J. OF THE NORTHEASTERN AGR. ECON. COUNCIL VOL. VII, NO. 2, OCTOBER, 1978

THE ANALYSIS OF SURF CLAM PRODUCTION USING AN EXHAUSTIBLE RESOURCE MODEL

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INTRODUCTION

The surf clam (sp. **Spisula solidissima**) is the predominant clam species harvested in the United States. Starting from modest beginnings as a New England bait clam fishery, surf clam meats are now used in virtually all processed clam products, having crowded out other species from their bate or processed goods markets over the past 20 years. This has been due primarily to the surf clams' greater availability, high meat yield and low cost of harvesting by mechanical means. In 1974, the surf clam fishery produced landings of 96 million pounds of meats, approximately 80 percent of the total catch of all species. The value of landings in 1974 was $12.2 million, over 30 percent of the value of all U.S. landings. Unfortunately, this trend is not expected to continue unabated. Catch in 1975 decreased by 10 percent to 87 million pounds. Current stocks available for harvesting are one-fourth of what they were in 1970 (Chang, Ropes, and Merrill). Due to the increased effort being applied to the remaining populations, it is doubtful that the resource will be able to reach previous harvest levels.

The spectre of declining output due to stock depletion has been the focus of attention by fisheries management authorities for several years. Studies (Gorham, Davis **et. al.**) have reviewed the commercial clam industries and have even suggested resource management strategies; but despite the critical condition of the surf clam resource and industry and the intensity of study it has generated, there has been little econometric research into the causes of the industry's troubles.

Our purpose is to focus on a portion of the Atlantic surf clam industry to illuminate statistically the causes of the industry's collapse. In the process, we describe briefly the industry as it exists, develop an econometric model of surf clam exploitation, present results of our empirical work, and draw conclusions in the final section.

The theme that emerges from our analysis is that the resource, although renewable[1] in theory, can be described as an exhaustible or nonrenewable resource when statistically analyzing the industry. The relatively slow growth rate of the species, the discrete spatial distribution of the beds and the sophisticated technology that is used to harvest surf clams create an environment where recruitment and species growth play a minor role on the supply side. A surf clam bed begins with a given resource base and that base grows very little in the interval from initial exploitation until harvests cease. This, of course, has important implications for management that are explored in the final section.

THE ATLANTIC SURF CLAM INDUSTRY

Surf clams began to be used for human consumption in the 1940's. At that time, large hard clams were being used in the manufacture of prepared clam products. Gradually, the generally greater availability and low cost of surf clams displaced the use of hard clams and other clam species in almost all prepared clam products. A number of major technological innovations helped secure this dominant position for surf clams in processed markets. Perhaps the first was the introduction of the drum washer in 1943, an effective method for removing sand from surf clam meats. This was followed by the introduction of the hydraulic jet cage dredge in 1945, which made harvesting an extremely efficient operation. The bottleneck to increased production of processed product, the hand method of shucking, was overcome with the introduction of automatic shucking machines in the early 1970's. Although technological breakthroughs have been the key to success in surf clam harvesting and processing, they have also been the reason for widespread deterioration of the resource base.

The resource base extends from Long Island to the mouth of the Chesapeake Bay. Clam beds are distributed in rather discrete units throughout that range and tend to decline as one moves further offshore. Beds are the result of the surf clams' spawn, usually occurring twice a year. It is estimated that 5 to 6 years are required to produce a commercial sized surf clam from larva.

The fleet and crew which harvests surf clams are very mobile, probably as the result of a continuously decaying resource base. Vessels off New York made it the leading surf clam producer in the fifties. Depletion of New York's beds and subsequent discovery of a very abundant base adjacent to New Jersey caused New Jersey to lead the industry in the sixties. Again, resource depletion and new discoveries shifted the industry south, this time to the waters off Maryland and Virginia. Although Virginia only began landing surf clams in 1969, it has been leading surf clam producers since 1974. Its ability to maintain the dominant role depends on how long southern surf clam beds can withstand the rapid production rates shown in Table 1.

Because the Virginia experience appears to be archetypical of surf clam exploitation and comes in a period of more available (and perhaps more reliable) data, it will serve as the basis for subsequent statistical analysis. Virginia landings, just as in other states, rose very rapidly and then begun to decline. Both events have occurred during a period when much interest was taken in surf clam production and added emphasis was placed on obtaining reliable data about the industry.

Surf Clams as an Exhaustible Resource

To adhere to common definitions of exhaustible or nonrenewable resources, a resource must not be significantly re-

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[1]Exhaustible and non-renewable resources are used synonomously as natural resources which are not naturally replenished (Ciriacy-Wantrup, Cummings).

TABLE 1.
Total Landings of Surf Clams by State, Annual, 1960-1975
(Meat weight)

Year	New York	New Jersey	Delaware	Maryland	Virginia	Other	Total[a]
				Thousand Pounds			
1960	722	23,448	478	420	—	3	25,071
1961	722	26,697	—	71	—	12	27,502
1962	840	29,830	99	75	—	10	30,854
1963	974	37,548	—	64	—		38,586
1964	1,218	36,875	—	38	—	13	38,144
1965	1,505	42,307	—	275	—	1	44,088
1966	1,840	43,174	—	64	—	35	45,113
1967	2,305	41,584	—	1,149	—	16	45,054
1968	3,008	32,181	—	5,328	17	18	40,552
1969	3,431	36,039	2,757	7,127	208	13	49,575
1970	4,182	39,669	8,734	13,681	889	163	67,318
1971	3,688	28,721	7,694	7,752	4,507	173	52,535
1972	2,713	21,332	8,551	7,330	23,384	161	63,471
1973	3,319	21,588	6,630	7,448	43,323	62	82,370
1974	3,951	22,657	5,817	5,426	58,220	39	96,110
1975	4,580	35,550	2,314	5,351	39,088	36	86,919

SOURCE: Dept. of Commerce NOAA/National Marine Fisheries Service Shellfish Market Review and Outlook. Current Economic Analysis S-35 April 1976.

[a] Note: Figures may not add to total because of rounding.

plenished by nature.[2] The significant refers to the economic relevance of the replenishment (Ciriacy-Wantrup). Oil, for instance, is generally agreed to meet these requirements because the rate of replenishment is so small relative to the rate of extraction. It is possible that if oil was replaced by other energy resources, it would fail to be an exhaustible resource. The definition thus has both a biological and economic foundation.

A rather extensive body of literature[3] has developed around exhaustible resources, and our intention is to use a narrow portion of that literature to assist in the statistical analysis of surf clam production. In particular, we use a supply curve with cumulative production as an argument following Hotelling, Gordon and Cummings.[4] That surf clams are exhaustible resources is not argued here; rather, the tact taken is that the surf clam stock can be statistically analyzed using an exhaustible resource model.

The reasons for taking this approach relate to the circumstances surrounding the Virginia surf clam experience. Since the onset of the directed surf clam harvest in 1972, Virginia's industry exhibits characteristics that make the growth rate of the stock zero for practical purposes. One characteristic is the relative slow growth of the species. It takes around five or six years before a spawned surf clam reaches commercial size. Secondly, because surf clams are not hermaphroditic, their fertility is considered low. Also, the resource is found in clusters or beds that are geographically fixed and, once located, are easily found again with new loran systems. Fourthly, the technology that is used to harvest them is very sophisticated and can deplete rapidly any beds found. Finally, the lack of ownership of these resources precludes any of the users from deferring production so that the resource can grow. Any user that practices deferred production runs the risk of having another clammer reap the deferred production.

These characteristics suggest that the surf clam resources are being harvested in rates much more than natural replenishment. Thus, for descriptive purposes, the industry may be best examined using an exhaustible resource model. Following Cummings, the production function and state constraint for mined resource is given by:

$$x(t) = f(E, X(t))$$

$$X(t) = X_o - \int_o^t x(t)\,dt$$

where:

$x(t)$ - is landings in period t,
E - is an index of factor inputs,
$X(t)$ - is the stock of resource in t,
X_o - is the initial resource deposit,
$\int_o^t x(t)\,dt$ - is the cumulative past landings.

The production function can also be expressed as:

$$x = y(E, X_o - \int_o^t x(t)\,dt)$$

This relation simply states that output is a function of effort and the remaining stocks. We postulate that there is a non-linear relationship between current production and remaining stocks.

[2] This statement is consistant with definitions offered for non-renewable resources (Ciriacy-Wantrup) and exhaustible resources (Cummings).

[3] An excellent review of the entire body of exhaustible resource literature is presented by Ward (1977).

[4] Although Cummings uses an existing stock term instead of cumulative extraction, the purpose was the same.

Early in the development of the fishery, the great abundance does not lead harvestors to seek the "best" beds and, as remaining stocks fall, more productive beds are discovered. Thus, a negative relationship exists between output and remaining stocks. However, at a later stage of development, declining remaining stocks have a negative impact on production because the beds are all discovered and being thinned over time.

A corresponding supply function is:

$$x = g'(c(E),\ X_o - \int_o^t x(t)\ dt)$$

where c(E) is the per unit cost of effort. The shape of the long-run cost curve developed using this model may be somewhat different than the typical equilibrium steady state model supply curve of most fisheries models (Bell, Gates and Norton). First of all, a steady state position may not be reached for positive levels of extraction. Rather, short-run marginal cost curves early in the period when landings were very small shift downward as more productive beds are discovered. After the discovery phase, the short-run marginal cost curve rises. This rise occurs when previous landings begin to cause catch per trip to fall as the resource beds are thinned. Thus, both in the production function and the supply curve, one expects a "developmental" stage during which inputs and expenditures add increasingly to output that is then followed by "depleting" stage during which inputs and expenditures add decreasingly to output.

THE HYPOTHESIZED MODEL

A marketing system in which quantity supplied is matched with quantity demanded is specified in this section. The short-run supply curve is, from previous discussion, a function of surf clam price (PS) and remaining resource stocks. However, because remaining stocks is a difficult variable to observe, a transformation is suggested. We know that remaining stocks are initial stocks minus what has been removed:

$$X(t) = X_o - \int_o^t x(t)dt$$

or:

$$Z(t) = X_o - X(t) = \int_o^t x(t)dt$$

where Z(t) is cumulative landings. Since X_o does not vary with time, remaining stocks are solely a function of cumulative landings. Remaining stocks move in exactly the opposite direction that cumulative landings do. Thus, since there is no data on remaining stocks, cumulative landings should act as a near perfect proxy for remaining stocks.

Three other points must be developed before the supply curve is complete. First, the relationship between quantity supplied and remaining stocks has been suggested to be non-linear. For our purposes, we use a simple quadratic form where low cumulative landings positively affect quantity supplied and high cumulative landings negatively affect quantity supplied. It is also hypothesized that quantity supplied in the summer months are substantially higher than during the rest of the year. Weather conditions are not as favorable in the winter. A dummy variable is introduced to account for this difference. The final variable included on the supply side is landings in New Jersey and Maryland (L_N). This term acts as a surrogate for boats transitting between the northern beds and Virginia. One expects the sign of this variable to be negative, as reduced northern landings contribute to increased Virginia landings.

The final form of the supply function is:

$$(3)\quad x_t^s = \beta_0 + \beta_1 PS_t + \beta_2 Z_{t-1} + \beta_3 Z^2_{t-1} + \beta_4 DS + \beta_5 L_N + e_t$$

where x_t^s is quantity supplied and it is expected that:

$$\beta_1 > 0,\ \beta_2 > 0,\ \beta_3 < 0, \beta_4 > 0,\ \beta_5 < 0.$$

The demand for surf clams is completely a derived demand from processed strip and chowder clams. We hypothesize that the derived demand is a function of the price of surf clams (PS), the price of hard clams (PH) and time. The larger "chowder" hard clams can act as a substitute for surf clams, although their high price often precludes it. However, several processors operate hard clam and surf clam processing lines with the same fixed capacity. Thus, to a degree, they would be substitutes. The variable time (T) is included as an attempt to pick up trends in industrial demands that are not contained in the price variables.

We select a double-logarithmic estimating form so that the final demand function is:

$$(4)\quad \ln x_t^d = \gamma_0 + \gamma_1 \ln PS_t + \gamma_2 \ln PH_t + \gamma_3 \ln T + \upsilon_t$$

where it is expected that:

$$\gamma_1 < 0,\ \gamma_2 > 0.$$

Finally, we include an identity that quantity supplied equals quantity demanded:

$$(5)\quad x_t^s = x_t^d$$

The data used for estimating surf clam demand and supply equations is based on National Marine Fisheries Service recorded quantity and value of landings for Northamption and Accomack Counties, Virginia. The landings in these two counties comprise virtually the entire surf clam catch taken in Virginia. All data used were monthly time series beginning in April, 1972 and ending in November, 1976 for a total of fifty-five observations on each variable over a five-year period. Landings of hard and surf clams refer to the aggregate landings of the above two counties measured in (millions of) pounds of meat. Ex-vessel prices were calculated on the basis of average dollars per pound of meat and then deflated by the consumer price index (all items, unadjusted series).

THE ESTIMATED SYSTEM

Given the monthly nature of the available data, the surf clam price variable was dropped from the supply equation. It was our conviction that surf clam vessels can not substantially vary output in a month when prices change. With this adjustment, equation systems (3), (4) and (5) were run using a two-stage least squares procedure to eliminate simultaneous equation bias (Johnston) in the estimated coefficient on the surf clam price variable in the demand equation. Ordinary least squares was used to estimate the supply function.

Results

The results of estimating the system for the sample of 55 observations are (t — statistics in parentheses):

$$\text{Demand: } \ln x_t^d = -2.21 - \underset{(7.6)}{1.04} \ln PS_t + \underset{(2.2)}{1.83} \ln PH_t + \underset{(3.9)}{.47} \ln T$$

$$\text{Supply: } x_t^s = 1.40 + \underset{(9.2)}{.09} Z_t - \underset{(9.8)}{.0006} Z^2 + \underset{(1.2)}{.26} DS - \underset{(1.4)}{.20} L_N$$

$$R^2 = .69 \qquad DW = 1.38$$

The model performs well and conforms to expectations. For the demand equation, t — statistics were significant for all variables at least at the 2.5 percent level of confidence. The signs for the estimated price coefficients were as expected. The own-price elasticity estimate shows monthly demand to be almost unitary elastic, deviating from one by only .04. It should be noted that this elasticity implies that landings restrictions placed on vessels would have little effect on the fishermen's income because price would rise nearly enough to completely offset the volume loss.

The cross-price elasticity for hard clams supported the contention that hard clams compete for either processor's limited capacity or budget. The estimate of 1.83 is higher than would be expected. This might have been due to the practice of reporting mahogany clams (or ocean quahogs) as hard clams. There is reportedly more substitution between mahogany clams and surf clams than between hard clams and surf clams.

The final demand variable, time, showed a positive effect on the demand for surf clams. The reasons for this could be many: rising population causing greater marketing of processed clams, gradual changes in the processing sector as they move to get closer to the raw product, decreasing volumes of substitute clams from the northern areas. The non-linear relationship estimated, however, is such that the increase in demand in later periods resulting from the passage of time is substantially (by an order of 10) less than in the early periods. Thus, most of the effect of this variable has already impacted on the demand and should not have much impact in the future.

For the supply equation, the results were also satisfying. The signs of the coefficients were as expected, and the coefficients (β_2, β_3) most critical to the "mined resource" argument were highly significant. The seasonal dummy (DS) indeed shifted the supply curve outward during the summer months, and it did appear that decreases in landings in the northern states had a positive impact on Virginia's surf clam supply.

The cumulative landings variable did precisely as expected. The quadratic relationship that was hypothesized worked well. It showed that over the early range of cumulative landings (up to 75 million pounds), there was a positive relation between previous landings and current landings. After that level, the negative effects of previous landings took hold and current landings fell as cumulative landings increased. The turning point of 75 million pounds of clam meat was reached in early 1974 so that it is safe to state that the industry is now in the "depleting" period.

CONCLUSIONS AND IMPLICATIONS FOR MANAGEMENT

The salient feature of the specified model is a supply function that is determined principally from past landings. The major reason for such a specification is that the growth rate of the species could be considered zero for the period of analysis. This formulation is based on the mild relationship between resource stock size and future population, the relatively slow growth of surf clams (5-6 years to commercial size), the sophisticated technology used in landing surf clams and the common property characteristics of clams. The statistical analysis lent strong support to these propositions, and now attention is directed to the implications that the analysis has for the industry and management of the industry.

Intitially, there is **prima facie** evidence that current landings have a negative impact on future landings and that this condition has been prevalent for approximately three years. It is, thus, imperative to decide whether the industry should continue unmanaged and eventually use up the existing resources or rather be managed in a manner that will provide for continued production well into the future. This last option, of course, presumes that the current stock levels of clams can be naturally repleted. This is a technological question that must be addressed by biologists.

Since the Mid-Atlantic Regional Council (a management agency formed by the Fishery Conservation and Management Act of 1976, PL-94-265) is in the process of developing plans for management of surf clams and ocean quahogs, it appears that the management option has already been selected. Given that this decision has been made, there is some information contained in our analysis that may be useful to the managers.

First, two rather important aspects of the estimated demand equation should be emphasized: the near unitary elasticity of own-price elasticity and the strong cross-price elasticity with respect to hard clams. The own-price elasticity of −1.04 suggests that reductions in the amount of landings will have little impact on revenues received by fishermen, at least in the short-run. This is because the price rises nearly in proportion to reductions in quantity supplied. Thus, restrictions on landings, if they were deemed an appropriate management tool, would not hurt the income in the harvesting sector substantially in the short-run. The question remains, however, whether the incomes in the processing sector would fall and, in the long-run, harvesting incomes also. This aspect, the retail elasticity of surf clams, deserves further study.

The strong cross-price elasticity of hard clams and surf clams indicates a need for comprehensive management plans, both across species and in the state-federal relationship. The decision by the Regional Council to include in one management unit for both surf clams and ocean quahogs is a positive step toward satisfying this need. It is also important that the authorities responsible for the management of state hard clam regulations are represented on the Regional Council. The strong relationship with hard clams indicates that changes in state policies that impact on hard clam prices may influence demand and prices of surf clams. The Regional Council should be aware of possible changes. A corollary to this suggestion that was beyond the scope of our analysis is that the state agencies must take their hard clam plans in conjunction with the surf clam/ocean quahog plans. Just as processors can substitute hard clams for surf clams, so can they substitute surf clams for hard clams. Hence, there might be interdependence between surf clam prices and hard clam demands. Before making regulations on hard clams, it would be appropriate to have some notion of what surf clam policies and prices are going to be. The astute reader will notice the simultaneity in these two suggestions and propose comprehensive federal-state actions. One can hope that this may become feasible but, in the meantime, separate yet informed policies may have to prevail.

On the supply side of one analysis, there are a couple of key points that should be highlighted. First, as mentioned earlier, there is a statistically significant negative relationship between past and current landings. New sources of supply or some form of management will be needed for continuing high surf clam production. Secondly, mobility among states is present, even on a monthly basis. This suggest that management plans must recognize the ability of surf clam vessels to respond to area closures by redirecting effort elsewhere.

Because of the apparent mobility and relatively slow growth of the species, it may be the most efficient management policy to "pulse fish" the surf clams similar to the strategy followed by the industry to date. Obviously, it must be at a rate less than in the past. It could be done by area closures that let beds lie fallow to replenish themselves. Of course, it could also be accomplished by leasing bottom where individuals made their own decisions on where, when and for how long a bed was to remain fallow. The precise management method deserves far greater attention than we can devote here.

In conclusion, it is hoped that the reader can generalize our approach to other species of fish. By going from the traditional steady state model to a less conventional model of resource mining, we explained many of the factors that underlie the supply of surf clams. However, the approach should not be considered specific to the surf clam resource but rather general to situations where the depletion or mining of the resource base is the predominant factor on the supply side. This could occur in shellfisheries, some finfisheries or even in coral reef communities. After all, the fisheries management is predicated on restraining resource depletion, not resource equilibria.

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