FINAL REPORT

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*

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Background

The Chesapeake Bay oyster, *Crassostrea virginica,* is a natural asset. The oyster resource supplies a flow of goods and services that contributes to the overall welfare of individuals and society as a whole[1]. The oyster's most obvious and easily measured value has been as a food resource. Consumer demand for oysters creates an opportunity for producers to earn income and business profits catching and processing oysters to satisfy that demand. Also contributing to the asset value of the oyster resource is its *in situ* value as an important habitat for other Chesapeake Bay species and its role as a filter feeder in the functioning of the Chesapeake Bay ecosystem (Newell 2004). The value of the oyster in this case is indirect; it is derived from the value that comes from the human use of species (both recreational and commercial) that benefit from oyster habitat or the benefits that humans perceive from the filter feeding role of oysters. There may also be a non-use value associated with Chesapeake Bay oysters that derives from individual's valuing the fact that oysters exist in the Bay, irrespective of any direct or indirect use value.

The direct use value and the indirect use value of oysters pose a potential conflict. For oysters to be of value as a food source, they must be removed from the Bay, thus affecting their ability to provide the indirect habitat and filtering services. The standard fisheries bioeconomic problem (Clark 1976) seeks to optimize the gains from removals while accounting for the contribution that harvested oysters would have made to growth and reproduction contributing to future harvests (i.e., the opportunity costs of harvest). Indirect values increase the opportunity costs of harvests, as harvested oysters no longer provide habitat for themselves or other species and they no longer provide filtering

[1] see Henderson and O'Neil (2003) for an overview.

capability. The failure to acknowledge the total opportunity costs of oyster harvest in Chesapeake Bay management strategies contributed to the long term decline of the resource and, consequently, its asset value. In the latter part of the twentieth century, the main value derived from the remaining natural oyster resource was seed production for either a principally private leased bottom fishery in Virginia or a repletion program on public grounds in Maryland. Finally, disease diminished even the value of oyster reproductive capacity since many of the seed oysters were unable to survive to market size.

The goal stated in the programmatic Environmental Impact Statement is to restore the Chesapeake Bay oyster population to a level that will sustain harvests comparable to harvests in the 1920-1970 time period. Historical harvest figures indicate that the annual average harvest (computed on a decadal basis) of Chesapeake Bay oysters from 1920-1969, ranged from 3.6 million bushels to 5.8 million bushels, and averaged 4.9 million bushels. Presumably, this number represents the harvest target range of the proposed objective. Although these harvest figures are mostly from the period prior to both the onset of outbreaks of MSX and then Dermo in Chesapeake Bay, and the period when the Maryland oyster repletion program started to return benefits, there is no evidence to indicate that these harvests were self-sustaining. Nevertheless, we will use this figure of a 4.9 million bushel annual harvest in the following analysis of the commercial industry, recognizing that the population to sustain such a harvest may be greater than the one that existed during the 1920-1969 period.

In order to achieve the stated goal, the EIS proposes eight alternatives, including a no action alternative and a combination of actions alternative. The remaining six proposed actions include:

1. Expansion of the existing native oyster restoration program.
2. A harvest moratorium with compensation for watermen
3. Aquaculture of native oysters
4. Aquaculture of triploid non-native oysters
5. Introduction of an alternative strain of *C. ariakensis* or an alternative non-native species.
6. Introduction of diploid *C. ariakensis* and termination of native oyster restoration programs.

The purpose of the economic analysis that follows is to summarize what is currently known about the economics of oyster restoration in order to inform the development of an economic impact statement. In section I we look at the direct benefits that might accrue from the proposed actions, that is, the benefits related to the oyster fishery. Section II examines what is known about the potential for aquaculture of *C. ariakensis* compared with performance of *C. virginica*. It is based principally on the field trials that were conducted in Virginia water using triploid *C. ariakensis.* Section III summarizes knowledge about other costs and benefits associated with oyster restoration.

I. Direct Benefits – the Oyster Fishery

The U.S. Oyster Market

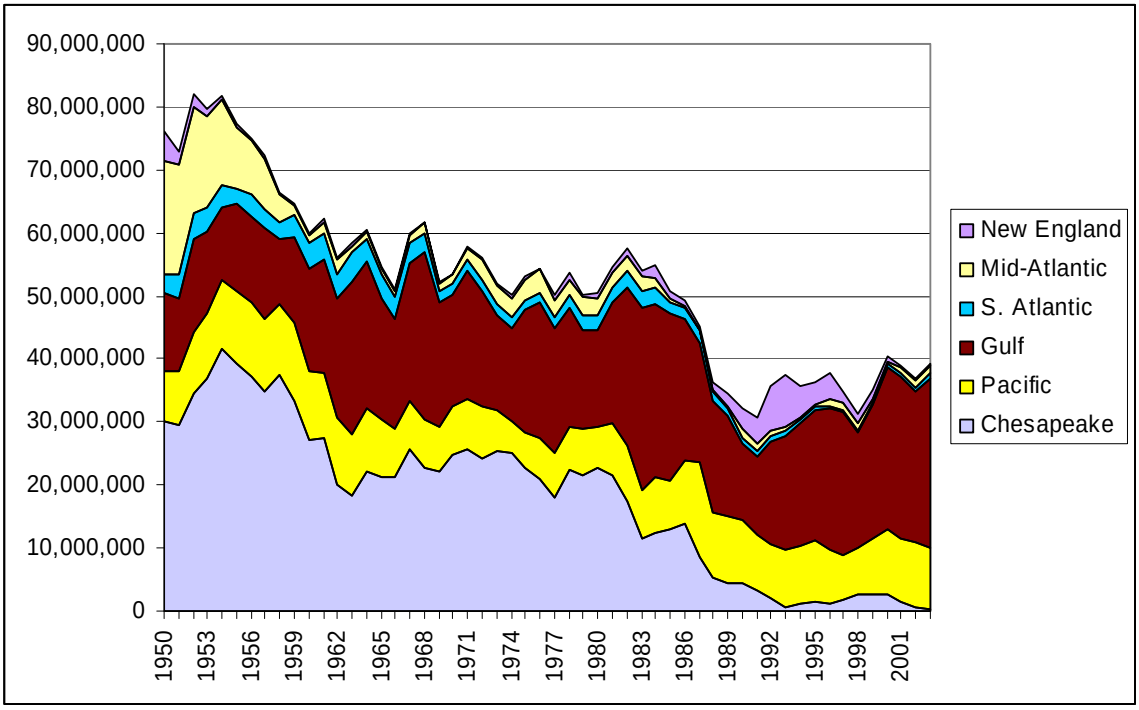
The Committee on Nonnative Oysters in Chesapeake Bay (CNOCB) report for the National Research Council (2004) does an excellent job of reviewing the current and

historical role of the Chesapeake Bay oyster fishery in the U.S. oyster market. We briefly review and update the supply and demand situation here, but refer the reader to that source and Lipton and Kirkley (1994) and Muth et al. (2000) for greater detail.

Production

As can be seen in Figure 1, the U.S. supply of oysters (including both *C. virginica* and *C. gigas*) has fallen by about 50% from around 80 million pounds of meats in the early 1950's to less than 40 million pounds in 2003.[2] Figure 2 uses the same landings data to show the production market share (i.e. volume, not value) provided by each region of the country. Small growth in Gulf and Pacific landings with a declining

Figure 1. U.S. Oyster Landings by Region (C. virginica and C. gigas)



overall harvest translates into large increases in market share so that in 2003, these two regions supplied 94% of the market. There is also an interesting period from 1988-1999

[2] A few other oyster species are harvested in the United States, but the level of landings is inconsequential compared to *C. virginica* and *C. gigas*.

where New England production had a significant market share with significant implications for oyster prices discussed below.

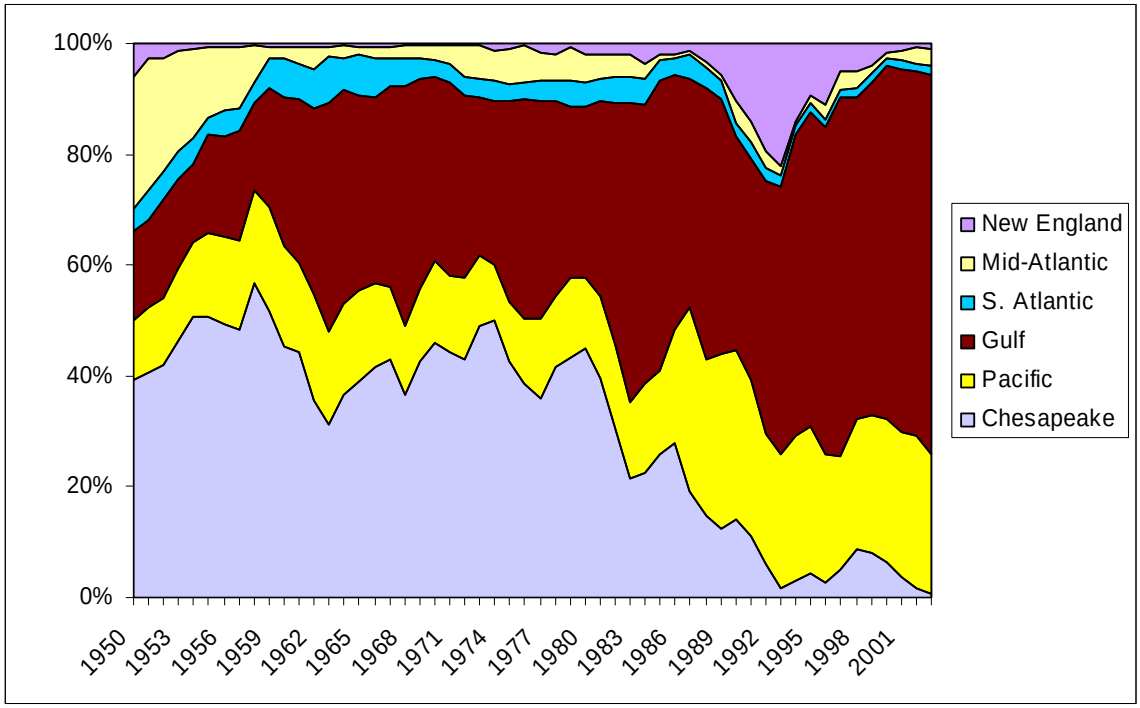


Figure 2. Market share (by volume) of oyster landings by region.

Demand

There are a limited number of studies of oyster demand (see Lin et al. 1991; Berry 1992; Keithly and Diop 2001), and few of recent vintage to provide meaningful information that can be used to predict the consumer response to a revitalized Chesapeake Bay oyster fishery. As can be seen in figure 3, one gets a different picture of price responses in the oyster fishery depending on whether they are looking at nominal or real prices. Nominal prices show a steady increase over the 1950-2003 period. However, when adjusting for inflation, we see a remarkably stable real price of around $3.00 per pound of meats, except for a brief period of unusually high prices from 1987-1992.

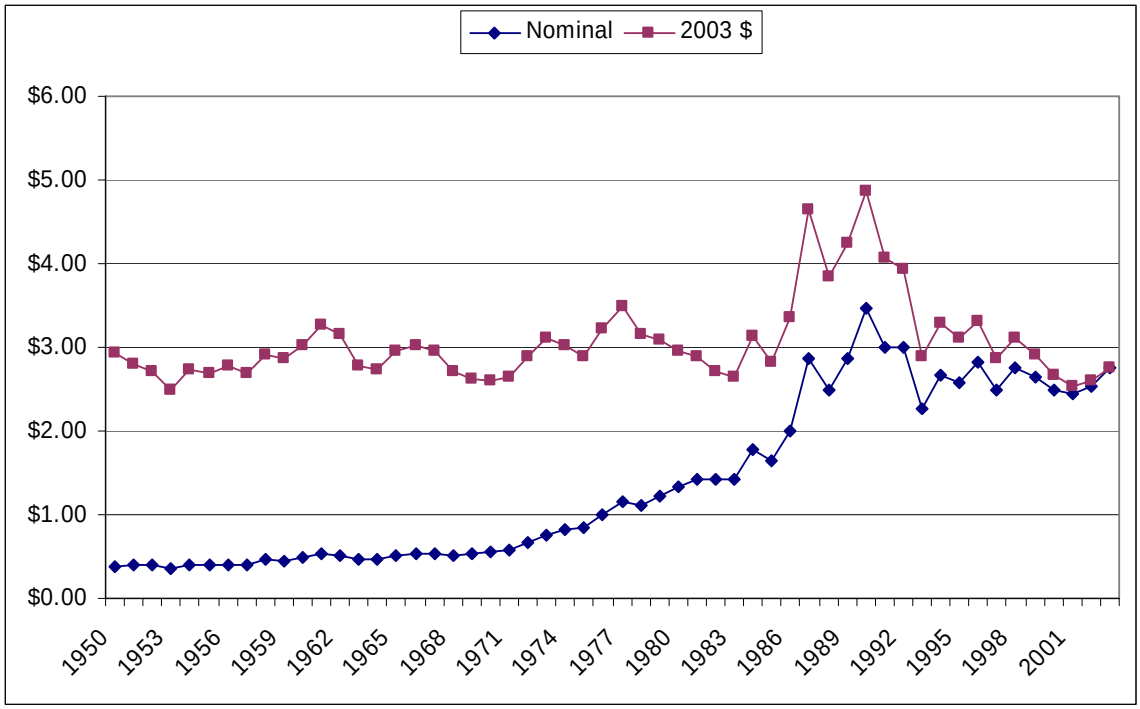


Figure 3. Nominal and current year (2003) U.S. oyster prices.

The increase in aggregate oyster prices from 1987-1992 corresponds with the period of increased production and market share expansion for New England oysters discussed above. New England oysters are mainly targeted for the higher value half shell market. In 1986, New England oyster prices rose 40% over the previous year's level. By 1993, production in New England hit an all time high for the study period of 8.4 million pounds of meats and a 22% share of the market by volume. But by 1993, New England oyster prices had dropped back down to 42% of the 1986 high. As a result, corresponding production fell back down from a peak of over 8 million pounds of meats to less than half a million. As a parallel to ecological sustainability, it appears that these higher oyster prices were not sustainable in the marketplace.

Given the decline in production and the relative unresponsiveness of real price to this decline, there is strong evidence that the demand for oysters in general has declined

significantly over the last fifty years. This is somewhat verified by the study presented in Lipton and Kirkley (1994) and detailed in Berry (1992) that compared oyster consumption in three different food consumption surveys in 1977, 1980, and 1987.[3]

A Model of Inverse Demand for Chesapeake Bay Oysters

Any serious attempt to enhance native fish or shellfish populations for commercial purposes should begin with an examination of the market. Boyce et al. (1993) conducted a study involving the intentional enhancement of a fishery resource. In this study the emphasis was on programs designed to enhance the population of native salmon for commercial purposes. Contrary to expectations, it was determined that the enhancement program actually decreased net social benefits and producer welfare because it facilitated the expansion of commercial production at the same time the supply of farm raised salmon increased in the market. This had the effect of substantially reducing welfare, and in particular, ex-vessel prices and producer welfare for Alaskan salmon.

Estimating the inverse demand for oysters (i.e., price as a function of quantity) can help in making projections about future oyster prices under different scenarios by providing price flexibility estimates. The inverse demand relationship can also be used to estimate changes in consumer surplus, an approximation of the welfare measure used in benefit cost analysis. This is a simple approach and it has limitations caused by failure to consider the entire system of demand and supply equations; the system of equations for each of the different types of oysters; a demand specification inconsistent with traditional

[3] These are the USDA National Food Consumption Surveys of 1980-1981 and 1987-1988 and the 1981 NMFS seafood consumption survey.

economic theory; and extremely limited data.[4] The results, therefore, should be viewed more from a qualitative rather than quantitative perspective.

Our inverse demand model is specified as:

$$P_{CB} = \alpha + \delta D + \beta_{CB} H_{CB} + \beta_{MA} H_{MA} + \beta_{NE} H_{NE} + \beta_{SA} H_{SA} + (\beta_G + \beta_{Vv} D_{Vv}) H_G + \beta_{PC} H_{PC}$$

where P is the ex-vessel price and H is reported landings subscripted by the region: CB = Chesapeake, MA = Mid-Atlantic; NE = New England; SA = South Atlantic; G = Gulf of Mexico and PC = Pacific coast. D corresponds to a dummy variable that takes the value 0 for the 1950-1978 period and 1 for the 1979-2003 period. The dummy variable tries to capture a structural shift in demand as suggested by the Berry (1992) study. There is also a binary dummy variable subscripted Vv, corresponding to the 1991-2003 period when California required warnings regarding consumption of Gulf of Mexico oysters because of the risk of the bacterial pathogen *Vibrio vulnificus*. Keithly and Diop (2001) found that the relationship of Gulf of Mexico oyster prices and Chesapeake prices dramatically shifted as a result of this concern. The subscripted α, δ and β correspond to model parameters to be estimated using ordinary least squares regression. The model is estimated for the 1950-2003 landings and value data available from the National Marine Fisheries Service.

Results from the inverse demand model estimation are given in Table 1. The model has strong predictive capability with an R^2 of 0.79. All model parameter estimates are significantly different from zero at the 95% confidence level except for New England landings which is not significant and the *Vibrio vulnificus* dummy variable which is significant at the 90% level. Chesapeake, Gulf and Mid-Atlantic landings negatively effected Chesapeake price, whereas, South Atlantic and West Coast prices had a positive

[4] See the recent work on inverse demand systems for fish by Park et al. (2004).

and significant effect. The dummy variable parameter was negative and significant indicating a downward structural shift in demand when comparing the pre 1979 period to the 1979-2003 period.

Table 1. Results from Chesapeake Bay inverse demand model.

	Coefficients	*Standard Error*	*t Stat*
Intercept	4.109317	0.478911	8.580544**
Chesapeake	-7.2E-08	1.1E-08	-6.57307**
Mid - Atlantic	-5.4E-08	1.53E-08	-3.50706**
New England	1.98E-09	3.65E-08	0.054304
South Atlantic	3.67E-07	6.94E-08	5.290569**
Gulf of Mexico	-5E-08	1.41E-08	-3.53745**
Pacific Coast	1.52E-07	2.77E-08	5.468255**
Dummy	-0.55648	0.167197	-3.3283**
Vibrio vulnificus	-1.5E-08	8.37E-09	-1.76588*

R^2 = 0.79; d.f. = 45; **significant at 95% confidence level; * 90% confidence level

Price flexibility, the inverse of elasticity, provides an estimate of the ratio of the effect of a percentage change in quantity on the percentage change in price. Calculated at the mean of the data used in the estimation, the price flexibility for Chesapeake Bay oyster production is -0.37. Thus, a 1% increase in Chesapeake Bay production will result in a 0.37% reduction in Chesapeake Bay price. But the current situation is no where near the mean of the data so that using this estimate of flexibility would not be reflective of expected changes from current conditions. The mean Chesapeake Bay catch for the 1950-2003 period is around 17 million pounds, whereas the 2003 harvest was only about 237 thousand pounds. Mean Chesapeake Bay price is $3.53 and the 2003 prices was $4.10.

To simulate the effect on Chesapeake Bay price of a large increase in local production from current levels we calculated a predicted price based on the last five years of data (1999-2003) for each of the areas of harvest. The predicted Chesapeake Bay

price, using Chesapeake Bay harvests equal to the five year average is $3.87 (in 2003 dollars).

To predict the ex-vessel price for Chesapeake Bay oysters under a restored fishery scenario, we convert the target level of 4.9 million bushels to pounds of meat using an assumption of 7 pounds of meats per bushel. Thus, Chesapeake production would be 34.3 million pounds of meats. Keeping all other area's production constant at the 1999-2003 production level, the predicted Chesapeake Bay price resulting from this increase is $1.51, which translates back to an exvessel price of $10.58 per bushel.

Because cost data is not collected for the oyster fishery, it is difficult to comment on the supply (harvest) response to an increasing stock of oysters in the Chesapeake Bay. However, an exvessel price of $10.58 per bushel in 2003 dollars is significantly below any historical low price for oysters and it is reasonable to assume that oystering at this price would not be profitable. Thus, although the restoration of a population of oysters sufficient to sustain harvests at the 4.9 million bushel level may be technically feasible; it is not economically feasible under projected market conditions and we would not expect a viable fishery at that level. It should be noted that this simple price response model does not capture the full suite of market interactions between regions. A more sophisticated multi-market model would need to be developed to reflect how increased supply from the Chesapeake region will affect prices and thus, production from other regions. Here, we have kept other region production constant. Nevertheless, ultimately the market place and consumer demand will determine the total harvest and price of oysters from Chesapeake Bay. The market will tend toward an equilibrium price and

harvest that equates prices across regions, although accounting for quality differences (e.g., perceived safety) and transportation costs.

An Industry-Informed Scenario of a Restored Oyster Fishery

For this section we surveyed the industry to gain insight into industry members' beliefs about the market that will result from a restored oyster fishery in Chesapeake Bay. Surveys were mailed or hand delivered to 16 oyster dealers in Virginia and 12 dealers in Maryland. Responses were received from 10 Virginia oyster dealers and 5 Maryland dealers. The information gained from this survey can be used to understand the beliefs held by key industry leaders regarding the economic consequences of particular actions taken in regard to the oyster fishery:

1) As an informed, but biased, prediction of potential industry status

2) To understand the motivation for the level of industry support for a particular proposed action

3) To compare with the results from the statistical modeling of the oyster market.

The first survey question attempted to determine what oyster dealers felt they would have to pay to oyster growers or watermen for either *C. virginica* or for *C. ariakensis* if Chesapeake Bay production of either oyster was equal to the stated goal (4.9 million bushels). With the limited knowledge they have about the market for *C. ariakensis*, Virginia dealers felt on average that it would sell at a premium relative to *C. virginica*; whereas, Maryland dealers felt that the native oyster would sell at a premium. The Virginia results are skewed by two responses (small sample size due to the small size of the extant industry is a problem for this entire part of the analysis) where the dealers guessed that C. *ariakensis* would have a huge premium over *C. virginica*. There were

seven out of ten Virginia dealers who felt that they would pay the same or a lower price for *C. ariakensis* than they would for *C. virginica*, and all the Maryland dealers felt the *C. ariakensis* price would be the same or lower than *C. virginica*.

Responses to the first question also provided an indication of industry beliefs regarding price responsiveness to the increased Chesapeake Bay production at the harvester level. For dealers in both states, they felt that oyster prices to harvesters would decline about 22% from current levels of $24 per bushel to $18.80 a bushel for a restored *C. virginica* fishery. The median response for most likely price for both species was $18.00 a bushel.

As evident from for the earlier analysis of oyster prices, the percentage of product that goes to the halfshell market will have a significant effect on industry revenues. We asked the dealers participating in the survey what they thought was the current size of the halfshell market for oysters harvested from Chesapeake Bay or for shellstock imported into the Bay region for distribution. There was a wide variation by dealer in response to this question, but the median response was that 35% of the current Chesapeake Bay oyster market is for halfshell.

So what does the industry think a restored oyster fishery market would look like in terms of halfshell versus shucked product? The median response was that a *C. virginica* fishery restored to historical harvest levels would consist of a 30% halfshell market. On the other hand, they thought a *C. ariakensis* based fishery, would be about 22% halfshell.

We polled the industry on how their output prices would change as a result of a restored fishery based on either *C. virginica* or *C. ariakensis*. We got responses for

prices for shucked and halfshell oysters and whether they were "wild" or "cultured". A summary of the median responses is given in Table 2.

Table 2. Median responses of oyster industry experts for wholesale oyster prices resulting from a restored fishery.

	C. virginica	*C. ariakensis*
Shucked, price per gallon	$38.00	$38.00
Wild, price per hundred	$20.00	$18.00
Cultured, price per hundred	$20.00	$17.50

Industry expectations are that their will be no difference in price between the species for the shucked product, but *C. virginica* will have approximately a $2.00-$2.50 premium per hundred count over the *C. ariakensis* price regardless of whether the product is harvested from the wild or cultured. Compared to recent Fulton Fish Market wholesale prices, the $38.00 price per gallon of shucked oysters represents a 21% decline in price for selects. Halfshell market prices are dependent on where the product is from. No recent prices for Chesapeake halfshell oysters were available, but the $17.50 - $20.00 price range is below the price of $40.00 per hundred count for Connecticut cultured oysters and above the $14.50 price for Gulf of Mexico wild oysters.

We also asked the industry to provide their estimates on how their profitability might vary depending on the species and product form. While not equal to economic rent and the appropriate welfare measure that we seek in a benefit cost analysis of the proposed actions, the responses do provide a relative indicator of the industry's perception of what the potential benefits may be. The results are given in Table 3.

Table 3. Industry expectations of profits based on product form.

	C. virginica	*C. ariakensis*
Shucked (wild), profit per gallon	$6.50	$8.00
Shucked (cultured), profit per gallon	$6.50	$7.00
Halfshell (wild), profit per hundred	$5.00	$5.00
Halfshell (cultured), profit per hundred	$5.00	$5.00

From the above, we can aggregate the data to develop a scenario of what industry experts feel a restored Chesapeake Bay fishery might look like. We are assuming that the industry will reach a state where it is harvesting 4.9 million bushels a year from the Chesapeake Bay. The industry believes that regardless of the species used, this will translate into an ex-vessel value or gross watermen/grower income of $88.2 million. Note that this is 25% lower than one would estimate using 2003 prices, so there is some acknowledgement in the industry responses that an increase in supply of oysters will lead to some decrease in price.

According to the survey participants, the difference between an industry based on *C. virginica* versus *C. ariakensis* starts to manifest itself in the difference regarding halfshell versus shucked product, with 30% and 22% going to the halfshell market for each species, respectively. The implication is that there will be a different value and profit at the wholesale level. To calculate the revenues and expected profits, we assume production of 1 gallon of oysters from a bushel and 225 oysters to a bushel. Thus *C. virignica*, under this scenario yields at the wholesale level $130 million worth of shucked product and $66 million worth of shell oysters for halfshell. The figures are slightly different for C. ariakensis with $145 million for the shucked market and $43 million for the halfshell market. While revenues are slightly higher for *C. virginica*, profits are higher for C. ariakensis with profits of $40 million compared to $37 million.

In summary, given limited direct knowledge regarding C. ariakensis and the large amount of uncertainty in projecting changes due to large scale shifts in the oyster market, industry experts see little difference in an industry based around *C. ariakensis* compared with *C. virginica*. This industry analysis does not address the time frame or the cost

necessary to create this new market level. Watermen or grower incomes and processing industry profits reported here are not welfare benefits that can be used in a benefit/cost analysis of the proposed actions.

Combining the Industry Scenario With the Inverse Demand Analysis

The industry scenario above appears reasonable in foreseeing a 22% decline in exvessel oyster prices with a restored oyster fishery, but seems overly optimistic when compared with the inverse demand analysis which predicted a 61% price decline. One possibility is that the industry has realistic expectations about what are sustainable exvessel prices relative to the upstream market they face and their costs of processing and handling oysters.

A reasonable approach would be to take the industry price predictions and then determine what size fishery would result in those prices. To do this we simply used our inverse demand estimating equation and solved for Chesapeake Bay landing as a function of predicted price and the harvest in all other regions at the average for the 1999-2003 period. Thus, the $18.80 price per bushel for either species would translate into an exvessel price of $2.69 per pound of meats.[5] Solving for the quantity that results in this price, yields an estimate of Chesapeake Bay landings of about 18 million pounds of meats or 2.57 million bushels. At this level, Chesapeake Bay watermen and producers gross income would be $48.4 million, significantly less than the industry prediction of $88.2 million, but significantly more than the 2003 income of under $1 million. Table 4

[5] This is one area where there may be a significant difference in impacts between the two species if *C. ariakensis* has a higher meat yield per bushel than *C. virginica*. See the discussion on Virginia field trials for more on this topic.

summarizes the scenario, carrying forward the analysis to the next market level, based on the industry scenario of wholesale prices.

Table 4. A scenario for a sustainable oyster industry in Chesapeake Bay.

Species	Harvest (million bushels)	Value ($ million)	Shucked Value ($ million)	Halfshell Value ($ million)
C. virginica	2.57	$48.4	$68.2	$34.6
C. ariakensis	2.57	$48.4	$76.1	$22.6

Welfare Implications of the Commercial Fishery

The exvessel and wholesale values of the oyster fishery calculated above are gross revenues and should not be interpreted as indicators of the net benefits from a restored oyster fishery in Chesapeake Bay. The appropriate welfare measure attempts to determine income or revenues net of all opportunity costs. For example, watermen income increases by $48.4 million, but oyster harvesting is not a costless activity, so costs such as fuel, gear and labor must be considered. Lack of cost data makes it difficult to calculate these expenses. Even with cost data an issue arises related to the opportunity cost of watermen's labor. Labor costs must consider the opportunity cost of labor, that is, what the watermen could have earned if they had not spent that time fishing. It is conceivable that some watermen have greater earning potential when they are not on the water, but forgo higher income because they prefer working the water to other forms of employment (Anderson 1980). An additional concern is the effect of the common pool nature of much of the fishery (i.e., for the part of the fishery that does not rely on leased bottom). In this case, the classic fishery problem resulting from attenuation of property rights may lead to economic overfishing even when regulations prevent biological overfishing. Economic overfishing is the dissipation of net economic benefits (resource

rents) that the fishery would otherwise produce (Gordon 1954). The result is that the $48.4 million income to watermen is an estimate of the upper bound of net benefits that must be adjusted downward to account for fishing costs and the opportunity cost of watermen labor.

The economic benefits to other market levels such as the wholesalers must be adjusted in a similar manner. The estimates of $102.8 million worth of wholesale product for *C. virginica* or $98.7 million for *C. ariakensis* are not welfare measures. First of all, these numbers double count the exvessel value, that is, the price of a wholesale oyster includes the price paid to the watermen for the oyster plus the expense of adding value by processing, packaging and transporting the product, plus the profit to the processor. Only that increase in profit to the processor is a potential welfare gain from restoration of the oyster resource, and even of that, only the profit that they earn from oysters over and above they might earn from investing in processing some other product would count. For example, if the processors earn greater profits because they no longer have to transport oysters from other regions, it would be that increased profit that would be the measure of the welfare gain, not the total value of their processing output. Even then, over time, market factors might shift to eliminate these benefits and the welfare gains to Chesapeake Bay processors might lead to welfare losses to Gulf of Mexico or other processors from outside the region.

Oyster consumers will unambiguously benefit from a restored Chesapeake Bay oyster fishery. They will have available to them, a greater quantity of oysters at a lower price. We can approximate this consumer surplus benefit from our estimated inverse demand if we assume that this demand curve represents a general equilibrium result so

that all the markets adjust to the increase in the availability of Chesapeake Bay oysters. Under that scenario, because exvessel demand is ultimately derived from consumer demand we can measure the consumer surplus with the single market demand curve (see Just et al. 2004). Using this approach, we find the gain in consumer surplus from an increase in Chesapeake Bay harvest of 2.57 million bushels of oysters is $11.6 million, annually.

Table 5. A summary of welfare gains (in million, 2003 dollars) from an increase in Chesapeake Bay oyster harvest to 2.57 million bushels per year.

	Gross value	Net Benefit	Comments
Harvesters/producers	$48.4	?	Depends on fishing costs and earning power of watermen in alternative employment.
Processors/Packers	$98.7-$102.8	?	Depends on costs of oysters, costs of creating value-added and profits relative to alternative investments.
Consumers	?	$11.6	Depends on assumptions regarding nature of inverse demand curve used to estimate.

Additional Issues

In addition to all the caveats mentioned above, there are a number of other issues that need to be considered related to the benefits of a restored commercial oyster fishery in Chesapeake Bay. For example, the above analysis does not reveal a large distinction in benefits between a fishery based on *C. virginica* versus a *C. ariakensis* fishery. The only major distinction taken into account above is due to a slight difference in industry beliefs about the size of the halfshell market for each species. If there is a major difference in demand for the two products, particularly if there are true taste and quality differences, this could have an impact on the results. Other factors that might impact results include differentials in the costs of harvesting and product yields.

Another important factor to considering when weighing the potential benefits of a restored fishery is the time frame over which the benefits might accrue. It will take several years to restore oyster resources in Chesapeake Bay to a level that would support the level of fishery we anticipate. Since much of the expense of the proposed alternatives will occur early in the process, this timing will have an impact on calculation of benefits. Lipton et al. (1992) discuss the role of the timing of benefits and costs related to the potential introduction of *C. gigas* into Chesapeake Bay. Since the data suggests that there might not be a significant difference in commercial fishery benefits, once the industry has been fully restored, regardless of the alternative chosen, the greatest difference among alternatives in this regard may be the timing of restoration. Thus, every thing else being equal, from the viewpoint of the commercial fishing industry and oyster consumers, the alternative that restores oysters the fastest will have the highest net benefits. As will be discussed later, not everything else is equal, particularly in relation to risks associated with the introduction of a non-native oyster.

II. Virginia Seafood Council Triploid Ariakensis Trials

Background

As part of it on-going competitive process the Virginia Fishery Resource Grant Program (VFRGP) funded a two-year project to provide overall project management for the Virginia Seafood Council's non-native oyster pilot grow-out study. The funding provided for a professional science manager to assist the VSC in conducting the research and providing liaison between industry and the various entities interested in the research

implementation. The position was funded for the two year grow-out experiment and information developed as part of this demonstration project is summarized herein.

The cooperative Virginia Seafood Council (VSC) Virginia Institute of Marine Science (VIMS) industry-based field trial was designed to address two main objectives. The first was to determine if growing triploid *C. ariakensis* in Virginia's Chesapeake Bay and the seaside of the Eastern Shore was economically feasible for both large and small companies. The second was to produce some initial market assessment of triploid *C. ariakensis*.

In order to determine economic feasibility each participant agreed to track their input costs including fuel, labor, supplies, etc. This information is meaningful when related to income generated from oysters sold into both half-shell and shucking markets. Another objective of this project involved the evaluation of differing grow-out methods. Several types of gear were used, which enabled some general comparison among grow-out methods and growth of *C. ariakensis* in various environments.

Methodologies Employed

Grow-out methods used in the VSC field trials included: traditional "Taylor Floats," off-bottom cages, long-line systems (bags on bottom), re-bar racks, land-based crab shedding tanks, and an experimental raft system. Some of these grow-out systems were part of separate VFRGP project grants, but were also components of the VSC field trials. For example, "Shores and Ruark Seafood" (Urbanna, VA) grew the triploid *C. ariakensis* in an experimental long-line system that was approved for development by a VFRGP grant. In addition, "Shore Seafood" (Saxis, VA) employed an experimental raft

system during the fall and winter to grow-out triploid *C. ariakensis* that was also part of a separate VFRGP grant.[6]

Generally the methods included:

- *Off-bottom cages* – ADPI/OBC bags constructed of rigid polyethylene with varying mesh and bag sizes were the primary method of containment. The mesh size used depends on the size of the oyster to be contained. The bags are then secured inside a 4' x 4' cage, with feet, constructed of metal with a total height of not more than 12" off the bottom. The cages can also be anchored using hooks made of iron reinforcing bar.

- *Bags on rack* – Racks consist of $^{3}/_{8}$" to $^{1}/_{2}$" reinforcing bar welded to produce vertical sides of approximately 18" and a length of 10' to 20'. These racks were driven into the bottom in rows, end to end, with working aisles of approximately 3' to 4' between rows. The racks have an off bottom height of not more than 12". ADPI/OBC bags were strapped side by side onto the rack using wire ties, nylon self-locking cables, or rubber bungee cords.

- *Long-lined bags on bottom* – ADPI/OBC bags were secured together by a long line and anchored to the bottom. The number of bags per line varied according to site. Hard bottom sites were typically chosen to ensure that bags did not become silted over.

[6]The use of this system had to be temporarily discontinued for summer 2004 due to the close proximity of units (stacks of tray inserts in the raft) and the possibility of reproduction imposed by the conditions set forth in the VSC's Army Corps of Engineers permit extension document. A complete description of the VSC FRGP project sites and methods may be found at <http://www.vims.edu/vsc/sites.html>

- *Floats* – "Taylor Floats" typically were used, consisting of a 4 inch PVC rectangular ring with a 1 inch coated hard wire basket secured using several tie wraps. Oysters contained within ADPI/OBC bags are then placed inside the floats.

- *Crab shedding tanks* – An existing land-based flow through system was used to further nursery seed from the deployment size of 20mm up to approximately 40mm.The rectangular wooden tanks, which typically house soft crabs before they molt, are approximately 36 inch x 60 inch x 12 inch with a central drain that was screened to prevent escapement. Oysters contained within ADPI/OBC bags were placed inside the tank.

A significant aspect of this project involved diverse marketing strategies employed by each grower. For example, some of the larger shucking facilities processed oysters on site and sold oysters via their established retail and food service customers. Alternatively, smaller aquaculture farms sold primarily "shell stock" oysters to retail, restaurant and food service institutions, and/or directly to the consuming public. A few aquaculture farms also sold shell stock oysters to larger shucking facilities to determine meat yields.

In conjunction with the VSC industry field trial, VIMS implemented a companion study entitled "Biosecurity and Comparative Field Trials of Triploid *C. ariakensis* with *virginica*" which enabled scientists, industry members, and state and federal agencies to collect and have access to related biological and ecological data.[7] (Hudson) The

[7] The VIMS biosecurity project is updated at http://www.vims.edu/vsc/

biological (growth and mortality) data are summarized here in conjunction with the economic information gathered from the growers.

As a result of damage sustained during Hurricane Isabel in September 2003, two participants were unable to participate in the VSC project. Therefore, only eight field sites housed oysters. Nine growers participated, however, as two growers occupied one field site and shared the 100,000 oysters.

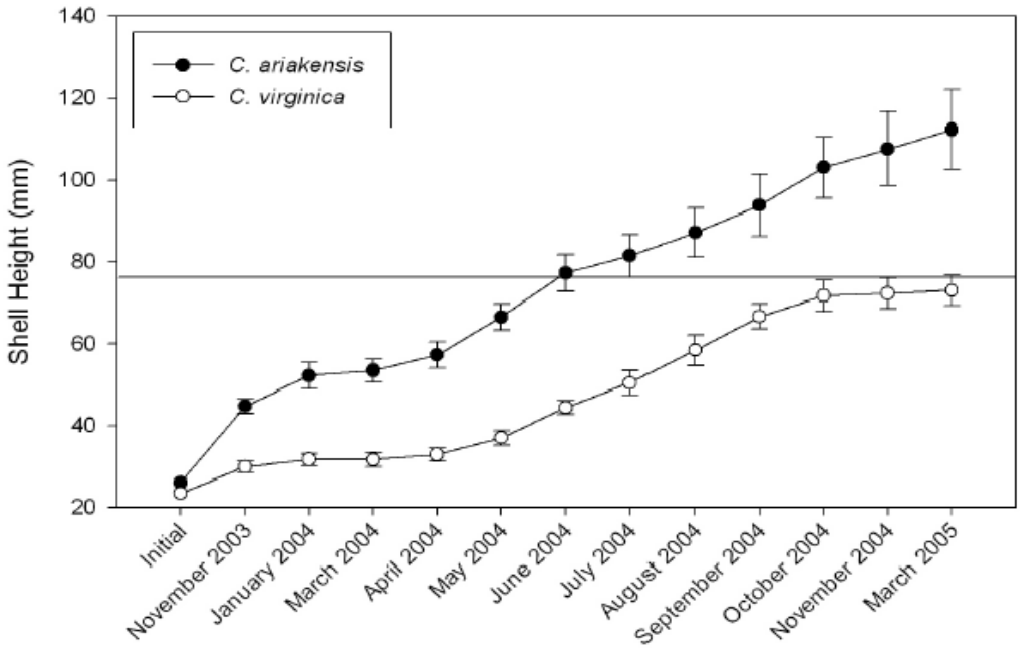
Results

C. ariakensis deployed at all sites during October, 2003 grew very well and generally obtained market size by the spring of 2004. Despite cooler water temperatures and potentially lower food availability, *C. ariakensis* grew quickly once acclimated to site specific environmental conditions. Triploid *C. virignica*, deployed concurrently, did not immediately grow like *C. ariakensis*. In fact, *C. virginica* generally grew very little from deployment until mid-spring 2004. On average across all sites *C*. ariakensis grew 38% faster (range 15%-65%) than *C. viriginica*. and suffered significantly less mortality (7% relative to 20% respectively)[8].

Some *C. ariakensis* were lost due to winter icing at the Saxis, Burgess, Kinsale, Urbanna, Yorktown (Crewe) and Chincoteague sites. Although *C. virginica* experienced little winter icing mortality, growers reported that *C. ariakensis* appeared to be more sensitive to severe cold temperatures if exposed.

[8] The mortality comparison is derived from the VIMS biosecurity project. C.ariakensis mortality within the commercial trials was reported to be 10%, there was no comparison with C.virginica as part of the VSC trial.

Figure 4. Comparison of average shell height growth for all VSC site for C. ariakensis and C. virginica. Error bars represent one standard error. (Hudson)



Within 7 months of field planting (Spring 2004) *C. ariakensis* were beginning to reach market size (76 mm.). Growers at higher and moderate salinity sites were marketing hundreds to thousands of *C. ariakensis* primarily for the half-shall market. *C. virginica* was growing but not nearly at the rate of *C. ariakensis* , nor were the *C. virginica* of marketable size. As depicted above, on average, C. ariakensis reached. market size within 9 months of deployment. In contrast, on average the *C.virginica* still had not reached market size after 18 months of deployment.

Given the delay in deployment and general disruption from Hurricane Isabel, a new federal permit extension was issued by USACOE on July 1st, 2004 which included nine additional grow-out conditions. This is noteworthy for this presentation as one condition required the growers to prematurely harvest oysters and/or further reduce the density of oysters per unit (i.e. cage, bag, or float). It is believed that this measure

directly impacted the results of the industry trials. This requirement imposed inefficiencies in terms of the grow-out economics as well as resulting product marketability. The new permit condition required the growers to purchase more gear while expending more labor in culturing the *C. ariakensis*. Additionally the condition put the growers in a position where they had to harvest smaller ("standard") oysters and disadvantageously sell the "culls" on the market at a time of the season when oyster product demand is comparatively low.[9] In summary, these additional constraints increased variable costs while also reducing per unit value.

Grow-out Costs

As depicted in Table 1, costs of production varied significantly from site to site . Some growers, (Sopko-Hudgins, Ruark-Urbana, and Crewe-Yorktown) used existing materials and supplies and primarily older cages to contain oysters. Other growers (Mason-Chincoteague, Bevans-Kinsale, and Leggett-Yorktown) chose to purchase new coated wire cages, which totalled from $1,000 to $4,000 in initial investment costs. In general, minimal initial investments were made in labor, fuel, and other miscellaneous aquaculture costs. Per-unit labor appears to be consistent with typical aquaculture techniques, although as noted above, increased biosecurity and required harvest and splitting of oysters as part of permit extension conditions increased these per-unit labor costs.

When using an imputed labor cost of $10.00/ hour the average wage bill for all trials was $4,095, or 37% of the variable costs of grow-out. The average annual cost of supplies was $5,740, or 52% of grow-out expenses. These supply costs vary

[9] The greatest demand for oysters occurs traditionally around Thanksgiving, Christmas and Lent.

considerably both in amount and type between the different grow-out methods outlined above. The treatment of most of these inputs as annual expenses (including such things as wire, cages, floats, bags, cables, etc.) likely understates the annual grow-out profit estimated here, as much of these materials may be re-used for more than one grow-out cycle. The decision to expense these costs here was made because of the variability of such costs and the fact that typically such materials may be expensed under Internal Revenue Service guidelines. Assigning a standard useful life to fabricated gear such as floats, cages, etc. would be arbitrary given their custom made nature. With the exception of the oyster culture raft (Saxis), which is depreciated over an estimated useful life of 7 years, other gear and equipment are expensed.

Table 6. Virginia Seafood Council Oyster Grow-out Average Cost and Returns 2003-2005

Cost Category	Average (Range)
Labor Cost	$4,095 ($2,580-$5,280)
Supplies	$5,740 ($700-$10,484)
Fuel	$223 ($50-360)
Seed	$879 ($773-1,000)
Electricity	$12.50 (0- $100)
Total Cost	$10,951 ($4,499-$16,035)
Oysters Sold	87,985 (77,320-99,998)
Total[10] Revenue	$20,999 ($18,557-$23,000)
Balance	$10,049 ($2,801-$17,677)

Grow-out Returns

Within 8 months of deployment, initial market information was gathered. From December 2003 through June 2004, growers reported approximately 204,940 triploid *C. ariakensis* had been sold to both the half-shell and shucked markets. Also, from July through August 2004 another 78,950 *C. ariakensis* were marketed in both sectors. Product was distributed to both novice and experienced oyster consumers, and large and small half-shell and shucked markets.

Overall, at the completion of the trials in March 2005 growers had marketed 703,878 *C. ariakensis* oysters reportedly worth $167,998.10. Oysters were sold both as shucked product and half-shell. The overall average sales price was $.24/oyster. The gross revenues reflected here include the shucked sales. When adjusting for the cost (value added) of the shucking operation the average revenue from oysters going into

[10] Oysters were sold both as shucked product and half shell. The gross revenues reflected here include the shucked sales. Overall average sales price was $.24/oyster. When adjusting for the cost (value added) of the shucking operation the average revenue from oysters going into shucking should be reduced by $.03-$.04 per oyster to an estimated $.20-$.21/ per oyster based upon the average price estimated by industry of $42-$44 per gallon.

shucking should be reduced by $.03-$.04 per oyster yielding an estimated $.20-$.21 per oyster.

Table 7. Combined Virginia Seafood Council Oyster Grow-Out Cost and Returns 2003-2005

	Kinsale	Burgess	Urbanna	Hudgins	Yorktown (Crewe)	Yorktown (Leggett)	Saxis	Accomack	Chincoteague
Labor Hours	516	528	344	258	149	223	445	483	330
Labor Cost	$5,160.00	$5,280.00	$3,440.00	$2,580.00	$1,490.00	$2,230.00	$4,450.00	$4,830.00	$3,300.00
Supplies	$5,553.00	$9,441.00	$9,516.00	$700.00	$202.00	$4,783.00	$10,484.00[11]	$2,342.00	$2,904.00
Fuel	$200.00	$275.00	$360.00	$295.00	$150.00	$175.00	$90.00	$190.00	$50.00
Seed[12]	$885.20	$939.00	$773.20	$924.00	$404.90	$499.98	$775.00	$837.58	$999.98
Electricity	$0.00	$100.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Total Cost	$11,798.20	$16,035.00	$14,089.20	$4,499.00	$2,246.90	$7,687.98	$15,799.00	$8,199.58	$7,253.98
Oysters Sold	88,520.00	93,900.00	\77,320.00	92,400.00	40,490.00	49,998.00	77,500.00	83,752.00	99,998.00
Total [13] Revenue	$21,244.80	$22,536.00	$18,556.80	$22,176.00	$10,122.50	$12,499.50	$18,600.00	$19,262.96	$22,999.54
Balance	$9,446.60	$6,501.00	$4,467.60	$17,677.00	$7,875.60	$4,811.52	$2,801.00	$11,063.44	$15,745.56

[11] The raft culture system capital cost ($6,500) is amortized (5%) over a 7 year expected useful life rather than expensed as other grower supplies.

[12] Each grower (8) paid $1000 for the triploid technology and nothing for the actual seedFor the sake of budgeting $0.01 per oyster is a reasonable proxy. Personal Communication, S.K. Allan, ABC. April 20, 2005.

[13] Oysters were sold both as shucked product and ½ shell. The gross revenues reflected here include the shucked sales. Overall average sales price was $.24/oyster. When adjusting for the cost (value added) of the shucking operation the average revenue from oysters going into shucking should be reduced by $.03-$.04 per oyster an estimated $.20-$.21/ each based upon the average price estimated by industry of $42-$44 per gallon.

Discussion

This pilot project has demonstrated that culturing triploid *C. ariakensis* is feasible in Virginia waters even under relatively rigid grow-out protocols. Initial investments ranged from a few hundred to a few thousand dollars depending on the purchase of new or used grow-out systems. One challenge for industry arises due to the fact that *C. ariakensis* have proven to grow quite fast, relative to the native oyster. This creates a situation where the *C. ariakensis* need to be tended on a more frequent basis than the native oyster. Otherwise, crowding and smothering may occur which ultimately leads to mortality.[14] Using existing aquaculture techniques, it appears as a result of this project, that a relatively small investment of $1,500 to $10,000 when combined with skilled shellfish culture management can realistically grow-out 100,000 triploid *C. ariakensis* with gross returns ranging from $18,600 to $23,000.[15]

Based upon these pilot demonstration projects, it is evident that a profit can be made with triploid *C. ariakensis* aquaculture. Even though initial investments in more elaborate systems can be high, such capital costs would be amortized over a period of time and the grow-out returns realized for several year classes of oysters. Further the relatively short period from field planting to market grow-out provides enhanced cash flow. This suggests that *C.ariakensis* is an attractive oyster for such small scale culture relative to other oyster varieties. Accelerated growth is additionally attractive to growers who, faced with decades of increasing oyster mortality due to diseases, value the reduced risk associated with a shorter grow-out period. Indeed, a positive grow-out cash flow in

[14] Given the rapid growth industry is considering relatively low stocking rates per bad to accommodate more rapid growth. This is expected to reduce labor costs and further minimize bio-security questions.
[15] The average price received for all sales of "half shell" C. ariakensis was $.215 each. The average price for shucked C. arikensis was $42-44 per gallon.

one to two years of operation is unprecedented in Virginia's molluscan shellfish aquaculture industry.

Preliminarily market returns indicate that this oyster is an exceptional shucking product. Growers were encouraged with meat yields as high as 11-14 pints/bushel compared to an expected range of 7-8 pints/ bushel for C. *virginica*. Furthermore industry's initial response to shucking *C. ariakensis* was positive. Operators of shucking houses grade oysters according to the number of pints that can be produced from a bushel of culled oysters. The relative quality of oysters is primarily determined by this yield. The table below summarizes shucking yield relative to industry evaluation of shucking quality.

Table 8. Oyster Yield Per Bushel and Industry Grade

4 Pints	Poor
5 Pints	Below Average
6 Pints	Average
7 Pints	Good
8 pints	Very Good
9-10 Pints	Exceptional

These results confirm that *C. ariakensis* presents the potential for an exceptionally profitable shucked product. Processors find it advantageous to buy oysters which yield the most meats per bushel reducing the volume of shell stock to be handled. This is reflected in the fact that, traditionally, processors pay premium prices for higher grade (yield) oysters. Additionally, shucking houses processing *C. ariakensis* reported that the oyster is easily opened and shuckers could readily remove the meat product from the shell stock.

In contrast, the *C. ariakensis* half shell product was reportedly not as well accepted, relative to *C. virginica*, as the shucking product. A relatively short shelf life seems predominant regardless of salinity. Oysters that were kept dry and in ambient air temperatures often lasted only one to two days. Oysters kept in cool storage (~ 45-50° F) survived for up to 3-5 days, although those oysters kept in cold storage (32°F) were subject to a slightly earlier mortality. Growers observed during in this initial trial that grow-out method may have an effect on shelf life. For example, oysters that have remained inter-tidally since deployment, even through the cold winter months, may have had a longer shelf life.

As reported, several grow-out methods were employed during the VSC demonstration project. Interesting differences and experiences were observed. For example, long-line bags on bottom (Urbana) seem to expedite the growth of *C. ariakensis*. This may be due in part to the native habitat of *C. ariakensis*, which can be muddy bottom. In addition, crab-shedding tanks, which are bio-secure, appear to be an effective intermediate step in culturing *C. ariakensis* (Burgess). Prior to field deployment, tanks can be used to increase shell height, possibly avoiding predation from crabs and/or skates. Industry members learned that oysters should be removed from tanks prior to freezing conditions; otherwise, mortality may become a problem. Floats encourage oysters to grow very quickly as they take advantage of surface phytoplankton blooms. Oysters in floats are also protected during freezing temperatures, as the basket of the float sits a foot or more below the water's surface. (VSC)

Discussion of Near-term Impacts

There are estimated to be approximately one to two dozen commercial oyster farms in Virginia, with annual production capability at around 250,000 oysters per farm.[16] Most animals are sold to local niche markets, including restaurants, grocery stores, and farmers markets, in addition to some online sales. While all growers are interested in increasing production, small- scale producer markets may not support significant increase. However, smaller scale aquaculture farms producing 300-900 bushels/year are considered realistic scenarios and a profitable scale of operation based upon current culture techniques. It appears that the culture of *C. ariakensis* represents a potential for expansion of this current capability as demonstrated in the VSC field trials.

The potential for large-scale oyster planting, such as traditionally practiced in Virginia, appears to be promising with the allowance of extensive culture of *C. ariakensis*. The current interest in remote setting and continued culture of triploid animals suggests a real development opportunity may be furthered with the use of non-native oysters. It is believed that current hatchery potential for triploid oysters is fixed; however, continued success in triploid grow-out would foster additional industry investment in existing commercial hatcheries. To summarize, based upon these initial grow-out trials, both on bottom culture of shucking products and expansion of aquacultured half-shell production may be economically feasible.

To put this investigation into the current economic context of Virginia's oyster industry, it is important to compare the VSC limited pilot trials (which produced gross

[16] Currently Virginia does not specifically license or permit shellfish aquaculture operations, therefore an exact accounting of the firms involved in shellfish aquaculture is not available. The estimates here are based upon informal market assessments conducted as part of the Virginia Fishery Resource Grants Program.

grower revenues of $168,000) with the entire traditional oyster fishery in Virginia. That industry reportedly harvested 23,804 lbs. of oyster meats valued at $100,972 during 2004.

Clearly, the prospect for significant enhancement of the oyster producing sector has been demonstrated with these trial introductions. The sales of the *C. ariakensis* contributed a total economic impact of $310,000 to the Commonwealth. When the production details of C. ariakensis are combined with the existing aquaculture capacity represented by small, yet knowledgeable, growers, the potential for immediate expansion seems clear. With implementation of *C. ariakensis* grow-out by the 24 small-scale oyster aqua-culturists in Virginia, a first year harvest of approximately 4 million oysters could be easily expected. The "farm gate" value based upon recent prices would approximate $1.0 million the first year, with a total economic impact to the state of Virginia of $1.84 million.

Detailed Production and Grow-out Results by Site

As with *C. Virginica*, *C. ariakensis* growth varies considerably from one region to another (and even from one part to another on the same ground) and from year to year on the same grounds.

Table 9. High Salinity VSC Sites Grow-Out Variable Cost and Returns 2003-2005			
Costs and Returns	Accomack	Chincoteague	Average
Labor Hours	483	330	406.50
Labor Cost	$4,830.00	$3,300.00	$4,065.00
Supplies	$2,342.00	$2,904.00	$2,623.00
Fuel	$190.00	$50.00	$120.00
Seed	$837.52	$999.98	$918.75
Electricity	$0.00	$0.00	0
Total Cost	$8,199.52	$7,253.98	$7,726.75
Oysters Sold	83,752	99,998	91,875
Total Revenue	$19,262.96	$22,999.54	$21,131.25
Balance	$11,063.44	$15,745.56	$13,404.50

Figure 5. Comparison of growth by VSC site for C. ariakensis and C. virginica at individual sites within the high salinity regime. Values represent shell height growth averaged at individual site. Error bars represent one standard error. (Hudson)

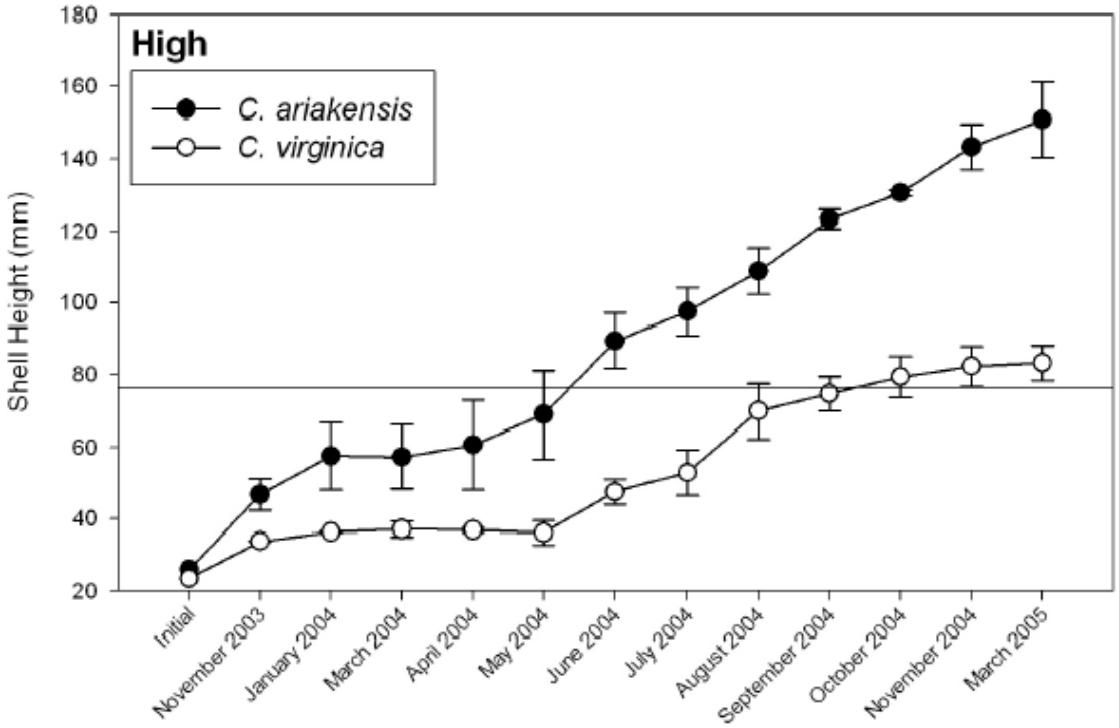


Table 10. Medium Salinity VSC Sites Grow-out Variable Cost and Returns, 2003-2005

Costs and Returns	Hudgins	Saxis	Yorktown Combined
Labor Hours	258	445	372
Labor Cost	$2,580.00	$4,450.00	$3,720.00
Supplies	$700.00	$10,484.00	$4,985.00
fuel	$295.00	$90.00	$325.00
seed	$924.00	$775.00	$904.88
electricity	$0.00	$0.00	$0.00
Total Cost	$4,499.00	$15,799.00	$9,934.88
Oysters Sold	92,400	77,500	90,488
Total Revenue	$22,176.00	$18,600.00	$22,622.00
Balance	$17,677.00	$2,801.00	$12,687.12

Figure 6. Comparison of growth for C. ariakensis and C. virginica in a medium salinity regime. Values represent shell height growth averaged over all sites with similar salinities. Error bars represent one standard error. (Hudson)

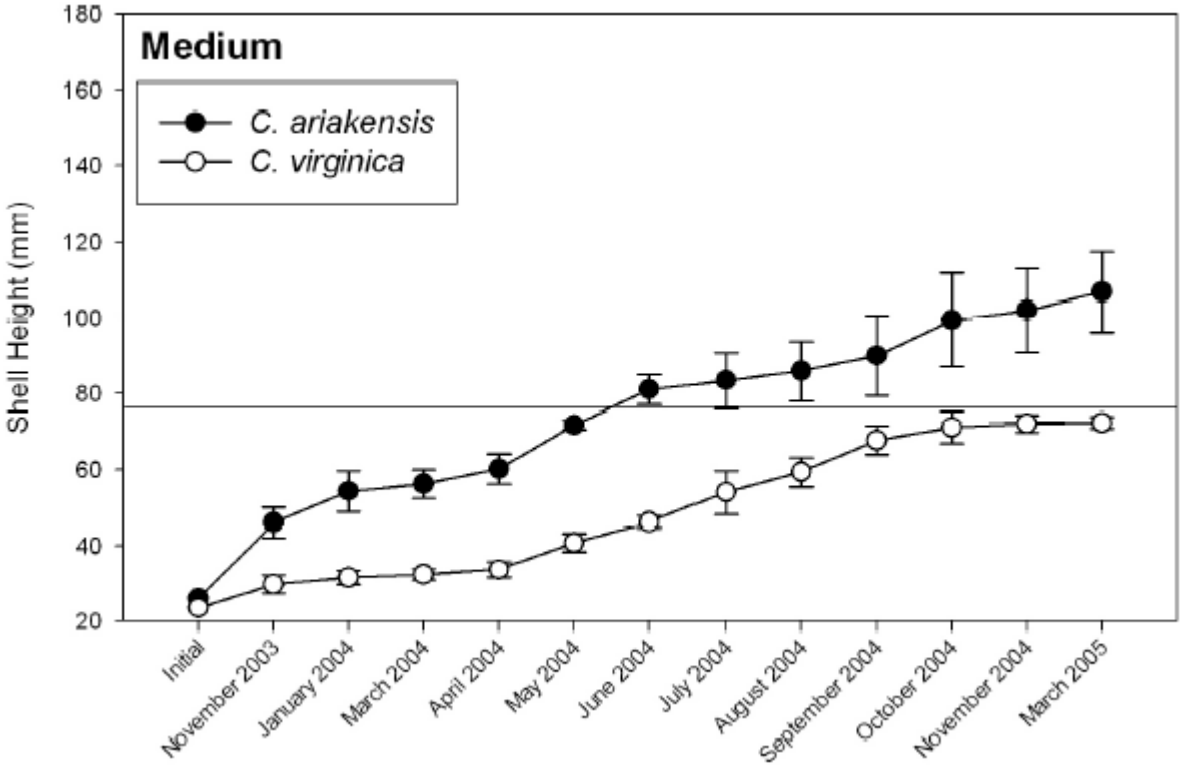
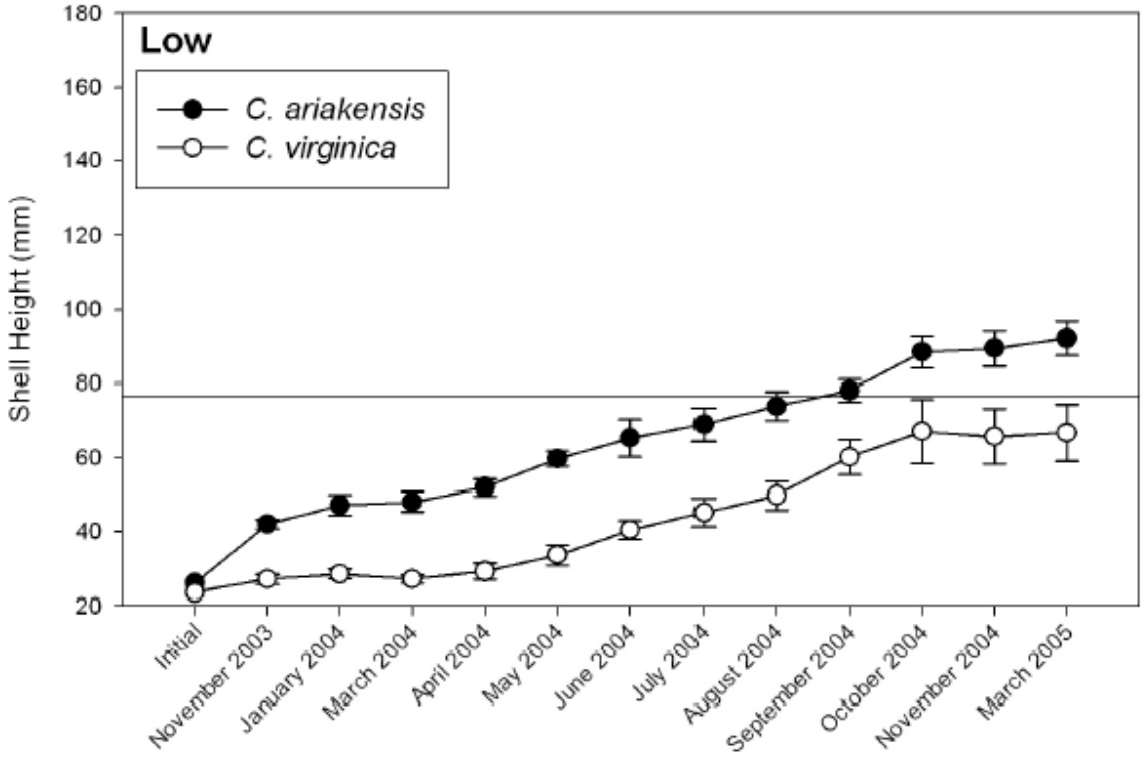


Table 11. Low Salinity VSC Sites Grow-out Variable Cost and Returns, 2003-2005

Costs and Returns	Kinsale	Burgess	Burgena	Urbana	Average
Labor Hours	516	528	344	463	
Labor Cost	$5,160.00	$5,280.00	$3,440.00	$4,626.67	
Supplies	$5,553.00	$9,441.00	$9,516.00	$8,170.00	
Fuel	$200.00	$275.00	$360.00	$278.33	
Seed	$885.20	$939.00	$773.20	$865.80	
Electricity	$0.00	$100.00	$0.00	$33.33	
Total Cost	$11,798.20	$16,035.00	$14,089.20	$13,974.13	
Oysters Sold	88,520.	93,90	77,32	865	

	00		0.00		0.00		80.00	
Total Revenue		$21,244		$22,5		$18,5		$20
	.80		36.00		56.80		,779.20	
Balance		$9,446.		$6,50		$4,46		$6,
	60		1.00		7.60		805.07	

Figure 7. Comparison of overall growth for C. ariakensis and C. virginica within a low salinity regime. Values represent shell height growth averaged over all sites with similar salinities. Error bars represent one standard error. (Hudson)



Overview of Comparative Growth and Mortality

Growth data show *C. ariakensis* outperforming *C. virginica* without exception at every site (every salinity regime). Disease sampling from all sites has indicated light infections for both species, a situation that might be peculiar to the time period of the project. However, it is also possible that triploidy, *per se,* may decrease the incidence of disease.[17] Except for a couple of incidents of icing that killed both species, mortality has

[17] Personal Communication. Stan Allen

been relatively low, somewhat higher in *C. virginica* than *C. ariakensis*. These results are also contrary to those of Grabowski et al. (2004) who reported relatively higher mortalities across sites, and higher mortality in *C. ariakensis* than *C. virginica* at high salinity.

It is likely that high salinity and most medium salinity sites can realize nearly 100% harvest within a year. Not known is whether the same can be realized at lower salinity sites, since growth is somewhat slower there. In addition to the clear advantage of improved cash flow and return on investment, a major advantage of a one-year crop rotation would be accommodation of the concerns for biosecurity in non-native *C. ariakensis* aquaculture.

The table below summarizes the disposition of oysters from the 9 individual grow-out investigations (8 sites) in terms of oysters sold and mortality per trial. Overall deployment of 790,054 *C. ariakensis* oysters was reported, with 703,878 oysters ultimately marketed and a final mortality rate of 10.3 % (81,796)[18].

[18] This compares with 7% mortality associated with the VIMS biological studies attendant to this grow-out project.

III. Indirect Use and Non-Use Benefits

It is likely that a large share of potential benefits from the proposed alternatives will be in the form of non-market, indirect use generated benefits. In this case, oysters are not valued directly, but instead for their contribution to the production of some other Chesapeake Bay good or service (Hicks et al. 2004), and there are no markets to acquire these goods and services.

Non-market goods are not traded and have no corresponding market price. Such goods include environmental and ecological resources, outdoor recreation, and numerous other amenities. As already suggested, nonmarket goods may have both direct and indirect use values. If an increased abundance of oysters improves water quality in some areas, housing prices for waterfront homes in those areas might have higher values[19]. There are five possible types of indirect use values (Kahn 1998): (1) existence, (2) bequest, (3) altruistic, (4) option, and (5) the value of ecological services.

All of these types of indirect use values, and particularly the value of ecological services, are likely to be important to the economic valuation of the proposed alternatives. Existence value is simply the welfare an individual receives from knowing a resource or state of the environment exists, even though that individual may never have any intention of using the resource. Bequest value is the economic value or benefit an individual receives by knowing that the resource will be available for use in the future for society to experience. Option value is the welfare an individual receives by maintaining or preserving the option to use the resource in the future. Altruistic value is similar to the "feel-good" value; that is, an individual values the opportunity for other people to enjoy

[19] see Leggett and Bockstael (2000) for a study demonstrating the impact of water quality, measured as fecal coliform, count on housing values in Anne Arundel County, Maryland.

the resource. Ecological values are those indirect use values generated from a state of the environment or resource (e.g., oysters filter algae, which in turn, improves water quality and may help maintain biodiversity).

A recent report prepared for the Chesapeake Bay Foundation by Hicks et al. (2004), examines the potential benefits of native oyster reef restoration Hicks et al. determined that just recreational anglers would realize benefits of approximately $640 thousand per year for restoring 1,890 acres at 73 reef sites in the Bay. The total cost of the restoration of the 1,890 acres was determined to equal $27.0 million. When calculating the net present value of the 30 year stream of benefits, assuming a discount rate of 3.0 %, it was determined that just the recreational benefits would equal approximately 50 % of the cost of the restoration.[20] However, since recreational fishing is just one class of benefits derived from oyster reef restoration, it is necessary to look at other large categories of benefits as well.

In the same study by Hicks et al., it was shown that there were other sources of indirect benefits.[21] Using a mail survey of residents of New Jersey, Delaware, Maryland, Virginia, and North Carolina, Hicks et al. determined that the potential economic value or non-use benefits of a ten year oyster reef project, consisting of 10,000 acres of oyster sanctuary and 1,000 acres of artificial reef, to be at least $115 million. These indirect uses include enhanced water quality; possible increased populations of other species of fish; improved fish habitat; and improved recreational boating and water-based activities.

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[20]Because of changes in individual preferences over time and inflation, it is necessary to convert future dollar values to present dollar values. This is done by dividing the annual value of $640.0 thousand by a factor of $(1.0 + 0.03)^t$, $t = 0,\ldots,29$, and indicates time. Note that any value raised to the power of zero equals one. The value 0.03 is the social time rate of preference for society. The cumulative value of $640.0 thousand over the 30 year horizon equals $12.9 million.

[21] Because the services provided by oyster reefs cannot be purchased or sold in a market, it is necessary to examine the potential non-market value using a hypothetical market (Hicks et al. 2004).

Unfortunately, the study by Hicks et al. (2004) focused solely on restoring native oyster reefs, and not actually on options for increasing the population of oysters in the Bay via enhancing the abundance of non-native (*Crassostrea ariakensis*) oysters. Given that respondents likely equated oyster reef restoration with enhanced abundance of native oysters, the results presented in Hicks et al. likely can be interpreted as being indicative of the value society places on improved resource levels of, at least, the native oyster. It remains uncertain as to how society might value differently the introduction of the non-native oyster. Society may view the introduction of the non-native as being too risky, and thus, they may be only concerned about the potential social costs of introducing *C. ariakensis*. Alternatively, society may have a clear preference only for restoring the native oyster, *C. virginica*.

There have been numerous studies on the introduction of non-native, exotic, or invasive species. In most cases, however, the introduction was accidental, and did not involve the introduction of oysters of any species. For example, a good case in point is the accidental introduction of zebra mussels and the Veined rapa whelk. Zebra mussels have been determined to negatively affect power plants and compete with indigenous populations for food. The potential harm caused by the Veined rapa whelk is still under investigation, but it is known that it preys on other mollusks in the Bay (e.g., oysters, clams, and mussels). In a 1993 report by the Office of Technology Assessment (OTA), it was reported that the monetary costs associated with biological invasions in the United States, alone, was between $4.7 and $6.5 billion annual. Most recent research has revised these estimates upward to $100.0 billion (Pimentel et al. 2000). Settle and Shogren

(2002), in an examination of the introduction of Lake trout to Yellowstone Lake, found that it would cost approximately $33.8 million to eliminate the non-native Lake trout.

Numerous studies have been conducted on determining the non-market value of the ecological services of various resources. For example, a study by Lynne et al. (1974) determined that the economic value of protecting marshes equaled $0.30, which equals approximately $0.94 in 2004 values, per acre relative to enhancing the population of blue crabs.[22] Much of the interest about introducing *C. ariakensis* is related to the perception of enhanced water quality and improved ecological services likely to result from an enhanced population of oysters in the Chesapeake Bay. In a 2004 study by Lipton, it was demonstrated that the economic value of improved water quality, just to Maryland boat owners, was approximately $7.3 million per year or $243 million in present value terms using a 3% discount rate. No attempt was made to estimate the economic value to Virginia boat owners or of the ecological services of improved water quality.

Unfortunately, there have been no economic studies linking ecological services and introduction of the non-native *C. ariakensis*. Significant contributions of social welfare or net benefits to society, however, are likely to be derived from the potential contributions to the production of other Chesapeake Bay goods and services (e.g., enhanced populations of blue crab and striped bass because of improved water quality and habitat). In many instances in which data are limited, limited estimates of benefits to society are possible using the methods of benefit transfer and meta-analysis (Songhen 2001). Both of these approaches, however, require estimates of the economic value from

[22]Hicks et al. (2004) provide numerous references on more recent studies; also, see the journal Ecological Economics, which contains numerous economic valuations of the ecological services of natural resources. For a comprehensive discussion on approaches for valuing ecological services, see Randall and Gollamudi (2001), "Dealing with the Analytical Challenges of Valuation: Aquatic Nuisance Species Control."

either the introduction of *C. ariakensis* elsewhere or the introduction of other, but similar (e.g., the introduction of *C. gigas* in the Pacific Northwest during the early 1900s), non-native species either in the same area or elsewhere. Unfortunately, there does not appear to have been any studies on the economic value of introducing similar non-native species in the United States, particularly in the Chesapeake Bay region.

Potential ecological benefits would be expected to mostly derive from enhanced water quality, which would be expected with higher resource levels of oysters. Improved water quality would be expected, in return, to improve resource levels of all the Bay's finfish and shellfish resources, along with improvements to submerged aquatic vegetation and essential fish habitat. All water-based recreational users (e.g., boaters and swimmers) would also be expected to realize increased benefits because of improved water quality. Waterfront property owners would also be expected to realize higher benefits because of improved water quality.

Cerco and Noel (2005), using existing Chesapeake Bay models have made some preliminary estimates of water quality improvements associated with and increase in oyster populations. Specifically, they have estimated how an increase in the population of oysters to the target level would reduce chlorophyll concentrations, decrease light attenuation, increase SAV biomass, and increase average summer dissolved oxygen compared to baseline 1994 levels. The economic study most directly tied to this estimate is the recreational striped bass fishing study by Lipton and Hicks (1999). The estimated that an increase in bottom dissolved oxygen in Chesapeake Bay so that levels of monitoring stations never fell below 5 mg/l (a much more optimistic scenario than the Cerco and Noel calculations) would result in annual net benefits to recreational fishermen

of only $254,000 in 2005 dollars. These values are low because the striped bass population, at least in terms of numbers, is relatively healthy. According to Lipton and Hicks, a decline in water quality from the baseline 1994 levels would result in a significant decline in striped bass catch rate with losses estimated to range from $6.5-$9.5 million per year.

Costs and Risks

The potential benefits of oyster restoration discussed above are the opportunity costs of the no action alternative. At the other extreme of economic value are the potential costs of introducing *C. ariakensis*. These potential costs include the cost of research; the cost of the actual introduction; the potential costs associated with the potential introduction of new diseases; the costs of resource management; the potential costs associated with the loss of the indigenous oyster, which is not known; and the potential failure of the introduction. It remains unknown how larger population levels of *C. ariakensis* will affect reproduction, recruitment, the weight and growth, and mortality of other finfish and shellfish in the Bay and associated tributaries.

Risk and uncertainty about the benefits of the alternatives are likely to be quite high as well. For example, market demand for oysters has been declining over years, and thus, will there be a sufficient market to handle increased supply? The analysis above relied on an assumption of stable demand. Despite the apparent large degrees of risk and uncertainty relative to the introduction of *C. ariakensis*, it is possible, when appropriate

information is available, to provide an assessment of the economic value or net benefits of introducing *C. ariakensis* to the Chesapeake Bay.[23]

[23] Russell (2001) provides a comprehensive review of methods and procedures, which can be used to assess the economic benefits in the presence of risk and uncertainty.

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APPENDIX 1

INDUSTRY OYSTER SURVEY

Dear Chesapeake Oyster Dealer,

An environmental impact statement is in the process of being prepared for a proposal to establish an oyster population that reaches a level of abundance in Chesapeake Bay that would support sustainable harvests comparable to harvest levels during the period 1920–1970. A variety of alternatives are being explored to achieve that goal including the introduction of a non-native oyster Crassostrea ariakensis, expansion of native oyster restoration and repletion programs and various combinations of alternatives.

As an industry leader we are interested in your expert opinion on important characteristics of the oyster market that will accompany a return to sustainable harvests of 4.9 million bushels a year from the Chesapeake Bay. Please use your industry knowledge to fill in all the responses to the current survey. There are no right answers; it is your expert judgment that counts. Once we collect completed surveys from all the major oyster dealers in the Chesapeake region, we will provide you with a summary of the survey results (i.e., industry average responses to all the questions).

1. According to preliminary Maryland DNR figures, in the most recent oyster season (2003-2004), the average bushel price to watermen for oysters was approximately $24. If Chesapeake Bay landings are 4.9 million bushels per year, what is your best estimate regarding

	for virginica	for ariakensis
a. The lowest price per bushel	$_____	$_____
b. The highest price per bushel	$_____	$_____
c. The most likely price per bushel	$_____	$_____

2. To the best of your knowledge, what range in percentage of the recent Chesapeake Bay harvest and shellstock brought into the region is destined for the halfshell market:

a. Lowest percentage halfshell	_____%
b. Highest percentage halfshell	_____%
c. Most likely percentage halfshell	_____%

3. What is your best estimate as to what percentage of a restored oyster fishery of 4.9 million bushels a year from the Chesapeake Bay will be sold for the halfshell market?

	for virginica	for ariakensis
a. Lowest percentage halfshell	_____%	_____%
b. Highest percentage halfshell	_____%	_____%
c. Most likely percentage halfshell	_____%	_____%

4. Looking at Fulton market data for 2003, the average annual price for select shucked oysters were approximately $48 per gallon. What price per gallon for select oysters would you expect if the Chesapeake Bay oyster fishery were restored to 2-3 million bushels a year?

	for virginica	for ariakensis
a. The lowest price per gallon	$_____	$_____
b. The highest price per gallon	$_____	$_____
c. The most likely price per gallon	$_____	$_____

5. Looking at Fulton market data for 2003, average annual shell oyster prices ranged from approximately $14.50 per 100 count box for Gulf of Mexico wild oysters and $40 per 100 count for cultivated Connecticut oysters. What price per 100 count would you expect if the Chesapeake Bay oyster fishery were restored to 2-3 million bushels a year?

	for virginica	for ariakensis
a. The lowest price per 100 count **WILD**	$_____	$_____
b. The highest price per 100 count **WILD**	$_____	$_____

c. The most likely price per 100 count **WILD**	$_____	$_____
	for virginica	for ariakensis
d. The lowest price per 100 count **CULTURED**	$_____	$_____
e. The highest price per 100 count **CULTURED**	$_____	$_____
f. The most likely price per 100 count **CULTURED**	$_____	$_____

6. Given the expected cost of shellstock, processing and handling costs, and wholesale prices for a restored Chesapeake Bay fishery, what is your best estimate of profit margins for the following products

	for virginica	for ariakensis	
a. The lowest profit per gallon	$_____	$_____	**WILD**
b. The highest profit per gallon	$_____	$_____	**WILD**
c. The most likely profit per gallon	$_____	$_____	**WILD**
d. The lowest profit per gallon **CULTURED**	$_____	$_____	
e. The highest profit per gallon **CULTURED**	$_____	$_____	
f. The most likely profit per gallon **CULTURED**	$_____	$_____	
g. The lowest profit per 100 count	$_____	$_____	**WILD**
h. The highest profit per 100 count	$_____	$_____	**WILD**
i. The most likely profit per 100 count	$_____	$_____	**WILD**
j. The lowest profit per 100 count **CULTURED**	$_____	$_____	
k. The highest profit per 100 count **CULTURED**	$_____	$_____	
l. The most likely profit per 100 count **CULTURED**	$_____	$_____	

7. With a restored oyster fishery in the Chesapeake Bay, how many full-time equivalent (FTE) jobs, other than watermen, will be necessary to support the processing, wholesaling and distribution of oysters
   a. The fewest number of FTE jobs _____FTE's
   b. The highest number of FTE jobs _____FTE's
   c. The most likely number of FTE jobs _____FTE's

8. Have you currently had any business-related experience with *Crassostrea ariakensis*?
   ____YES _____NO

9. Are there other issues related to the economics of a restored oyster industry in Chesapeake Bay that you think it would be important for us to know about?

_____
_____
_____
_____
_____
_____
_____
_____

Thank You