Managing Oyster Harvests in Maryland's Chesapeake Bay

Prepared for: NOAA Chesapeake Bay Office,
Non-native Oyster Research Program.

By: Robert Wieland,
Main Street Economics

Revised: March 4, 2008

Acknowledgments

In my background research for this paper I have received a great deal of help from a great many people. Watermen willingly provided harvest cost information useful to the study. DNR staff provided everything that was asked of them. And, other researchers working on the Chesapeake Bay oyster fishery provided comments and insight on the problems facing this fishery. At the risk of leaving anyone out, I wish to thank, especially, DNR staff Connie Lewis, Mick Astarb, Eric Campbell and Chris Judy. Chris Dungan at the Oxford Lab helped to clarify various knotty issues and, Gary Smith, formerly of the Oxford Lab and now with Random Motion, provided background on oyster habitat. Doug Lipton at the University of Maryland's Agricultural and Resource Economics Department provided useful direction at several junctures in the project and reviewed an earlier draft of the report. David Herberich, a graduate student in the department provided excellent research analysis for the returns to repletion research. Vic Kennedy and Roger Newell at UMCES' Horn Point Lab provided significant help at the start of the study and both reviewed an earlier draft of this paper. I am indebted to all of these for their help. The study was funded by NOAA's Chesapeake Bay Office. The product that I have generated with this help is not necessarily agreeable to all who have helped me, but it represents my best understanding of the issues considered. Any errors or omissions are my responsibility.

Managing Oyster Harvests in Maryland's Chesapeake Bay

Executive Summary 1
I. Introduction 4
II. Common Property and Resource Conservation in Maryland's Oyster Fishery 7
II.A. The Common Property Model 7
II.B. Managing Harvest Effort in Maryland's Oyster Fishery 10
1. Limiting effort by limiting the number of harvesters 11
2. Limiting harvest effort by limiting the time available for harvest 12
3. Limiting effort by gear restrictions 13
4. Restricting the area allowed for harvest 14
5. Restricting effort through catch limits 15
6. Economic Policies for limiting effort 16
II.C. Summary 18
III. Oyster Repletion and Restoration 20
III.A. Background on Oyster Repletion and Restoration 20
III.A.1. Historical Oyster Repletion 21
III.A.2. Maryland's Oyster Roundtable 23
III.A.3. Oyster Restoration 24
III.B. Estimating Returns to Management and Repletion 28
III.B.1. Previous Production Functions for Repletion Efforts 28
III.B.2. Modeling Recent Repletion Performance 30
III.C. Summary 33
IV. The Implications of Historical Harvest Management for the Proposed Introduction and its Alternatives 34
IV.A. Introducing Crassostrea ariakensis and Continuing Native Oyster Restoration. 34
IV.B. Prospects for aquaculture 38
IV.C. Change for sustainable benefits from the oyster fishery. 40
REFERENCES 42
Data Appendix 45

Executive Summary

The State of Maryland is considering the intentional introduction of a non-native oyster to its waters as a means to restore potential in the harvest industry and to regain ecological benefits associated with large oyster populations in the Chesapeake Bay. This report addresses the history of the state's management of oysters and oyster harvests over the years in which native oyster stocks have declined as background for that decision. It directly addresses incentive-based issues of concern for both the introduction of a non-native oyster and continued restoration of the native oyster, as well as the two aquaculture alternatives. While it does not directly address the moratorium alternative, the report provides background for that question.

Oyster harvests in Maryland's portion of the Chesapeake Bay peaked during the late 19th century. While direct estimates of oyster stocks are not available prior to the 1990s, it is generally thought that oyster stocks, like harvests, have trended downward since the late 1800s. During much of this period, stock declines are thought to have been a result of harvests, both directly through harvest mortality and indirectly through harvests' effects on oyster habitat. In the late-1980s a final collapse of oyster stocks followed disease epizootics. Oyster harvests have been small, relative to historical harvests, ever since.

Up to the present, the underlying principal for harvesting oyster stocks in Maryland has been that they belong to whoever takes them and that, within the constraints imposed by regulations, they can be freely harvested by anyone who wants to harvest them. The economic model that best fits a renewable resource with this kind of harvest regime is the common property model, first proposed by Gordon (1954). Under that model, economic rents in the fishery attract additional effort until those rents are eliminated, at which point stocks are, in the general case, also reduced. This is an inefficient outcome, in the sense that less effort could generate larger harvests if larger stocks were maintained. Moreover, if the resource generated any additional benefits such as ecological services, these would be undersupplied at this common property equilibrium.

The dissipation of rents in a fishery has much to do with excess fishing effort. The report reviews the regulatory constraints that have been imposed on oyster harvesters over time in search of limiting factors for excess fishing effort and finds no evidence that the regulations considered have restricted harvests below the common property equilibrium. Gear restrictions have limited the common property equilibrium by raising harvest costs, but limited-entry, time and catch limits, and area closures have done little to affect either the incentives of harvesters or the amount of effort extended to harvest available stock. Moreover, in recent years gear restrictions have been relaxed, effectively increasing fishing effort in the face of severely reduced stocks.

Management of oyster harvests is only part of the story, however. In addition to attempting to regulate harvests below the common property equilibrium, the state of Maryland has attempted to improve oyster stocks by spreading shell and seed oysters on

harvest bars and, more recently, by trying to restore stocks on permanent closures (sanctuaries) and on sites where harvests are more effectively constrained (managed reserves). The report reviews commercial oyster repletion efforts with respect to gross volumes and costs from 1960 to the present. It then describes similar measures for alternative oyster restoration from 2000 onward. While several innovations (use of disease-free hatchery-produced seed oysters, cleaning bars of existing, diseased oysters) are associated with non-commercial oyster restoration, these practices and resources are increasingly being applied on public harvest bars.

Following the description of historical practices aimed at improving oyster stocks, the report reviews several earlier efforts to develop bio-economic models and production functions for Maryland's oyster fishery. Among these, it focuses on an effort made by R.A. Cabraal (1978) to model returns to repletion effort with respect to fresh shell, dredged shell and seed oysters. Although Cabraal's study was undertaken before disease epizootics had severely reduced stocks in Maryland's portion of the Bay, it still reported mixed results in the efficacy of repletion. Over all, Cabraal found a positive rate of return on repletion efforts, but his measure of returns ignored private costs of harvest.

Using data from the period following the disease epizootic, the paper reports research undertaken for the current project and aiming to measure more recent returns to repletion. That study expanded Cabraal's analysis to include repletion's effect on harvester effort, as well as its effect on harvests. Even considering this additional effect from repletion, the study found only a small boost from repletion efforts and, when compared with costs, the commercial benefits of those efforts did not rise to the costs of achieving them. And, while a thorough cost analysis of harvest reserves created under more recent restoration efforts could not be specified, it is suggested that the costs of those activities are much higher than the costs of repletion and that they too do not generate a positive return on investment with respect to commercial harvests.

In the debate over management of oyster stocks in Maryland's Chesapeake Bay it is sometimes argued that unremunerated support for the harvest industry is necessary because, without it, the fishery would collapse and watermen would be driven out of business, irrevocably changing tidewater culture. However, the number of person days applied in the oyster fishery in 2006 was only ten percent of the person days applied in 1977, 30 years earlier. Over the period, labor that would have been applied to harvesting oysters, had larger oyster stocks been available, has been applied to other activities. By this measure, clearly, a large share of the economic adjustment has already been made.

In its final chapter, the report examines the implications of historical management of Maryland's oyster fishery for the introduction of a non-native oyster. While the nominal objective of the introduction of a non-native oyster is the restoration of oyster stocks, the same incentives that caused declines in oyster stocks from 1880 to 1980 are still in place. Without a significant change in those incentives, it is not clear how stocks of an introduced non-native oyster would increase as desired. If, under the current situation, future stock growth is traded for present harvests, it seems reasonable to expect similar treatment of an introduced oyster.

The final chapter also reviews the economic and regulatory constraints to the aquaculture alternative to the introduction of a fertile non-native oyster in Maryland. These constraints derive largely from the open access regime that defines Maryland's oyster fishery. Although efforts have been made to change the statutory basis for this, those efforts have not yet born fruit. Without a change in the regulations addressing oyster bottom and the creation of credible enforcement of those regulations, it does not appear likely that oyster culture will be taken up on a commercial scale in Maryland.

The report concludes with a recommendation that property rights to oysters in Maryland's Chesapeake Bay be assigned either to the state or to private enterprises. Assigning ownership of the resource to the State might permit its agencies to work in a more focused manner to restore stocks and ensure sustainable harvests. If managers were given a clear mandate to ensure long-term success of the resource, ownership of oyster stocks would allow them to assign a price to removals, reducing the open-access incentive to over harvest. Or, alternatively, managers could establish and more effectively enforce harvest allowances, based on biological and longer-term economic objectives. State ownership would also clarify illegal harvests as theft, allowing more credible penalties for those. Under the private sector alternative, costs of restoring bottom would be prohibitive to many private oyster growers, and it is not likely that the returns to bottom oyster aquaculture in Maryland's portion of the Bay is remunerative for the native oyster. Returns to a disease resistant oyster would be higher.

While state ownership of the oyster resource would not guarantee management that achieves optimal stock growth or maximum economic returns over time, it could change the incentives of managers to the extent that they could be brought to focus on the long-term prospects for the resource, rather than the short-term interests of the harvest industry. Moreover, in the case of an introduced non-native species, if the introduction goes awry and causes large social or private costs, it is likely that an effort would be made to hold the state accountable and, in that sense, the resource could be, *de facto*, owned by them.

I. Introduction

Eastern oysters (*Crassostrea virginica*) are a prolific, sessile species that was a fundamental component of the Chesapeake Bay ecosystem until recent times. The very large stocks of oysters that existed at the start of European settlement are thought to have played an important role in maintaining water quality and providing habitat and food for other aquatic species (Newell, 1988, Newell et al., 2005). As oyster stocks have declined over the past century in Maryland's portion of the Chesapeake Bay, water quality and ecosystem health have also declined (Kemp et al., 2005). While it is likely that causality flows both ways in this correlation, poor water quality, degraded ecosystems and diminished oyster stocks are a combined product of economic and biological factors and, to the extent that these things are managed, management.

In addition to their ecosystem services, oysters are a useful and easily captured food attracting harvest since the earliest days of human settlement around the Chesapeake Bay. Because oyster stocks were so massive and productive, relative to demand, little care was given to managing harvests from the start of European settlement until early in the 19th century. In the absence of harvest management, the idea of "open bottom" became widely entrenched across Maryland's portion of the Chesapeake Bay. Under this regime, estuarine bottom that held oysters was considered public ground and was open to anyone who wanted to harvest there (and, later, anyone who fit specific criteria, such as residing in the surrounding county and complying with other regulations).

In the early 19th century, a part of New England's oyster dredge fleet moved south to the Bay in search of more productive harvest areas[1]. These sail dredges were much more efficient than the tongs and rakes that predominated local harvests and – perhaps with concern for conservation, perhaps with concern that out-of-state harvesters were reaping too much of the bounty of the Bay – first Virginia and later Maryland passed laws restricting harvesting by sail dredges. With the passing of time, other regulations were placed on the fishery, such as seasonal limits, other gear restrictions, and tax and licensing requirements. However, dredging by harvesters who delivered to Maryland processors was eventually allowed.

Although the stated goals of resource managers have been to ensure (or, restore, maintain or sustain) oyster stocks and oyster harvests, these peaked in the 1880s. It is thought that the volume of oysters harvested annually from the Bay, then, was a greater reduction of stock than the resource could replace through natural recruitment (Newell, 1988). In particular, harvests tended to reduce the hard substrate required for recruitment (Rothschild, et al. 1994, Smith, et al. 2005). Over much of the period from 1900 to the present, oyster stocks and harvests trended downward. In the mid 1960's the disease MSX became endemic in regions of Chesapeake Bay with salinities > ~ 15 ppm (Ford and Tripp 1996). In response to these declining oyster stocks, Maryland DNR initiated

[1] Kennedy and Breisch (1981) give an extensively researched history of the oyster fishery and much of the description here is based on their work.

an oyster "repletion" plan that is credited with stabilizing harvests between 1966 and 1982. One consequence of this extensive movement of oysters was that another oyster disease, Dermo, was spread throughout Maryland's portion of Chesapeake Bay and contributed mortality in addition to mortalities associated with MSX. In a two year drought in the mid 1980s, salinities in the upper portion of Chesapeake Bay increased sufficiently to allow the disease MSX to move into areas of the Bay killing oysters previously unaffected by diseases and, as a result, harvests fell precipitously. Harvests have remained very low relative to historical harvests ever since that severe disease epizootic.

To the extent that the "open-bottom" property rights regime allows open access to oysters, they can be characterized as a common property resource. Common property resources are ones that can be taken by anyone who wants to take them. There is a considerable economic literature addressing the problem of common property fishery resources[2]. In general, this literature describes how a fish population's growth capacity, harvest effort, and individual incentives can all combine to generate economically inefficient outcomes and reduced stocks. In the absence of controls on fishing effort, resource rents[3] available in the fishery motivate increasing harvest effort until the resource is diminished and the rents are driven away[4]. This perverse outcome is variously known as the Tragedy of the Commons, or, the common property problem.

Given that the property rights regime under which oyster harvests have been managed is believed to motivate over-fishing, it should not be surprising that oyster stocks are now, after 200 years of commercial harvests, much diminished. However, the actual history of how Maryland's oyster stocks became diminished is not as simple as that general rule might be taken to imply. While harvests doubtlessly contributed to declines in stocks over part of the fishery's history, oyster repletion efforts seem to have achieved some stabilizing effect from the mid-60s to the early 1980s. Most importantly, the final decline since the mid-80s and the current diminished level of oyster stocks can be attributed to disease mortality as well as harvests.

In order to distinguish harvest impacts on oyster stocks in the Chesapeake Bay in other than a theoretical sense, it is necessary to have empirical data on: harvests and harvest effort over time, costs and prices, disease impacts, repletion activities, and, changes in stocks over time. The research reported in this paper has reviewed and compiled data on these factors, such as they are available. Unfortunately, much of this data is either limited or uncertain. Harvest and harvest effort data are based on incomplete reporting by oyster buyers and has been the victim of poor data management[5], harvest costs are variable and difficult to estimate, disease mortality is difficult to measure and accurate

---

[2] Starting with Gordon, 1954. A good bibliography is available in Clark, 1990.
[3] Resource rents are a part of the value of things that nature produces and are desired by people. Rents are the part of the value that exceeds all of the costs of bringing them to market.
[4] All of which presumes appropriate scale, technology and market demand conditions.
[5] Apparently, more precise data on harvests and harvest effort was maintained prior to 1989; however, those data were lost due to a computer programming error that deleted data beyond a certain age.

estimates of oyster stocks over time do not exist. These limitations are noted in the analysis.

The following chapter describes in greater detail the common property problem and management options for mitigating the effects of the perverse incentives that it generates. This includes a discussion of historical practices employed by oyster managers to conserve the resource up to the present. In the next chapter, active management practices undertaken by the State over the past 20 years are analyzed with respect to their technical and economic efficiency. Earlier research analyzing the economic efficiency of oyster repletion prior to the current disease epizootic is compared with these more recent outcomes and the implications discussed. In the final chapter, the implications of historical harvest management for the introduction of a non-native oyster, and that action's alternatives, are discussed.

II. Common Property and Resource Conservation in Maryland's Oyster Fishery

This chapter provides a description of the economic understanding of common-property fisheries and its relevance to the Chesapeake Bay oyster fishery. It is important to establish at the outset that Maryland's oyster fishery is not a "pure" common-property resource, as this would imply that exploitation was completely uncontrolled. However, as will be discussed, limiting harvest effort by imposing regulatory constraints aims at mitigating the outcomes motivated by the open-access property rights regime. Under an open-access harvesting regime, the resource is expected to be depleted. In this sense, the common-property model is a useful bellwether for understanding historical harvest effort and attempts to limit it below the open access equilibrium. Specific policies and programs employed by fishery managers will be addressed as they relate to harvests and harvest effort but, for a more complete history of management of Maryland's oyster fishery, see Kennedy and Breisch (1981).

II.A. The Common Property Model

In the preface to the second edition of his report for the Maryland Oyster Commission, established in 1882 "to examine the oyster beds and to advise as to their protection and improvement" W.K. Brooks notes:

> "…the oyster grounds of Virginia and North Carolina, and those of Georgia and Louisiana, are increasing in value, and many of our packing houses are being moved to the south, but there is no oyster farming in Maryland, and our oyster beds are still in a state of nature, affording a scanty and precarious livelihood to those who depend on them."[6]

Brooks, and other early oyster resource scientists, felt that unbridled access to oyster beds was undermining their productivity and that a change was needed in the property rights governing oyster harvests. In particular, these early scientists advocated for the privatization of the resource by the sale of bottom leases. By allowing individuals to control access to oyster bottom through leases, it was thought that they would better husband the resource and, in this way, prevent the over-exploitation that seemed to be diminishing oyster stocks at the time.

Interestingly, Brooks' assessment of likely production outcomes in the open-access versus private bottom regimes anticipated by 50 years Scott Gordon's seminal economic treatment[7] of the common-property fisheries problem. Using similar ideas about the effects of non-exclusivity in harvests, Gordon applied standard microeconomic theory to

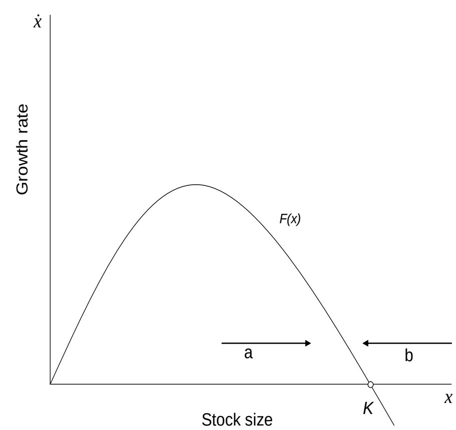
---

[6] Brooks 1905, cited from Kennedy and Breisch, 1981.
[7] H. Scott Gordon. 1954. "The Economic Theory of a Common-Property Resource: The Fishery". Journal of Political Economy, Vol. 62, No. 2.

a fisheries model that allowed for stock effects from harvests and showed that the equilibrium outcome of an open-access harvest regime was one in which the economic rents of the fishery are driven to zero. He showed in several ways how this outcome mirrors Brooks' "state of nature" oyster fishery, in which "scanty and precarious livelihood(s)" are all that fishermen can hope for.

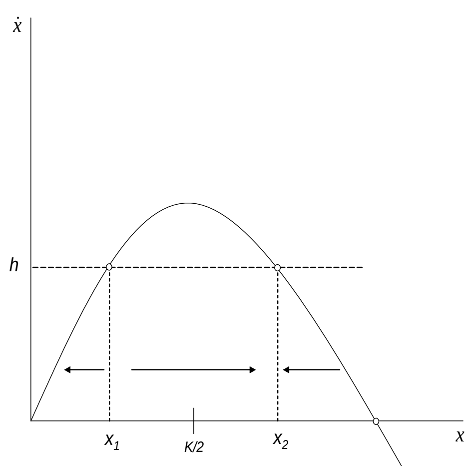
Although Gordon's paper focused on demersal marine fisheries, it has wider applications and is now generally accepted theory for common property capture resources. The description that follows will use Colin Clark's more recent treatment[8] of the problem. Clark's original treatment is presented with rigorous mathematical underpinnings, but the description below will be limited to an intuitive graphical and prose discussion of the problem and its equilibria. The reader who wishes to better understand the calculus behind this description is referred to Clark.

Figure 1: Growth rate as a logistic function of population



Clark begins by positing a logistic growth model for a fishery. Stock growth (F(x)) is taken to be a function of stock size, increasing as stocks increase up to some maximum rate and then decreasing to zero as a maximum ecosystem carrying capacity is reached. Growth at low stock levels is expected to be low because it is taking off from a small base and also at very high stock levels because, there, stocks are reaching their habitat's carrying capacity. At middling stock levels, growth is greatest, with the intuitive explanation that such populations have both greater productive capacity and, still, room to increase. Such a growth function is then shown to define the amount of harvest that can be taken from a given population in a given period without changing stocks over time. Figure 1 shows such a growth rate/sustainable harvest graph. Any one-off stock change (e.g., a, or b) would tend back to the equilibrium K, over time.

Figure 2: Effect of harvest on given population size

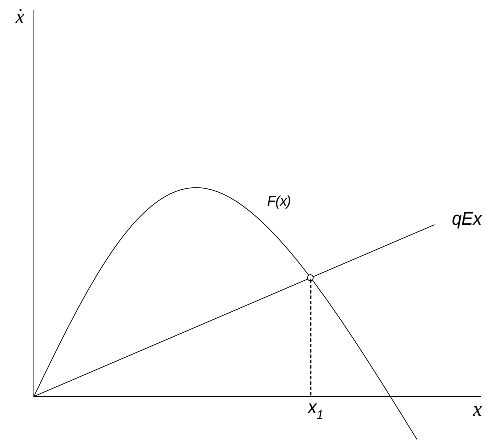


An important characteristic of this growth curve, relative to sustainable harvests, is that the same level of growth and sustainable harvest can be had at two different stock sizes, with the exception of a single maximum growth rate at the top of the curve. As shown in **Figure 2**, by

[8] Colin W. Clark, "Mathematical Bioeconomics", John Wiley & Sons, 1990.

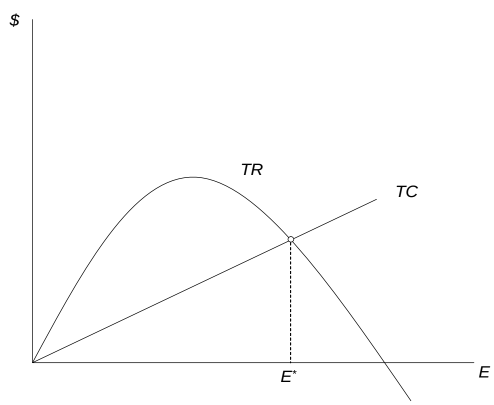
harvesting at some level ‘h’, stocks will tend toward the equilibrium stock size, x_2, as long as they are greater than stock size x_1. Stock sizes less than x_1 will tend toward zero if harvests are maintained at level ‘h’.

Figure 3: Harvest Yield for effort E and “catchability” q



Following his description of a “natural production function” for the fishery, Clark then examines the relationship between productivity and fishing effort. He posits that stock size is proportional to the catch rate, or catch per unit effort. If this is so, then Clark shows how for any amount of fishing effort and stock size in a specified range[9] there is a single, non-zero equilibrium harvest, or sustainable yield harvest. This allows one to create, as in **Figure 3**, a yield-effort curve based on the relationship between the fishery’s natural productivity and “catchability”, effort and stock size. In an intuitive sense, this graph reverses the horizontal axis of the growth graph. At higher levels of effort, fishing pressure will have reduced stocks and the consequent growth rate of the population. At lower levels of effort, higher growth rates will be associated with larger stock sizes. And, at very low levels of effort, lower growth rates will obtain due to large stocks and consequent environmental crowding.

Figure 4: Total Cost & Total Revenue Curves



Having established some fundamental relationships between the fishery’s productivity and effort, Clark then introduces economic value to the picture. This entails multiplying the yield-effort curve by a unit price for the resource; dockside price is a reasonable measure. By doing this, the yield-effort curve becomes a total revenue curve for the fishery as shown in **Figure 4**. The story is then completed by superimposing on this a graph of (constant) costs as a function of effort. An individual fishing firm would solve the problem posed by this graph by maximizing the difference between total costs and total revenues and fishing at that level of effort. But, while any single fishing operation might

[9] This range is defined by the “inherent growth rate” of the population [r] and the “catchability coefficient” [q] such that effort is less than r/q.

do this, the result of the pooled effort of all the independent, non-excludable fishermen doing it is that effort increases until total costs equal total revenues, at which point all of the rents in the fishery are dissipated and stocks are diminished.

There are a number of problems with this outcome. Most importantly, at lower levels of effort, more of the resource would be available to society and fewer resources would be required to bring this increased supply to market[10]. Moreover, if a fish stock produces any positive externalities, such as valuable eco-system services, reductions in stocks will reduce the total value of those services. An equilibrium at which stocks are reduced and higher costs are incurred to bring less of the resource to market does not seem very desirable and many policies have been devised to limit fishing effort so as to avoid that outcome.

II.B. Managing Harvest Effort in Maryland's Oyster Fishery

At the common property equilibrium, it is fishing effort in excess of fishery productivity that leads to reduced stocks. Fishing effort is expected to increase as long as there are rents available in the fishery; which is to say, as long as the returns to effort more than pay the harvesters' costs in applying that effort. The binding constraint on fishing effort in this model is its financial return. If it were possible to restrict effort in the face of profitable returns, then the inefficient common property outcome might be avoided. As will be discussed below, this is not easy.

Fishing effort has several dimensions. It is generally measured as either person- or boat-days but harvest technology is also an important aspect. The ways that harvest effort might be limited are discussed below[11] with regard to its various dimensions, including; 1) the number of harvesters who can work the fishery, 2) how much time is available for harvest, 3) the efficiency of gear (technology) in harvesting oysters, 4) the area available for harvest, and 5) catch limits. A final section discusses limiting effort by reducing the financial returns to harvest.

In the discussion that follows, the term "binding" and "bounded" will be used in a way that deserves explanation. In economics usage, a binding policy tool is one that is sufficient to either keep something from happening or to make something happen. If, in a market for some good or service, the going price for the good or service is $5 and a policy is enacted to cap the price at $10, that policy would not be considered binding. Some producers who might have wanted to charge $11 for their output may be constrained by the rule but, with respect to the market, the $10 cap is not binding. With

[10] This discussion has not addressed differences between near-term and long-term consequences. In the short-term, reduced effort will not necessarily generate increased harvests. Clearly, the rate at which stocks rebound will depend on a number of biological factors.

[11] Information about Maryland's regulations in what follows is based on a chronology of Maryland oyster regulations from 1929 to 1998 compiled by Mitchell Tarnowski, MD DNR. http://mddnr.chesapeakebay.net/mdcomfish/oyster/OYSREGtables3.cfm?which=oyster

respect to oyster policies considered below, a two year waiting period for a license may keep some harvesters out who would have liked to enter the fishery but, if there are excess licenses in the fishery (i.e., licensed harvesters who choose not to work the fishery for some other reason), such a rule would not be considered binding to fishing effort.

1. Limiting effort by limiting the number of harvesters

In order to achieve a reduction in harvest effort by limiting the number of harvesters, daily catch per unit effort must be relatively constant within a gear class and the time available for harvesting must be bounded. If the scale, technology or harvest time of an individual harvester can adjust to capture available rents, limiting the number of harvesters will not constrain harvest effort. Limiting effort by limiting the number of harvesters is a coarse management tool, usually used in conjunction with other policies.

In Maryland, even though there is currently a licensing policy described as "limited-entry" in effect, numbers of harvesters have not been bounded by regulation. From the start of public regulations on the fishery, harvest licenses have been required. But, those policies had more to do with raising revenue than limiting the number of harvesters. Limiting entry to the fishery by restricting licenses has only recently become a nominal management objective in Maryland.

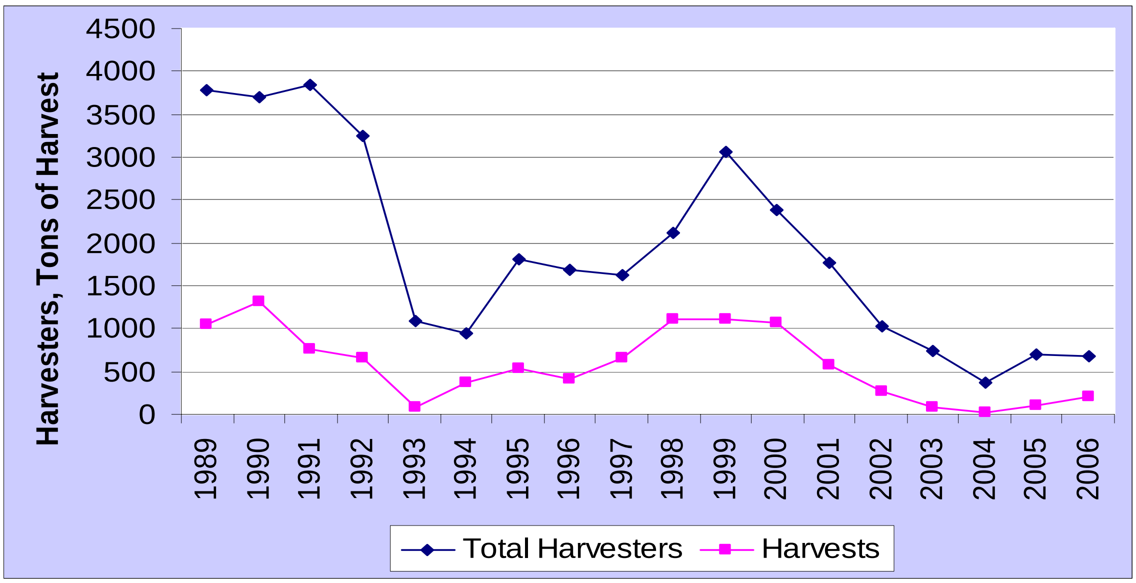
While restrictions on entry have not been binding for the Maryland's Bay at-large, there was for a long time a rule governing oystering in county waters that restricted potential effort on oyster bars there. Under that rule, which was struck down by Maryland courts in 1971, only watermen who resided in a given county could harvest oysters in its waters. Limiting the pool of harvesters to county residents would clearly exclude some potential harvesters. But, within a county, there was no limitation on how many of its residents could harvest oysters and that number was determined outside the regulation, by available labor and the net returns to harvesting.

The more recent effort to limit entry into the oyster fishery began in 1988 with the imposition of a two year waiting period for license applicants. By this time, however, there were two different licenses under which oysters could be harvested. The first of these is the traditional oyster-specific license – either an oyster harvester license (OYH) or an oyster dredge boat license. The second is a general commercial fishing license called an Unlimited Tidal Fish License (TFL) which allows the holder to harvest oysters, along with most other commercial species in the Bay. Since both of these licenses can be used to harvest oysters it makes counting oyster harvesters more difficult.

In 1998, the limited entry program was modified to operate under a targeted number of licenses. Currently, the target limit for OYH licenses is 800. However, in 2006, there was only demand for 661 of those licenses. Apparently, demand for licenses is being determined outside the regulation and, with respect to OYH licenses, the regulation is not binding. While many of the current 2,023 TFLs in use are not used to harvest oysters, they could be if the holder wished to use them that way. **Figure 5** shows the number of harvesters who worked in the fishery each year from 1989 to 2006.

The graphs in **Figure 5** indicate that the number of harvesters[12] working the fishery has much more to do with stocks than with regulations. The decline in the number of harvesters from 1991 to 1994 was not driven by regulations limiting entry, but by reduced stocks and harvests. And, the increase in harvesters from 1994 to 1999 was not a result of relaxed entry regulations (rather, they were strengthened over the period) but by an increase in stocks available for harvest. These data indicate that there is an abundance of licensed harvesters, some of whom do not harvest when stocks are low but who re-enter the fishery when stock abundance increases. Thus, limitations on effort by restricting the number of harvesters does not, under current conditions, provide a binding constraint on harvest effort.

Figure 5: Harvesters and Harvests, 1989 -- 2006



Source: MD DNR Commercial harvest data

2. Limiting harvest effort by limiting the time available for harvest

Limiting the time available for harvesting can limit harvest effort if harvest efficiency is fairly constant and if number of harvesters is bounded. If the number of harvesters or the productivity of daily effort can rise over time, the allowable harvest time would have to be shrunk to ever shorter periods in order to constrain harvest effort. In some fisheries, this has led to wasteful and dangerous harvest practices in which over-built boats race to capture a share of the available rents (Iudecello, et al., 1999, Int'l Pac. Halibut Commission, 1997).

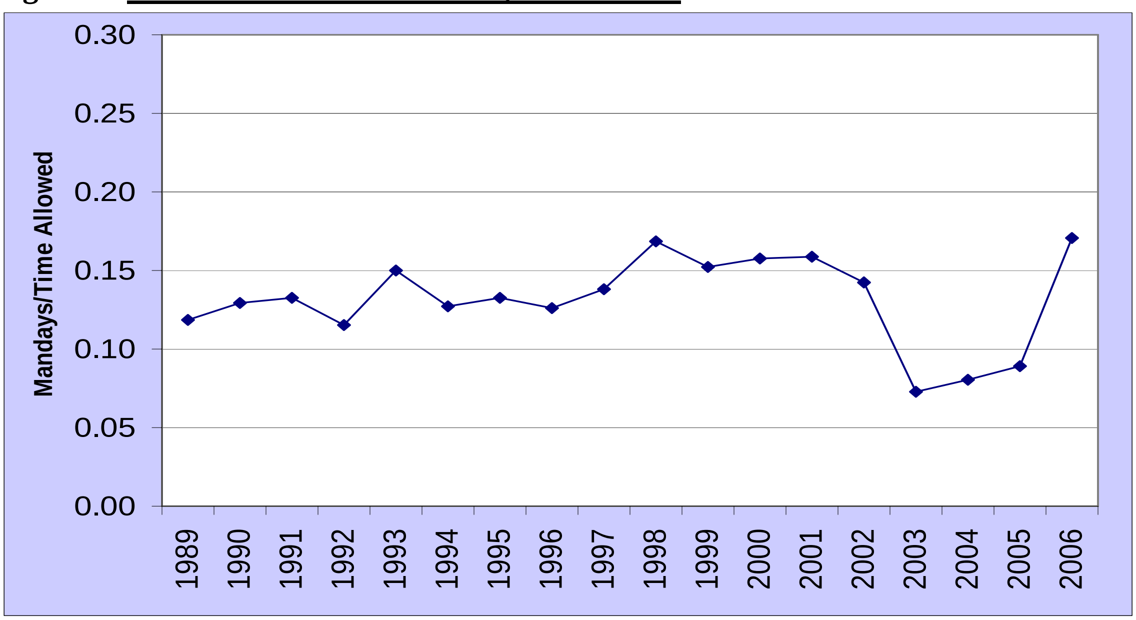
In Maryland's oyster fishery, time available for harvest has traditionally been limited by season, work days allowed in a week, and hours allowed for work in a single day. The season limitation restricts access to public bars during the summer months. In the early

[12] Number of harvesters is tracked in the MD DNR commercial harvest data as the total number of licensed harvesters reporting any harvest in a given season.

days of the fishery, the season ran from the start of September until the end of April. This has been gradually shortened over time so that, presently, tongers and divers begin at the start of October and dredge boats and power dredges start the first of November. The oyster season now closes, generally, at the end of March. In earlier times, fishing was allowed six days a week, from sunrise to sunset. Since 1992, days of the week have been reduced to 5 (Monday through Friday) and the time allowed per day from all daylight hours to sunrise to 3 PM.

Summing days and hours allowed, harvesters were limited to between 2,400 and 2,000 hours of effort per season, early in the 20th century. Assuming an average of eight hours to a workday, presently, this total time for harvest has reduced to just over 1,000 hours per harvester, per season. While this reduction in time seems substantial, it does not constitute a binding constraint on effort. This can be seen by considering actual application of fishing effort by harvesters, versus the total amount of time allowed by the regulation. **Figure 6** shows this by multiplying allowable days by the number of harvesters and dividing reported annual effort-days into that product. This calculation ignores inclement weather and other factors that might reduce the actual days that can be used for harvesting but a further halving of time allowed would still not generate a 50 percent time utilization rate over the period. If harvesters are not more fully utilizing their time allowed for harvest, it can be deduced that some other factor is limiting effort.

Figure 6: **<u>Utilization of Allowed Time, 1989 – 2006</u>**



Source: MD DNR Commercial Harvest Data

3. Limiting effort by gear restrictions

Limiting harvest efficiency through gear restrictions was one of the more effective effort-limiting policies used in the Maryland oyster fishery. Limiting technology is, by definition, economically inefficient, but it serves the management objective by raising harvest costs in a way that restricts harvest effort. Under gear restrictions, rents in the fishery are still fished to zero (for the given technology), but this happens at a stock level that is not as reduced as a more efficient technology could achieve. To see this, refer back to **Figure 4**. The TC curve on that graph would pivot downward if the unit costs of harvest effort were lower (i.e., if effort was more efficient) and would intersect the total revenue curve at a lower point, implying lower equilibrium stocks.

In Maryland's oyster fishery, gear restrictions have often been combined with area restrictions. Traditionally, shallower portions of the Bay were set aside for hand tongers and deeper areas were made available to dredge boats and patent tongs. Diving, a harvest technology that came to the Bay in the early 1970s has been restricted to bars that were formerly in hand tong areas. Since the late 1990s, power dredging, which had long been thought a too-effective technology, has seen its allowable area increase considerably. Within each gear-specific area, harvesters have been free to harvest to the limit of their technology and harvest returns – i.e., to the common property equilibrium.

While gear restrictions doubtless slowed the rate at which the harvest industry has depleted the resource, as stocks have now declined to levels that cannot support less efficient technologies, economic pressure to allow more efficient gear has proven inexorable. Under the common property expectations, this implies that stocks will be further reduced by more efficient fishing effort.

4. Restricting the area allowed for harvest

Given oysters' sessile life-style, restricting access to specific areas should remove harvest effects and allow stocks to rebuild within those areas. Historically, such restrictions have been implemented as time-limited closures on stock-depleted bars. After stocks recovered, those bars were opened to harvests again. Since the spread of disease, oyster stocks have been less likely to rebound on such closures and managers have simply left most public oyster bottom open, regardless of whether there are oysters on it or not.

More recently, managers have created permanent closures (sanctuaries) and limited closures (managed reserves) as a part of their effort to restore oyster stocks. While most of these more recent closures are less than seven years old, there is some evidence that they can generate stock growth when intensively stocked with hatchery reared seed oysters, even in the face of disease (Paynter, et al., 2005). Tarnowski (2005), on the other hand, suggests that "environmental factors are the overwhelming determinant of sanctuary success" and that the program has fallen far short of its promise.

The important question posed by permanent closures and managed reserves with respect to fishing effort concerns the degree to which they actually limit such effort. If a permanent closure removes productive bottom from harvest, it clearly reduces potential harvest effort by some portion. However, given that the vast majority of Maryland's oyster bottom is not only devoid of oysters but also degraded in habitat (Smith, et al. 2005), the actual reduction in available harvest area may be more (if it is an area more likely to receive natural spat-set) or less (if it is an area that is less likely to receive a natural spat-set) than the simple ratio of withdrawals to historical productive bottom. If the Maryland repletion program is the major source of harvestable oysters, as argued in the Chesapeake Bay Program's Oyster Management Plan (2005, pg 22), then acres taken out as permanent closures have only a minimal effect on the available resource. In this and other ways, it is not apparent that area closures actually constitute a binding constraint on harvest effort.

More than most regulations, area closures are difficult to enforce. Limited policing relative to the area that must be policed, high returns to ignoring the regulation and small penalties for breaking them combine to reduce the effectiveness of area closures as a means of limiting harvest effort. Poaching on sanctuaries has been reported in the popular press[13] and Paynter (2005) reports stock monitoring data that indicate poaching from a managed reserve. Natural Resources Police records report 71 incidents relating to "oystering in an oyster sanctuary" from 1996 to 2005.

In a review of judicial outcomes for a sample of 21 citations from the period 2003 to 2005, "dredging in a prohibited area[14]", 17 resulted in convictions and these carried average penalties, including court costs, of $140/conviction. If the probability of getting caught, cited and convicted is sufficiently low, a prospective cost of that magnitude is not very threatening. Reduced oyster abundance on public bars and higher stocking rates on sanctuaries generate larger incentives to disobey the regulation, as do higher oyster prices.

5. Restricting effort through catch limits

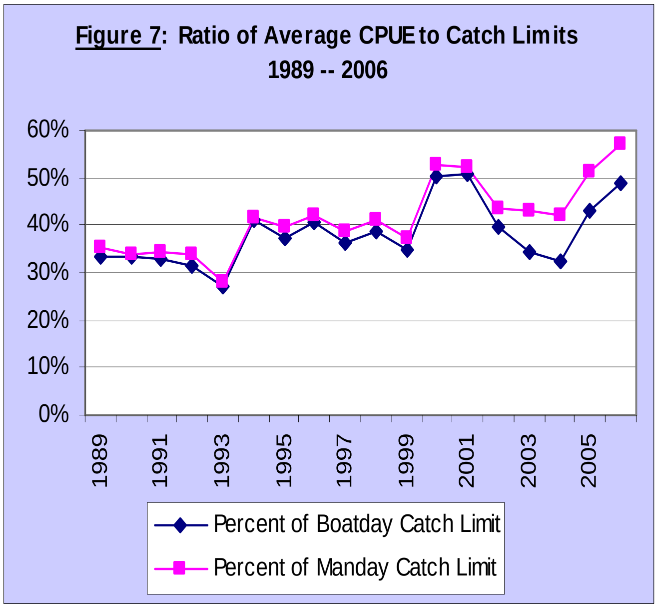
Catch limits include a broad range of policies; from tradable seasonal harvest allowances to daily catch limits. In the Maryland oyster fishery, catch limits have been of the latter variety. Daily catch limits began being used by oyster managers in the early 1970s. At that time they were set at 25 bushels per day per licensee, up to 75 bu/boat/day for hand tongers. Double patent tongs were allowed a higher boat limit (100 bu/day) and skipjacks were allowed 150 bu/day. When their technology was addressed in the regulations (1972), divers, were also limited to 25 bu/licensee/day and 75 bu/boat/day. Presently, tongers and divers are limited to 15 bu/licensee and 30 bu./boat, per day. Power dredges are limited to 12 bu/licensee and 24 bu/boat, per day. Skipjacks are still allowed 150 bu/day.

Daily catch limits are an imprecise means for limiting harvest effort and they tend to redistribute, rather than limit, effort. While historical daily harvest efficiencies are difficult to come by, Cabraal (1978) reports catch per boat days in the mid 1970s as being 19.2 bu/day for tonging boats and 105 bu/day for dredge boats. Given those rates, it is not likely that the catch limits were binding on harvests during the 1970s. Certainly, since 1989, when more complete data is available, daily catch limits do not appear to be a binding constraint on daily harvests.

---

[13] Baltimore Sun, November 1, 2000; US Fed News Service, Including US State News. Washington, D.C.: Jan 30, 2006.

[14] Note: This infraction includes a wider range of activities than just dredging on a sanctuary. But, NRP records do not break out dredging on a sanctuary from this wider category in its citation list, as it does in its list of "incidents". The sample targeted the Choptank River and cases adjudicated in Talbot County.



This is shown in **Figure 7,** which reports the percentage share of each year's average daily catch rate relative to the catch limit. Of course, these annual averages ignore differences in daily catch rates over a season and across gear types[15]. In some years, harvesters may be able to catch their limit early in the season. As the season lengthens and bars become fished out, daily harvests tend to decline. In addition, catch rates vary across harvesters. In these two ways, one can see that daily catch limits can spread harvest effort over more days and more harvesters. They do not, however, provide a binding constraint on harvest effort.

6. Economic Policies for limiting effort

Harvest effort can also be limited by removing the natural resource rents that motivate excess effort; either by taxing harvests or by allocating fixed shares of an allowable harvest and allowing these to be traded by willing buyers and sellers. Under a tax, managers would have to estimate the share of oysters' values that could be accounted as their resource rent and then set their tax to match this value. While theoretically possible, such estimation would require a much better understanding of harvest costs and returns to harvesting than is currently available. Under tradable harvest allowances (also known as quotas), the resource rent would accrue to whoever held the allocation, whether they used it to harvest oysters or sold it to someone else. Neither of these two measures has been used in the Maryland oyster fishery, though there is a nominal ($1.00/bu) tax on landings and a $300 fixed fee (surcharge) for entry.

At $1.00/bu., the tax on oyster landings constitutes between 2.5 and 5 percent of the dockside value of oysters, depending on the dockside price. Given the difficulty associated with enforcing this tax[16], it is doubtful that the charge binds effort even at the marginal harvester. In addition to the landing tax, however, a $300 annual surcharge has been assessed against oyster harvesters who sell their oysters. As a fixed fee, the oyster surcharge acts differently from the unit tax on harvest decisions. By raising the annual costs in a one-off fashion, it presents a choice at the start of the season whether or not

[15] Divers were the only gear type to come within more than 60 percent of the daily limit over the period.
[16] The tax is assessed on bushels purchased by licensed oyster-buyers and accounted by them through buy-tickets (state-supplied purchase invoices) which are required for all legal harvests. An unknown share of the harvest is sold outside the buy-ticket program.

such an additional cost can be recovered. For those who choose to pay the surcharge, it does not change the incentive to spread those fixed costs over as much harvest as practical.

DNR data show that, in fact, many harvesters pay the oyster surcharge, but never report any harvest. **Table 1** reports numbers of OYH licenses held, number of surcharges paid by OYH holders and number of those harvesters reporting a harvest, over the period 1995 to 2005. Over half the OYH licensees who held a license between 2001 and 2005 did not report a harvest. Paying the license fee may provide value to the harvester if he expects that he might one day use it, or if he believes it may have some other future value. But, paying the surcharge without harvesting provides no such benefit and it is somewhat puzzling that harvesters would do this. One possible explanation is strategic regulatory avoidance. There is a good likelihood that a harvester coming to port with oysters will be inspected at some point over the season, and he will want to be able to show both a license and proof that he paid the surcharge for that eventuality. Whether or not he then sells his harvest to a buyer who reports it is much more difficult to ensure.

Table 1: Numbers of OYH Licenses, Surcharges and Harvest Reporters, 1995 – 2005

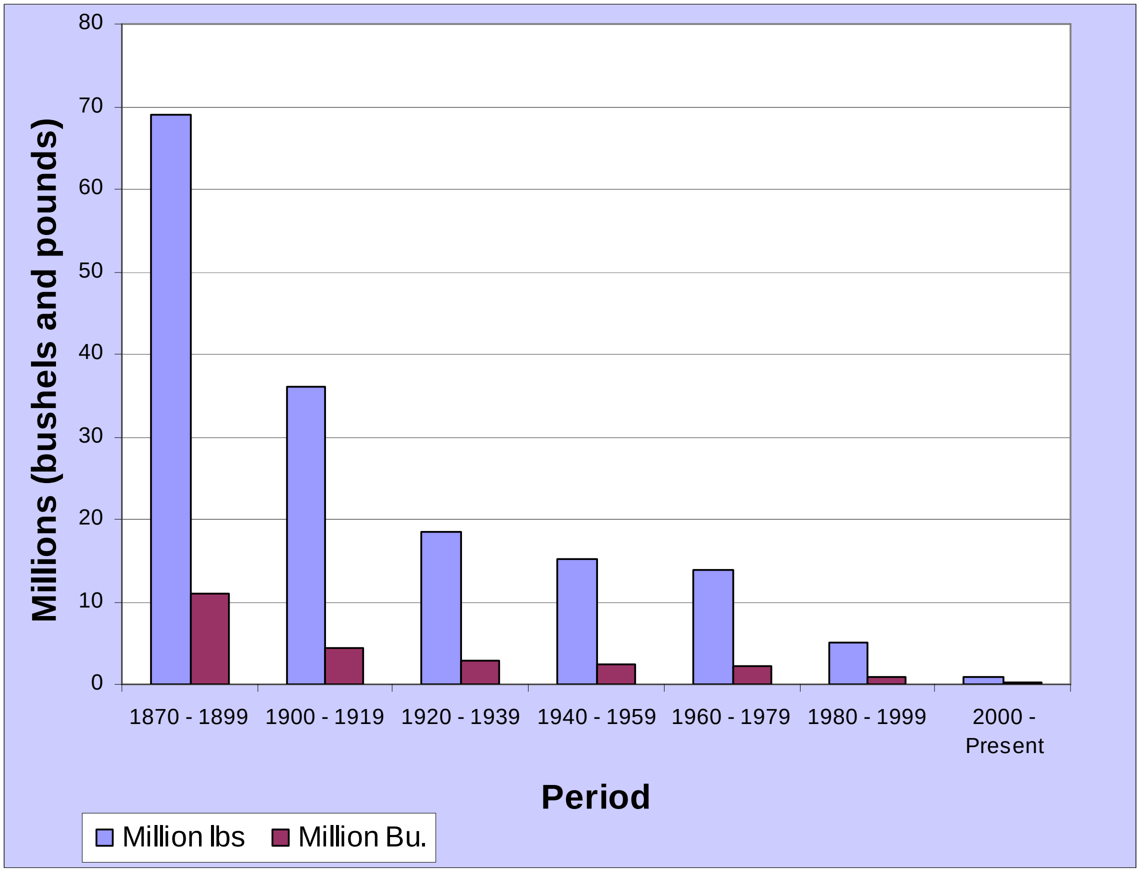
Harvest Year	Number of Licenses	Number Who Paid Surcharge	Number Reporting Oyster Harvests
1994	1464	251	174
1995	1035	379	300
1996	939	399	305
1997	900	348	262
1998	896	318	257
1999	832	400	359
2000	823	374	290
2001	807	355	268
2002	792	252	174
2003	767	128	75
2004	720	69	37
2005	682	99	57

Source: MD DNR Commercial harvest data

II.C. Summary

According to broadly accepted economic theory, an open access fishery will motivate a level of fishing effort at which, if possible, harvesters will remove the natural resource rents accruing to the fishery. This result is often referred to as "too much effort, pursuing too few fish" or "fishing beyond the biological optimum". The long-term history of commercial landings in Maryland's oyster fishery tracks such an outcome, as shown by **Figure 8**, below.

Figure 8: Periodic Maryland Oyster Harvest Averages 1870 – 2005



Source: 1870 to 1928 averages based on incomplete time series for the period (Fishery Statistics of the US and MD Department of Tidewater Fisheries, reported in Christy, 1966) and uses meats per bushel to estimate some bushel volumes. 1929 to present uses MD DNR Harvest data.

The trend in harvests shown in **Figure 8** mirrors the expectation of the common property model with respect to depleting fishery stocks and reducing productivity over time. While the absence of stock estimates precludes a calculation of the precise coefficients for the relationship between effort and stock levels, it is apparent that effort at the open-access equilibrium has been associated with diminishing oyster stocks. And, as has been discussed in section II.B, the same incentives that motivated this outcome are still largely in place. That is, harvesters are still able to apply effort until the marginal value of harvests approaches their unit costs in harvesting. With the opening of more areas to power dredging, it is likely that stocks will be further reduced. But, because effort has declined so dramatically since the late 1980s, and, because disease has become the dominant limiting factor for stock abundance, the possibility that there may still be too much effort in the fishery has been obscured.

The increase in harvests, stocks and effort in the 2006 season provides a case in point. For several years leading up to 2006, higher rainfall created conditions under which disease mortality declined and stocks grew. The consequent increase in market-sized oysters, accompanied by a spike in prices, motivated an 86 percent increase in 2006 person days compared to the previous season (which was up 100 percent from 2004). Given the long term stock effects of harvest effort in an open-access setting in Maryland's oyster fishery, it seems likely that the stock increases gained through reduced disease mortality in 2005 and 2006 will be lost to increased harvest mortality.

While disease has done much to limit effort by diminishing stock abundance, management has not provided such binding constraints. Indeed, rather than limiting allowable harvest effort to serve the goal of increasing stocks, managers have allowed an increase in harvest effort to mitigate the impact of reduced stocks on harvesters.

III. Oyster Repletion and Restoration

The preceding discussion of the common property model did not consider the possibility that the fishery's productive capacity could be significantly enhanced by management actions. That ignores an important assumption that underlay much of Maryland's oyster management in the second half of 20th century – that restoration activities could mitigate the stock effects of harvests and boost oyster productivity. If stock productivity could be enhanced by management actions, this could perhaps off-set the stock effects of harvests predicted under the common property model.

This chapter will examine efforts to increase stocks and stock productivity through active management. Historically, this activity has been known as repletion, and its objective has been to boost stocks available for harvest. More recently, managers have worked toward a goal of boosting stocks simply to preserve the resource, independently of harvests. Those efforts are discussed under the rubric of restoration. A brief description of repletion and restoration activities is provided below, with respect to effort and financing. This is followed by a review of several earlier studies that proposed economic models for assessing the fishery and repletion efforts. Finally, a brief description is provided of an economic analysis of repletion undertaken for the present study.

III.A. Background on Oyster Repletion and Restoration

Early in the 20th century, managers recognized that harvests were undermining stocks and productivity in Maryland's oyster fishery (Kennedy and Breisch, 1981). Since that time, a more active approach to maintaining oyster stocks has been pursued. The major concern before the onset of disease was that oyster habitat was being degraded by the constant removal of shell, which serves as a recruitment base for new oysters. Laws were enacted to ensure that some portion of the shell taken in harvests would be returned to the water. In the 1940s Maryland began a larger investment in seed oyster transport and planting. Early efforts at shell repletion and seeding were funded, in part, through regulation and taxes, but, the subsidy element in those activities (i.e., the part paid from general tax revenues) was over 50 percent.[17]

In the 1960s, shell repletion got a boost from the advent of more efficient shell dredging gear and, up to the present, the placement of dredged, or "fossil", shell has been a major component of oyster management activities. Collecting, transporting and planting wild seed oysters have been the other major component of repletion. As the two oyster diseases Dermo and MSX became more significant as mortality factors in Maryland's portion of the Bay, managers have rethought the process of planting wild seed oysters with respect to its potential for moving disease. In recent years, seed oyster planting has been constrained to the main stem of the Bay. But, up to the present, planting wild seed oysters has been considered an important management tool for sustaining oyster harvests.

[17] Kennedy and Breisch, pg 108

In the repletion program, the management costs that earlier oyster scientists (e.g., Brooks and others in the late 1800s) had suggested assigning to individual owners by leasing bottom to them came to be paid by public agencies. While a part of the funding for repletion has been generated by license fees and taxes on harvests, another generally significant fraction of that cost has been funded from State and federal tax revenue[18]. The assignment of management costs to public agencies has, over time, gathered the imprimatur of historical and political inevitability and, at present, few question this subsidy to oyster harvesters, processors, and consumers.

The spread of Dermo and MSX in Maryland waters changed the balance in stock repletion and harvests. The collapse in stocks caused by these two diseases and the consequent decline in harvests since 1985 has led to changes in both what managers attempt to do and how this is funded. As harvests have fallen, fewer dollars are generated from licenses and taxes on the fishery and a larger share of the costs of oyster repletion has fallen on the general tax base.

III.A.1. Historical Oyster Repletion

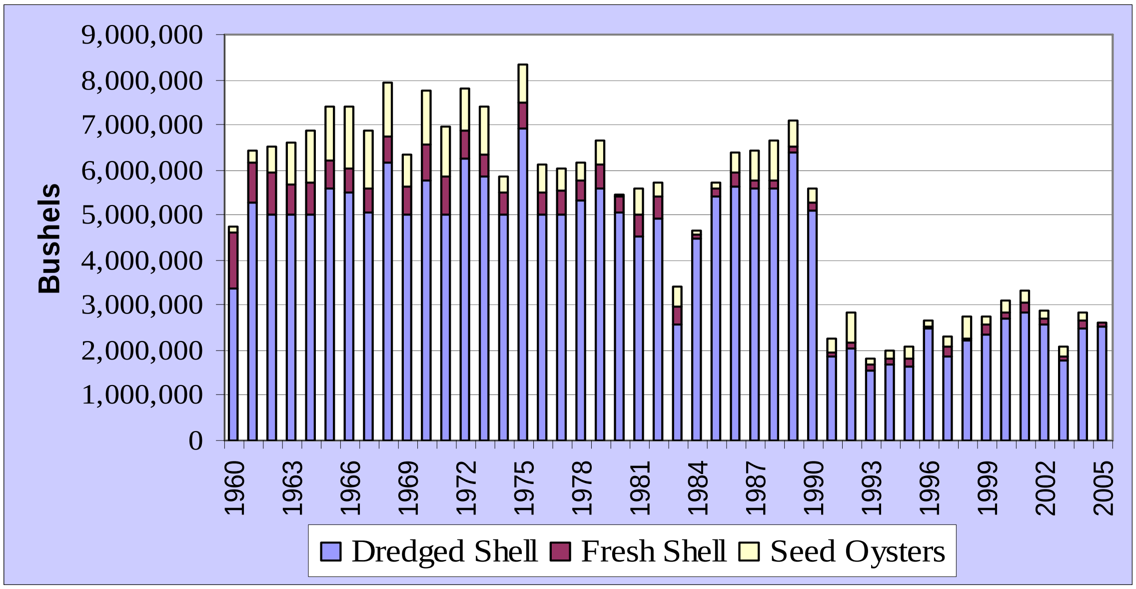
From the early 1960s through the 1980s, most active management in Maryland's oyster fishery was effected through the oyster repletion program. The program's principal objective was to maintain higher levels of harvests than would have been possible without active oyster management. The two major pillars of the program were: 1) planting dredged shell, primarily on seed oyster beds but also on natural oyster bars, and 2) transferring seed oysters naturally generated in seed areas to enhance production on harvest bars throughout Maryland's portion of the Bay.

The amount of effort that Maryland put into the repletion program over the years can be measured in several ways. Most directly, one can look at the amount of shell and seed oysters that were moved over the period. **Figure 9** does this for the period from 1960 to present. The data used to create this figure are from MD DNR[19] records. Post-1999 data used in this figure are net of dredged shell placed on sanctuaries and reserves. While some dredged shell was used for this purpose prior to 2000, DNR reporting did not consistently account those volumes in earlier Seed and Shell Reports so the total reported up to 2000 is counted toward repletion. Some seed oysters were also placed on sanctuaries and reserves over this period, but this was a small part of the total and is difficult to disentangle from repletion plantings. Consequently, seed oyster plantings are reported in this graph as being fully applied toward repletion.

[18] The average industry share of repletion costs (independent of restoration) from 1985 to 2005 is 38 percent and ranges in any year from 86 to seven percent of direct repletion costs.

[19] Chris Judy (DNR Shellfish program) provided 1981 – 2005 data. Earlier years were compiled by Eric Campbell and additional data from the Seed and Shell Reports were provided by Mick Astarb, both also of DNR's Shellfish program.

Figure 9: Maryland DNR Repletion Shell and Seed Planting, 1960 – 2005[20]



Source: MD DNR Shellfish Program Seed and Shell Reports.

There are clearly two different stages over the period covered by **Figure 9**. From 1960 through 1990, the combined effort (shell and seed oysters in bushels) averaged 6.1 million bushels per year. From 1991 onward, this average effort dropped to 2.5 million bushels per year. There was actually a period of overhang during the late 1980s when oyster harvests and state oyster revenues diminished but repletion continued unabated. But, in 1991 this stopped. The effect of disease mortality on stocks and harvests reduced the amount of money that the state could bring to bear on repletion and repletion activities declined[21]. This decline in available resources also motivated managers to attempt alternative restoration methods as described in more detail, below.

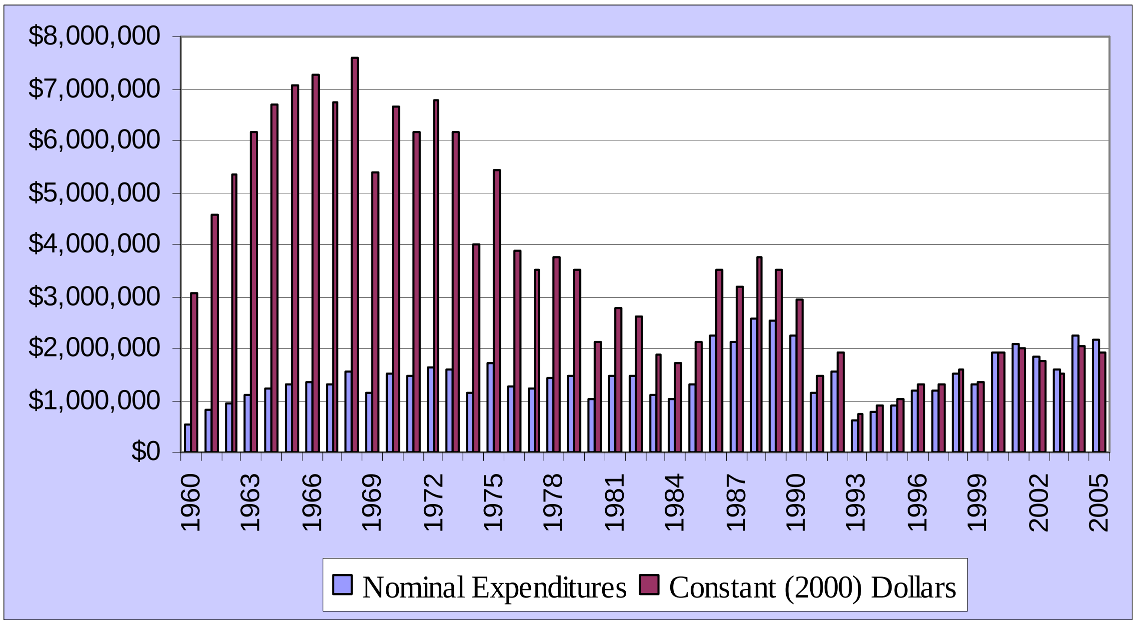
In addition to measuring effort on a volume basis, one can also track direct expenditures[22] for repletion activities. Shell and seed oyster planting costs from 1960 to 2005 are reported in **Figure 10**. The graph shows both nominal costs and constant dollar costs (deflated by the consumer price index, year 2000 = 1). Fresh shell and seed oyster costs for the years 1960 to 1971 are estimated on the basis of unit costs from later years, but all other costs are reported from DNR data. **Figure 10** is also based on data which are net of the costs of dredged shell placed on sanctuaries and reserves by DNR after 1999.

The drop in constant dollar expenditures after 1991 is apparent by visual inspection. However, for the past ten years, repletion efforts in Maryland (as well as Virginia) have

[20] These data are net of (i.e., do not include) hatchery-produced, disease-free seed oysters.
[21] For more information on management decisions in this context see Wolman, 1990.
[22] Expenditure figures do not include management and administrative costs incurred by the agencies that organize these efforts.

also benefited from direct Federal expenditures[23], particularly through the National Oceanic and Atmospheric Administration (NOAA) and the Army Corps of Engineers (ACOE). Moreover, a significant portion of MD DNR's oyster restoration funds are no longer accounted in the repletion budget.

<u>Figure 10</u>: Maryland DNR Repletion Costs: 1960 -- 2005



Source: MD DNR Shellfish program.

III.A.2. Maryland's Oyster Roundtable

In 1993, the State of Maryland gathered a group of scientists, managers, watermen and environmentalists to address the critical problems facing the oyster fishery. The group was convened as the Oyster Roundtable and its goal was to develop practical approaches for dealing with: disease, habitat/water quality, production/management, institutional and funding issues associated with the decline in oyster stocks[24]. Important among the many outcomes of the Oyster Roundtable's work were: closer cooperation between the harvest industry, scientists and managers; a commitment to create non-harvested and controlled harvesting restoration sites; decreased dependence on natural (and, often, diseased) seed oysters and increased production capacity for disease-free hatchery stock; new institutional arrangements; and, increased federal funding for oyster restoration.

Through the Oyster Roundtable, scientists and watermen achieved nominal agreement about the use of restoration effort and funding for establishing oyster recovery areas where harvesting could be restricted. Watermen saw the establishment of such sites as an

[23] In fact, earlier State expenditures also included significant Federal dollars, but authority in spending those dollars was vested in the State and they are not treated separately, here.

[24] Oyster Roundtable Steering Committee, 1998. Implementation of the Maryland Oyster Roundtable Action Plan: 1996 through 1998.

infringement on their right of “open bottom” and gaining their acceptance on this concept was considered an important achievement. Moreover, the traditional oyster repletion program had targeted the harvest industry as its *raison d’etre* and state oyster managers had to make considerable adjustments to accommodate this shift toward oyster restoration. Although the repletion effort has continued to use shell and natural seed oysters to improve stocks on public bars, those activities have become constrained by disease protocols and command a smaller portion of total oyster restoration effort over time, as managed reserves and sanctuaries have expanded.

The Oyster Roundtable also helped to change institutional arrangements for oyster restoration by laying the framework for non-governmental organizations to play a greater role in the process. Ultimately, the Oyster Recovery Partnership (ORP), a not-for profit organization funded largely by grants from the federal government, has come to play a central role in the application of restoration resources. This shift in the management of oyster restoration resources was made possible by the involvement of stakeholders, scientists and managers that were originally brought together through the Oyster Roundtable.

III.A.3. Oyster Restoration

While the repletion activities can be characterized as efforts to boost the number of oysters available for harvests, oyster restoration is a more generalized effort to simply boost oyster stocks (although, “simply” may be the wrong modifier in a case such as this, where new activities compete for available funding)[25]. Many of the funding resources that have come available since the late 1990s target this more general objective and the declines in DNR’s 2002 and 2003 repletion funding, shown in **Figure 10** are partly a result of increased applications of their resources for restoration activities. The graph shows repletion rebounding in 2004 and 2005, but this is due to an increase in total oyster funding in Maryland’s State budget (e.g., from general tax revenues).

Since the Oyster Roundtable process, federal funding for oyster restoration in Maryland’s portion of the Chesapeake Bay has increased. This increased funding has flowed, primarily through two agencies: the National Oceanic and Atmospheric Administration’s (NOAA) Chesapeake Bay Office (NCBO) and the Army Corps of Engineers (ACOE), Baltimore and Norfolk District offices[26]. A large part of NOAA’s oyster funding has been applied to on-the-ground restoration, primarily through cooperative agreements with ORP, and through small-scale community-based field activities. Another considerable portion of NCBO’s oyster funding has been applied to an oyster disease research program and to research addressing the introduction of a non-native oyster to the Bay[27]. **Table 2**

[25] Important reasons given for shifting oyster stock enhancement efforts away from commercial harvests include environmental and ecological benefits. However, as described in these pages, it is very difficult to ensure that ecological restoration resources do not function as commercial oyster restoration.
[26] In the table and discussion, only funding for Maryland’s portion of the Bay is accounted
[27] For full disclosure, the present study is funded by the NOAA Chesapeake Bay Office under its Non-native Oyster Research Program.

tracks NCBO funding for oyster restoration, net of this oyster disease research and the non-native oyster work.

<u>Table 2</u>: Repletion and Restoration Expenditures in Maryland 1995 – 2005*

	FY95	**FY96**	**FY97**	**FY98**	**FY99**	**FY00**	**FY01**	**FY02**	**FY03**	**FY04**	**FY05**
MDDNR	1035	1299	1287	1600	1343	1914	2019	1760	1508	2064	2169
NOAA	110	13	71	43	464	582	964	1246	1206	1906	1958
ACOE	168	232	431	319	696	144	24	714	766	618	614

Source: MD DNR Shellfish Program Seed and Shell Reports, NOAA Chesapeake Bay Program Office Program Accounting Reports; ACOE Activity Reports.
* Thousands of constant year 2000 dollars

ACOE (Baltimore[28]) has focused its oyster restoration efforts on habitat enhancement, primarily by planting shell but also by cleaning bars in preparation for shell and seed oyster plantings (see below). The figures reported in **Table 2** are contracted expenditures for moving shell and undertaking some bar cleaning. They do not include any administrative overheads incurred by ACOE in managing this effort[29].

Adding federal funding for oyster restoration to the chart of constant dollar oyster repletion expenditures would generate a different picture from that shown in **Figure 10**. Adding restoration with repletion expenditure would show that total oyster spending has grown at a healthy clip over the past ten years, achieving a 30 year high in 2005. However, as described below, pooling repletion and restoration expenditures confuses two similar activities with two very different expected outcomes.

Oyster restoration activities differ from oyster repletion activities in objectives and, to some extent, method. With respect to objectives, repletion activities aim to boost stocks available for harvests; restoration seeks to boost oyster stocks more generally and more permanently. With respect to methods, both activities seek to enhance oyster habitat through the placement of suitable substrate. Both restoration and repletion activities add seed oysters to their targeted sites, but most restoration activities use hatchery produced, disease-free seed oysters, while repletion activities traditionally use naturally spawned seed oysters. This is not a hard and fast rule, however. Restoration activities do not generally make use of natural seed oysters[30] but hatchery disease-free oysters are increasingly used on harvest bars.

Table 3, reports numbers of estimated wild seed oysters and hatchery produced disease-free seed oysters for the past six years. In terms of the number if oysters produced, the

---

[28] ACOE oyster restoration efforts in the Chesapeake Bay are managed from two separate offices: Norfolk and Baltimore. In general, the Baltimore office extends effort in Maryland's portion of the Bay and the Norfolk office does its work in the Virginia portion of the Bay.
[29] Some Government funds are absorbed by the implementing agency as administrative costs and others flow though without such burdening. As administrative costs have not been accounted earlier, they are excluded, here, to the extent possible. NCBO cooperative agreement funds provide overheads for ORP that are difficult to disentangle.
[30] An exception to this is Chinks Point Sanctuary at the mouth of the Severn River which was seeded with natural seed oysters in 1999. Those plantings were beset by disease by 2004 (Tarnowski – 2005).

Horn Point Hatchery[31] has gone from producing a fraction of the seed oysters moved by the repletion program in 2000 to producing many multiples of the natural seed oyster planting in 2006. Increased production of larvae and improved efficiency in setting and placing those larvae has generated a rapid increase in hatchery disease free seed oyster production. At the same time, declines in spat set in traditional state seed areas have led to a decline in the repletion program's wild seed oyster resource. While most hatchery produced oysters are used for restoration activities on sanctuaries and managed reserves, in a year such as 2005 when spat set from the previous year was so low that there was no significant natural seed planting, and in 2006 when natural spat set was also low, hatchery produced oysters are seen as a useful addition to natural seed oyster plantings on harvest bars.

Table 3 Production and Disposition of Seed Oysters 2000 – 2005 (millions of oysters)

	2000	2001	2002	2003	2004	2005	2006
Disease Free Hatchery Production	**38.3**	**54**	**76.4**	**181.6**	**76.1**	**189.7**	**334.8**
Used in Sanctuaries and Reserves	31.59	49.59	73.8	171.65	58.553	161.511	221.285
Used on Harvest Bars	4.20	1.41	2.42	7.73	16.70	28.18	113.53
Percent used on harvest bars	11.7%	2.8%	3.2%	4.3%	22.2%	14.9%	33.9%
Natural Seed Oysters*	223.1	82.4	77.5	208.3	119.0	0.0	24.6

Source: ORP data and MD DNR Seed and Shell Reports
* Estimated from Seed and Shell Report weighted average seed oysters per bushel times bushels planted**.**

In addition to shell and seed oyster plantings, recent restoration work has employed a practice known as "bar cleaning" to reduce the likelihood of large disease mortalities on restoration sites[32]. Under this practice, sites are cleaned of existing oysters if these have a certain level of disease prevalence. Most restoration sites are bar cleaned before having shell and seed oysters planted on them. In addition, some state seed areas were bar cleaned in the late 1990s and, in recent years, ORP has been bar cleaning harvest bars near restoration sites in order to ensure that disease is not extended to restoration sites from those reservoirs. More recently, it has been recommended (Paynter - 2005) that when disease prevalence rises above 50 percent on restoration sites, those oysters should be removed – either by harvest or bar cleaning.

Bar cleaning involves hiring watermen to remove oysters from a given site by dredging it until the dredges bring up very few live oysters. This dredging is typically done during the spring and early summer and not during the harvest season. The oysters are taken a

[31] Horn Point Hatchery is Maryland's single most important source of seed oysters.
[32] Bar cleaning is an ambiguous term that has been used for the purpose discussed above as well as a practice that seeks to clean silted shell by dredging it up and washing it off. In this paper bar cleaning will only be used in the sense of "cleaning oysters off a bar" for disease control.

distance away from the cleaned site and deposited for later (re)harvesting. The watermen who dredge are paid for their service and the costs of bar cleaning can be quite substantial. In its 2004 – 2005 budget, ORP spent $298,272 on bar cleaning, up from $89,209 in 2003 – 2004. In both years, this funding was divided between harvest bars and restoration sites. Those same two years, DNR spent about $223,398 on bar cleaning. If the policy of removing oyster populations from restored sites with rising disease prevalence is adopted, these costs will increase substantially.

The productivity of restoration efforts is difficult to assess, not least because the scale of those efforts are rapidly changing. As shown in **Table 3**, hatchery seed oyster production is increasing at an impressive rate. Bar cleaning and shell plantings are increasing to keep pace with this increased seed oyster production. However, the stock impacts of these increases in restoration effort are not yet known. Tarnowski (2005) provides a table showing an average biomass index for 17 sampled sites that implies some (small) progress toward increased biomass. But, those data are based on 2004 sampling of sites that received treatments when restoration efforts were still at a relatively low level. It is not yet clear what the impacts will be of the larger efforts of more recent years.

Productivity on managed reserves can be assessed with respect to harvests from them. Unlike public bars, which are generally unconstrained in access, managed reserves are opened to harvest in a highly constrained manner. First, they are closed until most of the oysters on them reach four inches in size. When a site is judged ready for harvest, effort is regulated by limiting the number of days it is open. Three managed reserves were opened for a total of 30 days during the 2005 harvest season. Over those days, harvesters applied 261 person days and 178 boat days of effort and harvested 2,828 bushels[33]. If we consider the average catch per person per day over the period 1986 – 2005 (6.24 bushels) and assume a 100 day working season, then an average annual harvest (per harvester) would be in the range of 624 bushels. If that is so, then the managed reserves supplied 4.5 person years of harvest in 2005. In the 2006 harvest season, ORP reports harvests from managed reserves of about 5,000 bushels. That harvest might support 8 harvesters over an entire season.

Managed reserves are clearly limited in scale, relative to the number of harvesters who would remain in the fishery in order to harvest 624 bushels per year. This problem is amplified by the problem of cost. A precise accounting of the cost per harvested bushel of creating and maintaining managed reserves is beyond the scope of the present report. However, early indications are that each bushel harvested from a harvest reserve carries a cost that is several multiples of its dockside value. That level of loss will not be compensated in expanded volume. As will be shown below, repletion, which was a simpler and lower-cost affair than managed reserves, has not been able to increase stocks in a manner that recovered its costs over the past twenty years. It should not be surprising that managed reserves are also not able to achieve cost-recovery in their operations.

[33] Terra Lederhouse, 2005.

III.B. Estimating Returns to Management and Repletion

It is sometimes claimed that the oyster repletion program generates positive economic returns for the state by increasing the available harvest resource which in turn generates benefits to harvesters, packers, retailers and consumers[34]. However, those benefits have rarely been assessed in scientific manner, in large part because the data required to assess them are disparate and only variably available. Below, we assess some studies that have addressed returns in Maryland's oyster fishery and present results from research undertaken for the present report, focusing on primary returns to oyster repletion since the disease epizootics of the 1980s.

III.B.1. Previous Production Functions for Repletion Efforts

There have been several attempts to develop bio-economic models for the Chesapeake Bay oyster fishery including, among others: Christy (1964), Suttor and Corrigan (1970), Angello and Donnelley (1975), and Cabraal (1978). All of these studies note that reliable economic and productivity data and, in particular, reliable stock estimates are generally not available. In the absence of productivity data the researchers have to assume specific types of relationships between harvests and stocks and, depending on those assumptions, different results are obtained. Moreover, each study used a different time period and their results were affected by harvest trends during those periods.

Suttor and Corrigan (1970) proposed that growth of oyster stocks could be described as an increasing function of prior year stock weight (estimated as a function of prior year harvests). Their period of focus covered the years 1951 to 1981, using data from 1951 to 1966 to project to later periods. Their model estimated a maximum sustainable yield stock of around 10 million bushels of oysters. They also predicted that a 23 percent exploitation rate of those (maximum yield) stocks would be sustainable over time, but note that, over the time interval that they examined, equilibrium landings were rising; implying that stocks were smaller than maximum yield stocks and that a reduction in effort would generate an increase in harvests.

Angello and Donnelley (1975) suggested that, due to the common property aspect of oysters in the Chesapeake Bay and efficiency-limiting regulations aimed at reducing harvest effort, returns to either capital or labor will be lower in an open-access setting, compared with a private property regime. Using 1945 to 1969 harvest data from the Virginia and Maryland portions of the Bay, they modeled several different scenarios to estimate labor productivity in the fishery. Those modeled scenarios generated estimates that predicted a 50 percent increase in harvester incomes if common-property regimes were replaced by a leased bottom regime. No attempt was made to estimate the stock implications of such a shift, but it was implied that stocks would increase.

Cabraal (1978) used more refined data in his analysis than either of the aforementioned studies, both with respect to repletion efforts and harvests. He gathered repletion

[34] 2004 Chesapeake Bay Oyster Management Plan, Chesapeake bay Program, 2005.

information and data on harvests and effort by regions of the Bay, and used those data to estimate, among other things, returns to repletion efforts. His data period tracked a period of generally increasing harvests and consistently strong repletion efforts. But, given the trends in effort during these years of increasing harvests, he found evidence that catch limits were not binding in any of the four study regions and that catch per unit effort was trending downward with time[35].

Cabraal's (1978) model regressed yearly catch on: effort (measured in boatdays); catch per unit effort in the previous year; spatset from 3, 4, and 5 years before; seed oyster plantings 1, 2 and 3 years before; shell plantings in prior years; and dummy variables for subsets of his four regional groupings. He ran these regressions for four distinct regions of the Bay; Eastern Bay (and the lower Choptank), Tangier Sound, the Bay mainstem, and the Potomac and Patuxtent rivers. Each of the four regressions had a high R^2 and in each, effort accounted for more than 80 percent of the variation in catch. Each showed constant returns to scale[36]. Natural spatset lagged by three years was significant in three of the regions, but relationships between shell and seed oyster plantings versus harvests produced less consistently robust estimates across the four regressions.

Seed oyster plantings produced significant coefficients in only two regions and in these the coefficients showed harvest impacts of 12 and 19 additional bushels of harvest per hundred bushels of seed oysters planted. Fresh shell planting showed a significant impact on harvests in three of the four regions, ranging from an additional 93 bushels to 7 bushels per hundred bushels planted. Dredged shell showed only a small impact on harvests (5 bushels per hundred bushels planted) in one region. In dollar terms, the value of output per dollar of repletion inputs ranged from $1.60[37] (seed oysters in the mainstem) to $21.40 (fresh shell in the mainstem).

Cabraal (1978) then used the significant estimates of returns to derive a total repletion program impact on harvests, estimating this at about 300,000 bushels, annually. This is a little better than ten percent of annual harvests for the years 1970 to 1976. The direct costs of those repletion efforts were estimated to be about $3.33/bu, at a time when the dockside price for oysters was around $4.00/bu. Thus, independent of capital and administrative costs of the agency funding the repletion program and ignoring the costs of harvest, a return of $0.67 per bushel (16.75%) is implied.

In separate research undertaken for this project (Wieland, 2006), a sample of watermen was surveyed to ascertain their fixed and variable costs in harvesting oysters. The data generated by that study indicated that, at (exceptionally high) 2006 dockside prices and catch rates, between 42 (divers) and 76 percent (shaft tongers) of harvesters' average daily receipts were consumed by costs. In 2006, both prices paid and daily catch rates had risen significantly from previous years. In 2005, at average catch rates, the corresponding cost ratios were 74 and 150 percent. Considering that catch rates in 2006 were almost 50 percent lower than the average catch rates reported by Cabraal in the

[35] Cabraal (1978), pp 60 - 61
[36] Harvest in each of the different regions was dominated by skipjacks, patent tongs or shaft tongs.
[37] Nominal, 1967 dollars

1975 – 76 season, the share of costs in harvest returns during the mid 1970s might have been closer to half their current levels, i.e., on the order of 38 percent. Harvest costs at that level erase the returns to the repletion program (16.75%) as estimated by Cabraal (1978).

III.B.2. Modeling Recent Repletion Performance

In gathering repletion volume and cost data for this study, a dataset was developed that tracked repletion activities by oyster bar from 1986 to 2005. These bars could be located by three digit NOAA spatial codes. Harvest and effort data which could be located under this same code were then obtained. With these data, it was possible to consider harvest effects from repletion in a manner similar to Cabraal's earlier analysis. A principal difference between Cabraal's work and the current analysis is the examination of outcomes prior to the onset of high disease mortality in the fishery in the former and post-onset in the latter.

Area-based harvest data, repletion activities and several bio-physical parameters such as spat-set, salinity, and dissolved oxygen were assessed in an economic model that assumed harvests to be a function of fishing effort and stocks (Herberich, 2006). Because stock levels are unknown, repletion activities and other variables were used to proxy for stocks in the model. This allows the repletion activity coefficients to be interpreted as rates of change in harvest due to a given repletion activity. To this point, the study closely mirrored Cabraal's analysis. The earlier analysis did not look into the effect of repletion activities on effort however, and it is likely that effort would be affected by the knowledge of such activities. To fully account for the effects of repletion, Herberich's model considers both the direct impact the activities have on harvest and the indirect impact the activities have on harvest by influencing effort.

It should be noted that the harvest data used in Herberich's (2006) analysis are not only fishery-dependent but are also used as the basis for assessing a tax liability. Given this, and a presumption of some degree of tax-avoidance, it can be anticipated that the data understate actual landings. Moreover, because of a previous policy that allocated repletion resources on the basis of harvest productivity, there may be some bias in reporting the area of harvest. These problems not-withstanding, the data showed some expected outcomes. For instance, a simple comparison of means distinguishing between areas that received seed or shell and areas that did not showed some significant positive impacts of repletion activities on harvest volumes. Similar positive effects showed up in a regression analysis as well. There were some unexpected results in the regression, however, such as the effect on harvests on bars that received shell in the past year (a weak positive effect) and on bars receiving shell three years prior (a weak negative effect). There is no known bio-physical reason why sites receiving shell in the previous year should have increased harvest and it is unexpected that sites should have relatively less productivity three years after receiving shell.

The regression model was run as a Cobb-Douglas log-linear function and the repletion variables' coefficients are interpreted as elasticities, measuring the percentage change in harvests, given a one percent change in the mean of any given variable. In Herberich's harvest equation, only shell in the past year had a significant estimator (among the repletion factors). As noted above, this correlation was unexpected. Measuring the effect in terms of harvest productivity, the estimator for shell placed one year ago implies that 297 bushels of additional shell would generate about three quarters of a bushel of harvestable oysters in the current season.

In the effort equation, more significant repletion estimators were found, namely, seed one and two years prior and shell one and three years prior. Harvest effects of effort were estimated by multiplying marginal effects in the effort equation times the effort coefficient in the harvest equation. Using deflated average costs for seed and shell and similar averages for harvests, these harvest effects could then be valued and compared with costs for a rate of return calculation. **Table 4** reports the harvest effect of the significant repletion variables, the value of this effect at an average of annual dockside prices (deflated by the CPI, year 2000=1), and the net gain (loss) accruing to that activity[38].

Table 4: Marginal Effects and Returns to Repletion Activities

	Increase in harvest per one bushel increase (Bshls)		Inc. in dollars from harvest per one bushel inc.		Per period return		Total net return
Repletion effort	Harvest	Effort	Harvest	Effort	Harvest	Effort	
shell t-1	0.002553	0.012389	$ 0.05	$ 0.27	10%	50%	Shell: -77%
shell t-3		-0.009087		$ (0.19)		-37%	
seed t-1		0.095609		$ 2.05		52%	Seed: -22%
seed t-2		0.047052		$ 1.01		26%	
Avg. cost of seed/bu	$	3.96					
Avg. cost of shell/bu	$	0.53					
Avg. price of oysters/bu	$	21.42					

Source: Herberich, 2006

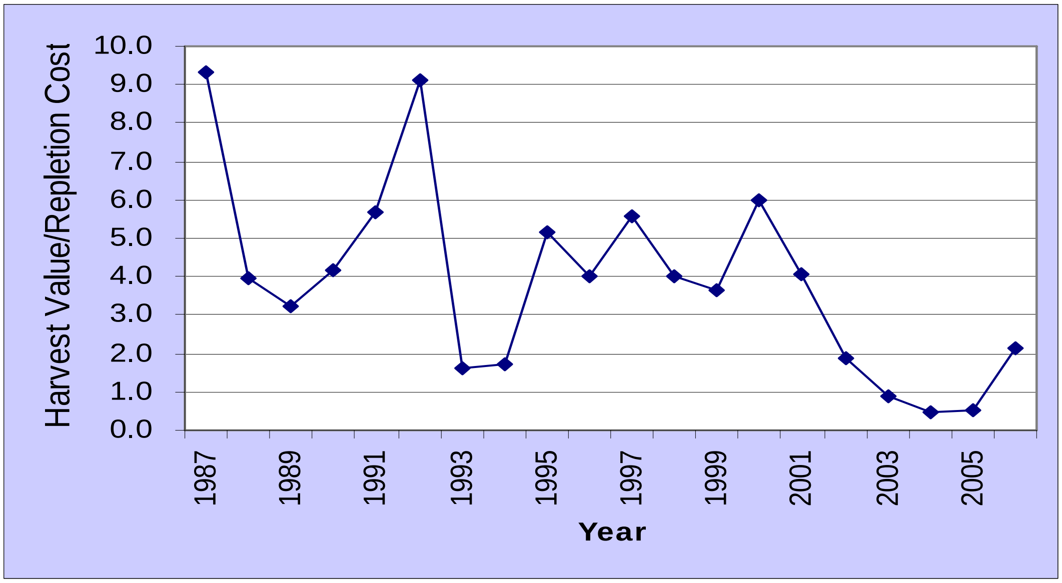
The last column in Table 4 provides a measure of the return generated by the two repletion activities, given their estimated effects on harvests. The combined effects of shell planting imply that for every dollar invested in this activity, a little more than 13 cents is returned, for a loss of 87 percent. Seed oyster plantings fared a little better, generating a 78 percent return, implying a loss of 22 cents for every dollar invested. These figures say that, on average, the harvest benefits from repletion over the period do not rise to the cost of obtaining them. Because they are based on averages of both input

[38] Measured as the value of the harvest increase divided by the cost of the activity. This can be thought of as returns in cents, per dollar invested.

costs and output prices over the period, in a year such as 2006 when dockside price increased dramatically they may mask occasional positive returns. But, as with Cabraal's estimates of returns, these estimates use dockside values as a measure of repletion's benefits and there are clearly additional (private) costs to harvesting the oysters and bringing them dockside.

While some of the estimates generated under Herberich's (2006) model are puzzling, the picture of repletion effects that do not rise to the costs of obtaining them is supported for recent years by a much simpler consideration of costs and returns. **Figure 11**, below, reports the ratio of annual dockside value to the previous year's repletion costs (excluding non-commercial, restoration costs). In this ratio, a number greater than one implies that harvest value exceeds repletion costs and a number less than one implies that repletion costs are greater than annual harvest values. Depending on what portion of the total harvest one imagines that repletion supplies, this graph shows a mixed story.

Figure 11: Ratio of Harvest Value to Repletion Costs, 1986 - 2005



Source: Harvest Value from MD DNR Commercial harvest data; Repletion Costs from Shellfish Program Seed and Shell Reports.

If repletion generated approximately ten percent of harvests as implied by Cabraal's work in the mid-1970s, then there has not been a positive return on repletion efforts in any year over the entire period. It is more likely, however, that as stocks have fallen the relative importance of repletion activities for total harvests has risen. Still, from 2003 to 2005, even if repletion was generating the entire reported harvest, it cost more than the value of those harvests to achieve them.

III.C. Summary

While the oyster repletion program has doubtless provided a boost to oyster harvests over its lifetime, its benefit has diminished since the spread of MSX and dermo. Using data from the post-disease period and an economic model which accounted indirect effort effects in addition to direct harvest effects from repletion, this benefit was barely perceptible and did not cover the cost of achieving it.

It can be argued that cost-recovery should not be a requirement for oyster repletion – that there are downstream benefits to processors and consumers that more than compensate the loss in oysters' primary production. But, given the increased use of guest workers in seafood processing and the ready availability of alternatively-sourced oysters in the marketplace, it is not clear how great those benefits are or how widely distributed. Another common argument for unremunerated support for the harvest industry is that, without it, the fishery would collapse and watermen would be driven out of business, irrevocably changing tidewater culture. While there are many historical examples of failed attempts to maintain a fading industry by subsidizing its inputs[39], the more direct response to the "dying culture" argument is that the number of person days applied in the oyster fishery in 2006 was only ten percent of the person days applied in 1977, 30 years earlier. Over the period, labor that would have been applied to harvesting oysters, had larger oyster stocks been available, has been applied to other activities. In other words, the lion's share of the adjustment has already been made.

Restoration that aims to restore oysters not just for immediate harvest but for more permanent stock increase is too new to thoroughly assess at present. It is apparent that the harvest portion of those restoration efforts are too small to have a significant impact on the harvest industry and that, at their current costs, they too have higher costs than commercial benefit. With respect to permanent closures, the difficulty of enforcing them is a constraint to success. There is also much uncertainty about whether permanent closures are accruing biomass in a way that will make any difference to stock levels over the longer term, given disease and other environmental factors.

[39] See for instance, DeMoor, A & P. Calamari (1997) Subsidizing Unsustainable Development. The Hague, Institute for Research on Public Expenditure, or, Wren, C. (1996) Industrial Subsidies: The UK Experience, London, St Martin's Press.

IV. The Implications of Historical Harvest Management for the Proposed Introduction and its Alternatives

The purpose of the non-native oyster EIS is to evaluate several oyster restoration alternatives and to identify one that will re-establish stock levels capable of supporting sustainable harvests similar to those enjoyed during the period 1920 – 1970. This wording should not obscure the fact that over much of this period harvests in Maryland were not sustainable, but trended downward as shown in **Figure 8**, above. However, the EIS addresses the entire Chesapeake Bay oyster fishery including Virginia's portion, which differs from Maryland's portion on at least two important counts. Virginia's waters tend to be saltier than Maryland's and, in part because of this; diseases were more of a problem, earlier, there. Secondly, the major portion of Virginia's harvest, until disease entered the picture, derived from sustained private production on leased bottom (Stagg, 1985).

Given the expected equilibrium of the common property harvest regime discussed above, it would be worthwhile to consider achievement of the EIS objective and its sustainability with respect to property rights and harvest management as well as stock levels. The need to consider property rights and management is implied both in the action itself and in its alternatives three and four concerning aquaculture. In this chapter, implications of the property rights regime for the introduction and some of its alternatives are considered.

IV.A. Introducing Crassostrea ariakensis and Continuing Native Oyster Restoration.

The proposed deployment of *C. ariakensis* would take place "first on State designated sanctuaries, where harvesting would be prohibited permanently, and then harvest reserve and special management areas where only selective harvesting would be allowed." Depending on the size and scope of these sanctuaries, managed reserve and special management areas, they imply some change in the regulatory regime for public oyster beds in Maryland's portion of the Bay. As the proposed action would continue native oyster restoration, deployment sites for the non-native oysters would presumably be in areas other than existing restoration sites. Harvest from public bars is not addressed under the proposed introduction.

Stock growth and the likelihood of introduced stocks radiating out from sanctuaries and other deployments are biological questions that are being studied by others under the EIS[40]. Depending on their findings, harvests of an introduced non-native oyster will presumably be constrained at the start of this process. The level at which effort will actually be limited will depend on the management objectives. Under an objective to spread introduced stocks as quickly as possible, harvests might be limited to zero early in

[40] A team led by Jon Volstad (Versar) is developing a population dynamics model and projections of stock growth for the EIS

the process, when the value of an additional oyster for producing progeny may be higher than its value in harvest. On the other hand, if the objective is to maintain the harvest industry, then some stock growth might be traded for nearer term harvests.

This trade-off between faster stock growth and current harvests is very similar to the one faced by managers in Maryland's native oyster restoration effort; with the important exception that native oyster restoration is further restricted by the increased likelihood that larger, older oysters will die from disease.[41] While managers in Maryland's oyster fishery have used this increased likelihood as a rationale for continuing to harvest under the common property harvest regime and to increase, through relaxed gear restrictions, harvest effort, Klinck and others (2001) address the question of optimal harvests with regard to the extent to which fishing mortality is additional versus compensatory to disease mortality. That is, they attempt to distinguish between harvest that removes oysters that would not have died from disease (additional mortality) versus harvest that takes oysters that would have died from disease anyway (compensatory mortality).

Klinck and others (2001) attempt to determine an optimal maximum allowable catch for oysters facing disease epizootics based, in large part, on the timing of harvests. This maximum allowable catch is, in the first instance, bounded by the objective of no net change in the abundance of market-sized oysters[42]. In further applications of their model, Klinck and others (2001) consider the level of harvest allocation possible for a range of stock rebuilding plans. Higher rates of increase, measured as the abundance of market sized oysters in the next year divided by abundance in the current year, require greater constraints on harvests. The relevance of this work for Maryland's oyster fishery is two-fold. First, it supports the expectation that, in the general case under current conditions, more oysters will generate greater increase in stock biomass over time. Secondly, these findings address management choices that, up to the present, have not been available to oyster managers in Maryland (i.e., determining an optimal allowable catch in the oyster fishery is not part of Maryland's current planning process and, if it were, it is not clear how such a cap could be implemented).

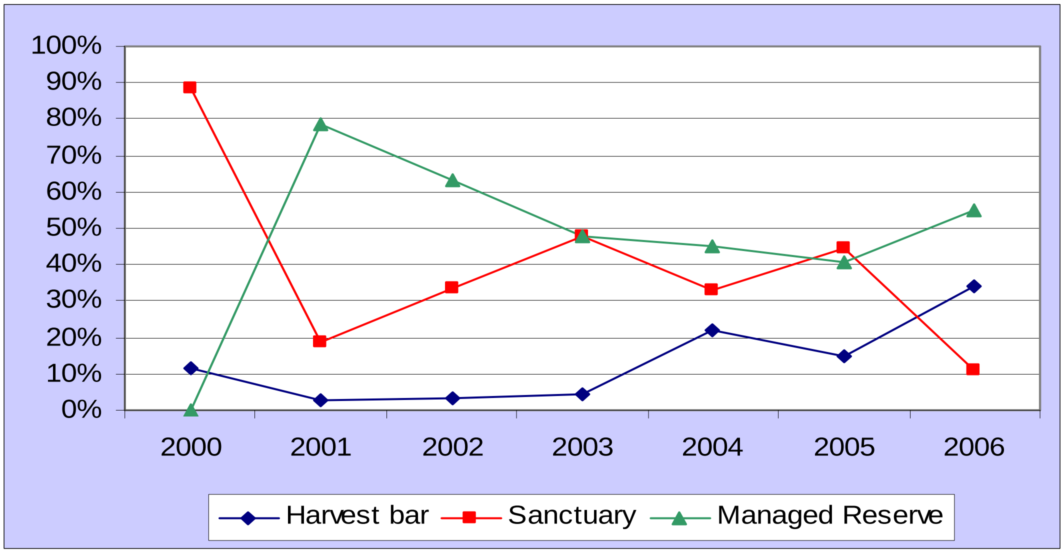
To the extent that additional oysters are expected to be associated with higher growth rates, *ceteris paribus*, stock growth should be greater in the absence of harvest. In the six years since the start of ORP's principal role in allocating restoration resources, sanctuaries have received about 32 percent of annual seed oysters with the rest going to

[41] Disease virulence is related to salinity and other habitat conditions and, because of the variability of nature and the imprecision of measurements and limited monitoring, it is difficult to correlate actual mortality against actual salinity to obtain robust estimators for this relationship.

[42] The model that Klinck and others report is based on harvest practices and data from Delaware Bay. While the biological factors in that fishery are similar to (though, less diverse than) those in Maryland's Chesapeake Bay, the harvest regime is quite different. In Delaware Bay, seed oysters were traditionally moved by harvesters from lower salinity seed beds higher in the bay to leased beds in the lower bay. As disease has made that model less profitable, production has come to focus on direct harvests from the seed beds. In order to protect the productivity of those beds, managers in New Jersey's fishery have the authority to establish a maximum allowable harvest with binding limitations on effort. This authority is lacking in Maryland's oyster fishery, with the exception of restoration areas comprising managed reserves.

managed reserves and harvest bars. **Figure 12** shows relative shares of hatchery produced seed oysters planted by year, 2000 to 2006. If additional (unharvested) oysters lead to greater stock increase, it is difficult to square this allocation with maximum stock growth. In addition to the 32 percent of total hatchery seed production used for sanctuaries over the period, one half was applied to managed reserves and 19 percent has been placed on harvest bars.

Figure 12: Relative Shares of Seed Oyster Plantings by ORP 2000 - 2006



Source: ORP Data.

In the conclusion to their article on property rights and efficiency in the oyster industry, Agnello and Donnelley (1975) note that, "considerations other than economic efficiency are used by states relying on common property for the oyster industry." That appears to be true in the Maryland oyster fishery, thirty years on. If additional stock is associated with higher growth rates, and larger shares of available resources are being used for harvest-oriented activities rather than non-harvestable restoration, then neither does maximizing biomass appear to be the primary objective[43] for restoration managers in Maryland. And, if neither economic efficiency nor maximum stock growth is a functional management objective to the present, then it is not clear on what basis either objective should be expected in the introduction of a non-native oyster.

A more compelling functional objective for managers in Maryland's oyster fishery is the short-term minimization of harm to harvesters from reductions in stocks from one year to the next. Clearly, repletion activity – as a put-and-take production process – has served such an objective. The relaxation of gear restrictions in the face of stock collapse also fits well under such an objective, as does the increasing application of "restoration" resources for harvest bars. These policies imply either a very high discount rate for future harvests or an inability to focus on the resource as opposed to the industry that depends on the resource. The question for the EIS is: to what extent might this inferred

[43] A distinction is being made here between nominal and functional objectives.

short-term focus undermine long term stock growth for either native or non-native oysters? An answer awaits results from the biological modeling that is being undertaken by others and a monetary return estimation including biological and economic expectations, with and without harvest mortality.

Independent of the question of how to achieve restored stocks of oysters, there is also a question about the benefits that would accrue if oyster stocks somehow were restored. Lipton, and others (2006) address this question. Basing their analysis on market demand for oysters and historical relationships between prices and quantities harvested in different regions of the United States, their model predicts that an increase in harvests on the order of the restoration objective would be accompanied by a drastic decline in unit prices. Because the unit oyster price that their model generates at the restoration objective is well below any historical price in the Chesapeake Bay oyster fishery, they propose that, even with a restored fishery, harvests would be limited to some fraction of their potential. The authors provide clear caveats on their analysis and data and, importantly, they do not address the likelihood of achieving stock levels that could support the level of harvest that they are considering. Rather, their focus is on what is implied if those stock levels were achieved, and they provide a warning that the benefits to producers may not be as great as expected, due to limited demand and consequent price adjustments.

In a background study for the present paper (Wieland 2006), operating costs of oyster harvesters in Maryland's portion of the Bay were estimated using data generated by a 2005 survey of oyster harvesters. That study suggested daily operating costs ranging from $375/day (high-end power dredges) to $176/day (low-cost shaft tongs). Cost estimates were composed of a constructed daily "indirect cost", fuel costs and labor costs. Indirect costs were summed from reported maintenance, repair and replacement costs. Fuel costs were estimated using reported average consumption and 2005 fuel prices. And, labor costs were estimated on the basis of hourly wage rates received in alternative employment[44]. While these estimates are based on a very small sample and could be biased in an unknown direction, they are the only cost estimates available for this fishery.

At the operating cost estimates reported above and Lipton and others' (2006) estimate of oyster prices at full achievement of the restoration objective ($10.58/bu), it would take daily harvests of 35.4 bushels for a high-end power dredge to break even. Given that single dredges operating in Delaware Bay averaged over 35 bushels per day between 1996 and 2005[45] even in that greatly diminished fishery, it does not seem unreasonable that Maryland dredgers could manage a positive return at such lower prices, if stocks grew sufficiently. What is less clear is how such harvests could be sustained, given common property expectations for the stock effects of harvests.

---

[44] Lipton notes the possibility that the lowest acceptable return on labor in the oyster fishery may be lower than alternative employment, owing to harvester preferences. Because of this, imputed wages in the cost study may overstate expected returns to time spent harvesting.

[45] J. Kraeuter, et al. (eds) 2006.

IV.B. Prospects for aquaculture

Lipton and others (2006) describe and analyze the Virginia Seafood Council's aquaculture trials that started in the fall of 2003 using both the native oyster and infertile (triploid) *C. ariakensis*. In those trials, triploid *C. ariakensis* performed much better than triploid *C. virginica*, achieving market size in nine months, on average. The bio-hazard rules imposed on the trials were thought to have artificially raised costs and lowered returns, but even so, average gross revenues from the trials were almost twice reported average costs. Those costs also assumed a one year cost recovery for some supplies that may have a longer useful life, though they do not account some other capital costs[46].

It appears likely from Lipton and others' (2006) report on the triploid *C. ariakensis* trials that triploid aquaculture in Virginia could be successful on commercial grounds (e.g. net of the potential cost of an unintended introduction). However, whether similar success could be expected in Maryland is more problematic. Because Maryland's waters are not as salty as Virginia's, it is doubtful that as rapid growth rates could be achieved in Maryland. Furthermore, Maryland has never had a significant oyster aquaculture industry and there are both regulatory and economic reasons for this. In order to create an enabling environment for such an industry, those economic and regulatory constraints would need to be overcome.

Regulatory constraints to traditional oyster aquaculture (i.e., bottom culture, as opposed to newer innovations, some of which involve growing oysters off of the bottom) derive from the long-entrenched idea of "open bottom" described in the introduction to this paper. Because this property rights regime has generated commercial benefits for those who harvest oysters, it has so far been impossible to undo. Under the public choice economics literature[47], such an outcome is expected if the benefits that accrue to one group provide economic incentives to defend them against the interests of a larger group (among which the losses are more dispersed). Even the loss of both oysters and the necessary environmental conditions for oyster habitat on the vast majority of traditional oyster bottom has been insufficient to enable a change in this regime.

At the start of the 20th century, the Maryland State legislature passed the Haman oyster bill which, as amended in 1912, allowed individual leases of up to 30 acres in county waters and up to 500 acres in the state's Chesapeake Bay waters (Kennedy and Breisch 1981). These leases were to be limited to "barren bottom" so not to restrict the original endowment of public bottom available to harvesters. Even so limited, the law met with continued opposition and was ultimately undermined by crippling amendments. Eventually, many tidewater counties were granted legislated provisions banning new leases within their waters.

---

[46] Neither capital nor depreciation costs of boats was captured in this accounting.
[47] See G. Tullock and others, 2002. Government Failure: A primer in public choice. Cato Institute.

While Maryland has recently enacted a new law[48] which streamlines the process for obtaining bottom new leases, this law does not remove existing bans on leases in most county waters. Moreover, it does not strengthen the enforcement of property rights to the oysters that are grown on leases, which, along with the absence of resource, is a major constraint to oyster aquaculture. Without removing these impediments, it is doubtful that oyster aquaculture that is based on bottom grow-out will be adopted, let alone successful, in Maryland. Even alternative forms of oyster aquaculture which do not involve spreading oysters on the bottom for grow-out and harvest (i.e., bags, cages and floats) would require property rights that restrict ownership of the growing oysters to the person who placed them there. Such rights would have to be enforced by credible policing and penalties that are not yet in evidence.

Independent of regulatory constraints, aquaculture often implies added production costs relative to working the wild fishery and, up to the present, these do not appear to have been attractive to oyster harvesters or other potential aquaculturalists in Maryland. Simply put, the principal economic constraint to aquaculture derives from the sentiment, “why buy a cow when milk is so cheap?” In light of the subsidy provided through both the repletion and restoration programs, this is not unreasonable. If public agencies will bear a significant share of the costs of ensuring supply on public bars, then rational harvesters would prefer taking whatever oysters are generated there rather than producing their own. Unless aquaculture provides some additional benefit such as more dependable supply or higher valued output, it is not clear why producers would choose it over working the (subsidized) public fishery.

Another economic impediment to aquaculture in Maryland is the absence of a smoothly functioning input market for either seed oysters or substrate. Virginia, with its history of oyster aquaculture, has seen a rapid growth in the production and setting of triploid oyster larvae over the past year and it is possible that, with demand for those inputs, such production capability would develop in Maryland[49] as well. But, it would be unwise to simply assume it so. Follow-on work to the current study will examine the potential for creating market-based oyster larvae production and setting in Maryland.

As noted above, it is possible that more dependable oyster supply could provide an added benefit to producers or that oysters produced in an aquaculture setting might have a higher market value that would justify their higher production costs. Alternatively, if the harvest industry was denied the subsidy on wild oysters or if they were required to pay those production costs in full, interest in aquaculture would likely be much greater.

[48] HB-971. See: Webster, D. and D. Merritt. 2005. New Law Streamlines Aquaculture in Maryland. Maryland Aquafarmer, 2005-01. www.mdsg.umd.edu/Extension/Aquafarmer/Summer05.html#1

[49] Interestingly, many of the triploid larvae used in Virginia are produced at the Horn Point Hatchery in Maryland. (Don Webster, personal communication) What remains to be developed is an efficient mechanism for making these larvae available to aquaculturalists.

IV.C. Change for sustainable benefits from the oyster fishery.

The objective of the EIS is to determine an alternative which would lead to a re-establishment of robust oyster stocks in the Chesapeake Bay. This objective serves, in turn, the two goals of renewed delivery of oysters' ecological services and commercial benefits from harvest. It was noted, in the conclusion of the description of the common property model, above, that under an open-access harvest regime joint products such as environmental benefits would be under-supplied at the (open access) market equilibrium. Thus, the two subsidiary goals of the EIS imply the challenging mandate that managers attain two potentially conflicting goals. This conflict becomes relatively more likely under Maryland's current harvest regime and, in light of that, a change in the management of harvests is recommended.

Under Maryland's Natural Resource Law, Title 4, subtitle 10**,**

Any resident of the State may catch oysters or clams on any area in the waters of the State from which catching oysters or clams is permitted under the provisions of this subtitle. This section applies to catching oysters or clams by rakes, tongs, patent tongs, dredges, handscrapes, or by other means permitted by law for the particular area.

Although the state owns the bottom on which oysters (or, clams) grow, the resource itself is un-owned until someone harvests it. While the state has the authority to regulate gear types, time allowed for harvest, catch limits and other harvest factors, the author has not yet found a legal opinion that holds that the state or anyone else "owns" the oysters on public oyster bottom. Along with being un-owned, oysters on public oyster bottom are unvalued[50]. This economic characteristic is elementary to the common property problem. Thus, a policy for ensuring that the common property equilibrium is avoided for either the native oyster or an introduced non-native oyster might include reassigning ownership, or, property rights to the resource from no one to someone.

In the case of either the proposed introduction or restoration of the native oyster, such a re-assignment of property rights could remove current incentives to fish the resource to the common property equilibrium. If ownership of the resource were assigned to the State, its agencies could work in a more focused manner to restore stocks and to ensure sustainable harvests. While trees are a much different resource than oysters, DNR's management of forests on State-owned forestland provides an example of conservative resource management – with adequate policing and enforcement. Over the roughly 100 years of state management of publicly held forests, managers have mitigated the impact of numerous introduced pests and diseases and, most importantly, have limited commercial harvests to a level that does not diminish the resource base. As a

[50] It could be argued that the oyster surcharge and landing tax constitute a valuation of oysters on the bottom but, see section II. B. 6., above. Alternatively, it could be argued that repletion and restoration funding represents a valuation of oyster stocks in the water but, as has been discussed, the vast majority of oyster repletion and restoration efforts target harvestable stocks, which are different from stocks intended to live out their life on the Bay's bottom.

consequence, state-owned forestland is accruing biomass and the forests on those lands are healthy.

In the case of an introduced non-native oyster, reassigning property rights to stocks to the State would lay a stronger foundation for those stocks to be managed for optimal growth over the long-run. If *C. ariakensis* is assessed to have the proper characteristics for biological success in the Chesapeake Bay and, if managers are given a clear mandate to ensure long-term success of the resource, ownership of the resource would allow them to assign a price to removals, reducing the open-access incentive to over harvest. Or, alternatively, mangers could establish and more effectively enforce harvest allowances, based on biological and longer-term economic objectives. State ownership would also clarify illegal harvests as theft, allowing more credible penalties for those.

State ownership of the oyster resource would not guarantee management that achieves optimal stock growth or maximum economic returns over time. But, it would change the incentives of managers to the extent that they could be brought to focus on the long-term prospects for the resource, rather than the short-term interests of the harvest industry. Moreover, in the case of an introduced non-native species, if the introduction goes awry and causes large social or private costs, it is likely that an effort would be made to hold the state accountable. In that sense, the resource might be, *de facto*, owned by them.

An alternative to re-assigning ownership of the oyster resource to the state is to assign them to private lease-holders. However, the costs of restoring oyster bottom and oyster populations in specific areas are high, and it is doubtful that many of the current oyster harvesters have the financial resources to undertake oyster bottom restoration. As well, success of native oysters remains constrained by environmental conditions that are impossible to control and this makes them not a good candidate for dependable returns on investment. While triploid aquaculture holds some commercial promise, it is not a means for re-establishing large, self-sustaining populations of oysters. A fertile non-native oyster might, on the other hand, repopulate traditional oyster bottom and in so doing provide the necessary return for private investment. But, this abstracts from potential external costs to such an introduction that have been enumerated elsewhere (Lipton and others 2006).

A shift in the ownership of oysters in Maryland's Chesapeake Bay would undo both 200 years of tradition and, potentially, an equal period of resource debasement. It has been recommended before[51] and rejected in favor of the perennial hopefulness of harvesters and resource managers that the resource will somehow prevail. But the resource has clearly not prevailed, as the consideration of the drastic step of purposefully introducing an exotic species to replace it shows. Even if an introduced non-native oyster proves to be biologically successful in the Chesapeake Bay, without changing the terms under which it is harvested there is little reason to suppose that it will be economically successful over the long term.

[51] Brooks (1905) and Green (1916), cited from Kennedy and Breisch (1981)

REFERENCES

Agnello, A.J. and L.P. Donnelley. 1975. Property rights and efficiency in the oyster industry. Journal of Law and Economics, 18:512-533

Cabraal, R.A. 1978. Systems analysis of the Maryland Oyster Fishery: Production, management and economics. Unpublished Ph.D. Dissertation, Department of Agricultural Engineering, Univ. of MD, College Park.

Chesapeake Bay Program. 2005. 2004 Chesapeake Bay Oyster Management Plan. CBP/TRS277/06.

Christy, F.T. 1964. The exploitation of a common property resource: The Maryland oyster fishery. Unpublished Ph.D. Dissertation, Univ. of Michigan, Ann Arbor.

Clark, C.W. 1990. *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*. Wiley Interscience, New York.

Ford, S.E, and M.R. Tripp. 1996 Diseases and Defence Mechanisms. In The Eastern Oyster, Crassostrea virginica, V.S. Kennedy, R.I.E. Newell and A. Eble (Eds), Maryland Sea Grant Publication, College Park, MD, USA. pp 581-660.

Gordon, H.S. 1954. The economic theory of a common property resource: the fishery. J.Polit.Econ. 62:124-142.

Herberich, D. 2006. Estimated Return to Harvest due to the Maryland Department of Natural Resources Repletion Activities 1990-2006. Report for the NOAA Chesapeake Bay Office.

International Pacific Halibut Commission (IPHC). 1997. 1996 Annual Report. Seattle, Washington.

Iudicello, S., M.Weber and R.Wieland. 1999. Fish, Markets, and Fishermen. Island Press.

Kennedy, V.S. and L.L.Breisch. 1981 Maryland's Oysters: Research and Management. Maryland Sea Grant Publication UM-SG-TS-81-04.

Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Mar Ecol Prog Ser. Vol. 303 1-29.

Klinck, J.M, E.N. Powell, J.N. Kraeuter, S. Ford, and K.A. Ashton-Alcox. 2001. A fisheries model for managing the oyster fishery during times of disease. Journal of Shellfish Research, Vol. 20, No. 3.

Kraeuter, J., E. Powell, and K. Ashton-Alcox (eds). 2006. Report of the 2006 Stock Assessment Workshop for the New Jersey Delaware Bay Oyster Beds. Haskin Shellfish Laboratory, Rutgers.

Lederhouse, T. M. and Paynter, K. T. 2005. Harvest efficiency in managed oyster reserves. Estuarine Research Federation 2005 Conference.

Lipton, D., J. Kirkley, and T.J. Murray. 2006. A Background Economic Analysis for the Programmatic Environmental Impact Statement Regarding the Restoration of the Chesapeake Bay Oyster Fishery Using the Non-Native Oyster, Crassostrea ariakensis. Report for Maryland DNR.

National Research Council. 2004. Non-native oysters in the Chesapeake Bay. National Academies Press, Washington.

Newell, R.I.E. 1988. Ecological Changes in the Chesapeake Bay: Are They the Result of Overharvesting the American Oyster, *Crassostrea virginica*?. Proceedings of the conference *Understanding the Estuary: Advances in Chesapeake Bay Research*. Chesapeake Research Consortium Publication 129.

___________, T.R. Fisher, R.R. Holyoke, and J.C. Cornwell. 2005. Influence of eastern oysters on Nitrogen and Phosphorus regeneration in Chesapeake Bay, USA. Pages 93-120 In: *The comparative Roles of Suspension Feeders in Ecosystems*. R. Dame and S. Olenin (Eds.) Vol 47 NATO Science Series: IV - Earth and Environmental Sciences. Springer, Netherlands.

New Jersey Oyster Industry Revitalization Task Force. 2005. Oyster Industry Revitalization Task Force Final Report. For the Governor and Legislature of New Jersey.

Paynter, K., M. Chen, J. Goodwin, S. Allen and L.Kellog. 2005. Harvest Reserve Monitoring Report. Report for MD DNR and the Oyster Recovery Partnership.

Rothschild, B.J., J.S. Ault, P. Goulletquer and M. Heral. 1994. “Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing.” Mar. Ecol. Prog. Ser., Volume III: 29-39.

Smith G.F., D.G. Bruce, E.B. Roach, A. Hansen, R.I.E. Newell and A.M. McManus. 2005. “Habitat conditions of mesohaline oyster bars in the Maryland Chesapeake Bay: An assessment of 40 years of oyster management”. North American Journal of Fisheries Management. 25:1569-1590.

Stagg, C. 1985. An Evaluation of the Information Available for Managing Chesapeake Bay Fisheries: Preliminary Stock Assessments. Volume I. Chesapeake Bay Commission. UMCEES(CBL) 85 -29.

Suttor, R.E. and T.D. Corrigan. 1970. The Chesapeake Bay oyster fisheries: An econometric analysis. University of Maryland Agricultural Experiment Station publication #740.

Tarnowski, M. 2005. An Evaluation of the Maryland Oyster Sanctuaries Monitored by the MDNR Shellfish Program's Fall Oyster Survey. Maryland DNR.

----------------- 2006. Maryland Oyster Population Summary Status Report: 2005 Fall Survey. Maryland DNR Publication #17-511206-128.

Tullock, G., A. Seldon, and G.L. Brady. 2002. Government Failure: A primer in public choice. Cato Institute.

Ulanowicz, R.E., W.C. Caplins, and E.A. Dunnington. 1980. The forecasting of oyster harvests in central Chesapeake Bay. Estuar. Coastal Mar. Sci. 11:101-106.

Webster, D. and D. Merritt. 2005. New Law Streamlines Aquaculture in Maryland. Maryland Aquafarmer, 2005-01.

Wieland, R.C. 2006. Operating Costs in the Chesapeake Bay Oyster Fishery. Report for the NOAA Chesapeake Bay Office.

Wolman, M. G. 1990. Recommendations of the Governor's Committee to Review State Policy for Funding Maryland's Chesapeake Fisheries - The Role of the State of Maryland in Oyster Fisheries Management. MD. Y3. Oy 98:2/W/990

Data Appendix

Compiled from MD DNR commercial harvest data 1989 to 2006, the following 4 tables provide background for the harvest – effort analysis.

Harvests (Bushels)

Year	Divers	Pat. Tong	Dbl PT	Shaft Tong	Pwr Dredge	Total Harvest
1989	42729	23038	10822	297374		373963
1990	47853	16223	15084	300247		379406
1991	74306	46607	59120	197006		377039
1992	53227	59039	48974	122068		283307
1993	25113	8128	10595	38643		82480
1994	19589	6255	5352	58939		90135
1995	29146	18542	13670	124552		185910
1996	25671	26942	10927	111138		174678
1997	16780	12044	3664	137864		170352
1998	37477	20288	10027	218422		286213
1999	58826	25651	10408	245606		340490
2000	58486	35828	8107	268771	16455	387647
2001	74697	30993	11541	151086	18076	286392
2002	30284	18816	8017	50606	17575	125297
2003	9745	16546	2081	4953	12386	45711
2004	5366	3521	965	2004	13034	24889
2005	13431	5346	1135	4729	37273	61914
2006	31747	38690	5372	23095	28857	127761

Price Per Bushel by Gear Type

	Divers	Pat. Tong	Dbl PT	Shaft Tong	Pwr Dredge	Wtd Average Price
1989	20.1365	32.6332	19.5361	21.0247		21.5953
1990	25.6151	24.4170	22.0395	23.1206		23.4477
1991	23.6246	21.5033	21.7117	21.8217		22.1204
1992	20.9900	18.8755	19.1891	20.6616		20.0965
1993	22.1038	21.6378	21.2676	21.3306		21.5882
1994	17.9225	18.5586	17.4386	17.7937		17.8537
1995	21.8872	19.2446	19.6017	17.9459		18.8151
1996	18.3724	17.9515	17.3223	18.0944		18.0649
1997	22.8707	21.9057	21.9196	20.5987		20.9433
1998	21.2935	21.7125	20.5046	20.1743		20.4415
1999	20.7378	20.5473	19.8103	17.6484		18.4667
2000	20.3904	19.8306	18.6541	18.7437	20.7551	19.1761
2001	20.5909	20.8562	20.2434	18.6246	21.0331	19.5962
2002	20.1634	19.5249	19.2003	20.4838	21.2357	20.2857
2003	27.2320	29.4253	27.5649	26.9921	32.1798	29.3558
2004	27.2676	30.3852	24.1844	25.8413	26.9992	27.3337
2005	19.2118	18.0703	23.1683	17.8188	13.7597	15.7971
2006	30.5000	30.4800	30.4700	30.0000	32.3300	30.8156

Boat Days by Gear Type

	Divers	Pat. Tong	Dbl PT	Shaft Tong	Power Dredge	Total Boat Days
1989	2733	2298	740	31693		37464
1990	2963	2099	1096	31945		38103
1991	5285	5211	3605	24202		38303
1992	4672	6293	3359	15709		30033
1993	1920	1067	756	6395		10138
1994	1207	772	310	5052		7341
1995	1737	2210	914	11739		16600
1996	1474	2700	622	9538		14334
1997	1033	1679	319	12710		15741
1998	1911	2050	639	20112		24712
1999	4355	2807	876	24419		32457
2000	2497	2822	496	18795	1175	25785
2001	3106	2475	684	11575	885	18725
2002	1384	1772	651	5394	1370	10571
2003	548	1646	240	709	1277	4420
2004	342	459	95	308	1362	2566
2005	597	605	114	550	2949	4815
2006	1275	2833	309	2187	2112	8716

Man Days by Gear Type

	Divers	Pat. Tong	Dbl PT	Shaft Tong	Pwr Dredge	Total Man Days
1989	6453	3072	1534	59123		70182
1990	7506	2569	2212	62796		75083
1991	12826	6401	7168	46645		73040
1992	11317	8562	6454	29805		56138
1993	4798	1418	1519	11953		19688
1994	2824	877	608	10182		14491
1995	3976	2605	1782	22840		31203
1996	3770	3610	1199	19147		27726
1997	2298	2160	609	24173		29240
1998	4876	2659	1251	37378		46164
1999	10296	3765	1827	44645		60533
2000	6692	3432	1014	35331	2396	48865
2001	8566	2910	1389	21458	2108	36431
2002	3627	2216	1309	9293	2698	19143
2003	1277	2010	471	1171	2131	7060
2004	756	511	187	452	2023	3929
2005	1414	717	166	832	4884	8013
2006	3101	3792	571	3664	3785	14913

Background data for **Figure 6.** Number of weeks and allowable week days from calendars and Maryland Natural Resource regulations. Number of boat and licensee days from MD DNR commercial harvest data.

Season Days and Utilization

	Weeks in season	Days of week	# of Harvesters	Total Boat Days	Total Man Days	Allowable days	Ratio used/allowed
1989	26	6	3784	37464	70182	590304	0.1189
1990	26	6	3707	38103	75083	578292	0.1298
1991	26	5.5	3843	38303	73040	549549	0.1329
1992	26	5.8	3242	30033	56138	488893.6	0.1148
1993	24	5	1094	10138	19688	131280	0.1500
1994	24	5	947	7341	14491	113640	0.1275
1995	26	5	1816	16600	31203	236080	0.1322
1996	26	5	1691	14334	27726	219830	0.1261
1997	26	5	1624	15741	29240	211120	0.1385
1998	26	5	2108	24712	46164	274040	0.1685
1999	26	5	3058	32457	60533	397540	0.1523
2000	26	5	2384	25785	48865	309920	0.1577
2001	26	5	1765	18725	36431	229450	0.1588
2002	26	5	1034	10571	19143	134420	0.1424
2003	26	5	745	4420	7060	96850	0.0729
2004	26	5	375	2566	3929	48750	0.0806
2005	26	5	690	4815	8013	89700	0.0893
2006	26	5	672	8716	14913	87360	0.1707

The following table reports long term harvest estimates used for **Figure 8.** 1870 to 1928 data are from Fishery Statistics of the US cited from Christy 1965. 1929 to present is MD DNR harvest data and NMFS reporting (sourced from MD DNR).

Year	Pounds	Bushels	Year	Pounds	Bushels
			1925	28800000	2370000
1870	58793123	8950000	1926	15958871	2570000
1875	91966896	14000000	1927	16083065	2590000
1879	69632078	10600000	1928	12357258	1990000
1880	71900000	10945243	1929	17743034	2772349
1884	98535960	15000000	1930	17105969	2672808
1887	55200000	8403024	1931	11674450	1824133
1888	57800000	8798818	1932	12985364	2028963
1889	68975172	10500000	1933	11684784	1825748
1890	70900000	9950000	1934	13917300	2174578
1891	67400000	11630000	1935	15583800	2434969
1892	66610309	10140000	1936	16060000	2509375
1893			1937	20729700	3239016
1894			1938	19363000	3025469
1895			1939	20342300	3178484
1896			1940	19743200	3084875
1897	49200000	7250000	1941	18816400	2940063
1898			1942	13767700	2151203
1899			1944	14126600	2207281
1900	37377974	5690000	1945	15033500	2348984
1901	38500000	5860805	1946	13590300	2123484
1902			1947	13076500	2043203
1903			1948	13285100	2075797
1904	29300000	4500000	1949	13717720	2143394
1905			1950	14406000	2250938
1906	40925268	6230000	1951	14521900	2269047
1907			1952	16287600	2544938
1908	39500000	6013033	1953	17433900	2724047
1909			1954	20363206	3181751
1910	22991724	3500000	1955	17271900	2698734
1911			1956	15843900	2475609
1912	37300000	5678130	1957	14732400	2301938
1913			1958	12026700	1879172
1914			1959	11966200	1869719
1915			1960	11769700	1839016
1916	25583871	4120000	1961	10336600	1615094
1917	15275806	2460000	1962	8137500	1271484
1918	23162097	3730000	1963	7756400	1211938
1919	28502419	4590000	1964	7947700	1241828
1920	30800000	4960000	1965	8620100	1346891
1921	27570968	4440000	1966	11788700	1841984
1922	22913710	3690000	1967	16729800	2614031
1923	21361290	3440000	1968	14873800	2324031
1924	17325000	2790000	1969	14721200	2300188

Year	Pounds	Bushels
1970	16625200	2597688
1971	17116900	2674516
1972	19052800	2977000
1973	20422200	3190969
1974	18284100	2856891
1975	16402300	2562859
1976	14880300	2325047
1977	13028200	2035656
1978	14372900	2245766
1979	13489000	2107656
1980	14944273	2335043
1981	15722239	2456600
1982	12274847	1917945
1983	7445232	1163318
1984	8042404	1256626
1985	8597664	1343385
1986	7961730	1244020
1987	3830892	598577
1988	2408884	376388
1989	2453938	383428
1990	2848145	445023
1991	2331964	364369
1992	1263546	197429
1993	541617	84628
1994	840510	131330
1995	1310458	204759
1996	1094259	170978
1997	1509057	235790
1998	2458579	384153
1999	2540324	396926
2000	2389192	380675
2001	631480	347968
2002	566990	148155
2003	158873	55840
2004		26471
2005		72218
2006		154355

The following Table reports MD DNR Shellfish income from harvests and expenditures for repletion. State seed area shell costs are lagged one year. Income data are from the MD DNR Shellfish Program and repletion costs are from the Seed and Shell Reports.

	Shellfish Program Income			Repletion Costs		
Year	Oyster Severance Tax	Oyster Harvest License Sales	Oyster Surcharge	Seed planting cost	SSA Shell costs	Public Bar Shell
1986	822,431			376,403	314,745	1,084,066
1987	524,925			547,164	397,079	915,053
1988	197,621			860,249	639,736	821,504
1989	221,869			555,917	634,328	1,190,731
1990	156,302			332,475	719,078	619,491
1991	285,062	80,921		399,574	275,733	32,837
1992	372,952	63,243	445,200	857,768	682,142	120,050
1993	158,584	82,150	307,200	189,917	575,706	30,597
1994	93,879	48,200	163,250	259,892	331,378	42,645
1995	200,000	53,681	274,926	342,366	412,076	48,748
1996	230,000	55,900	297,000	156,464	422,889	99,228
1997	190,225	45,325	248,100	294,202	899,602	229,506
1998	317,713	47,240	300,235	538,465	991,855	622,922
1999	484,526	41,650	339,350	187,525	605,040	415,273
2000	439,305	43,578	306,100	330,052	901,246	450,806
2001	416,721	41,800	300,634	276,073	750,979	543,463
2002	171,302	40,734	217,916	235,690	957,631	604,846
2003	67,721	38,700	138,950	410,912	947,368	183,077
2004	30,811	36,660	86,100	278,670	889,508	911,077
2005	79,058	34,500	124,910	0	1,050,863	1,035,076

The following table reports volumes and costs of repletion activities from 1960 to 2005. Fresh shell costs are contained in "total shell planting costs". Deflated "total costs" are calculated using the CPI (year 2000 = 1). Source MD DNR Shellfish Program.

Fiscal Year	Dredged Shell Planted (Bushels)	Dredge Shell Costs $	Total Shell Planting Costs $	Seed Oysters Planted (Bushels)	Seed Planting Costs $	Total Costs (nominal)	Total Costs (deflated)
1960	3,373,484	418,937	459,057	150,765	65,628	524,685	3,052,390
1961	5,263,128	663,521	693,757	237,000	103,166	796,923	4,589,637
1962	5,012,639	654,653	685,256	573,000	249,427	934,683	5,329,547
1963	5,009,258	668,306	690,832	932,000	405,700	1,096,531	6,170,675
1964	5,013,296	662,972	685,675	1,191,000	518,442	1,204,117	6,688,677
1965	5,585,396	751,422	772,063	1,192,000	518,878	1,290,941	7,057,144
1966	5,509,798	755,490	772,755	1,364,000	593,749	1,366,504	7,262,718
1967	5,034,336	733,329	751,752	1,278,000	556,313	1,308,065	6,743,976
1968	6,170,192	987,281	1,005,388	1,213,496	528,235	1,533,623	7,588,789
1969	5,021,465	816,319	837,033	710,042	309,081	1,146,115	5,377,682
1970	5,782,008	788,957	979,468	1,183,430	515,147	1,494,615	6,633,317
1971	5,016,617	821,510	1,024,510	1,100,000	427,000	1,451,510	6,171,605
1972	6,253,754	1,070,274	1,220,274	900,000	422,000	1,642,274	6,765,540
1973	5,847,076	975,227	1,096,227	1,089,585	489,000	1,585,227	6,148,110
1974	5,015,903	846,086	980,086	375,815	168,000	1,148,086	4,010,150
1975	6,915,142	1,139,968	1,300,968	834,955	395,000	1,695,968	5,428,359
1976	5,015,303	832,099	986,099	600,000	290,000	1,276,099	3,861,938
1977	5,019,036	833,160	971,160	500,000	258,000	1,229,160	3,492,762
1978	5,309,251	979,349	1,145,904	401,785	275,122	1,421,025	3,753,076
1979	5,605,105	945,730	1,132,948	508,507	348,199	1,481,147	3,513,135
1980	5,054,879	862,452	1,009,813	10,305	10,304	1,020,117	2,131,846
1981	4,512,831	781,383	987,282	559,540	468,586	1,455,868	2,757,981
1982	4,942,840	1,015,335	1,222,960	290,210	244,552	1,467,512	2,618,711
1983	2,554,749	536,901	706,877	446,148	378,968	1,085,845	1,877,334
1984	4,478,159	942,612	995,773	48,171	36,722	1,032,495	1,711,219
1985	5,423,831	1,124,230	1,195,712	137,434	123,965	1,319,677	2,111,974
1986	5,644,908	1,731,185	1,856,241	445,865	377,831	2,234,072	3,510,102
1987	5,567,978	1,554,789	1,564,489	642,306	545,000	2,109,489	3,197,659
1988	5,588,336	1,610,273	1,681,775	918,792	902,481	2,584,256	3,761,698
1989	6,378,553	1,909,809	1,975,749	565,420	555,917	2,531,666	3,515,749
1990	5,093,102	1,836,971	1,897,928	341,857	329,346	2,227,274	2,934,480
1991	1,850,400	714,979	762,874	332,937	397,194	1,160,068	1,466,694
1992	2,018,128	695,756	777,231	662,102	785,686	1,562,917	1,918,277
1993	1,553,079	361,975	440,487	130,078	189,917	630,404	751,250
1994	1,705,684	484,369	528,777	180,115	259,891	788,668	916,388
1995	1,633,040	471,637	573,523	232,597	342,365	915,888	1,034,881
1996	2,481,400	998,830	1,026,787	130,687	156,468	1,183,255	1,298,639
1997	1,869,710	819,948	920,191	218,326	279,715	1,199,906	1,287,376
1998	2,229,605	1,000,052	1,016,363	466,257	498,377	1,514,740	1,600,235
1999	2,351,890	993,700	1,103,139	195,284	196,117	1,299,256	1,342,928
2000	2,720,326	1,536,797	1,081,704	282,513	325,052	1,406,756	1,406,756
2001	2,832,626	1,691,568	1,587,329	271,381	276,073	1,863,402	1,812,869

Fiscal Year	Dredged Shell Planted (Bushels)	Dredge Shell Costs $	Total Shell Planting Costs $	Seed Oysters Planted (Bushels)	Seed Planting Costs $	Total Costs (nominal)	Total Costs (deflated)
2002	2,571,941	1,544,412	1,130,394	150,343	210,689	1,341,083	1,283,683
2003	1,770,000	1,189,555	229,825	242,959	361,411	591,236	553,320
2004	2,503,169	1,909,510	1,432,022	202,756	293,955	1,725,977	1,573,390
2005	2,527,393	2,168,992	1,644,555			1,644,555	1,450,038