Coastal marine wetlands,¹ in their natural state, are important biological and hydrological resources. Wetlands yield numerous valuable services such as provision of nursery and feeding habitat for fish and wildlife, and the assimilation of wastes. Wetlands, when filled or otherwise altered, also provide valuable sites for residences, marinas, or ports. Because well defined and vendable property rights are lacking for natural unaltered wetland services but are available for development services, the unregulated market will tend to reflect only the benefits of development. The result has been a rate of conversion of tidal wetlands that has been unsatisfactory to many individuals [23].

In response to such dissatisfaction, recent federal and state legislation now requires public management of wetlands that includes specific consideration of natural values. For example, Section 404 of the Federal Water Pollution Control Act Amendments of 1972 gave the Army Corps of Engineers jurisdiction over coastal wetlands. Present Corps policy for evaluating permit applications with regard to their impact on wetlands requires that permits will not be granted unless an analysis indicates "...that the benefits of the proposed alteration outweigh the damage to the wetlands resources and the proposed alteration is necessary to realize those benefits" [8]. Similarly, Virginia’s Wetlands Act declares it to be the Commonwealth’s policy to grant a permit for wetlands alterations only if the permit boards find "...that the anticipated public and private benefit of the proposed activity exceeds the anticipated public and private detriment" [24].

This need to weigh the benefits and costs of altering wetlands has stimulated interest in deriving monetary values for nonmarket ecological services.² If such values were available, the opportunity costs of wetlands development could be more clearly identified and compared with the benefits of wetlands development. A major constraint on such measurement efforts is the lack of markets for services of natural wetlands' values; market-generated prices on which to base estimates of natural wetlands' values are either inaccurate or absent. Therefore, some form of shadow pricing for natural wetlands services is needed to provide economic measures that can aid in determining the allocation of wetlands between natural and development uses.

The authors provide a methodology and an empirical estimate of the economic value from one unaltered wetlands service: Chesapeake Bay oyster (Crassostrea virginica) propagation. An appropriate measure of the economic value of wetlands as an input in oyster production is the wetlands' marginal value product. Once estimated, the marginal product can be compared with the marginal value product emanating from alternative competing uses of wetlands. Because most wetlands alteration decisions involve changing the use of small acreages or fractions of acres of wetlands, the usual appropriate comparison would be among various marginal value products.

The authors estimate the marginal value product accruing to society from the wetlands contributions to Virginia oyster production. First a physical production function relating Virginia oyster harvest and Virginia coastal wetlands as inputs is estimated. This oyster yield function then is used to derive the marginal value product (MVP) where the variable input is wetlands acreage.

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¹A marine wetland is defined by the Virginia Code (62.1-13.2(1f)) as "all land lying between and contiguous to mean low water and an elevation above mean low water equal to 1.5 times the mean tide range and upon which grow one or more specific kinds of vegetation."

²Gosselink, Odum, and Pope’s *The Value of the Tidal Marsh* [11] is a major contributor in the area of wetland service valuation. However, serious questions have been raised about their estimates of marsh value. See [21].
BIOECONOMIC MODEL OF WETLANDS AS INPUTS IN OYSTER PRODUCTION

For the purposes of this study, oysters are assumed to have a well defined production process which, when estimated, will yield parameters that lend themselves to marsh value estimation. This production function is assumed to be:

\[ Y_{tj} = f(X_{tjk}) \]

where

- \( Y_{tj} \) = the output of oysters in time period \( t \) in region \( j \) measured in pounds harvested
- \( X_{tjk} = \) the acres of wetlands of similar biological quality in time period \( t \) and region \( j \); \( j \) varies from 1 to 2 where 1 is the wetlands with highest biological quality for oyster production and 2 is the wetlands with the lowest biological quality
- \( X_{tjk} = \) the number of labor-days spent in the oyster fishery in time period \( t \) and region \( j \)
- \( X_{tjk} = \) the quantity of capital used in the oyster fishery in time period \( t \) and region \( j \); \( k \) varies from 1 to 2 where 1 is the number of hours that tongs are used and 2 is the number of hours that dredges are used in the fishery
- \( X_{tjk} = \) management and institutional factors that influence the potential harvest in region \( j \) over time period \( t \) and
- \( X_{tjk} = \) environmental variables such as salinity conditions, number of predators, water quality, water temperature, time period \( t \) in region \( j \).

Given that there is a price per pound of oysters, \( P_{tj} \), the marginal value products (MVP) of acres of wetlands of various biological quality by region would be the first derivative of the production function (1) with respect to \( X_{tjk} \) where \( k \) varies from 1 to 2, multiplied by \( P_{tj} \) or

\[ \text{MVP} = P_{tj} f'(X_{tjk}) \]

DATA AVAILABILITY

Unfortunately, the estimation of a physical production function that captures the technical linkages between Virginia oyster harvest and wetlands acreage requires numerous specification compromises because of the paucity of physical, biological, and economic data. Ideally, the estimated physical production function would accurately relate wetlands’ acreage to oyster biomass, and oyster biomass to oyster harvest given the inputs of applied labor and capital in a specified institutional arrangement of property rights. However, many of the important linkages are not well understood. It is known that the wetland acreage provides food for the oyster in the form of decayed plant material (detritus) [4, 16, 17, 22] and is instrumental in maintaining necessary water quality by controlling erosion [5, 9, 14, 19].

However, biomass available in any year is a function of many other variables such as suitable substrate, water temperature, water quality, water salinity, cultivation and management practices, number of predators, presence or absence of disease, as well as marsh acreage. Another complication is the fact that the oyster is sedentary; an adult oyster is permanently located on the substrate. Though many oysters can be located within wetlands, others survive and prosper adjacent to wetlands or near river outlets. The linkages between oyster biomass and wetlands acreage is not known with precision. Furthermore, the wetlands in most regions are known to be of differing biological quality in terms of oyster propagation, but available wetland acreage inventories do not differentiate with respect to biological quality.

ESTIMATION OF THE PRODUCTION FUNCTION

A 17 Virginia county cross-section model was selected:

\[ Y_{tj} = f(E_{tj}, R_{tj}, PR_{t+j}, W_{tj}, S_{tj}) \]

where

- \( Y_{tj} = \) oyster harvest in pounds of shucked oysters by Virginia coastal county in 1969
- \( E_{tj} = \) principal component index of effort input consisting of .52888 × number

*Tongs are hand-operated devices attached to long poles or cables, and are used over the side of a drifting or anchored oyster boat. Dredges resemble a large scrape with a trailing bag made of light chain or cable mesh. Dredges are dragged behind a moving boat to capture oysters.
of oyster tongs by Virginia coastal county in 1969 + .52688 X number of oyster dredges by Virginia coastal county in 1969 (both oyster tong and oyster dredge variables were standardized to a mean of 0 and a variance of 1)

\[ R_{tj} = \text{number of acres of leased oyster grounds by Virginia coastal county in 1969} \]

\[ PR_{t+7j} = \text{number of acres of open access property oyster grounds by Virginia coastal county in 1976} \]

\[ W_{tj} = \text{number of wetland acres by Virginia coastal county in 1969} \]

\[ S_{tj} = \text{salinity dummy which took the value of 0 for those Virginia coastal counties with high salinity waters in 1969 (} \geq 17 \text{ ppt}) \text{ and 1 for those with salinity (} \leq 17 \text{ ppt})] \]

\[ t = 1969 \text{ and } j = 17 \text{ Virginia counties.} \]

The major assumptions used in selecting this model were:

1. Oysters are harvested in waters adjacent to the counties where the harvest data are reported.
2. All of a county’s wetlands contribute equally to the oyster biomass in waters adjacent to the counties.
3. Across all counties, the numbers of hours of use per tong or dredge were identical.
4. Measurement error was nil and there were no errors in reporting.

The model has only two biological variables, wetland acreage \((W_{tj})\) and salinity \((S_{tj})\). This assumption may not be as constraining as it first appears. Menzel et al. [15] indicated that salinity could be the most important limiting factor on oyster population, partly because low salinity precludes the presence of many oyster predators. An offsetting factor is that oyster’s reproducing and setting capabilities seem to be retarded in low salinities [16, 13]. However, evidence from several authors suggests that major predation problems increase in waters of greater than 17 ppt salinity, and predation was believed to be the more limiting biological constraint in oyster production [2, 3]. A salinity of 17 ppt was used for diving low and high salinity waters. Determination of the appropriate salinity classification for each county was made from isohalines compiled for fall and summer seasons [6].

The wetlands data \((W_{tj})\) were collected from United States Geological Survey (USGS) quadrangles using both 1:1 Polar compensating planimeters and 400 point/square-inch grids. Marine wetland acreage contributing to oyster production varied considerably across the 17 counties, from a high of 63,915 acres in Accomack County to a low of 436 acres in Virginia Beach County. Each of these counties had different amounts of acreage in the various biological quality classifications. However, no distinction was made among various biological qualities of the wetlands types for this study because of lack of appropriate delineation on the maps. This is a weakness in the model, as it can be assumed that an acre of high quality wetland marsh with strong tidal washing will be likely to produce more inputs to oyster production than an acre of poor quality marsh, ceteris paribus. Thus, any estimates of marginal productivities derived from the undifferentiated wetlands biological quality data will be marginal productivities for “average” wetland qualities.

The other variables in the study are the effort inputs \((E_{tj})\) and the institutional structure of oyster grounds property rights \((R_{t}, PR_{t+7j})\). The effort variable is a composite variable that incorporates the different technologies that are most prevalent in the oyster industry. Two methods of harvesting oysters are used in the Chesapeake Bay, harvesting by use of tongs and by use of dredges. There is a constant ratio of men to each piece of equipment—one man per tong and two men per dredge. The catch per unit of dredge is much higher than that for tongs. No data were available on the number of days spent fishing; however, the National Marine Fisheries Service (NMFS) supplied data on the number of oyster tongs and dredges by oyster producing county for 1969. These variables were combined in an effort input index by use of principal components analysis. The first factor scoring \((E_{tj})\)

\[^{1}\text{1976 data for public (natural) grounds by county were used in the absence of any other available data. However, there is evidence suggesting little change has taken place in the quantity of available public grounds since 1969.}\]
\[^{2}\text{This variable took a value of 1 and e when the model was specified in natural logarithms.}\]
\[^{3}\text{Setting is the biological process whereby free-swimming larvae of the oyster become attached to hard clean substrate to begin the sessile portion of their life.}\]
that resulted was a combination of the two variables equally weighted.

\[ E_{ij} = 0.52688 (\text{Dredges}_{ij}) + 0.52688 (\text{Tongs}_{ij}) \]

The portion of the total variance accounted for by this component was 94 percent. The decision to exclude the number of oystermen from the analysis was based on the premise that there is a constant relationship between the number of oystermen and the other effort inputs used; hence, any inclusion of the labor input would be redundant. Data on other inputs such as quantity of spat seeding were unavailable.

The property rights variables \( r_{i(t+2)} \) and \( PR_{i(t+7)} \) were included to account for the availability of oyster-growing grounds, and the effects of the different management and technologies used there. Virginia's oystering grounds are publicly owned but are divided into leased and open access property. All natural oyster grounds have been reserved for public use, and are open access property resources. Laws pertaining to the use of these open access grounds prohibit the use of dredges and allow only less efficient hand operated tongs to be used. Furthermore, harvest on open access grounds usually is restricted to the fall, winter, and early spring. The leased grounds, in contrast, are areas that are not naturally suited for the growth of oysters, but will support oyster production if privately cultivated and managed. These grounds are leased from the state by private individuals and may be harvested year round. Dredging is permitted on these leased grounds if the grounds are under cultivation. Agnello and Donnelley report these leased grounds produce more oysters per acre than the open access grounds, despite the private ground's physical inferiority. This observation is not surprising if one considers the common property nature of those grounds not under private management. Data for these public and private grounds were obtained from the Virginia Marine Resources Commission (VMRC).

Data on oyster catch \( Y_{ij} \) were provided by the National Marine Fisheries Service. These figures are based on shucking house taxes levied by Virginia and collected by VMRC. Some errors in reporting are suspected because oyster processors may not fully report the quantity processed at their plants.

### THE MODEL'S FUNCTIONAL FORM

The model was specified in Cobb-Douglas form and estimated as a logarithm-logarithm function by use of ordinary least squares regression. The Cobb-Douglas function is a suitable choice of functional form for a limited data base. Marginal product curves derived from the function are well behaved within the range of data considered. The use of the Cobb-Douglas function to describe yield will result in an indeterminate maximum sustainable yield, that is, the estimated total physical product will not reach a maximum; however, it is doubtful that the range of data used in this study extends beyond the area of maximum sustainable yield. The resulting equation in Cobb-Douglas form is shown in Table 1, equation 1.

#### TABLE 1. UNCORRECTED AND CORRECTED COBB-DOUGLAS MODELS OF OYSTER YIELDS FOR 17 VIRGINIA COUNTIES IN 1969

<table>
<thead>
<tr>
<th>Equation 1: Uncorrected ( R^2 )</th>
<th>( R^2 ) = 0.558</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y_t = 31400 + 0.357 LE + 0.2277 LP + 0.2275 LW + 1.003 LE )</td>
<td>(2.6030) (0.2977) * (0.0812) (0.189) (0.4518)</td>
</tr>
</tbody>
</table>

---

*Significant at 10 percent level of confidence.

**Significant at 5 percent level of confidence.

aThe \( R^2 \) of this model is valid for the untransformed variables [12]. The \( R^2 \)'s shown in equations 2 and 3 were calculated using the new coefficients and the untransformed variables and are, therefore, only approximate. In Equation 1, the standard errors associated with the estimates are inefficient. Values for standard errors for Equations 2 and 3 are asymptotically efficient.

bValues in parentheses are standard errors.

---

1Principal components analysis is a method of producing a set of orthogonal factors that are the best linear combination of \( k \) related variables. Each component is defined as the best linear summary of the variance left in the data after previous components are formed. Efficiency differences are accounted for by normalizing each variable to a mean of 0 and a variance of 1.

2Dredges and tongs first were used separately in the model. However, as these two variables showed some degree of linear dependence (0.80114) and as they described the same input effort, they were combined in the index variable, \( E_{ij} \).

3Spat are oyster spawn.

4Lease fees include an initial fixed cost of approximately $68-183 plus an annual fee of $1.50/acre. Leases are for 20 years [225].
Some heteroscedastic disturbances were evident in this model which suggested that estimates of the variance for the estimated coefficients were biased and, as a result, tests for significance were inefficient. Correction techniques as set forth by Glesjer [10] and Park [18] were performed by generalized least squares procedure. The resulting equations are reported in Table 1 as equations 2 and 3. The nature of the heteroscedasticity suggests that the estimates of coefficient standard error in equation 1 were larger than in reality. The correction technique is such that the estimators of the corrected model are consistent, as well as being asymptotically efficient. However, with a small sample size, N = 17, the standard errors must be interpreted with caution.

The standard errors, as presented in equation 3, suggest only two variables are significant at the 10 percent or greater level of significance. These variables are the logarithm of the effort index variable (Ei) and the logarithm of the salinity dummy variable (Si). The logarithm of the wetlands variable (Wj) in the equation 3 specification was significant at approximately the 75 percent test level. Other specifications of the model were attempted; some of them yielded significant coefficients on the wetlands variable, but at the expense of omitting other variables from the model.11 These results suggest that, though the method of using a Cobb-Douglas function for evaluating the natural wetlands service of oyster production is promising, the model suffered from the paucity of refined data with which to specify the bioeconomic model (1).

The marginal value product (MVP) for the wetlands was calculated by differentiating the function (equation 3, Table 1) with respect to the wetlands (W) variable and then multiplying by the dockside price of oysters per pound per county. That is, equation 3 is equivalent to

\[
(4) \quad Y = 61.05 \lambda W^{2.494}
\]

where

\[
\lambda = E^{.6278} PR^{.308} R^{.4884} S^{.8466}
\]

and 61.05 = antilogarithm of 4.1117.

Then:

\[
(5) \quad \frac{\partial Y}{\partial W} = (2.494)(61.05) \partial W^{-7506}
\]
equals the marginal product of wetlands, and

\[
(6) \quad P_c = 15.225 \partial W^{-7506} P_c
\]
equals the marginal value product of wetlands where \(P_c\) is the dockside price of oysters in the county of interest. By substituting county observations for the variables represented by \(\lambda\), the marginal value product for each county can be obtained estimated at the county's actual wetland acreage. For illustration, Table 2, column 4, shows the marginal value product for seven of the 17 counties. The values of the 17 counties' wetlands marginal value products range from a high of $141.46 in Northumberland County to a low of a $1.13 in Accomack County.

The MVP estimates in column 4 in Table 2 represent 1969 annual values. To obtain estimates that represent the value of continuing annual flows, the values in column 4 should be discounted by use of the formula:

\[
(7) \quad PV_m = \frac{MVP}{r}
\]

where

\[
PV_m = \text{the discounted present value of marginal value product and}
\]

\(r = \text{the discount rate.}\)

"Several other specifications were tried, each yielding comparable R's and greater significance levels. One such specification is:

\[
LY = 7.8609 + .8103 LE + .1134 LPR + .3514 LW + 1.5667 S
\]

\(\text{R}^2 = .759\)

** = Significant at 10% level.

However, these models came at the expense of removing \(R\), the private oyster grounds, which was deemed not justifiable because other researchers have found this variable to be significant. Also, the model used in this article was chosen because, by use of the Glejser test for homoscedasticity, the specification showed the least amount of disturbance. Use of the model specified above for calculating marginal value product would have resulted in larger estimates than those obtained from the use of equation 3, Table 1.
TABLE 2. CALCULATED MARGINAL VALUE PRODUCTS AND CAPITALIZED VALUES FROM OYSTER HARVESTING ACCRUING TO WETLANDS IN SEVEN VIRGINIA COUNTIES

<table>
<thead>
<tr>
<th>County</th>
<th>Total Number of Wetland Acres</th>
<th>Discounted Price of Oysters Per Pound, 1969</th>
<th>Equation 1</th>
<th>Marginal Value Product, 1969</th>
<th>Marginal Value Product* at r = .10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accomack</td>
<td>43,915</td>
<td>.6978</td>
<td>1.23</td>
<td>11.34</td>
<td></td>
</tr>
<tr>
<td>Isle of Wight</td>
<td>6,207</td>
<td>.6375</td>
<td>1.13</td>
<td>11.34</td>
<td></td>
</tr>
<tr>
<td>James City</td>
<td>5,614</td>
<td>.6375</td>
<td>1.66</td>
<td>14.39</td>
<td></td>
</tr>
<tr>
<td>Northumberland</td>
<td>1,128</td>
<td>.6279</td>
<td>141.16</td>
<td>1,414.39</td>
<td></td>
</tr>
<tr>
<td>Virginia Beach</td>
<td>.675</td>
<td>.6755</td>
<td>6.26</td>
<td>47.37</td>
<td></td>
</tr>
<tr>
<td>Westmoreland</td>
<td>2,282</td>
<td>.6601</td>
<td>107.22</td>
<td>1,072.21</td>
<td></td>
</tr>
<tr>
<td>York</td>
<td>6,622</td>
<td>.6795</td>
<td>1.88</td>
<td>18.82</td>
<td></td>
</tr>
</tbody>
</table>

aSlight differences arise from use of formula 7 and reported figures due to rounding.

Column 5 reports discounted present values when the discount rate (r) applied is 10 percent.

From Table 2, it is apparent that the marginal values not only reflect the quantity of wetland acres but also the amount of effort employed and the salinity of the water. For example, the County of Northumberland with a high marginal value of $141.46 (column 3) has a relatively small amount of wetland acres (1,128) (column 2). It also lies in a low salinity region, employs 26 dredges and 386 tongs, and has a 23,728 acres of public grounds and 6,595 acres of private grounds. In comparison, another low salinity region, James City, has a marginal value of $1.64. This county has 5,614 acres of marsh, employs only 4 dredges and 10 tongs, has no public grounds nearby, and has only 3,346 acres of recorded private oyster planting ground. Although James City is a productive area for oysters, the combination of abundant wetlands and low capital input reduces the marginal value of the wetlands.

The estimates in Table 2 do not reflect any differences in wetland quality and, at best, represent only “ballpark” estimations. However, even these approximations are useful in providing a perspective for comparing development and preservation services, although the 95 percent confidence intervals around these estimates are large. For example, the upper limit to the 95 percent confidence interval for the marginal value product of Virginia Beach County is $126.21. The maximum likelihood estimate reported in Table 2 is $4.24. Yet these values by themselves do not compare favorably with development values. For example, Shabman and Bertelsen [20] estimate that the discounted present marginal value associated with the amenity of a residential development on Virginia Beach wetlands is approximately $17,650 per acre when valued at r = 9 percent; this study suggests a wetlands marginal value product of $47.11 per acre (±$1,402.33) if the wetlands are preserved for oyster production. Of course, oyster production is only one of the many natural services provided by unaltered wetlands. When this value is added to other possible values such as erosion control, wildfowl habitat, or fishery nursery provision the amount may or may not exceed the average $17,650 per acre, the estimated present marginal value in development.

CONCLUSIONS

Present public policy requires the weighing of public and private benefits and detriments of proposed alterations. It is appropriate for economic researchers to aid in the establishment of values associated with services stemming from alternative uses of wetlands. This study provides a first attempt to estimate the economic values from one natural wetland service—oyster propagation. This study provides a methodology for wetland oyster evaluation and, although hampered by the lack of technical and biological data, estimated values for the returns to wetlands as an input to oyster production. If refined data sets were available to specify the bioeconomic model, equation (1), then presumably estimates with smaller confidence intervals of the marginal value product of wetlands in oyster production could be obtained. At a minimum, these data sets should include the change in acres of wetlands by biological qualities over time (Xtjk). Better estimates of all variables (Xijk) as described in the general bioeconomic model (1) can be expected to improve the explanatory power of the specified equation.

Other important considerations for marginal value product estimation of wetlands as inputs in oyster production are the impact of changing oyster and input prices over time. These considerations are themselves a subset of a broader concern: incorporation of the influence of uncertainty in the estimation of future resource values. This last point is of particular concern when consumer surplus and option demand values are included in the analysis. Other possible considerations include the indirect effects of oyster harvest on regional employment and income, the possibility of substituting more intensive cultivation techniques in place of wetland acreage, and the possibility of substituting higher quality wetland acreage for lower quality acreage.

The important conclusions to be reached from this study are not based on the estimated
values *per se*. Rather this study suggests that refined estimates of value are probable if appropriate data can be obtained over time as well as cross-sectionally on wetlands acreage, property rights structure, effort variables, biological variables, and price data. The refined estimates for these and other natural wetland services would provide some of the necessary information base for more informed and reasoned management of the nation's coastal wetlands.

REFERENCES


