Optimal Capacity Utilization of Shellfish Aquaculture Farms Producing Pacific Oyster (Crassostrea gigas) and Manila Clam (Venerupis philippinarum) under a Multi-species licence.

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TABLE OF CONTENTS

ABSTRACT

Shellfish aquaculture producers often apply for multi-species licences that allow for the production of more than one species on a single shellfish farm. Diversifying species production gives the producer some protection against loss due to diseases and parasites and acts as a hedge against market price volatility. In the short term, shellfish farm tenures are limited in size and the producer must determine what proportion of the tenure should be allocated to the production of each species that will result in the optimal revenue from sales. The concept of Optimal Capacity Utilization was used to analyze shellfish farms that produce both Pacific Oyster (*Crassostrea gigas*) and Manila Clam (*Venerupis philippinarum*) jointly on the same tenure. Regression analysis was used to estimate equations to describe possible species production and sales revenue for aquaculture farms of fixed tenure size. When these equations are graphed, lines representing production isoquants and revenue isoquants are produced whose intersections indicate optimal production for farms of tenure size up to about 4 hectares in size. Farms that are greater than 4 hectares in size should abandon the joint production of Pacific Oyster and Manila Clam and should specialize in the production of Manila Clam only.

RÉSUMÉ

Producteurs de l'aquaculture des mollusques s'appliquent souvent pour les licences multi-espèces qui permettent la production de plus d'une espèce sur une seule ferme aquacole. Diversifier la production des espèces donne au producteur une certaine protection contre les pertes dues aux maladies et aux parasites et agit comme une couverture contre la volatilité des prix du marché. À court terme, les tenures agricoles crustacés sont limités en taille et le producteur doivent déterminer quelle proportion de la durée du mandat devrait être alloué à la production de chaque espèce qui se traduira par des recettes provenant de la vente optimal. Le concept d'Optimal utilisation de la capacité a été utilisé pour analyser les exploitations conchylicoles qui produisent à la fois du Pacifique huître (*Crassostrea gigas*) et palourde japonaise (*Venerupis philippinarum)* conjointement sur le même mandat. L'analyse de régression a été utilisée pour estimer les équations pour décrire la production d'espèces possible et le chiffre d'affaires pour les fermes aquacoles de la taille de mandat fixe. Lorsque ces équations sont tracées, les lignes représentant isoquantes de production et isoquantes de revenus sont produites dont les intersections indiquer une production optimale pour les exploitations de taille d'occupation jusqu'à environ 4 hectares. Exploitations qui sont plus de 4 hectares devraient abandonner la production conjointe de huître creuse du Pacifique et palourde japonaise et devraient se spécialiser dans la production de palourde japonaise seulement.

INTRODUCTION

The aquaculture industry in British Columbia is jointly regulated by the Province of British Columbia and the Government of Canada through the Department of Fisheries and Oceans. Since most shellfish aquaculture sites are located on Crown Land, the Province of British Columbia is responsible for issuing a land tenure that allows the use of Crown Land for the culture and harvest of shellfish. The Department of Fisheries and Oceans is responsible for aquaculture licencing as well as monitoring and enforcing the conditions of licence through its regulatory arm Aquaculture Management.

Many shellfish growers apply for a multi-species licence that allows for the culture of more than one species of shellfish on the same aquaculture tenure. There are many reasons why a shellfish grower may wish to diversify production: to protect against diseases and parasites or to hedge against market price volatility. Once the decision to diversify production has been made, the shellfish grower must then determine what proportion of the shellfish tenure should be allocated to the production of each species that will result in optimum revenue.

Economic Production Theory may be used to construct a model of multi-species aquaculture production. The relationship between production and the spatial distribution of shellfish density within a limited licenced area has been investigated by Brigolin et al (2008). Furthermore, the Farm Aquaculture Resource Management (FARM) model put forth by Ferreira, Hawkins and Bricker (2007) uses the Cobb-Douglas production function to screen for economically optimal production for shellfish species grown under polyculture. A previous study by Coffen and Charles (1991) used Production Economics to construct a multiplicative form of the Cobb-Douglas Production Function to describe production as a function of the inputs of capital and labour.

The concept of Optimal Capacity Utilization may provide the best framework for constructing a model to determine the economically efficient combination of species grown in polyculture. Optimal Capacity Utilization has its roots in early industrialization when attempts were made to determine the optimal output from factories of fixed size. This approach may be easily adapted to shellfish aquaculture by determining the optimal production from an aquaculture farm of fixed tenure size. In this scenario, a shellfish farm employing polyculture on a farm of fixed tenure size will experience optimal production when the combination of product produced and sold to market generates the highest possible revenue.

METHODOLOGY

Data was collected from information contained in the Annual Aquaculture Statistical Reports (AASR) and the AQUIIS aquaculture licencing database both maintained by Aquaculture and Resource Management, the aquaculture management arm of Fisheries and Oceans Canada. The Annual Aquaculture Statistical Report is a condition of licence that requires all licence holders to report on the species cultured, biomass produced and the farm gate value received at harvest in addition to other relevant information for each farm tenure under licence. The AQUIIS licencing database provided physical data for licenced tenures including latitude and longitude, the management area in which the tenure is located and the size of the tenure measured in hectares. Data was collected on 83 sites located around Vancouver Island spanning the 2012 and 2013 reporting years and collated into an Excel spreadsheet. A regression analysis was performed using Eviews statistical software.

An important constraint on the productive capability of a shellfish aquaculture site is the physical size of the farm tenure. A regression analysis was performed to measure the relationship between the size of a shellfish aquaculture tenure measured in hectares and the biomass of Manila Clam and of Pacific Oyster produced on site. Other variables such as the culture type whether subtidal or deepwater, the management area in which the site was located and whether other species in addition to Manila Clam and Pacific Oyster were grown on site. The following regression was tested:

$$\mathbf{Ln(TENURE) = Ln(OYSTER) + Ln(CLAM) + DEEP + OTHER + AREA13 + e} \qquad (1)$$

In the regression described in equation (1), TENURE is the size of the farm site measured in hectares, OYSTER is the biomass of Pacific Oyster produced measured in tonnes, CLAM is the biomass of Manila Clam produced measured in tonnes, DEEP is a dummy variable taking the value of 1 if the tenure uses a deep water culture method, OTHER is a dummy variable taking the value of 1 if other species in addition to Manila Clam and Pacific Oyster are grown on site and AREA13 is a dummy variable taking the value 1 if the site is located within management area 13. The last independent variable was selected since it is the most northerly management area in the sample and thus reflects the influence of latitude on production. A double log form of the regression was used to mitigate against heteroskedasticity. The regression produced the following estimate:

Ln(TENURE) =	**0.656 +**	**0.108Ln(OYSTER) +**	**0.252Ln(CLAM) +**	**0.396DEEP +**	**0.476OTHER**	**- 0.655AREA13**
SE	**(3.12)**	**(1.81)**	**(5.69)**	**(2.44)**	**(3.21)**	**(-3.87)**
P-val	**(0.00)**	**(0.07)**	**(0.00)**	**(0.01)**	**(0.00)**	**(0.00)**

By taking the antilog of both sides of the estimate, the following equation is obtained:

$$\text{TENURE} = e^{0.656}\text{OYSTER}^{0.108}\text{CLAM}^{0.252}e^{0.396\text{DEEP}}e^{0.476\text{OTHER}}e^{-0.655\text{AREA13}} \quad (2)$$

For aquaculture tenures that are not using deep water culture methods, nor growing other species and are not located in management area 13, equation (2) simplifies to:

$$\text{TENURE} = 1.93\text{OYSTER}^{0.108}\text{CLAM}^{0.252} \quad (3)$$

When the dependent variable TENURE is fixed at different sizes measured in hectares, the graph produced is a series of downward sloping curved lines as shown in figure 1. These lines are production isoquants and represent the elasticity of production between Manila Clam and Pacific Oyster that may be produced on a farm of fixed tenure size. The slopes of the production isoquants indicate the marginal rate of substitution between species produced on a farm of fixed tenure size. For example, moving down the isoquants from left to right will indicate the amount of production of Pacific Oyster that must be forgone in order to gain an additional amount of production of Manila Clam on a farm of fixed tenure size. As tenure size increases, the isoquants move upward and to the right indicating the possibility of increased production of both species.

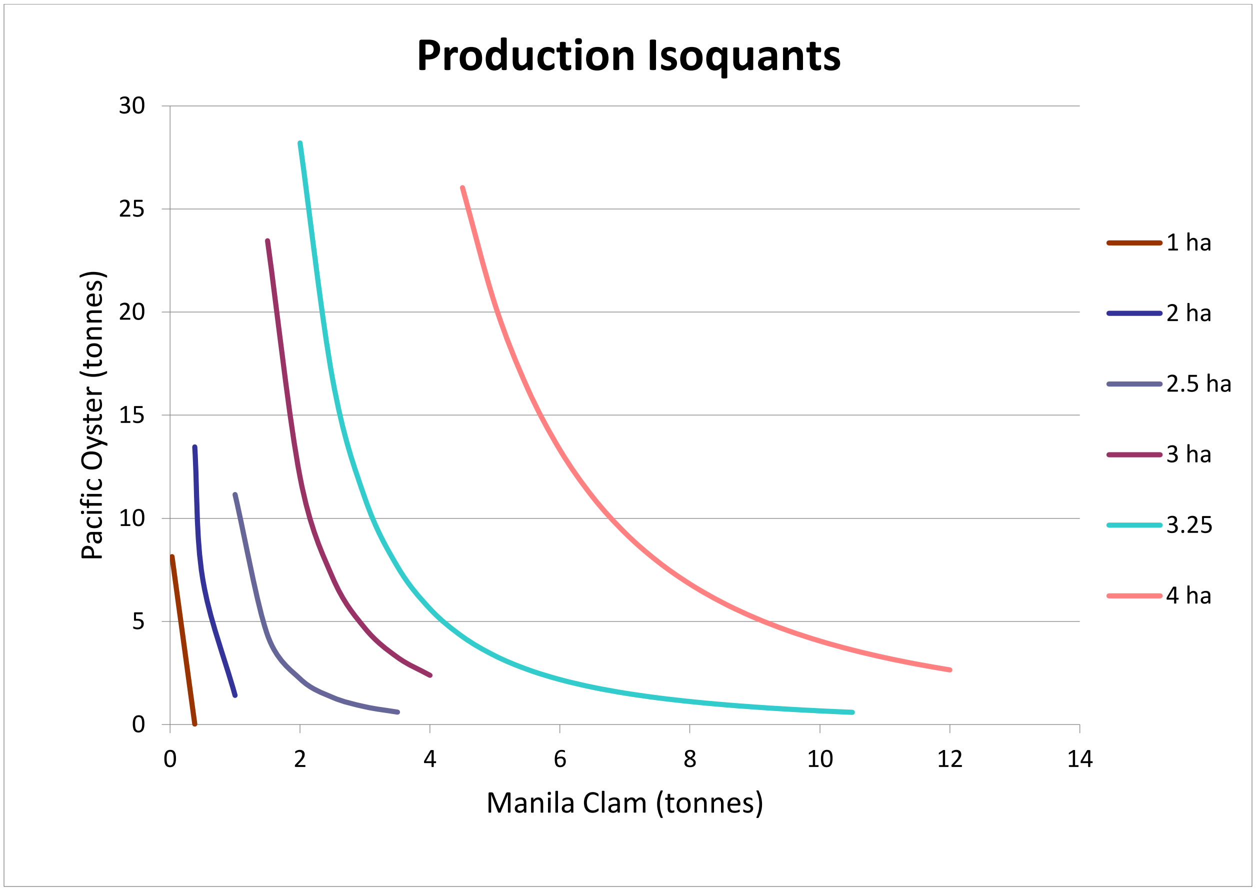

Figure 1

A second regression analysis was performed to measure the relationship between the total revenue generated by shellfish tenures from the sale of both Manila Clam and Pacific Oyster against the size of the aquaculture tenure size measured in hectares for each site. The regression took the following form:

$$\mathbf{Ln(REVENUE) = Ln(TENURE) + e} \tag{4}$$

The regression produced the estimated equation:

Ln(REVENUE) =	**9.35 +**	**0.858Ln(TENURE)**
SE	**(0.16)**	**(0.10)**
P-val	**(0.00)**	**(0.00)**

Taking the antilog of the estimated produces the equation:

$$\mathbf{REVENUE = e^{9.35} TENURE^{0.858}} \tag{5}$$

Next, a regression was performed on the revenue generated from the sale of Pacific Oyster against the production of Pacific Oyster per hectare and the total size of the aquaculture tenure measured in hectares for each site producing both Pacific Oyster and Manila Clam. The regression took the following form:

$$\mathbf{Ln(OYSTER\ REVENUE) = Ln(OYSTER/TENURE) + TENURE + e} \tag{6}$$

The regression yielded the following estimated equation:

Ln(OYSTER REVENUE) =	**8.05 +**	**0.766Ln(OYSTER/TENURE) +**	**0.900Ln(TENURE)**
SE	**(0.13)**	**(0.05)**	**(0.07)**
P-val	**(0.00)**	**(0.00)**	**(0.00)**

The antilog of the estimate yields the equation:

$$\mathbf{OYSTER\ REVENUE = e^{8.057}(OYSTER/TENURE)^{0.766}\ TENURE^{0.900}} \tag{7}$$

A similar regression may be constructed to measure the revenue generated from the sale of Manila Clam against the production of Manila Clam per hectare and the total size of the tenure measured in hectares.

$$\mathbf{Ln(CLAM\ REVENUE) = Ln(CLAM/TENURE) + TENURE + e} \tag{8}$$

When the above regression is run, the following estimate is produced:

Ln(CLAM REVENUE)	**8.459 +**	**0.955Ln(CLAM/TENURE) +**	**0.985TENURE**
SE	**(0.12)**	**(0.05)**	**(0.07)**
P-val	**(0.00)**	**(0.00)**	**(0.00)**

Taking the antilog of the estimate produces the equation:

$$\textbf{CLAM REVENUE} = e^{8.459}\,(\textbf{CLAM/TENURE})^{0.955} + \textbf{TENURE}^{0.985} \qquad (9)$$

Since the revenue generated from the combined sale of the tonnes Pacific Oyster and the tonnes of Manila Clam produced on an aquaculture tenure must be equal to the revenue generated by the sale of the tonnes of Pacific Oyster produced on site and the revenue generated by the tonnes of Manila Clam produced on site, the estimated equations (5),(7) and (9) may be combined to produce the equation:

$$1499\textbf{TENURE}^{0.858} = 3155(\textbf{OYSTER/TENURE})\textbf{TENURE}^{0.900} + 4717(\textbf{CLAM/TENURE})^{0.955}\,\textbf{TENURE}^{0.985} \qquad (10)$$

By fixing the size of tenure in equation (10), the relationship between the revenue generated from the sale of Pacific Oyster measured in tonnes and the revenue generated from the sale of Manila Clam measured in tonnes may be illustrated graphically in figure 2. The lines in the graph are revenue isoquants and represent combinations of the sale of Pacific Oyster and Manila Clam that when sold to market will generate the expected revenue for an aquaculture site of fixed tenure size. The revenue isoquants illustrate optimal combinations; areas below the lines are possible but are sub-optimal while areas above the lines are not feasible. The revenue isoquant lines are downward sloping indicating the inverse relationship between the production of Manila Clam and Pacific Oyster. Given an aquaculture farm of fixed tenure size, a greater production of one species will require a reduced production of the other and will be reflected by a change in revenue from the sales of production.

The slope of any revenue isoquant represents the marginal rate of substitution between the production of Oyster and Manila Clam required to maintain constant expected revenue for a farm of fixed tenure size. Moving from right to left on any isoquant, for example, will indicate the amount of Pacific Oyster measured in tonnes that must be forgone to produce additional Manila Clam measured in tonnes such that the expected revenue generated from the combined sales remains constant on an aquaculture of fixed tenure size. As tenure size is increased, the lines move upward and to the right to reflect greater possibilities of production for both Manila Clam and Pacific Oyster. The slopes of the isoquants in figure 2 become steeper as the sizes of the aquaculture tenures increase representing a diminishing marginal rate of production for Pacific Oyster. As tenure size increases, a greater amount of Pacific Oyster production must be forgone so that Manila Clam production may be increased to maintain constant expected revenue for a aquaculture tenure of fixed size.

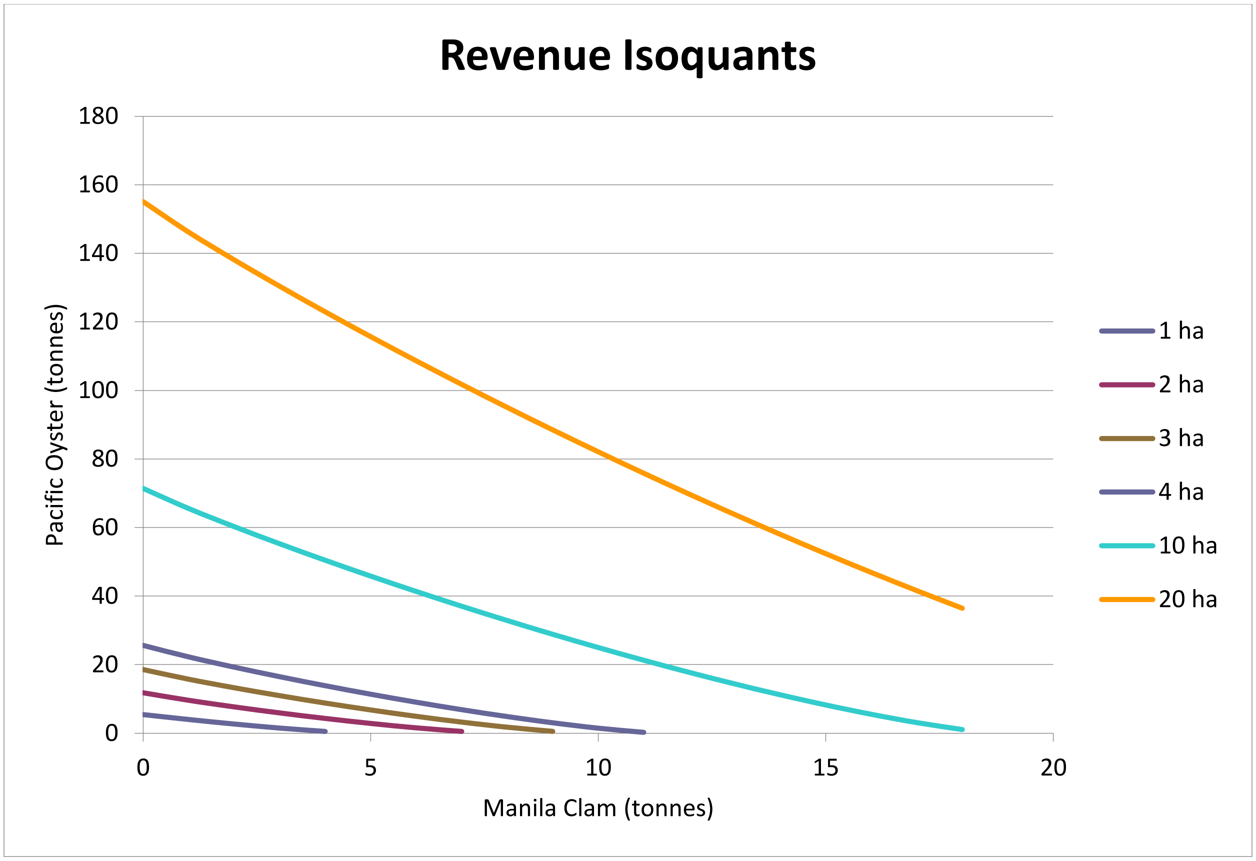

Figure 2

ANALYSIS

Optimal production of both Pacific Oyster and Manila Clam for a given tenure size is a short-run concept of capacity utilization. The aquaculture grower will produce a combination of Pacific Oyster and Manila Clam that will generate the maximum revenue. This combination is indicated graphically in figure 3 as the point of intersection between the production and revenue isoquants. In the long run, tenure size may be increased and new optimal combinations of production will be established by the intersection of the production and revenue isoquants that reflect the increased tenure size. When the points of intersection are connected together by a line illustrated in figure 4, an expansion path is created that represents a combination of production of Pacific Oyster and Manila Clam that maximizes revenue as the size of the tenure expands.

The expansion path in the case of shellfish tenures producing both Pacific Oyster and Manila Clam is non-linear in shape. For example, as the tenure size increases from 1 hectare to 2 hectares, the production of both Pacific Oyster and Manila Clam increases.

An increase in tenure size from 2 hectares to 2.5 hectares will again result in an increase of production of both species but at a much slower rate for Pacific Oyster. A further increase of tenure size from 2.5 hectares to 3 hectares shows that optimal

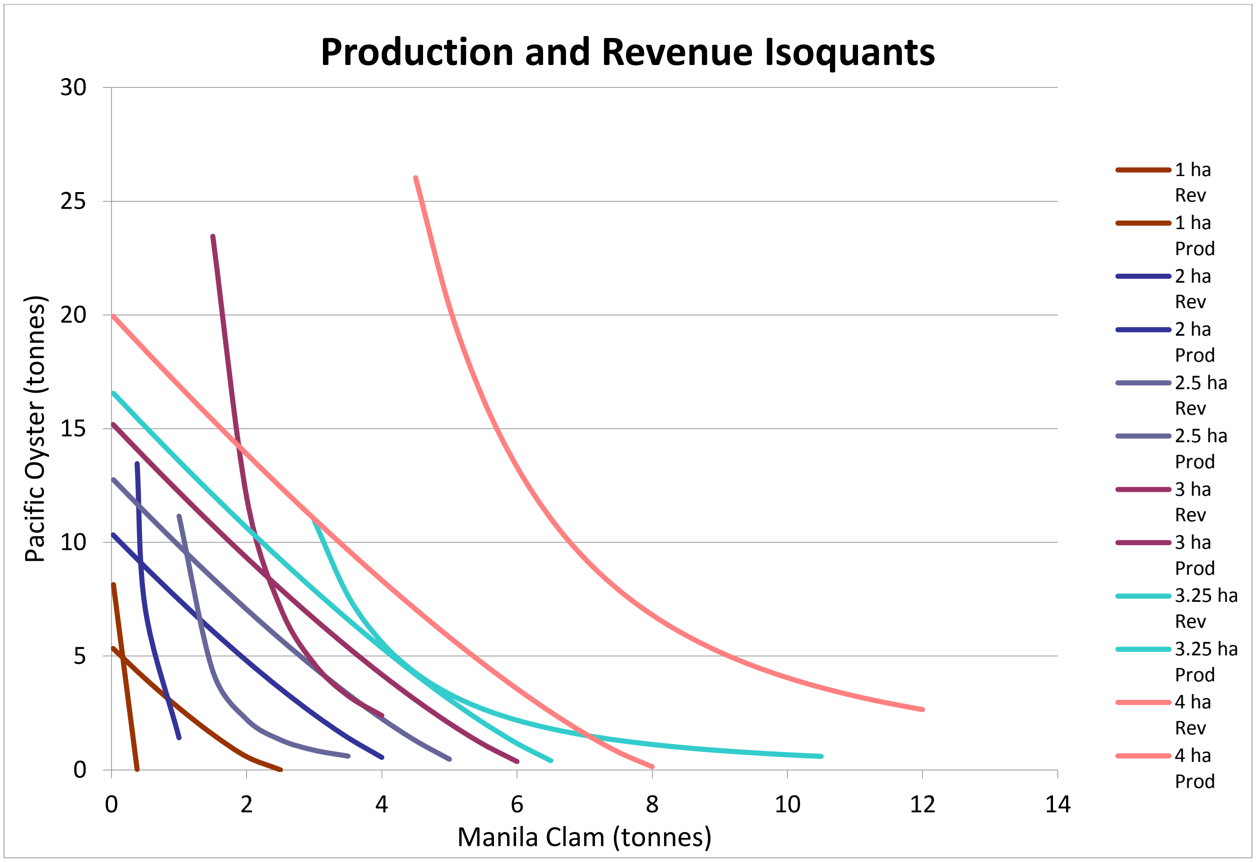

Figure 3

capacity utilization occurs with an increase in production of Manila Clam but at the expense of a decrease in production of Pacific Oyster. An increase in tenure size from 3 hectares to 3.5 hectares requires a substantial reduction in Pacific Oyster production in order to achieve optimal capacity utilization. Finally, an aquaculture farm tenure of 4 hectares in size produces a revenue isoquant that falls below the corresponding production isoquant indicating that any joint production of Pacific Oyster and Manila Clam will be sub-optimal. At this point, the aquaculture grower should abandon multi-species production and should specialize in the production of Manila Clam.

The expansion path may be deconstructed to illustrate the individual changes in the quantity of Pacific Oyster produced and the quantity of Manila Clam produced as the size of the shellfish tenure increases as depicted in figure 5. On aquaculture sites producing both Pacific Oyster and Manila Clam the production of Pacific Oyster peaks when tenure size reaches about 2.5 hectares and drops to zero when tenures reach about 4 hectares in size.

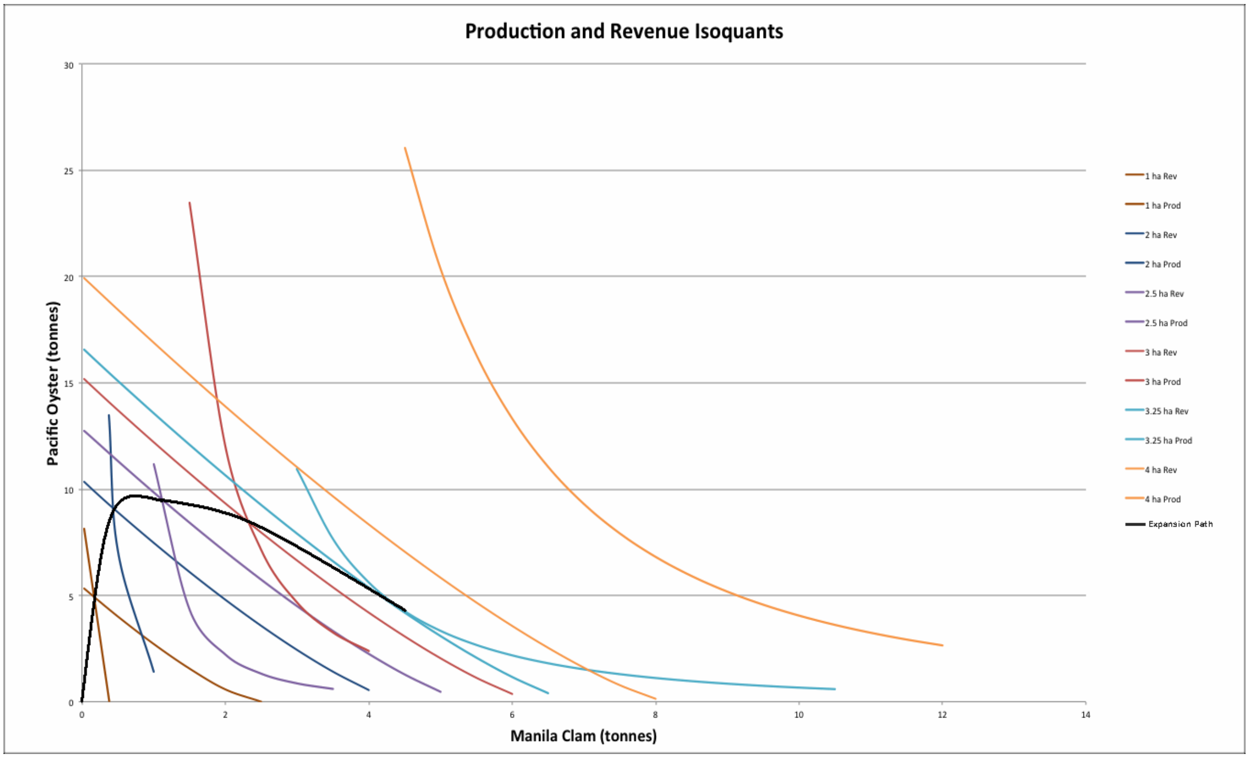

Figure 4

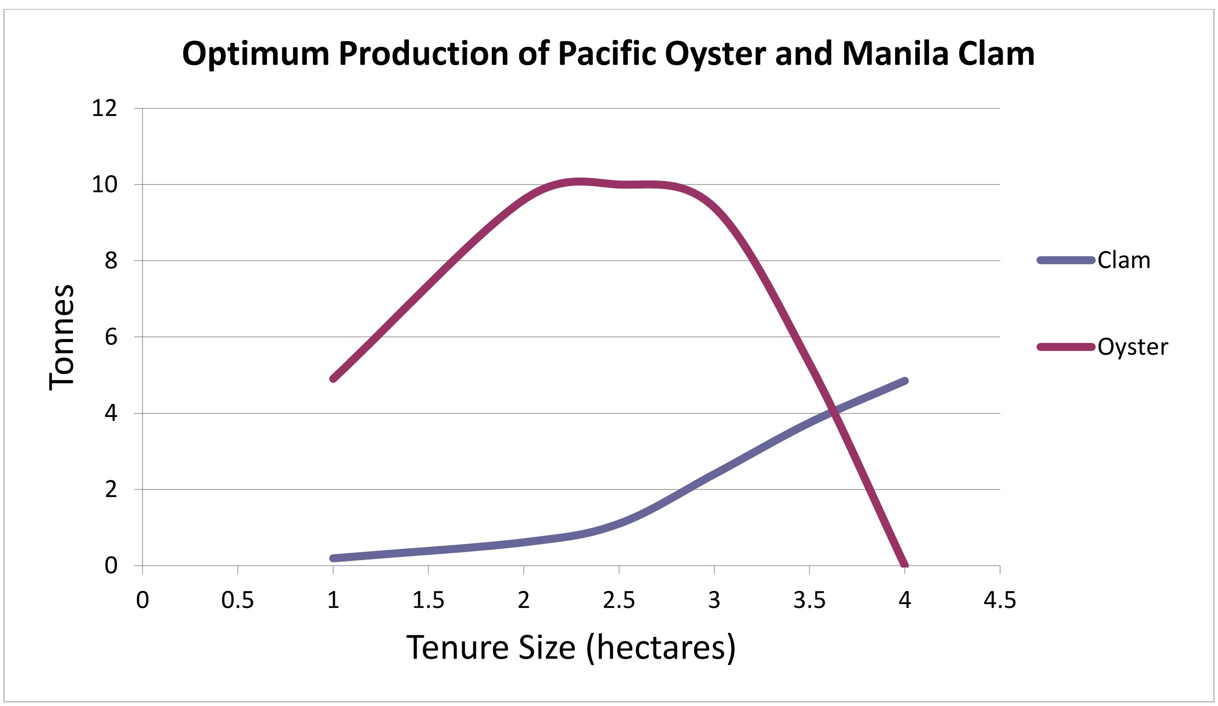

Figure 5

The limits to the production of Pacific Oyster on aquaculture sites producing both Pacific Oyster and Manila Clam appears to be understood by most shellfish growers on a practical level. Figure 6 shows the production of Pacific Oyster in tonnes as a percentage of total production from shellfish sites that cultured both Pacific Oyster and Manila Clam throughout the 2012 and 2013 reporting years. As tenure size increases, the percentage of total production attributed to Pacific Oysters decreases. Conversely as shellfish tenure size increases, the percentage of total production comprised of Manila Clam increases as shown in figure 7. Furthermore, both of the graphs in figure 6 and 7 show joint production of Pacific Oyster and Manila Clam clustered when shellfish tenures are less than 5 hectares in size.

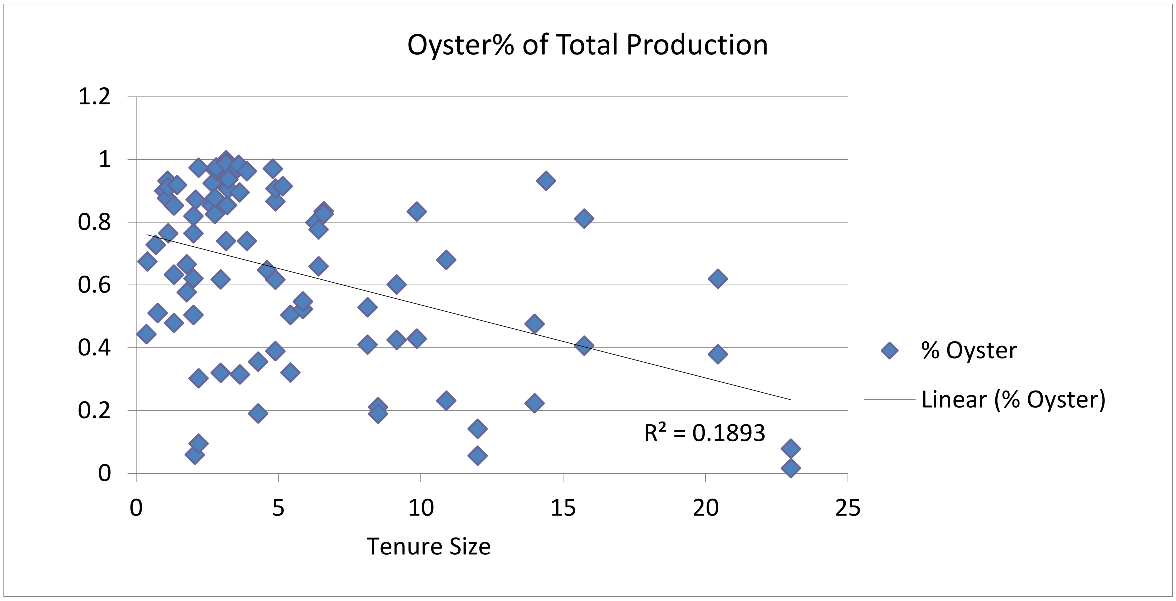

Figure 6

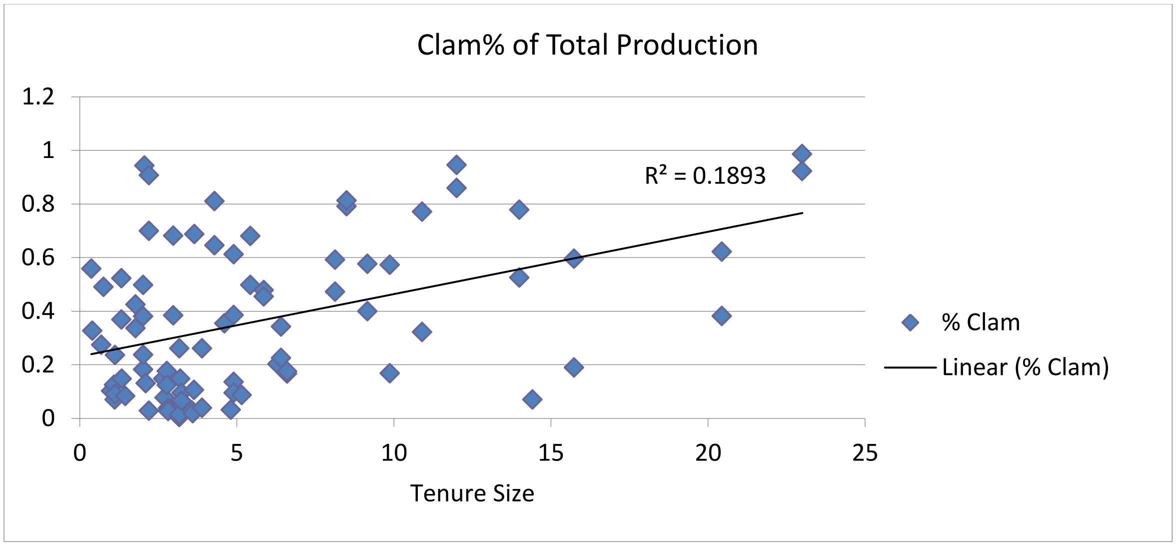

Figure 7

CONCLUSION

An analysis of the data returned from the Annual Aquaculture Statistical Report combined with information contained in the AQUIIS licencing database was used to perform a statistical analysis of shellfish aquaculture sites that produce both Pacific Oyster and Manila Clam. By using the concept of Optimal Capacity Utilization found in Economic Production Theory, production and revenue isoquants were constructed whose intercepts reveal the optimal combination of production of Pacific Oyster and Manila Clam for an aquaculture farm of fixed tenure size. The results of the statistical analysis leads to the conclusion that the joint production of Pacific Oyster and Manila Clam may be grown on an aquaculture site operating at optimal capacity for sites less than about 4 hectares in size. For aquaculture sites of greater tenure size, the joint production of Pacific Oyster and Manila Clam can only be achieved if the aquaculture site is operating at sub-optimal capacity. Therefore, aquaculture sites on tenures that are greater than about 4 hectares in size should specialize in the production of Manila Clam only.

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APPENDIX

First Regression

Dependent Variable: Ln(TENURE)
Method: Least Squares
Sample: 1 83
Included observations: 83
White heteroskedasticity-consistent standard errors & covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.655844	0.209750	3.126797	0.0025
Ln(OYSTER)	0.108035	0.059659	1.810874	0.0741
Ln(CLAM)	0.252110	0.044253	5.696998	0.0000
DEEPWATER	0.396372	0.162052	2.445956	0.0167
OTHER SPECIES	0.476427	0.148341	3.211694	0.0019
AREA13	-0.655333	0.169097	-3.875485	0.0002

R-squared	0.548507	Mean dependent var	1.364639
Adjusted R-squared	0.519190	S.D. dependent var	0.909351
S.E. of regression	0.630549	Akaike info criterion	1.985090
Sum squared resid	30.61455	Schwarz criterion	2.159946
Log likelihood	-76.38124	Hannan-Quinn criter.	2.055337
F-statistic	18.70909	Durbin-Watson stat	1.440319
Prob(F-statistic)	0.000000	Wald F-statistic	21.93745
Prob(Wald F-statistic)	0.000000		

Second Regression

Dependent Variable: Ln(OYSTER VALUE+CLAM VALUE)
Method: Least Squares
Sample: 1 83
Included observations: 83

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9.353605	0.166349	56.22895	0.0000
Ln(TENURE SIZE)	0.857532	0.101629	8.437882	0.0000

R-squared	0.467798	Mean dependent var	10.52383
Adjusted R-squared	0.461228	S.D. dependent var	1.140126
S.E. of regression	0.836865	Akaike info criterion	2.505493
Sum squared resid	56.72777	Schwarz criterion	2.563778
Log likelihood	-101.9780	Hannan-Quinn criter.	2.528909
F-statistic	71.19785	Durbin-Watson stat	1.359466
Prob(F-statistic)	0.000000		

Third Regression

Dependent Variable: Ln(OYSTER VALUE)
Method: Least Squares
Sample: 1 83
Included observations: 83

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	8.057217	0.135012	59.67795	0.0000
Ln(OYSTER/TENURE)	0.766189	0.052805	14.50983	0.0000
Ln(TENURE)	0.900795	0.078443	11.48338	0.0000

R-squared	0.757858	Mean dependent var	9.626478
Adjusted R-squared	0.751805	S.D. dependent var	1.193361
S.E. of regression	0.594523	Akaike info criterion	1.833360
Sum squared resid	28.27659	Schwarz criterion	1.920788
Log likelihood	-73.08444	Hannan-Quinn criter.	1.868484
F-statistic	125.1925	Durbin-Watson stat	1.357610
Prob(F-statistic)	0.000000		

Fourth Regression

Dependent Variable: Ln(CLAM VALUE)
Method: Least Squares
Sample: 1 83
Included observations: 83

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	8.458760	0.123715	68.37309	0.0000
Ln(CLAM/TENURE)	0.955170	0.053773	17.76286	0.0000
Ln(TENURE)	0.985293	0.074171	13.28400	0.0000

R-squared	0.864242	Mean dependent var	9.437409
Adjusted R-squared	0.860848	S.D. dependent var	1.636284
S.E. of regression	0.610385	Akaike info criterion	1.886023
Sum squared resid	29.80563	Schwarz criterion	1.973451
Log likelihood	-75.26995	Hannan-Quinn criter.	1.921146
F-statistic	254.6409	Durbin-Watson stat	1.586123
Prob(F-statistic)	0.000000		