP determine the limits of natural (unaided by man) seed and market oysters produced annually on Baylor grounds. Annual natural seed production was estimated by averaging seed harvest reported in VMRC Annual Reports and VMRC Oyster Repletion and Production Data for the years 1976-1983. It was then assumed that some of that production had been man-induced. The quantity of man-induced seed oyster production can be calculated by multiplying the number of acres shelled in the James River seed area in the previous year by the corresponding seed oyster productivity coefficient*. This estimate of man-induced seed oyster production was then subtracted from total seed production to obtain an estimate of naturally produced seed. This quantity is estimated with the following formula:

Natural $Seed_t$ = Total Seed $Harvested_t$ - (Acres Seed Beds $Shelled_{i,t-1}$) x ($Productivity_i$).

where: i = river system
t = time

Natural market-oyster production was calculated in a similar manner. Total public ground market-oyster production was averaged over the same eight-year period. The 1983 repletion program was chosen as a representative repletion year. The man-induced market oyster production was then estimated by summing the product of repleted acres in each river system and the appropriate market-oyster productivity coefficient. Total man-induced market oyster production was then subtracted from total public grounds production to obtain an estimate of "natural" market oyster production. In formula form this coefficient may be expressed as;

Natural Market Oyster Production = Total Public Grounds $Production_t$ -
Sum(Repleted $Acres_{i,t-z}$) x (Productivity $Coefficient_i$j)

where: i = river system
t = time
z = maturation period, ie. for:
j = type of repletion activity
j = shell-harvest, z = 3
j = seed-transplant-harvest, z = 2.

The RHS coefficient for the BT row represents the total funds available to VMRC to carry out its repletion activities. This coefficient was estimated by averaging VMRC expenditures for repletion purposes over the years 1979-1982. VMRC Annual Reports were used to obtain the necessary data.

The coefficient for the prespecified harvest goal was determined by averaging oyster production from both public and private grounds to determine a total market oyster production goal. This coefficient provides a harvest goal under current repletion policies and budgetary levels. The initial production goal can be varied and the cost and policy implications of an increased harvest goal examined. Harvest on public grounds was averaged over the 1976-1983 period. VMRC production and repletion data were used for this average. Private grounds market-oyster production data from VMRC Annual Reports were available only for the years 1976-1980. The sum of average public and private market-oyster production was then calculated to estimate current average annual market-oyster production.

The remaining rows in Figure A.4 are transfer rows whose RHS coefficients are by definition equal to zero. These rows will not be further discussed.

Section 4.0: Estimation of Matrix Elements

The following discussion will deal specifically with the matrix elements of the model tableau. Once again Figure A.4 will be used as a reference. The matrix elements in the

*The term "productivity coefficient" refers to the total production of seed or market oysters per unit of a seed or market-oyster production activity. The estimation of these coefficients is discussed in the next section.

RBF, RBS, and RL rows indicate the amount of Baylor or lease acreage required to undertake any given activity. A coefficient of 1 will be found in the intersection of any one of these rows and market or seed oyster production columns. The interpretation of these coefficients is that for every unit of a seed or market oyster production activity one acre of bottom must be used.

All matrix elements denoted by the letter F represent the quantity of fresh shell required by employing a unit of any particular oyster production activity. Similarly the letter D represents the quantity of dredge shell required per unit of given oyster production activity. An inspection of these coefficients shows that all of them are associated with public grounds repletion activities. Estimation of these coefficients is based, therefore, on shelling rates recommended by VMRC pesonnel.

The next set of matrix coefficients is denoted by the letter B in Figure A.4. These coefficients define the expenditures required by VMRC to undertake an acre of any public grounds seed or market oyster repletion activity. VMRC contracts private individuals to carry out its repletion activities. The value of these services represents the cost or budget requirement for a particular repletion activity. These costs are reported in the VMRC Annual Reports on a total cost-per-river-system basis. Also reported is the total amount of shell or seed placed in each river system.

The coefficient B was estimated by calculating the per-bushel cost of planting fresh or dredge shell or seed by river system. The per-bushel cost of planting shell or seed was multiplied by the respective shell or seed per acre planting rates. The resulting product yields the estimated budget requirement of undertaking an acre of a given repletion activity. In formula form, this relationship may be expressed as follows:

$$\text{Bushels/acre}_{r,i} = (\$/\text{bu}_{r,i}) \times (\text{planting rate}_j).$$

where: i = river system
r = type of repletion activity
j = material planted, ie. shell or seed.

The elements denoted by T determine the amount of dollars generated by initiation of any public grounds market-oyster or seed-oyster harvest activity. The coefficient T is a function of the quantity of seed or market oysters harvested on public grounds and the per-bushel price of the seed or market oyster. The tax revenues come directly from the public rocks oyster repletion tax which is levied on all oysters harvested on public grounds, with the amount of the tax depending on the per-bushel sale price of the harvested oysters. Tax rates from seed and market oysters were obtained from Laws of Virginia (1980). The coefficient T was then estimated by multiplying the appropriate tax rate ($.50 for all market oysters and $.10 for all seed oysters) by the number of bushels of seed or market oysters produced when a given seed or market oyster production activity was initiated.

The matrix coefficients denoted by SR and SRL indicate bushel-per-acre seed-planting rates by public-market oyster repletion and private-market oyster production activities, respectively. Seed-planting rates for public grounds market-oyster repletion activities were determined through personal interview with VMRC repletion officers. Seed planting rates for private grounds market oyster production activity were determined by a literature search to be 750 bushels of seed per acre, (Haven et al. 1981a; Bailey and Biggs, 1968).

Initiation of any public or private market-oyster production activity results in a specific level of market-oyster harvest which contributes toward the satisfaction of the prespecified market-oyster harvest goal. These coefficients are indicated by the letter G in Figure A.4. An examination of these coefficients shows that they all correspond to either a shell-harvest activity on public grounds or a seed-transplant-harvest activity on public or private grounds.

Seed-transplant-harvest coefficients were determined by establishing a relationship between bushels of market oysters produced per bushel of seed planted. This relationship is easily expressed as a ratio that can be estimated. According to Haven et al. (1981a) long run trends indicate that the bay-wide average for this ratio is 1:1 or one bushel of market oysters harvested for every bushel of seed planted. This ratio does, as one might expect, vary depending on the receiving system. A lack of data made quantitative estimation of the seed-market oyster relationship impossible to determine on a river system by river system basis. This problem was overcome by asking VMRC repletion officers to rank each river system relative to the 1:1 ratio. Based on their personal experience in the field each river system was ranked according to its relative productivity. In several instances it was possible to obtain quantitative estimates of the seed-market oyster relationship for specific river systems. Using these quantitative estimates and the qualitative rankings, it was possible to estimate a seed-market oyster ratio for each river system on both public and private grounds. The actual seed-transplant-harvest production coefficients were estimated by multiplying the seed-market oyster ratios for each river system by seed planting rates for public and private grounds.

Although the 1:1 ratio claimed by Haven et al. is confirmed by other researchers (Bailey and Biggs, 1968) and is quite often cited as being the industry standard, there exist no attempts in the literature surveyed to estimate this ratio by different river systems. The problem comes down to a lack of data. This data problem relates particularly to the unavailability of bar-specific harvest data. It is known, for example, where VMRC places its shell, but without bar-specific harvest data it is not possible to determine the quantity of market oysters which were produced as a result of that repletion effort.

The second market-oyster-producing activity is the shell-harvest activity. Ideally a similar ratio comparing bushels of market oysters harvested to every bushel of shell planted should be used. Unfortunately, as before, the data necessary to calculate this ratio is lacking, and VMRC personnel were unable to rank or estimate the shell-seed-market oyster relationship for any of the river systems considered in the model. What is required is an estimator for this relationship that can serve as a suitable proxy for the shell-seed-market oyster relationship.

The purpose of shelling oyster bottoms is to ensure that oyster larvae have a suitable substrate upon which to attach. Shelling oyster bottoms, if done at the appropriate time, enhances the possibility that a successful strike of seedling oysters will result. If the assumption is made that an oyster bar repleted by shelling is at least as productive as an unrepleted "natural" bar and if it is possible to determine the per acre adult oyster population density on the unrepleted bar, then it may be assumed that the adult oyster population on the unrepleted bar provides a lower bound to mature oyster densities on the repleted bar. Fortunately, mature oyster-per-acre population densities are reported by Haven et al. (1981a). In the manner described above, these population density estimates were used as proxies for the shell-seed-market oyster relationship.

The final coefficient to be discussed here is denoted by SP in Figure A.4. These coefficients represent the quantity of seed produced by shelling and acre of seed bed. Once again Haven et al. (1981a) was relied upon for estimates for these coefficients. The lack of quantitative data is as much a problem here as it was for the previous two coefficients. Like the seed-transplant-harvest productivity coefficients, the shell-seed productivity coefficients involve estimating a ratio. Here the ratio is bushels of seed oysters produced per 100 bushels of shell planted. Shell-seed ratios are reported in Haven et al. (1981a) only for the Piankatank and the Great Wicomico. Both of these river systems were not productive of seed prior to intensive shelling efforts on the part of VMRC. This unusual situation allowed Haven et al. to estimate the shell/seed ratios for these two systems by making the assumption that all seed produced in these river systems was attributable to VMRC's shelling activities.

Similar situations, however, do not exist for the James, Corrotoman, or Mobjack Bay areas. Shell/seed ratios for these systems were determined by ranking all the river systems in terms of their historical production and importance as a seed area. This ranking (from most to least important) is as follows: James, Great Wicomico, Piankatank, Corrotoman, and Mobjack Bay. As stated earlier, quantitative estimates of the shell/seed ratio exist for both the Great Wicomico and the Piankatank rivers (1:5 and 1:7 respectively). The James has been and remains the most important seed area in the Virginia portion of the Bay. For this reason, the shell/seed ratio for the James was set higher than either the Great Wicomico or the Piankatank at 1:4. Neither the Corrotoman nor the Mobjack Bay are currently productive of seed but could possibly be brought into seed production if VMRC chose to shell these areas heavily (Haven et al., 1981a). The seed production potential of these systems is unknown and the shell/seed ratios for these areas were, therefore, set arbitrarily low at 10 to 1. The actual shell-seed production coefficient for each river system was estimated by multiplying the shell/seed ratios by the number of bushels of shell planted on firm Baylor grounds*.

*The shelling rate for firm bottoms was chosen because it reflects the minimum amount of shell required to provide sufficient quantities of exposed shell to ensure satisfactory spat settlement. The shelling rate for soft bottoms includes additional shelling to firm up the bottom. This shell becomes buried and is not available as a setting material. As a result, shell/seed coefficients would be biased upwards because of the additional non-productive shell.

Appendix B

Demand For Chesapeake Bay Oysters
Oral Capps and Leonard Shabman

Appendix B

Demand For Chesapeake Bay Oysters

Oral Capps and Leonard Shabman

This appendix reports upon an econometric demand model estimated for Chesapeake Bay oysters. The model structure and estimations were developed during 1984. During 1985 and 1986 attempts were made to secure data suitable for updating the model. However, retail price series are no longer available and time lags in publication of data for other variables made model updating infeasible.

Section 1.0: General Background

The model was estimated using time series data to identify demand relationships for Chesapeake Bay (both Maryland and Virginia) oysters. No consideration is given to oyster price differentials by state or by grounds. There was little evidence that average ex-vessel prices differed by state; however, there is some evidence that prices may differ by grounds type (JLARC, 1983).

The estimation of a demand system independent from the supply sector is justified by the nature of the commercial oyster harvest industry. First, the supply is determined completely within the harvest sector; the retail and wholesale sectors merely accept the given supply, they do not determine it. Second, the harvest in a particular year is determined by the costs of harvesting in that year (which the fisherman presumably knows before harvesting) and the ex-vessel prices received in previous years. It is assumed that individual fishermen use previous prices to form expectations of current prices, which they further use to decide (along with knowledge of current costs) whether or not to participate in the season's harvest; once they have decided to do so, they harvest as much as they can, regardless of the price they are receiving for their harvest. These two factors together imply that demand and supply can be modeled separately, since the current price has no effect on current supply.

Third, consumer demand for oysters is price-dependent; i.e., instead of the market price determining the quantity purchased, with the quantity purchased variable and the price fixed (at a market-clearing level), it is assumed that in seafood markets, a fixed quantity (determined by the harvest sector) of the product reaches the market, and this quantity is priced to clear the market. Thus, the dependent variable in the consumer (retail) demand equation is not the quantity of oysters purchased, but the retail price; as in traditional demand theory, however, prices of substitute (e.g., other meat, poultry, and fish products) and complement products, income, and other economic and demographic factors could influence the dependent variable.

Fourth, and finally, the approach to modeling oyster demand assumes that retail, wholesale, and ex-vessel prices are all determined simultaneously; i.e., each price appears on the right-hand side of the equations explaining the other prices. This simultaneous determination of prices is in large part due to the fact that the price equation for each sector is in reality not a demand equation for that sector but a reduced form equation for the sector, a combination of the corresponding demand and supply functions: the wholesale price equation, for example, is a combination of the equation explaining the demand for wholesale seafood (which is determined largely by the retail demand, as represented by the retail price) and the supply of wholesale seafood (which is determined largely by the cost of producing seafood at the wholesale level as represented by the ex-vessel price, which is the cost of the raw input used in the wholesale sector). Together, along with consideration of the model requirements, these four factors led to development of an oyster demand model which is developed separately from supply; the demand model comprises a set of three simultaneous equations, explaining the corresponding retail, wholesale, and ex-vessel prices.

Model requirements and economic theory together were used to determine the overall structure of each model; i.e., they determined the types of variables to be included in each model, as well as how in general these variables would relate to one another. Final specification of the variables and functional relationships depended in large part, however, upon consideration of factors peculiar to the species under consideration, the importance of the Chesapeake Bay harvest of these species relative to harvests from other regions, and a number of other economic and institutional factors. In general, these factors fill in the "holes" that model requirements and economic theory cannot fill; for example, they determine whose disposable income should appear in the retail price equations as a determinant of consumer demand.

Oyster markets extend outside the Chesapeake Bay area; i.e., the product is sold not only in the Maryland-Virginia-Washington, D.C. area, but elsewhere in the United States. Thus, the retail and, to a lesser but still significant extent, wholesale prices for Chesapeake Bay oyster products are set in national markets; retail demand is thus in part determined by national disposable income, the national average prices of other goods, and other national economic and demographic variables.

The structure of the ex-vessel market varies considerably, depending on species. Chesapeake Bay oysters are relatively homogeneous; i.e., Maryland-harvested oysters and Virginia-harvested oysters are largely indistinguishable. Therefore, ex-vessel prices for oysters harvested in the two states are nearly identical. Only one ex-vessel price equation is needed for the oyster model.

Section 2.0: Chesapeake Bay Oyster Demand

Because of the interdependency between Maryland and Virginia in oyster processing and distribution, a single system of demand equations is developed for Chesapeake Bay oysters. Equations (1) to (3) represent this demand system. Prices at three separate levels of the oyster industry are explained: consumer or retail level, intermediate or wholesale and processor level, and production or ex-vessel level.

$$RPOY = i(WPOY, C, Y, CPIMPF, POP, TIME) \quad (1)$$

$$WPOY = j(RPOY, OYEXVP, QBAY, QSG, IIGS, TIME) \quad (2)$$

$$OYEXVP = k(RPOY, WPOY, QBAY, TIME) \quad (3)$$

where:

RPOY = nominal retail price of oysters (standards) at Baltimore, Maryland (dollars per pound)

C = total consumption of U.S. oysters including western oysters and imports (millions of pounds)

Y = nominal total disposable personal income in the United States (billions of dollars)

CPI = consumer price index of meat, poultry, and fish (1967 = 100)

WPOY = nominal wholesale price of oysters (standards) at Norfolk, Virginia (dollars per pound)

QBAY = landings in the Chesapeake Bay (millions of pounds)

QSG = landings in the South Atlantic and the Gulf (millions of pounds)

IIGS = index of cost for intermediate goods and services (1967 = 100)

OYEXVP = nominal ex-vessel price of oysters, weighted average value of Maryland and Virginia landings (dollars per pound)

POP = civilian population of the United States (millions)

TIME = time trend.

The relationships among ex-vessel, wholesale, and retail prices depend upon consumer demand, product supply, and costs of marketing (Gardner 1975; Heien 1980). Specifically, retail price influences wholesale and ex-vessel price wholesale price influences retail and ex-vessel price, and ex-vessel price, influences wholesale price. The interdependent nature of oyster price determination constitutes a simultaneous system in which the endogenous variables are the market prices at the three levels in the marketing chain. However, it does not follow that prices at the three levels necessarily change together.

The time divisions used in this analysis are probably the major contributors to the simultaneity of the determination of price levels. With data for short time units, a recursive or causal chain system for price determination might be more appropriate than a simultaneous equation system. However, in this case, the data interval corresponds to one year, and hence, the simultaneous system is preferable.

Implicit in this system is a price-dependent demand (Fox 1953; Waugh 1964) for oysters. Chesapeake Bay landings in any time period are not responsive to current ex-vessel prices because harvest effort (labor and seed planting) responds to price with a time lag. A similar logic is presumed to apply to landings outside the Bay region which also may respond to prices with a time lag. Thus, landings and totai consumption in any year are treated as being exogenous when the parameters in the model are estimated. Total consumption is set equal to total U.S. landings plus imports.

It is hypothesized that in the retail price equation, the coefficient on consumption is negative, reflecting the usual inverse relationship to price. The coefficient on income is hypothesized to be positive, reflecting the argument that oysters are normal goods. CPIMPF is an index used to measure the price of substitute products such as meat, poultry, fish, and shellfish. As such, it is hypothesized to be positively related to the retail price of oysters. Income and prices of substitute products, time and population are also hypothesized to be positively related to retail price. The wholesale price is also expected to be positively related to retail price.

At the wholesale level, it is hypothesized that Bay landings and South Atlantic and Gulf landings have inverse impacts on the wholesale price. Therefore, the coefficients are expected to be negative. The unavailability of time-series data on wholesale cost components led to the use of the index of intermediate goods and services (IIGS) as a proxy variable for marketing costs other than raw materials. IIGS is an index developed by the USDA to measure trends in marketing costs for the food processing sector. As such, it can be assumed to represent costs in the oyster processing sector. Ex-vessel prices, which are the raw material costs, are expected to be positively related to wholesale price. Retail price is also hypothesized to be positively related to wholesale price. The coefficient on the time trend variable is hypothesized to be positive, reflecting a general upward price trend over the period.

In the ex-vessel price equation it is expected that landings will be inversely related to price. Coefficients on wholesale price and retail price are expected to be positive. The time trend variable is expected to be negative to reflect the fact that nominal ex-vessel prices over the time period did not rise with general inflation trends.

The demand model was estimated using annual data for 1960 to 1980. Collecting historical data for each of the variables identified in the model specification step was required to estimate the parameters of the equations. Fisheries-specific information on prices was collected from the Shellfish Market Review and the Fishery Statistics of the United States, both published annually (or more frequently) by the National Marine Fisheries Service, a division of the U.S. Department of Commerce. Data on national income, interest rates, consumer price indices, and other national economic and demographic variables were obtained from various Department of Commerce and Department of Agriculture publications. In general, annual data for the 1960-1981 period were obtained.

Ordinary least squares (OLS) could not be used to estimate the parameters of the demand sub-models because of the simultaneous structure of these submodels. In the situation where two or more variables are jointly determined in a set of structural equations, as is the case here (where the retail price determines the wholesale price, and the wholesale price determines the retail price, etc.), OLS produces coefficient estimates that are biased (i.e., the expected value of the parameter estimate is not the true parameter value). To overcome this bias, the two-stage least squares (2SLS) estimation technique was employed to estimate the parameters. This commonly employed statistical technique produces coefficient estimates that are asymptotically unbiased (i.e., unbiased for very large samples), and that are also less biased for finite samples than are the corresponding OLS coefficient estimates. However, attempts to estimate the simultaneous equation system using the traditional methods of two-stage and three-stage least squares were plagued by deleterious collinearity problems. The presence of collinearity in the first stage and the second stage regressions was confirmed by examination of the singular value decomposition of the data matrix, the variance-decomposition proportions, and the variance inflation factors (Belsley et al., 1980). According to Belsley, Kuh, and Welsch, strong variable intercorrelations, which ultimately lead to degradation of structural parameter estimates, exist in the case of condition indices in excess of 30, variance-decomposition proportions in excess of 0.5, and variance inflation factors in excess of 10. These various measures not only provide reference points to determine the seriousness of the collinearity problem but also pinpoint the variables that share in the collinearity. Also, these measures constitute generalizations of the traditional detection devices of collinearity, namely, the use of pairwise correlation coefficients of the data matrix and the use of eigenvalues and eigenvectors of the matrix of correlation coefficients. Not surprisingly, due to the nature of the data, almost all the variables in the simultaneous equation model participate in the collinearity.

To overcome the effects of collinearity in the simultaneous equation system, this study employs the adaptation of ridge regression with two-stage least squares (Capps, 1982; Vinod and Ullah, 1982; and Maasoumi, 1980). Although successfully used in economic research to reduce the effects of collinearity in single-equation applications (Brown, 1973; Brown and Beattie, 1975; Vinod, 1976; Watson and White, 1976; Moscardi and de Janvry, 1977; Belongia, 1979), the use of ridge regression in conjunction with simultaneous systems has rarely been previously attempted. However, the adaptation of ridge regression with two-stage least squares provides a reasonably straightforward method to potentially improve the structural estimation of simultaneous models.

In this application, the ridge regression modification occurs in the second-stage estimations, where the emphasis lies with structural estimation. The first-stage estimations are oriented towards obtaining predictions of right-hand side endogenous variables, wherein each endogenous variable is expressed as a function of all predetermined variables in the models. Consequently, given the emphasis on prediction rather than on structural estimation in the first-stage estimations, the ridge regression modification to circumvent the collinearity problem occurs only in the second-stage estimations.

In brief, the procedure entails the addition of small positive increments, k-values, to the correlation matrices of the second-stage equations. The selection of the k-values for the respective equations is based on the Ridge Trace (Hoerl and Kennard, 1970). The Ridge Trace is a plot of the structural coefficients versus various k-values. The choice of the k-values is indicated by the point at which the structural coefficients begin to stabilize. A draw-back to this criterion rests on the fact that the k-value selection process is subjective.

The interaction of ridge regression with two-stage least squares reduces the effects of collinearity, thereby making it possible to partition the separate effects of the various factors influencing the nominal price at each level of the marketing chain. Structural parameter estimates of the equations are exhibited in Table B.1. The standard errors of the coefficients of each equation are placed in parentheses below the coefficients. Although conventional tests of significance are not exactly applicable to parameters obtained from estimating simultaneous equation models, the estimated structural parameter is judged to be significantly different from zero when the ratio of the parameter estimate to the associated estimate of standard error is greater than two.

All estimated coefficients in the model have signs consistent with prior theoretical expectations. The model explains approximately 99 percent of the variation in the retail and wholesale prices of oysters and over 90 percent of the variation in ex-vessel price. The conventional goodness-of-fit statistic, R^2, for each of the three equations is the square of the Pearson product-moment coefficient of actual and predicted prices.

Durbin (1957) and Malinvaud (1970) have suggested that the conventional single-equation Durbin-Watson statistic be used to check for serial correlation of disturbances in the simultaneous equation setting. The appropriate number of degrees of freedom is (k,T) where K is the number of predetermined variables used in the first-stage estimations and T is the number of observations. For this application, K = 8, and T = 21. The Durbin-Watson statistics are 0.7703 for the retail price equation, 1.2658 for the wholesale price equation, and 1.0085 for the ex-vessel price equation. The null hypothesis of no autocorrelation is not rejected for any of the equations.

Overall, the Theil U_2 statistics for the market price equation indicate that the model is unequivocally better than the naive, no extrapolation model. The U_2 statistic for the no extrapolation model is unity. While no rigorous test has been developed to judge whether the difference between two U_2 coefficients is statistically significant, all but one of the U_2 coefficients of the model are much lower than the U_2 coefficients of the naive, no extrapolation model. The range of the U_2 coefficients for the retail, wholesale, and ex-vessel price equations range from 0.6647 to 1.1532.

Table B.1.: Demand Estimation: Chesapeake Bay Oyster Industry			
	Retail Price (RPOY)	**Wholesale Price (WPOY)**	**Ex-Vessel Price (OYEXVP)**
Intercept	-0.6186 (0.3584)	0.3393 (0.2140)	0.5927* (0.1415)
RPOY	--	0.1720* (0.1732E-01)	0.1348* (0.2010E-01)
WPOY	0.6250* (0.5564E-01)	--	0.3714* (0.4706E-01)
OYEXVP	--	0.5434* (0.8665E-01)	--
QBAY	--	-0.5195E-02 (0.4910E-02)	-0.1332E-01* (0.5219E-02)
QSG	--	-0.8241E-02 (0.4325E-02)	--
IIGS	--	0.1605E-02* (0.3574E-03)	--
TIME	0.1700E-01* (0.2445E-02)	0.1290E-01* (0.2977E-02)	-0.1870E-01* (0.4181E-02)
C	-.07191E-03 (0.3702E-02)	--	--
Y	0.4650E-03* (0.3288E-04)	--	--
CPIMPF	0.5237E-02* (0.7357E-03)	--	--
POP	0.3971E-02* (0.1578E-02)	--	--
R^2	0.9908	0.9881	0.9197
D-W	0.7703	1.2658	1.0085
U_2	0.6647	0.7621	1.1532
K	0.10	0.05	0.05

*Indicates significance.

In summary, the retail price of oysters is responsive to the wholesale price; income; the general price level for meat, poultry, fish and shellfish; population; and time trend. The key determinants of the wholesale price of oysters are the retail price, the ex-vessel price, the time trend, and marketing costs. The ex-vessel price of oysters in the Bay is responsive to Bay landings, the retail price, the wholesale price, and the time trend.

The impact of exogenous variables on prices at each market level is determined from the analytically derived, reduced form equations. These are reported in Table B.2. It is the analytically derived, reduced form multipliers that are used in the price simulation for the primary analysis of this report.

Table B.2: Analytically Derived Reduced Form Equations for Chesapeake Bay Oyster Demand

RPOY = 0.124665 - 0.0120494 QBAY - 0.00798671 QSG + 0.00155547 IIGS + 0.0236945 TIME - 0.000890018 C + 0.000575522 Y + 0.00648174 CPIMPF + 0.00491484 POP

WPOY = 0.790295 - 0.0192791 QBAY - 0.0127787 QSG + 0.00248876 IIGS + 0.0107112 TIME - 0.000273468 C + 0.000176836 Y + 0.00199159 CPIMPF + 0.00151014 POP

OYEXVP = 0.869411 - 0.0221045 QBAY - 0.00582263 QSG + 0.001134 IIGS - 0.115278 TIME - 0.00022154 C + 0.000143257 Y + 0.00161342 CPIMPF+ 0.00122339 POP

Appendix C

The Budget Simulator

Appendix C

The Budget Simulator

Section 1.0: Budget Format

25 harvesters shown in Section 6 of Appendix A, Part 2 were estimated with a budget simulator. The budget simulator employs a spreadsheet program to evaluate changes in net returns associated with a policy change. The spreadsheet program allows the use of a fixed-format budget in which formulae are imbedded for each budget item. The individual components for each budget item are listed outside of the budget format. Table C.1 illustrates the spreadsheet format for the private planter budget.

Lines 1 through 25 of Table C.1 comprise the budget portion of the spreadsheet. The budget formulae are listed in column 2 of Table C.1. The budget components in each formula are identified by a row and column number. For example, the formula in row 4 column B is 1xB33. meaning that the cost per bushel of planting seed is 1 multiplied by the value that appears in row 33 column B. Lines 31 to 41 are the names and values of the budget items. These values are choice values that set the parameters under which net returns are to be computed. Given these values, the spreadsheet program performs all the computations indicated in the budget. The resulting computed budget for the selected parameter values shown in Table C.1 is shown in Table C.2. The data sources for the parameter values shown in this appendix are discussed in Section 2.3 of Appendix A, Part 2.

The impact on net returns under any given management policy may easily be assessed by adjusting the budget parameters to reflect the conditions that would exist under the new policy.

In a similar fashion to that described above, budgets for public grounds tongers and dredgers can be formulated. The budget format and a sample computed budget for a representative public grounds tonger are presented in Tables C.3 and C.4 respectively. Likewise, Tables C.5 and C.6 present the budget format and sample computed budget for a representative dredge harvester.

Table C.1: Budget Spreadsheet Format for a Representative Private Grounds Planter

	A	B
1		Seed Planting Cost/bu.
2		
3		
4	Seed Planting Cost	1 x B33
5	Seed Purchase Price	1 x B34
6	Seed Transport Price	1 x B35
7	Seed Tax Rate	1 x B36
8		
9	Total per Bushel Cost	B4 + B5 + B6 + B7
10		
11		
12		Cost per Acre
13		
14	Total Planting Cost	B9 x B39
15	Harvest Cost	B38 x B37
16		
17	Total Cost	B14 + B15
18	Average Cost	(B/14/B15) x (B38 x B41)
19		
20		Returns Per Acre
21		
22	Bushels Harvested	1 x B38
23	Pounds of Meats Yielded	B38 x B41
24		
25	Total Returns	B23 x B40
26	Net Return	B25 - B17
27	Average Net Return	B26/B23
28		
29		
30		
31		Budget Parameters
32		
33	Planting Cost per bu.	.55
34	Seed Cost	2.38
35	Seed Transport	.3685
36	Seed Tax	.1
37	Harvest Cost	1.602
38	Productivity	750
39	Bushels of Seed Planted	750
40	Ex-Vessel Price/lb.	.85889
41	Convert Bu. to Lbs.	4.5919

Table C.2: Per Acre Returns to Fixed Costs and Management For A Representative Private Planter

Seed Planting Cost/bu.	
Seed Planting Cost	.55
Seed Purchase Price	2.38
Seed Transport Price	.3685
Seed Tax Rate	.1
Total per Bushel Cost	3.3985
Cost per Acre	
Total Planting Cost	2548.875
Harvest Cost	1201.5
Total Cost	3750.375
Average Cost	1.08898277402
Returns Per Acre	
Bushels Harvested	750
Pounds of Meats Yielded	3443.925
Total Returns	2957.95274325
Net Return	-792.42225675
Average Net Return	-.230092774015

Table C.3: Spreadsheet Budget Format for a Representative Public Grounds Hand Tonger

	F	G
1		Annual Hand Tonger Budget
2		
3		
4	Nominal Variable Costs	
5	Vessel Maintenance	1 x G26
6	Gear Maintenance	1 x G27
7	Fuel	G28 x G29 x G30
8	Wages	G31 x G32
9	Miscellaneous	1 x G39
10		
11	Total Nominal Variable Cost	G5 + G6 + G7 + G8 + G9
12	Real Variable Cost (1983 $)	(G11/G37) x G38
13		
14		
15	Returns	
16	Annual Catch, (Pounds)	G33 x G36 x G30
17	Total Revenue	G16 x G35
18	Net Revenue	G17 - G12
19	Repletion Taxes Paid	G33 x G34 x G30
20	After-Tax Net Revenue	G18 - G19
21		
22		
23		
24		Budget Parameters
25		
26	Vessel Maintenance	85
27	Gear Maintenance	35
28	Fuel Price, ($/Gallon)	.5
29	Fuel Usage, (Gallons/Day)	2.2
30	Days Fished	75
31	Wage Rate, ($/Hour)	3
32	Hours of Labor Hired	113.11
33	Daily Catch, (Bushels)	20
34	Market Oyster Repletion Tax	.5
35	Ex-Vessel Price	.85889
36	Conversion Rate (Pounds/Bushel)	4.8833
37	CPI 1961	.896
38	CPI 1983	2.984
39	Miscellaneous Expenses	0

Table C.4: Annual Returns to Fixed Costs and Management for a Representative Public Grounds Hand Tonger	
Nominal Variable Costs	
Vessel Maintenance	85
Gear Maintenance	35
Fuel	82.5
Wages	339.33
Miscellaneous	0
Total Nominal Variable Cost	541.83
Real Variable Cost (1983 $)	1804.48741071
Returns	
Annual Catch, (Pounds)	7324.95
Total Revenue	6291.3263055
Net Revenue	4486.83889479
Repletion Taxes Paid	750
After-Tax Net Revenue	3736.83889479

Table C.5: Spreadsheet Budget Format For A Public Grounds Dredger

	J	K
1		Annual Dredge Budget
2	Nominal Variable Costs	
3		
4	Vessel Maintenance	1 x K24
5	Gear Maintenance	1 x K25
6	Fuel	K26 x K27 x K28
7	Wages	K29 x K30
8	Food	1 x K31
9	Miscellaneous	1 x K32
10		
11	Total Nominal Variable Cost	K4 + K5 + K6 + K7 + K8 + K9
12	Real Variable Cost (1983 $)	(K11/K37) x K38
13		
14		
15	Returns	
16	Annual Catch (Pounds)	K33 x K34 x K28
17	Total Revenues	K16 x K35
18	Net Revenues	K17 - K12
19	Repletion Taxes Paid	K33 x K36 x K28
20	Net After-Tax Returns	K18 - K19
21		
22		
23		Budget Parameters
24	Vessel Maintenance	1800
25	Gear Maintenance	350
26	Fuel Price, ($/Gallon)	.5
27	Fuel Usage, (Gallons/Day)	14
28	Days Fished	75
29	Wage Rate, ($/Hour)	3
30	Hours Hired (Year)	1187.5
31	Food Expense	675
32	Miscellaneous	0
33	Daily Catch	160
34	Conversion Rate (Pounds/Bushel)	4.8833
35	Ex-Vessel Price	.85889
36	Market Oyster Repletion Tax	.5
37	CPI 1961	.896
38	CPI 1983	2.984

Table C.6: Annual Returns to Fixed Costs and Operator Labor for a Public Grounds Dredge Harvester	
Nominal Variable Costs	
Vessel Maintenance	1800
Gear Maintenance	350
Fuel	525
Wages	3562.5
Food	675
Miscellaneous	0
Total Nominal Variable Cost	6912.5
Real Variable Cost (1983 $)	23021.09375
Returns	
Annual Catch (Pounds)	58599.6
Total Revenues	50330.610444
Net Revenues	27309.516694
Repletion Taxes Paid	6000
Net After-Tax Returns	21309.516694

Appendix D

Contribution of the Oyster Industry to the Virginia Economy and Tax Base

Appendix D

Contribution of the Oyster Industry to the Virginia Economy and Tax Base

Section 1.0: Introduction

This section provides preliminary estimates of the contribution of the commercial oyster industry to the economy and tax base of Virginia. The primary purpose of this section is to provide economic impact estimates for the simulation model of this report. A second, and more long term purpose, is to generally describe the basic framework for economic impact analyses in order to illustrate basic data needed for making future improvements to such analyses.

Section 2.0: Measuring the Regional Economic Impact of the Oyster Industry

The contribution of an industry (economic sector) to the economy of a region extends beyond the dollar value of production of that single industry. The effect of any one industry on the economy involves an interdependence with numerous economic sectors through the purchase and sale of labor and materials from other industries. For example, oyster harvest requires purchase of inputs from sellers of fuel, labor, and fishing gear. Sales of harvested oysters go to processors, wholesalers, or retailers. All these parties are affected by the fact that the oyster harvest activity exists within the region. Additionally, income paid to households employed by the affected sectors of the economy is, in turn, spent on a wide array of consumer and investment items further extending the initial effect of the oyster harvest.

In this study, estimates of the impact of the oyster industry on the Virginia economy are based on a multiplier analysis. Multipliers indicate the aggregate effects, on the economy of an area (state or region), of some level (or change in the level) of a specific industry. There are many multipliers from which an analyst might choose, depending upon the particular measure used to evaluate economic activity--output and value-added are the two measures discussed here.

An output multiplier indicates the change in industry and business output in the regional economy resulting from a one-dollar change in a specific sector's sales to final demand. Sales to final demand are all sales to buyers outside the economy being studied plus sales to households, governments and net capital expenditures within the region's economy; final demand excludes sales of a sectors output which are used as inputs by other firms in the regional economy. Thus, if the output multiplier for the oyster industry in Virginia is 2.0, then $1.0 million of final demand for oysters results in total output in the state's economy of $2.0 million. The problem with this multiplier is that total dollar output includes expenditures made by all affected firms to purchase inputs necessary for their production. Thus, the output multiplier provides a "gross" rather than "net" income measure.

The value-added/output multiplier indicates the effect of a change in final demand on the aggregate level of value-added--the value of output less the value of inputs used. The concept of value-added is closely related to the familiar macro-economic measure Gross Domestic Product (GDP). Value-added is a better measure than output of aggregate economic activity since it excludes purchases made for inputs and, therefore, is a "net" income concept.

The output and value-added/output multipliers for the Virginia oyster industry, used in this appendix, are based on an existing input-output model for the Commonwealth. The model was developed by the Regional Science Research Institute for the use of Virginia Tech. It is based on the 1972 input-output model of the United States but has been adjusted to reflect the structure of the Commonwealth's economy (Regional Science Research Institute, 1981).

Input-output models portray the economic relationships between the various sectors in an economy. Since every industry must purchase its inputs from other industries, a series of relationships ensue which create complex linkages between almost all sectors. For example, consider fish harvest. This sector purchases inputs from a rather limited group of sectors including the agricultural, forestry, and fishing services industry; the manufactured ice industry; the apparel industry; the ship building and repairing industry; transportation; and certain other services. However, these industries must, in turn, purchase inputs from other firms. After a few rounds of purchases, almost all sectors will be influenced somewhat by the original purchases of the fishing industry.

Input-output calculates the level of production required from all other sectors by a change, for example, in final demand from the oyster harvest sector. Since each sector is linked to others in a unique manner, each sector will generate a unique multiplier effect. The original final demand for a sector is commonly referred to as the direct effect; the impacts in affected sectors are referred to as indirect effects. The sum of sectoral outputs (other than the original final demand) is therefore referred to as indirect output. Input-output models generate estimates of output multipliers by calculating the following ratio:

$$\text{Output Multiplier} = \frac{\text{direct output} + \text{indirect output}}{\text{direct output}}$$

Input-output models assume that all expenditures for purchased inputs by firms are constant proportions of their output. Therefore, the levels of value-added are fixed as a proportion of the output levels of each sector. Thus it is possible to develop a multiplier which indicates the value added to the economy stemming from a level of final demand in a particular sector.

$$\text{Value-added/Output Multiplier} = \frac{\text{direct value-added} + \text{indirect value-added}}{\text{direct output}}$$

The value-added/output multiplier can be used as an accounting device to divide existing state GDP among the various economic sectors in the state's economy. Specifically, given final demands for each sector in the state's economy and a sector's value-added/output multiplier, the value added in the economy derived from each sector's final demand can be computed. Summing these value-added impacts across all sectors will closely approximate the GDP for the state. However, it does <u>not</u> follow that elimination of the industry would reduce state GDP by the calculated amounts because the resources used in production would be diverted to some alternative use. It would only be the case that GDP would fall by the calculated amount if all labor and capital inputs used in the affected industries had no value in any other use.

Section 3.0: Virginia's Commercial Oyster Industry

In Virginia the oyster industry includes the harvest, processing, and distribution of shellfish products. Each of these general activities requires the purchase of production inputs from other sectors of the economy and sale of final products to other sectors. These purchases from and sales to other sectors set in motion a multiplier effect which results in additional output and value-added in the larger economy as a result of the oyster industry activity. Figure D.1 is a general depiction of the flows of oyster products in the Virginia industry. Harvested products move either to consumers through wholesale and retail distribution channels or move to processing before being delivered to consumers. In addition the processing sector may import products harvested outside the state for processing.

In order to compute the economic contribution of the oyster industry to the Virginia economy, three types of information must be known: (1) value and quantity of harvest in Virginia; (2) proportion of harvest processed in Virginia and imports to Virginia; and, (3) value of processed product. For purposes of this analysis, value and quantity of harvest information were taken from the simulation model. However, no data exist to determine how much of the harvested product is processed before being distributed. To make such estimates interviews with persons familiar with the industry had been conducted. Also, it was assumed for this study that fifty percent of the oysters processed in Virginia are imported (Virginia Marine Resources Commission, 1980). It was also assumed that there were no imports by wholesalers for further distribution. Last values of processed oysters were not available for recent years, and approximations of these values were made.

Section 4.0: The Multiplier Effects of Virginia's Oyster Industry

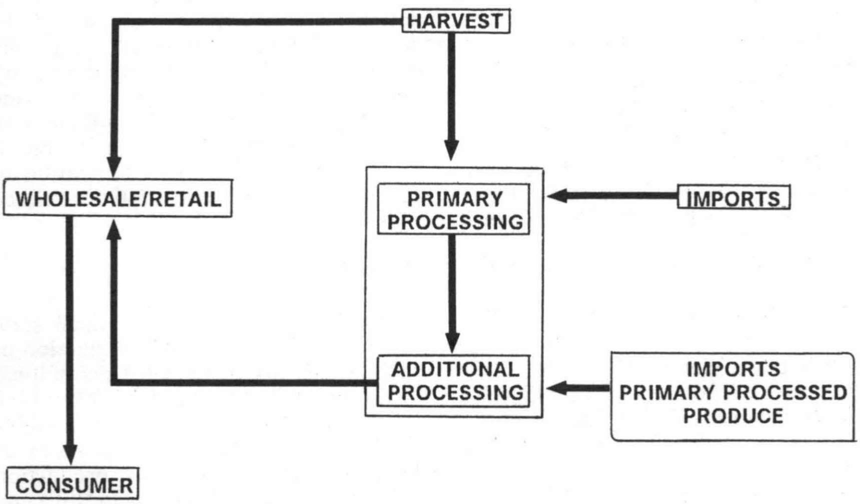
Two distinct multipliers were identified for the Commonwealth's oyster industry. These include the multiplier effects from: (1) seafood sold fresh to households in Virginia and buyers outside the state, and (2) oysters processed in state. The multiplier effects of these activities are provided in Table D.1. Oysters marketed through the fresh market generated the largest aggregate effect on value-added, because of the relatively high labor intensity involved in harvest. It is important to keep in mind that these multipliers refer to dollar units and not physical units. The total value-added in the economy per pound of harvested fish would be lower for fresh fish than for processed fish since the latter would include the value-added of the raw product plus value-added in processing.

The use of the multipliers reported in Table D.1 is illustrated by the following general example. Assume 200 pounds of product is harvested in Virginia with a dockside value of $100. Fifty percent of the landings move on to processing and the rest is distributed to consumers. Thus $50 of final demand exists at the harvest level. At the processing sector 100 pounds of raw product harvested in Virginia is processed to provide 75 pounds of processed product (25 pounds are waste). The processed product sells for $2.00 per pound yielding a final demand of $150 at the processing level.

Using the multipliers from Table D.1, the total effect of these two final demand levels on the economy can be calculated as shown in Table D.2. From Table D.2 it is shown that $100 of landing generated $295.55 of output and $127.95 of value-added in the regional economy.

Figure D.1

Product Flows in the Virginia Seafood Industry



Key

Harvest: Oyster landings made at Virginia ports for ultimate use by consumer.

Imports: Oysters in unprocessed condition (or at a stage of preliminary processing) brought into the state for processing prior to distribution to wholesale or retail distribution.

Primary Processing: Defined here to include shucking of oysters.

Additional Processing: Includes preparation of prepared shellfish products to decrease consumer preparation requirements (ex. breaded oysters).

Wholesale/Retail: Assembly and transportation to consumers including restaurant and institutional use.

Section 5.0: Estimated Impacts of the Oyster Industry

The results for the oyster industry are shown in Table D.3. Assumptions made for each computation are indicated in footnotes to the table. Output effects are, of course, substantially larger than value-added effects from the industry. However, the value-added effects are a more meaningful measure of the "net" contribution of the seafood industry to the Virginia economy.

Section 6.0: Future Research Needs

This preliminary economic impact analysis can be improved upon by improvements in basic data about the seafood industry and by refinements of the estimated multipliers from the existing input-output model. The existing input-output multipliers are for aggregated activities and can only be approximations for the more specific activities considered in this paper. For example, the multiplier used for oyster harvest was the forestry/fishery multiplier from the existing model. Estimation of multipliers specifically for individual species harvest, processing, and distribution activities will require primary survey data from fishermen, processors, and wholesalers on (1) the expenditures made for various purchased inputs necessary for their production and (2) the volume and distribution of their sales. Such information can only be gathered from a sample of representative local fishermen, processors, and wholesalers. Thus the cooperation of those whose earn their living from the seafood industry is necessary if more refined estimates than those provided here are to be developed.

Section 7.0: Indirect Tax Revenue from the Oyster Industry

The value added to the state economy represents a tax base upon which state general tax revenues are earned. For purposes of this study, only an approximation of the indirect tax revenues was made. This estimate begins by assuming a definitional identity between reported measures of value-added from the input output model and the Gross State Product. In fact, the accounting relationship between GSP and value-added is as follows. GSP is the value of all final goods produced in the State; final goods do not include products that were used as production inputs into other production processing. GSP less capital depreciation allowances equals net state product (NSP) and NSP is an accounting identity with value added from the input-output analysis.

There are no published state value-added or NSP figures. Therefore, a rough identity of GSP and value-added was assumed. Data were collected for GSP (Cox, 1986) and total state tax revenue United States Department of Commerce, various years). With these two data series, the percent of GSP realized in taxes for years 1980-1984 was estimated (Table 4). Applying the 1980-1984 average percentage of 13.784% to the estimated state value-added from oyster production, yields the indirect tax estimate reported in the main text of this report.

Table D.1: Multipliers for the Virginia Oyster Industry form the Virginia Input-Output Model		
	Harvest*	Oyster Processing**
Output	1.417	1.498
Value-Added/ Output	0.882	0.599

*From Virginia input-output model, sector 9 (fishery and forestry products).

**From Virginia input-output model, sector 37 (canned and cured seafood products); assumes 50 percent of raw products to be processed are imported into the state.

Table D.2: Example of Calculation of Output and Value-Added Effects					
Output					
Processing	.498	*	$150	=	$224.70
Harvest	1.417	*	$ 50	=	$ 70.85
Total					$295.55
Value-Added					
Processing	.599	*	$150	=	$ 83.85
Harvest	.882	*	$ 50	=	$ 44.10
Total					$127.95

Table D.3: Economic Impact of the Oyster Industry

Output

Harvest*	$986,300	*1.417	=	$1,397,587
Processing**	$34,044,006	*1.498	=	$50,997,920
Total				$52,395,507

Value Added

Harvest*	$986,300	*.882	=	$869,916
Processing**	$34,044,006	*.599	=	$19,030,599
Total	$19,900,515			

*10 percent of $9,863,000 value of oysters landed is assumed to be distributed without shucking.

**Assumes one half of oysters processed in Virginia are imported from elsewhere (primarily Maryland); assumes 40,000 gallons of shucked oysters are sent to additional processing (breading; stews, etc.); final demand at primary processing equals $33,057,006 based upon price of shucked meats of $2.09 per pound; final demand at additional processing equals $987,000 based upon $2.82 pound for oyster meat after further processing.

Table D.4: Virginia State Tax Revenues as a Percent of Gross State Product

	Virginia GSP ($ Billion)	Tax Revenue ($ Billion)	Tax Revenue as a % of GSP
1980	59.113	6.712	11.35
1981	65.671	7.883	12.11
1982	71.184	8.643	12.14
1983	77.860	9.098	11.69
1984	87.451	10.018	11.46

References

Bailey, R. S. and F. C. Biggs. 1968. Let's Be Oyster Farmers. Gloucester Point, Virginia: Virginia Institute of Marine Sciences.

Baker, Samuel H., Frederick H. Harris and Carlisle E. Moody. 1977. A Benefit-Cost Analysis's of the Virginia Oyster Subsidies: An Historical Appraisal and Proposals for the Future. Williamsburg, Virginia: Department of Economics, College of William and Mary.

Belongia, M. 1979. "Application of Ridge Regression with Verification of New Procedures." Agricultural Economics Research. 31:36-39.

Belsley, D. A., E. Kuh and R. W. Welsch. 1980. Regression Diagnostics: Identifying Influential Data and Sources of Collinearity. New York, New York: John Wiley and Sons.

Brown, W. G. 1973. "Effect of Omitting Relevant Variables Versus Use of Ridge Regression in Economic Research." Corvallis, Oregon: Oregon Agricultural Experiment Station Special Report 394.

Brown, W. G. and B. R. Beattie. 1975. "Improving Estimates of Economic Parameters by Use of Ridge Regression with Production Function Application." American Journal of Agricultural Economics 57:21-32.

Campbell, D. W., and R. H. Forste. 1978. The Biological and Economic Aspects of Oyster Propagation in Maryland. (no. FA-MRR-78-2). Annapolis, Maryland: Maryland Department of Natural Resources.

Capps, O., Jr. 1982. "Treatment of Multicollinearity in Simultaneous Systems of Linear Equations." Staff Paper SP-82-1. Blacksburg, Virginia: Department of Agricultural Economics, Virginia Polytechnic Institute and State University.

Corps of Engineers. 1961. Chesapeake Bay Fishery Harbors Economic Study, Maryland and Virginia. Washington, D. C.: Board of Engineers for Rivers and Harbors.

Cox, Robert W. 1986. "Virginia Annual Gross State Product, 1958-1985." Charlottesville, Virginia: Tayloe Murphy Institute, University of Virginia.

Durbin, J. 1957. "Testing for Serial Correlation in Systems of Simultaneous Regression Equations." Biometrica 370-377.

Federal Reserve Bulletin. 1984. "A Financial Perspective on Agriculture." Washington, D.C.: Board of Governors of the Federal Reserve System.

Fishery Statistics of the United States (FSUS). 1950-1976. Washington D. C.: U.S. Department of Commerce, National Marine Fisheries Service.

Fox, K. 1953. The Analysis of Demand for Farm Products. Technical Bulletin No. 1081. Washington, D. C.: United States Department of Agriculture.

Gardner, B. L. 1975. "The Farm-Retail Price Spread in a Competitive Food Industry." American Journal of Agricultural Economics 57:399-409.

Haven, Dexter S., W. J. Hargis and P. C. Kendall. 1981a. The Oyster Industry of Virginia: It's Status, Problems and Promise. Special Papers on Marine Science No. 4. Gloucester Point, Virginia: Virginia Institute of Marine Sciences.

Haven, Dexter S., J. P. Whitcomb and P. C. Kendall. 1981b. The Present and Potential Productivity of the Baylor Grounds in Virginia. (no. 243). Gloucester Point, Virginia: Virginia Institute of Marine Science and Ocean Engineering. Vol. I&II.

Heien, D. M. 1980. "Markup Pricing in a Dynamic Model of the Food Industry." American Journal of Agricultural Economics. 62:10-18.

Hoerl, A. E. and R. W. Kennard. 1970. "Ridge Regression: Applications to Nonorthogonal Problems." Technometrics 12:69-82.

Joint Legislative Audit and Review Commission (JLARC). 1977. Program Evaluation Marine Resource Management Programs in Virginia. Richmond, Virginia: Commonwealth of Virginia.

Joint Legislative Audit and Review Commission (JLARC). 1984. The Economic Potential and Management of Virginia's Seafood Industry. House Document No. 2. Richmond, Virginia: Commonwealth of Virginia.

Kennedy, Victor S. and L. L. Breisch. 1981. Maryland's Oysters: Research and Management. (no. UM-SG-TS-81-04). College Park, Maryland: Maryland Sea Grant.

Laws of Virginia Relating to the Marine Resources of the Commonwealth. 1980. Newport News, Virginia: Virginia Marine Resources Commission.

Maasoumi, E. 1980. "A Ridge-Like Method for Simultaneous Estimation of Simultaneous Equations." Journal of Econometrics 12:161-176.

Malinvaud, E. 1970. Statistical Methods of Econometrics. Chicago, Illinois: Rand McNally and Company.

Merritt, Donald W.. 1977. Oyster Spat Set on Natural Cultch in the Maryland Portion of the Chesapeake Bay. University of Maryland College of Environmental Studies Special Report No. 7. Cambridge, Maryland: Horn Point Environmental Laboratories.

Moscardi, E. and A. de Janvry. 1977. "Attitudes Toward Risk Among Peasants: An Econometric Approach." American Journal of Agricultural Economics 59:710-716.

Regional Science Research Institute. 1982. Basic Regional Input-Ouput for Transportation Impact Analysis: Handbook 1. Amherst, Massachusetts: Regional Science Research Institute.

Santopietro, George D.. 1986. The Evolution of Property Rights to a Natural Resource: the Oyster Grounds of the Chesapeake Bay. Blacksburg, Virginia: Department of Agricultural Economics, Virginia Tech (Dissertation).

Shabman, Leonard A. and Oral J. Capps. 1986. Econometric Demand and Supply Models of Selected Chesapekae Bay Seafood Products: Report 1: Oysters. Blacksburg, Virginia: Department of Agricultural Economics, Virginia Tech. (Unpublished Working Paper).

Shabman, Leonard A. and Thomas Johnson. 1986. Contribution of the Commercial Seafood Industry to the Virginia Economy: A Preliminary Assessment. (#SP-82-8). Blacksburg, Virginia: Department of Agricultural Economics, Virginia Tech.

Shellfish Market Review. 1981. Washington, D. C.: U.S. Department of Commerce, National Marine Fisheries Service,

Thunberg, Eric. 1985. A Decision Model to Evaluate the Cost-Effectiveness of Alternative Virginia Oyster Grounds Management Strategies. Blacksburg, Virginia: Department of Agricultural Economics, Virginia Tech. (Unpublished Thesis).

Vinod, H. D. 1976. "Application of New Ridge Regression Methods to a Study of Bell Systems Scale Economics." Journal of the American Statistical Association 71:835-841.

Vinod, H. D. and A. Ullah. 1982. Recent Advances in Regression Methods. New York, New York: Marcel Dekker, Inc.

Virginia Marine Resources Commission (VMRC). 1982. Annual Reports for 1981 and 1982. Newport News, Virginia.

Virginia Marine Resources Commission (VMRC). An Overview of the Virginia Oyster Fishery Management Plan. Fisheries Plans and Statistics Section, Fisheries Management Division. Newport News, Virginia: Virginia Marine Resources Commission. (Unpublished Draft).

Watson, D. E. and K. J. White. 1976. "Forecasting the Demand for Money Under Changing Term Structure of Interest Rates: An application of Ridge Regression." Southern Economic Journal 43:1096-1105.

Waugh, F. V. 1964. Demand and Price Analysis. Technical Bulletin No. 1316. Washington, D. C.: United States Department of Agriculture, Economics Research Service.

[illegible] Johnson. 1986. "Contributory [illegible] Language" [illegible] Functions. A [illegible] 1986 [illegible] [illegible] Journal of Agricultural Economics [illegible]

[illegible] 1985. [illegible] Models [illegible] [illegible]

[illegible] Models [illegible] in the [illegible] management systems [illegible] Virginia [illegible] Thesis.

[illegible] of New Kids. Regression Methods [illegible] Journal of the American Statistical [illegible]

[illegible] Statistical [illegible] in Regression [illegible] Marcel Dekker, Inc.

[illegible] (SAS) [illegible] 1985. SAS [illegible] User's Guide: [illegible]

[illegible] Research Commission (1986) [illegible] Statistics [illegible] Virginia [illegible]

[illegible] 1987. [illegible] Virginia [illegible]

[illegible] Economics [illegible] Journal of [illegible]

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