

Introduction

Pilot giant clam farming has been practiced or experimented with in several U.S.-affiliated Pacific islands, in Solomon Islands and Australia and elsewhere. The two fastest-growing species are being cultured in these locations: *T. gigas* and *T. derasa*.

The key to the success of the giant clam industry, like that of any other industry, is coordination of the marketing and production operations. To evaluate the potential of the giant clam industry, information on market and production economics are urgently needed. The markets of the giant clam products have been studied (Shang et al. 1991, 1993). However, information on production economics is very limited.

The purposes of this production economics study are:

1. to document and compare production costs of giant clam culture systems in the U.S.-affiliated Pacific islands; and
2. to identify the optimal harvest age for giant clam (*T. derasa*).

Production cost comparisons of giant clam culture systems in the U.S.-affiliated Pacific islands

There are two distinct culture systems being experimented with in the Pacific island countries. One system uses land-based tanks/raceways while the other system uses floating tanks in the hatchery and nursery phases (Figure 18.1).

Production cost data were collected during 1991 and 1992 from giant clam culture facilities in the following U.S.-affiliated Pacific islands: the Republic of Palau, the Republic of Marshall Islands, Kosrae, and American Samoa. Wherever possible, information was collected for the three phases of clam production, i.e., hatchery, nursery and growout. Information was obtained through personal interviews with facility managers at each site. Discounted costs were estimated at the various stages of production using a discount rate of 10% and assuming an operation life of 20 years. The analysis also assumed that 100% of the required capital is borrowed at an annual interest rate of 10% with a 10-year loan period. Sensitivity analyses were also performed on key production and financial parameters. The results of the analysis are detailed in the following sections.

Republic of Marshall Islands

Two systems of culturing *T. gigas* are being experimented with by Mr Neal Skinner in the Republic of Marshall Islands. One system uses raceways in the hatchery phase while the other system uses floating tanks. These two systems are designed for small operations and mainly rely on solar energy to generate electricity. In the nursery

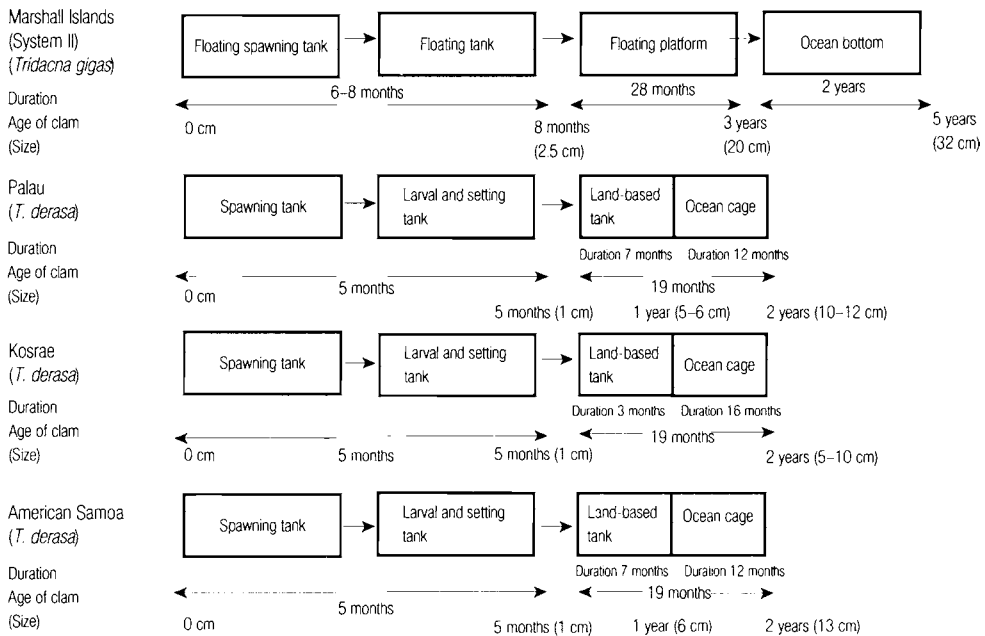


Figure 18.1 Giant clam production system.

phases, both systems utilise floating platforms with plastic trays. Clams are then grown-out on shallow fringe reefs. Figure 18.1 summarises the major production phases and the associated ages and sizes of clams at the various stages.

Hatchery

For the hatchery phase, a target of 40000 clams is assumed to be produced in eight months to an average size of 2.5 cm. The capital costs for both the raceway system and the floating tank system are shown in Appendix Tables A18.1a and A18.1b respectively. As expected, total capital costs for the raceway system are higher than the floating tank system, \$12330 vs. \$10135. Typical annual operating costs for the raceway system are estimated to be \$16881 and for the floating tank system, \$9753. Breakdowns of the annual operating costs for the two systems are shown in Appendix Tables 18.2a and 18.2b, respectively. The annual operating cost breakdowns are similar for the two systems, with labour costs (wages and salaries) accounting for over 70% of total operation costs (Figures 18.2 and 18.3). The estimated cost of producing 8-months old *T. gigas* using the raceway hatchery system is \$0.41/clam while the cost for the floating tank system is \$0.23/clam.

Figures 18.4 and 18.5 show, respectively, the sensitivity of production cost to the changes in major cost items for the hatchery phase of both systems. As expected, changes in labour costs have the most effect on cost of production. A 10% increase in labour cost would raise the production cost per clam by 7.3% (from \$0.41–0.44/clam) for the raceway system and by 8.7% (from \$0.23–0.25/clam) for the floating tank system.

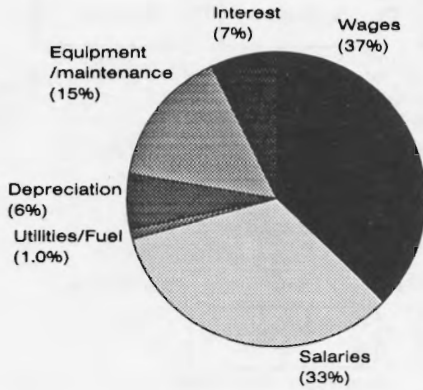


Figure 18.2 Annual operating costs of hatchery operation (raceway system) on Marshall Islands (to nearest percentage point).

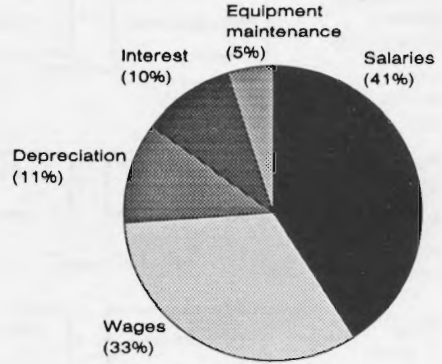


Figure 18.3 Annual operating costs of hatchery operation (floating tank system) on Marshall Islands (to nearest percentage point).

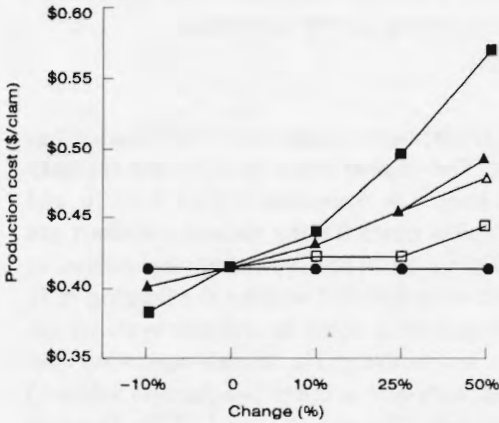


Figure 18.4 Sensitivity of production cost to changes in labour costs, energy costs and capital costs for hatchery operation using raceways on Marshall Islands.

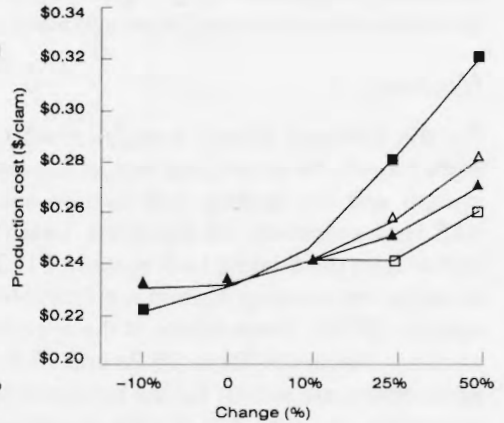


Figure 18.5 Sensitivity of production cost to changes in labour costs and capital costs for hatchery operation using raceways on Marshall Islands.

Legend:
 Wages -▲-; Salaries-△-; Total labour costs -■-; Energy costs -●-; Capital costs -□-.

Nursery

The nursery phase assumes an annual target production of 800 clams to be raised from 2.5–20 cm in 28 months. Survival rate is assumed to be 80%, i.e., stocking rate is assumed to be 1000 clams. It is assumed that there are 15 floating platforms which can hold 9 trays each and each tray can hold twelve 3-year-old *T. gigas*. The nursery capital costs are shown in Appendix Table A18.3. The annual operating costs for nursery are shown in Appendix Table A18.4 (assuming juvenile clams are from the raceway hatchery system). The estimated cost of raising a clam to 3-year-old is about \$5.08/clam if the stocking cost per clam is \$0.41 (i.e., juvenile clams from the raceway hatchery system). However, if the stocking cost per clam is \$0.23 (i.e., juvenile clams from the floating tank hatchery system), the estimated cost decreases to about \$4.83/clam.

The percentage breakdowns of annual operating costs for the nursery phase are very similar for either system used in the hatchery phase, since the only difference is in stocking costs which is higher if the juveniles are from the raceway hatchery system (Figures 18.6 and 18.7). The percentage changes in major cost items also have similar effect on the production cost per clam for both hatchery systems with labour costs the most sensitive as expected (Figures 18.8 and 18.9).

Growout

The ocean growout phase assumes a 2-year cycle with an annual target production of 720 clams. Three-year-old clams of about 20 cm are assumed to grow to 32 cm in two years with 10% mortality. The capital cost for ocean growout is shown in Appendix Table A18.5. Appendix Table A18.6a shows the annual operating costs assuming the stocking cost of a 3-year-old *T. gigas* is \$5.08 and Appendix Table A18.6b shows the annual operating costs assuming the stocking cost of a 3-year-old clam is \$4.83. Estimated total cost of producing a 5-year-old clam is \$9.44 if the raceway hatchery system is used. The cost is lower, \$9.13/clam, if the floating hatchery system is used.

As in the nursery phase, the percentage breakdowns of annual operating costs for the ocean growout phase using either hatchery system are almost identical (Figures 18.10 and 18.11). As a result, changes in production cost parameters have similar effects on the cost of producing a 5-year-old clam by either system (Figure 18.12 and 13). Stocking cost shows the greatest effect on production cost for both systems since it constitutes the largest cost item.

Republic of Palau

The Micronesian Mariculture Demonstration Center (MMDC) in the Republic of Palau uses a land-based hatchery and a combined land-based and ocean-cage nursery system to produce 2-year-old *T. derasa*. The hatchery phase takes about 5 months and produces clams of about 1 cm. The nursery phase consists of 7 months in land-based tanks and 12 months in ocean cages. The 1-year-old clam

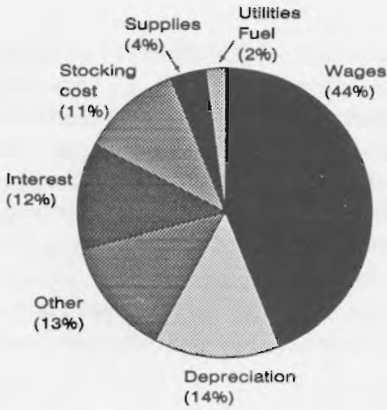


Figure 18.6 Annual operating costs of nursery operation using raceway hatchery system on Marshall Islands (to nearest percentage point).

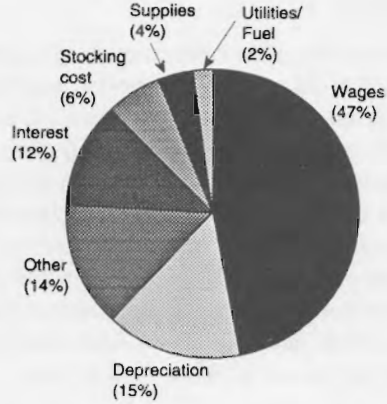


Figure 18.7 Annual operating costs of nursery operation using floating tank hatchery system on Marshall Islands (to nearest percentage point).

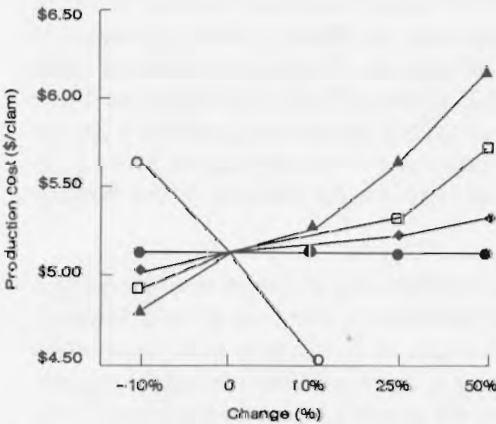


Figure 18.8 Sensitivity of production cost to changes in wages, energy costs, capital costs, stocking cost and survival rate for nursery operation using raceway hatchery system on Marshall Islands.

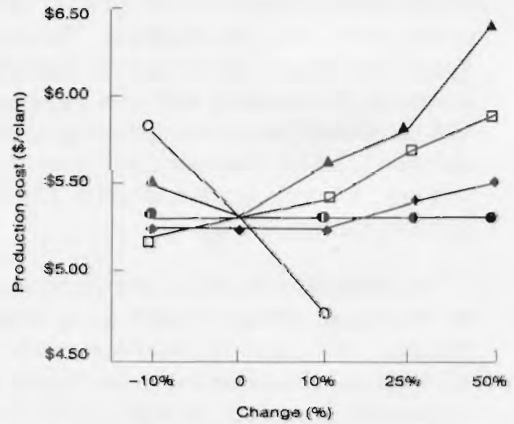


Figure 18.9 Sensitivity of production cost to changes in wages, energy costs, capital costs, stocking cost and survival rate for nursery operation using floating tank hatchery system on Marshall Islands.

Legend:

Wages -▲-; Survival rate -○-; Stocking cost -◆-; Energy costs -●-; Capital costs -□-

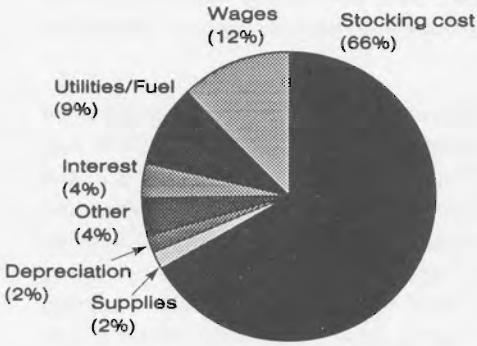


Figure 18.10 Annual operating costs of growout operations using raceway hatchery system on Marshall Islands (to nearest percentage point).

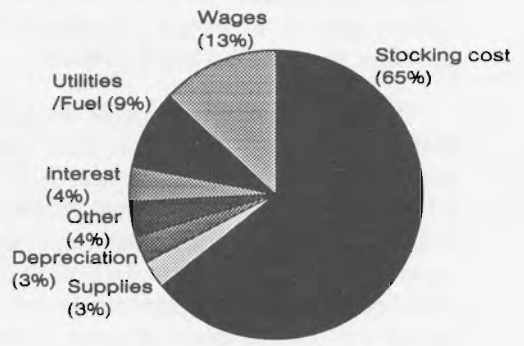


Figure 18.11 Annual operating costs of growout operation using floating tank hatchery system on Marshall Islands (to nearest percentage point).

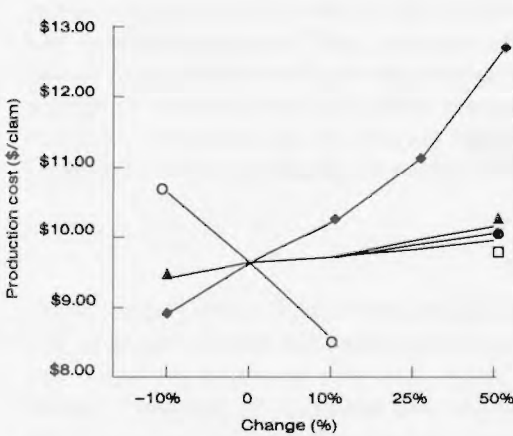


Figure 18.12 Sensitivity of production cost to changes in wages, energy costs, capital costs, stocking cost and survival rate for growout operation using raceway hatchery on Marshall Islands.

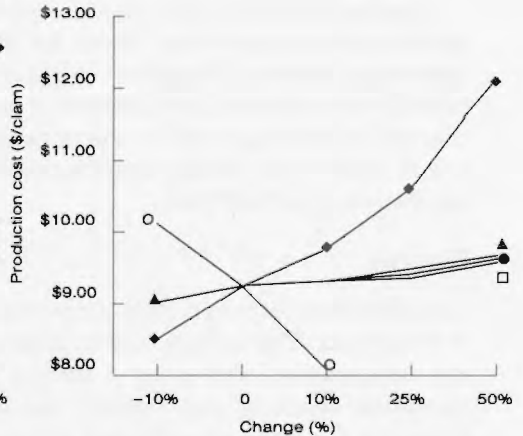


Figure 18.13 Sensitivity of production cost to changes in wages, energy costs, capital costs, stocking cost and survival rate for growout operation using floating tank hatchery system on Marshall Islands.

Legend:
 Wages -▲-; Survival rate -○-; Stocking cost -◆-; Energy costs -●-; Capital costs -□-.

after the land-based nursery is about 5–6 cm and the 2-year-old clam after the ocean cage nursery is about 10–12 cm. Figure 18.1 provides a summary of the culture system at MMDC. Details of the production system can be found in Heslinga, Watson and Isamu (1990).

The annual throughput of the hatchery and land-based nursery is assumed to be 200 000 1-year-old *T. derasa*. Total capital costs amount to about \$299 000 and annual operating costs amount to \$173 433 (see Appendix Tables A18.7 and A18.8 for detailed breakdowns). Production cost of a 1-year-old clam is estimated to be about \$0.82. The ocean cage nursery assumes a 75% survival rate with an annual production target of 150 000 clams. Capital costs and annual operating costs are detailed in Appendix Tables A18.9 and A18.10, respectively. The estimated total cost of producing the 2-year-old clam is \$1.41. The estimated costs of production are well below the farm-gate prices charged by MMDC for 1 and 2-year-old clams which are \$1.00 and \$3.00/clam, respectively.

The percentage breakdowns of annual operating costs for the combined hatchery and land-based nursery and ocean-cage nursery are shown in Figures 18.14 and 18.15, respectively. With the combined hatchery and land-based nursery, labour (wages and salaries), depreciation, and interest payment accounted for 78.6% of total annual operating costs, while for the ocean-cage nursery, these costs are less than 23%. The major cost item for the ocean-cage nursery is stocking cost.

Figures 18.16 and 18.17 show, respectively, the sensitivity of production cost to the changes in major cost items for the hatchery and land-based nursery and ocean-cage nursery. Production cost is most sensitive to relative changes in capital costs for the hatchery and land-based nursery while it is most sensitive to relative changes in stocking cost for the ocean-cage nursery. A 10% increase in survival rate in ocean-cage nursery operation would reduce the production cost from \$1.41 per clam to \$1.28 per clam.

Kosrae

The giant clam farm in Kosrae is operated by the government of the Federal States of Micronesia. The culture system used is adapted from the MMDC. However, it is still experimental and is on a smaller scale than the operation in Palau. The combined hatchery and nursery operations are assumed to produce 100 000 2-year-old *T. derasa* annually with an average size of 5–10 cm. The hatchery phase takes about 5 months. Clams are then transferred to land-based nursery tanks and kept there for 3 months. Finally, clams are planted in ocean nursery cages for 16 more months or until they reach 2 years of age (see Figure 18.1).

The total capital costs for this operation are about \$183 000 and the annual operating costs amount to \$116 040. The production cost for a 2-year-old clam is estimated to be \$1.23. It should be noted that electricity and fertiliser costs are provided by the government, therefore, the production cost per clam would increase slightly if electricity and fertiliser costs are included.

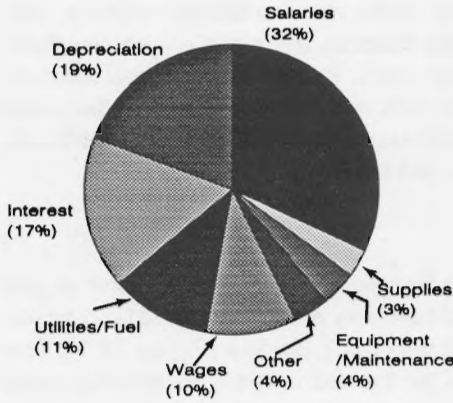


Figure 18.14 Annual operating costs of combined hatchery and landbased nursery operations in Palau (to nearest percentage point).

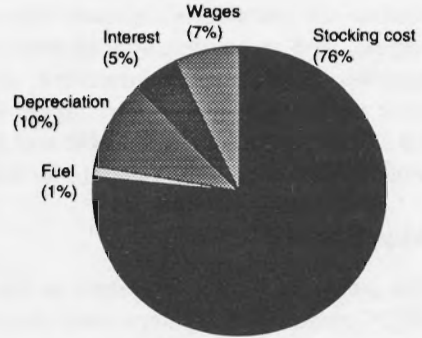


Figure 18.15 Annual operating costs of ocean-cage nursery operation in Palau (to nearest percentage point).

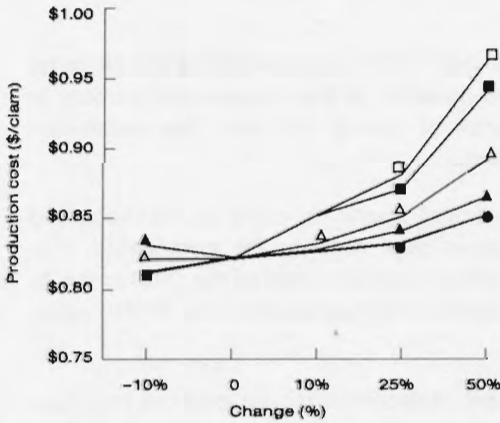


Figure 18.16 Sensitivity of production cost to changes in labour costs, energy costs and capital costs for combined hatchery and land-based nursery operations in Palau.

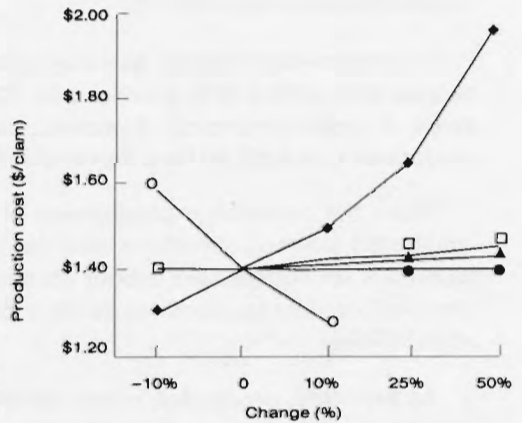


Figure 18.17 Sensitivity of production cost to changes in wages, energy costs, capital costs, stocking cost and survival rate for ocean-cage nursery operations in Palau.

Legend:
 Wages -▲-; Salaries-△-; Total labour costs -■-; Energy costs -●-; Capital costs -□-.

When the percentage breakdown of operating costs of the hatchery and nursery phases are considered, almost 60% of total costs are for labour (salaries and wages). The remaining 40% of total costs are interest, depreciation, utilities/fuel, supplies, equipment maintenance, and other costs. Production cost per clam is most sensitive to labour and capital costs. A 10% rise in labour and capital costs would result in additional \$0.08 and \$0.04 increases in production cost per clam, respectively. (For details of data for this case, see Leung et al. 1993.)

American Samoa

The giant clam culture system in American Samoa is also an adaptation of the MMDC system. The system uses a land-based hatchery and a combined land-based and ocean-cage nursery system to produce 2-year-old *T. derasa* (Figure 18.1). The hatchery and land-based nursery operations are located in the same facility, while ocean-cage nursery operations are located in three different villages: Ofu, Alofau, and Nu'uuli.

The goal for the hatchery and land-based nursery operations is to produce 100000 1-year-old *T. derasa* annually. The hatchery phase spans about 5 months and the land-based nursery lasts about 7 months. 1-year-old clam is about 6 cm in length. Currently, only a small amount of 1-year-old clams are distributed to the three nurseries. The remaining clams are used for teaching and training purposes, replacement, and sales. Total capital costs and annual operating cost are estimated to be about \$52940 and \$77560, respectively. The cost of producing a 1-year-old clam is about \$0.76.

The ocean-cage nursery assumes a total of 3050 clams stocking for all three nursery sites with a 60% survival rate. The duration of the ocean-cage nursery is about 1 year, producing 2-year-old clams of about 13 cm. The estimated production cost is \$3.40 for a 2-year-old clam.

When the percentage breakdowns of annual operating costs of hatchery and land-based nursery operations and the ocean-cage nursery are considered, it is found that for both phases, labour accounts for more than half of the total costs. In terms of percentage, labour costs are substantially higher than for the MMDC operation in Palau.

As expected, production cost is the most sensitive to labour costs in hatchery and land-based nursery operations as well as for the ocean-cage operation. A 10% increase in survival rate for the ocean-cage nursery operation would reduce the cost of production per clam by \$0.31. (For details of data for this case see Leung et al. 1993.)

Discussion

Although not directly comparable, the estimated costs of production for the cultured systems in the Republic of Marshall Islands for the various sizes of *T. gigas* appear to be well below the farm-gate prices charged by MMDC for *T. derasa*. The farm-gate

prices charged by MMDC for 3- and 5-year-old *T. derasa* are \$9.00 and \$50.00/clam, respectively. Production cost for the floating tank hatchery system in the Marshall Islands is lower in comparison with the raceway hatchery system. However, it has not been demonstrated whether the two systems will provide the same consistent production levels. It seems that the floating tank system is riskier and may not provide consistent production as compared to the land-based raceway system.

For the purpose of comparison, Tisdell et al. (1990) estimated the cost of producing 1-year-old *T. gigas* in Australia to be between A\$0.32–A\$1.57 depending on the size of operation. (These figures need to be reduced by about 25–30% to give U.S. dollar estimates, because of the exchange rate difference). The higher estimated cost in Australia is expected as production costs especially labour costs are generally higher than developing nations such as the Republic of Marshall Islands.

The system used in Kosrae is similar to the MMDC system for culturing *T. derasa* and hence the estimated production costs are very similar. In fact, the estimated cost of producing 2-year-old *T. derasa* is \$1.23/clam in Kosrae. Although the system used in American Samoa is adapted from the MMDC system, it has a much higher cost of producing a 2-year-old *T. derasa*, \$3.40 vs. \$1.41. This is because of high labour costs associated with the training and teaching components of the American Samoa system. Otherwise, production costs for the two systems would be quite similar. Table 18.1 provides a summary of the production costs of giant clams for the various phases in the U.S. affiliated Pacific islands.

It appears that the current giant clam culture production technology as practiced or experimented with in the U.S.-affiliated Pacific islands can be profitable. However, efforts in coordinating the supply from the entire Pacific region producing giant clams to the various demand centres may be necessary in order to ensure the continuing growth in this industry.

Table 18.1 Production cost comparisons of giant clam in the U.S.-affiliated Pacific Islands—1991, 1992 (U.S.\$)

Site	Age of clam				
	8 months	1 year	2 years	3 years	5 years
Marshall Islands					
Raceways in the hatchery phase	0.41			5.08	9.44
Floating tanks in the hatchery phase	0.23			4.83	9.13
Palau		0.82	1.41		
Kosrae			1.23		
American Samoa		0.76	3.40		
1991 farmgate price (MMDC, Palau)		1.00	3.00	9.00	50.00

Economic optimal harvest age for giant clam *Tridacna derasa*¹

Much technical progress has been made in giant clam, *Tridacna derasa*, culture in the past decade and, according to Tisdell (1986) and Heslinga and Fitt (1987), it is not unrealistic to envision large-scale commercial farming in the Pacific by the end of the 1990s. As Watson and Heslinga (1988) put it, 'It is now possible to begin quantitative assessment of the question: What is the best time to harvest cultured specimens?' In their paper, they analysed the optimal harvest schedule that permitted the clam farmer to maximise average annual production of biomass per unit area. This section extends their analysis in addressing the question of identifying the optimal harvest schedule (replacement cycle) to maximise economic returns.

Tisdell (1986) constructed a model to estimate the optimal length of the growout period that maximised the net present value of a batch of juvenile clams for a range of interest rates. Using growth estimates for *T. gigas* and mortality estimates for *T. derasa*, he estimated that the optimal growout period is 7 years, assuming that the meat can be sold for A\$1.5/kg (the only marketable product from the clam)² and that the real interest rate is 10%. (Real interest rate is used to account for the effect of inflation and can be defined simply as the nominal interest rate less the expected inflation rate.) At this interest rate, the net present value of a juvenile clam is A\$1.37. He concluded that clam farming can be quite profitable, since the price of a juvenile was around A\$1.00 at the time of his analysis. It should be noted that his analysis incorporated no other cost. He also recognised that the analysis assumed that available space was not a major constraint on clam farming and suggested further work should be done to assess the optimal growout period if space was a constraint. However, he pointed out that it seems likely that a growout period of about 4 years will be optimal.

Watson and Heslinga (1988) recognised that when space is a constraint, forest management techniques can be useful in managing *Tridacnid* clam resources. They used the basic principle of biological rotation of maximum biomass production and applied it to the size-at-age data for a cohort of *T. derasa* spawned at the Micronesia Mariculture Demonstration Center (MMDC), Republic of Palau, in 1979. This data is the most comprehensive set available for cultured *Tridacna* containing age-weight data for adductor muscle, other soft tissue, and shell. Using the principle that maximum biomass production occurs at the age when mean annual growth equals periodic annual increment, they found that the optimal harvest age for adductor muscle is 6 years, that for other soft tissues is 6 years, and that for shell is greater than 7 years. The objective of this section is to use Watson and Heslinga's (1988) data to determine the optimal length of the replacement cycle that maximises economic returns.

¹ This section is based largely on Leung et al. 1993.

² A\$1 = U.S.\$0.78 at the time of this (1986) writing.

Methods

Optimal harvest age for maximum biological production

The point of maximum biomass production occurs when mean annual growth equals periodic annual increment (Avery 1975; Watson and Heslinga 1988). Mean annual growth is also referred to as average growth, and periodic annual increment is also referred to as marginal growth. If a growth equation for each clam product can be estimated, then this equation can be used to determine marginal growth by taking the first time derivative of the growth equation. Average growth is simply total growth divided by time.

Optimum harvest age for maximum economic returns: the Faustmann model

Maximising biological production does not usually maximise economic returns. With limited space, one generation of clams is in competition with a younger generation for the same area. By harvesting older clams whose marginal values are decreasing, space can be made available for younger clams, which grow faster and thereby yield a greater increase in value. This problem is similar to the optimal rotation problem in forest management as developed by Faustmann (1849). Clark (1976) and Bjorndal (1988) have demonstrated the use of Faustmann's model in fishery and aquaculture management, respectively. For the mathematical details of the Faustmann's model as applied to giant clams culture, readers are referred to Leung et al. (1993).

Assumptions

To apply the Faustmann rule, assumptions on survival, price of clam products, annual operating cost, and juvenile cost have to be made. Munro (1988) estimated a constant survival rate of 0.9873 after one year of growth, using the same set of data that are analysed in this section. The constant survival rate did not seem appropriate since clam survival rate tends to increase with age. For this reason, the survival rates shown in Table 18.2 were assumed.

Table 18.2 Assumed survival rates of giant clams

Years of growout	Survival rate (%)
1	90
2	95
3	97
4	98
5	100

The farm-gate prices were assumed to be U.S.\$0.60/kg for shell, U.S.\$22.00/kg for muscle (Heslinga and Watson 1985) and U.S.\$2.20/kg for other meat (Kona Clam Co. Ltd 1986). Cost of juveniles was assumed to be U.S.\$1.50 per clam if purchased (including packing and shipping cost) (MMDC 1989) and U.S.\$0.53 per clam if produced on farm (unpublished data). Annual operating costs were adapted from unpublished data as shown in Table 18.3. Real interest rate was assumed to be 10%.

Table 18.3 Annual operating cost, MMDC unpublished data

	Year in growout		
	1	2	3
Fuel (U.S.\$/clam)	0.64	0.36	0.01
Number of trips	104	52	2
Cost per trip (U.S.\$)	10	10	10
Number of trays	60	60	60
Number of clams/tray	27	24	22
Labour (U.S.\$/clam)	0.64	0.33	0.01
Depreciation (U.S.\$/clam)	0.16	0.16	0.10
Total (U.S.\$/clam)	1.44	0.88	0.13

To take into account the various possible farm configurations, four cases were analysed. They were:

Case 1 Clams were situated far from shore, so boat and scuba diving gear were needed; annual production cost included fuel, labour, and depreciation; juvenile cost was assumed to be U.S.\$1.50/ clam.

Case 2 Clams were close to shore, so boat and scuba diving gear were not needed; only labour cost was assumed to be incurred; juvenile cost was assumed to be U.S.\$1.50/ clam.

Cases 3 and 4 were the same as Cases 1 and 2 except that seed was assumed to be produced on the farm at U.S.\$0.53/clam.

The annual production costs for the four cases are presented in Table 18.4.

Table 18.4 Annual production cost (U.S.\$/clam) under different farm configurations: Case 1—Clams were situated far from shore and juvenile cost was U.S.\$1.50/clam; Case 2—Clams were situated close to shore and juvenile cost was U.S.\$1.50/clam; Case 3—Clams were situated far from shore and juvenile cost was U.S.\$0.53/clam; Case 4—Clams were situated close to shore and juvenile cost was U.S.\$0.53/clam.

Year in growout	Case 1	Case 2	Case 3	Case 4
1	2.94	2.14	1.97	1.17
2	0.88	0.36	0.88	0.36
3	0.13	0.01	0.13	0.01

Results and discussion—estimated growth equations

Using the seven years of *T. derasa* growth data from Watson and Heslinga (1988), the following growth equations were found to be most plausible for each commercially important product:

Shell	$WS = 9114.30 [1 - e^{-0.31(t-1.63)}]^3$	$R^2 = 0.99$	D-W = 2.81
	(6.05) (6.70)(8.64)		
Adductor muscle	$WM = 95.78 [1 - e^{-0.69(t-2.16)}]^3$	$R^2 = 0.97$	D-W = 2.82
	(9.39) (4.02)(5.81)		
Other meat	$WO = 831.26 [1 - e^{-0.49(t-2.05)}]^3$	$R^2 = 0.99$	D-W = 2.86
	(6.15) (3.71) (4.98)		

where: WS, WM, and WO are weights in grams for shell, muscle, and other meat respectively; t is age in years; numbers in parentheses are t-statistics; D-W is the Durbin-Watson d-statistic. A juvenile is approximately 2 years old; consequently, t = 7 refers to the seventh year of age or the fifth year of growout. The functional form employed in estimating the above equations is the von Bertalanffy (1938) growth function, which is commonly used in describing shellfish growth.

The estimated growth equations are generally very well-fitted as shown in Figure 18.18. The purpose of estimating these equations is to facilitate the calculations of the optimal replacement cycle which will be discussed later.

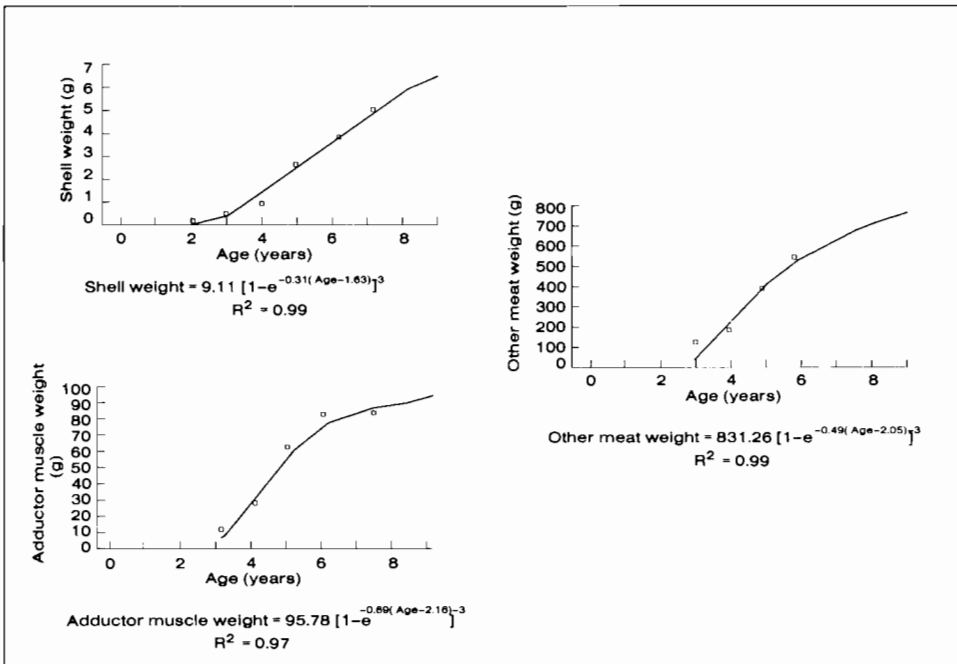


Figure 18.18 Average shell weight, adductor muscle weight, weight of other meat and their estimated growth equations.

Optimal harvest age for maximum biological production

Using the estimated growth equations for each clam product, the optimal harvest age for maximising biological production can be calculated by equating the average growth and marginal growth. The optimal harvest age for shell was estimated to be 8.8 years, that for muscle was 5.9 years and that for other meat was 7.0 years. The results are slightly different from Watson and Heslinga's (1988) because estimated growth equations were used. They estimated the optimal harvest age for both muscle and other meat to be 6.0 years. The similarity of the results between these studies indicates that the estimated growth equations can approximate the actual growth process very well.

Optimal harvest age for maximum economic returns

Table 18.5 shows the optimal harvest time of the four cases for each individual clam product and some combinations of products. This table also shows the changes in optimal harvesting time when clam product prices vary within $\pm 25\%$ of the assumed prices. The optimal harvest time for shell, in terms of clam age, ranged from no production to 13.2 years. No muscle production should be carried out except for higher prices, and no other meat production should be done except in the case where the price is the highest and the production cost is the lowest. 'No production' refers to the case where NPV (net present value) is negative indicating an unprofitable situation; hence, the best decision is not to grow clams.

Table 18.5 also shows the optimal harvest time assuming (a) all the products could be sold, and (b) only the meat products could be sold. In (a), the optimal harvest time ranged from no production, where the prices were the lowest and the production cost was the highest, to 10.7 years, while in (b), it ranged from no production, where product prices were low and production costs were high, to 9.0 years.

Table 18.6 presents the corresponding net present values at optimal harvest time for each case. If only shell was assumed to be saleable, the net present values were generally positive except for Case 1 and Case 3 with lower prices. If only muscle or other meat was saleable, the net present values were generally negative except for Case 4 with higher product prices. If all the products were saleable, all the net present values were positive except for Case 1 with lower product prices. If only meat could be sold, the net present values were positive only if the production costs were low and product prices were high. The results indicated that if all the products could be sold, clam farming was generally economically feasible and the optimal harvest time, in terms of clam age, ranged from 7.0–10.7 years. If only meat was assumed to be saleable, clam farming could be profitable only when the product prices are high and production costs are low and the optimal harvest time, in terms of clam age, ranged from 6.5–9.0 years. In general, the results indicated that as clam product price increases, the optimal harvesting time decreased as expected. The optimal harvesting time decreased with decreasing costs as well. Sensitivity analysis (not shown here) also shows that optimal harvesting time decreased with increasing survival rates and decreasing real interest rates.

Table 18.5 Optimal harvesting time (in years) under different farm configurations: Case 1—Clams were situated far from shore and juvenile cost was U.S.\$1.50/clam; Case 2—Clams were situated close to shore and juvenile cost was U.S.\$1.50/clam; Case 3—Clams were situated far from shore and juvenile cost was U.S.\$0.53/clam; Case 4—Clams were situated close to shore and juvenile cost was U.S.\$0.53/clam. The numbers in bold are the assumed prices and the numbers above and below are $\pm 25\%$ of the assumed prices. Note: No indicates that 'no production' is the best choice since the cost of production is higher than the revenue.

Saleable product	Product price (U.S.\$/kg)	Case 1	Case 2	Case 3	Case 4
	0.45	No	13.2	No	
Shell only	0.60	No	10.9	12.3	9.0
	0.75	13.0	9.9	10.6	8.5
	16.50	No	No	No	No
Muscle only	22.00	No	No	No	9.2
	27.50	No	No	No	7.5
	1.65	No	No	No	No
Other meat only	2.20	No	No	No	No
	2.75	No	No	No	10.5
All products					
Shell	0.45				
Muscle	16.50	No	9.7	10.7	8.0
Other meat	1.65				
Shell	0.60				
Muscle	22.00	10.7	8.5	9.0	
Other meat	2.20				
Shell	0.75				
Muscle	27.70	9.3	7.9	8.2	7.0
Other meat	2.75				
Meat only					
Muscle	16.50				
Other meat	1.65	No	No	No	7.8
Muscle	22.00				
Other meat	2.20	No	9.0	No	7.0
Muscle	27.50				
Other meat	2.75	No	7.8	8.3	6.5

Table 18.6 Net present values at harvest time (in U.S.\$/clam) under different farm configurations: Case 1—Clams were situated far from shore and juvenile cost was US \$1.50/clam; Case 2—Clams were situated close to shore and juvenile cost was U.S.\$1.50/clam; Case 3—Clams were situated far from shore and juvenile cost was U.S.\$0.53/clam; Case 4—Clams were situated close to shore and juvenile cost was U.S.\$0.53/clam. The numbers in bold are the assumed prices and the numbers above and below are $\pm 25\%$ of the assumed prices. Note: N indicates that the net present value is negative.

Saleable product	Product price(U.S.\$/kg)	Case 1	Case 2	Case 3	Case 4
	0.45	N	0.16	N	0.47
Shell only	0.60	N	0.48	0.02	0.82
	0.75	0.03	0.82	0.38	1.17
	16.50	N	N	N	N
Muscle only	22.00	N	N	N	0.04
	27.50	N	N	N	0.24
	1.65	N	N	N	N
Other meat only	2.20	N	N	N	N
	2.75	N	N	N	0.07
All products					
Shell	0.45				
Muscle	16.50	N	0.60	0.14	0.97
Other meat	1.65				
Shell	0.60				
Muscle	22.00	0.30	1.13	0.69	1.50
Other meat	2.20				
Shell	0.75				
Muscle	27.50	0.84	1.66	1.24	2.01
Other meat	2.75				
Meat only					
Muscle	16.50				
Other meat	1.65	N	N	N	0.32
Muscle	22.00				
Other meat	2.20	N	0.23	N	0.66
Muscle	27.50				
Other meat	2.75	N	0.56	0.13	1.00

One of the weaknesses of this study is the use of the estimated growth equation beyond the data for which the equation is estimated. However, the results are fairly plausible using the von Bertalanffy functional form. With longer growth data series available in the future, the present analysis can be updated.

Recently, two other giant clam products have been identified as having strong potential markets. They are small clams for sushi and for the aquarium trade. When more pricing information becomes available, this study can be extended to include these products.

Acknowledgments

This study was supported by a grant from the Center for Tropical and Subtropical Aquaculture (CTSA), financed by the U.S. Department of Agriculture. The authors greatly appreciate the generous assistance of Mr Neal Skinner of the Republic of Marshall Islands, Dr Gerald Heslinga of the Republic of Palau, and the managers of the giant clam facilities in Kosrae and American Samoa for providing the detailed production cost information. This chapter is an edited version of Leung, Shang, Wanitprapha and Tian (1993).

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Appendix 1

Table A 18.1a Hatchery capital costs, raceway system—Marshall Islands

Item	No of units	Cost/unit (U.S.\$)	Total cost (U.S.\$)	Useful life (years)	Annual depreciation (U.S.\$)
Spawning tank	1	2000	2000	20	100
Solar panels	1	3000	3000	20	150
Battery	1	500	500	5	100
Battery charger	1	150	150	3	50
Generator	1	600	600	3	200
Raceways	2	1500	3000	20	150
Trays	64	1	80	10	8
Diesel pump (back up)	1	2000	2000	10	200
Solar pump system	2	500	1000	10	100
Total			12330		1058

Table A 18.1b Hatchery capital costs, floating tank system—Marshall Islands

Item	No of units	Cost/unit (U.S.\$)	Total cost (U.S.\$)	Useful life (years)	Annual depreciation (U.S.\$)
Floating spawning tank	1	3500	3500	10	350
Solar panels	3	300	900	20	45
Batteries	3	200	600	5	120
Floating settlement tanks	2	2500	5000	10	500
Trays	108	1.25	135	10	13.5
Total			10135		1029

Table A 18.2a Hatchery annual operating costs, raceway system—Marshall Islands

Item	U.S.\$	Total (%)
Salaries		
Manager	3600	21.3
Technician	2000	11.8
Wages	6240	37.0
Overhaul of diesel pump	500	3.0
Diesel fuel	150	0.9
Repairs and maintenance	2000	11.8
Solar pump replacement	100	0.6
Interest	1233	7.3
Depreciation	1058	6.3
Total	16881	

Table A 18.2b Hatchery annual operating costs, floating tank system—Marshall Islands

Item	U.S.\$	Total (%)
Salaries:		
Manager	2000	20.5
Technician	2000	20.5
Wages	3210	32.9
Repairs and maintenance	500	5.1
Interest	1014	10.4
Depreciation	1029	10.6
Total	9753	

Table A 18.3 Nursery capital costs—Marshall Islands

Item	# of units	Cost/unit (U.S.\$)	Total cost (U.S.\$)	Useful life (years)	Annual depreciation U.S.\$
Tray platform	15	120	1,800	5	360
Tray	135	1.25	169	5	34
Boat	1	3000	3000	20	150
Total			4969		544

Table A 18.4 Nursery annual operating costs using raceway hatchery system—Marshall Islands.

Item	U.S.\$	Total (%)
Wages ^a		
Tray separation ^b	1215	33.0
Diving ^c	405	11.0
Harvesting ^d	117	3.2
Miscellaneous	500	13.6
Dive gear	150	4.1
Fuel ^e	60	1.6
Stocking cost ^f	230	6.2
Interest	466	12.6
Depreciation	544	14.8
Total	3687	

^aU.S.\$1.50/hr; ^bOnce a month, 30 minutes/tray; ^cOnce a month, 10 minutes/tray; ^dHarvesting, cleaning, 5 minutes/clam; diving, 5 minutes /tray; ^eU.S.\$5/trip ^fU.S.\$0.23/clam.

Table A 18.5 Growout capital costs—Marshall Islands

Item	No of units	Cost/unit U.S.\$	Total cost (U.S.\$)	Useful life (years)	Annual depreciation U.S.\$
Boat	1	3000	3000	20	150
Total			3000		150

Table A 18.6a Growout annual operating costs using raceway hatchery system—Marshall Islands

Item	U.S.\$	Total (%)
Wages ¹		
Diving ²	624	11.0
Harvesting ³	126	2.04
Miscellaneous	250	4.06
Dive gear	150	2.43
Fuel ⁴	520	8.43
Stocking cost ⁵	4064	65.92
Interest	281	4.56
Depreciation	150	2.43
Total	6165	

¹U.S.\$1.50/hr; ²Checking clams twice a week, 4 hrs/trip, 2 trips/wk; ³Harvesting: cleaning, 5 minutes/clam; diving, 2 minutes per clam; ⁴U.S.\$5/trip, 2 trips/wk; ⁵U.S.\$5.08/clam

Table A 18.6b Growout annual operating costs using floating tank hatchery system—Marshall Islands

Item	U.S.\$	Total (%)
Wages ¹		
Diving ²	624	10.5
Harvesting ³	126	2.1
Miscellaneous	250	4.2
Dive gear	150	2.5
Fuel ⁴	520	8.7
Stocking cost ⁵	3864	64.8
Interest	281	4.7
Depreciation	150	2.5
Total	5965	

¹U.S.\$1.50/hr; ²Checking clams twice a week, 4 hrs/trip, 2 trips/wk; ³Harvesting: cleaning, 5 minutes/clam; diving, 2 minutes per clam; ⁴U.S.\$5/trip, 2 trips/wk; ⁵U.S.\$4.83/clam

Table A 18.7 Hatchery and nursery capital costs—Palau

Item	No of units	Cost/unit U.S.\$	Total cost (U.S.\$)	Useful life (years)	Annual depreciation U.S.\$
Tanks w/ditches	50	2000	100000	15	6667
PVC pipes	50	200	10000	5	2000
Sea water pumps	5	600	3000	2	1500
Air blowers	20	500	10000	2	5000
Hatchery building w/pad & security service	1	30000	30000	15	2000
FRP tanks and equipment	1	10000	10000	15	667

Table A 18.7 (contd.) Hatchery and nursery capital costs—Palau

Item	No of units	Cost/unit U.S.\$	Total cost (U.S.\$)	Useful life (years)	Annual depreciation U.S.\$
Office building	1	30000	30000	15	2000
Computer and printer	1	12000	12000	5	2400
Copier	1	2000	2000	5	400
Fax	1	1000	1000	5	200
Binder	1	500	500	5	100
Broodstock	1000	50	50000	50	1000
Pickup truck	1	10000	10000	5	2000
Microscopes	2	2500	5000	5	1000
Centrifuge	1	500	500	5	100
Tools and misc. hardware	1	5000	5000	5	1000
Nursery trays	50	250	12500	5	2500
Dive gear	5	1000	5000	2	2500
Misc. equipment	1	2500	2500	5	500
Total			299000		33534

Table A 18.8 Hatchery and nursery annual operating costs—Palau

Item	U.S.\$	Total (%)
Electricity	12000	6.9
Phone, fax and telex	6000	3.5
Wages		
Technicians	10000	5.8
Aids	7000	4.0
Fuel/Lubes	600	0.3
Gravel	600	0.3
Air blowers	3000	1.7
Sea water pumps	1200	0.7
Filter bags	1000	0.6
Office supplies	2400	1.4
Lab supplies	2400	1.4
Fertiliser	600	0.3
Misc. hardware	2000	1.2
Maintenance	2000	1.2
Salaries		
Manager	30000	17.3
Farm manager	26000	15.0
Accounting	1200	0.7
Legal	2000	1.2
Interest	29900	17.2
Depreciation	33533	19.3
Total	173433	

Table A 18.9 Ocean-cage nursery capital costs—Palau

Item	No of units	Cost/unit U.S.\$	Total cost (U.S.\$)	Useful life (years)	Annual depreciation U.S.\$
Trays ^a	12000	1.25	15000	5	3000
Boat	1	2500	2500	10	250
Boat engine	1	1000	1000	5	200
Cages ^b	6000	15	90000	5	18000
Snorkels, fins, masks	6	100	600	2	300
Total			109100		21750

^aTwo trays per cage; ^bOne cage can hold 25 2-yr-old clams, 150000 clams output/25 = 6000 cages.

Table A 18.10 Ocean-cage nursery annual operating costs—Palau, Marshall Islands

Item	U.S.\$	% of total
Stocking cost ^a	164000	76.3
Wages ^b	15600	7.3
Fuel ^c	2600	1.2
Interest	10910	5.1
Depreciation	21750	10.1
Total	214860	

^a U.S.\$0.82/clam; ^bU.S.\$1.25/hr, one full time worker can handle 1000 cages, 6000 cages/1000 cages/worker = 6 full time workers; ^cU.S.\$5/trip, 10 trips/wk.

19 Economics of Australian Tridacnid Production and Future Research Needs

Clem Tisdell

Yung C. Shang

PingSun Leung

Abstract

This chapter uses Australian data to estimate the costs of production of *T. gigas* seed by techniques similar to those employed at the Orpheus Island Marine Research Station of James Cook University. Economies in scale of production are shown to be very strong in the hatchery/nursery stage of giant clam farming. The economics of ocean growout of *T. gigas* using the intertidal method developed at James Cook University is examined. Possible internal rates of return are estimated, assuming that the clams are to be marketed for their meat. The internal rate of return is expressed as a function of the number of years of ocean growout of the clams, and the profit-maximising duration of growout is estimated. Even allowing for loss in weight of the clam meat due to drip-loss, it is shown that, for conservative price estimates, at least a modest profit from the ocean farming of *T. gigas* is achievable. Comparisons are made between these results from Australian data and those of Shang, Leung and co-researchers from data from U.S.-affiliated territories in the Pacific. In conclusion, unresolved socioeconomic issues affecting giant aquaculture are highlighted. These would benefit from further research.

Introduction

The previous chapter examined the economics of producing giant clams in the Pacific islands affiliated with the United States, concentrating on the production of *T. derasa* and *T. gigas*, and considered alternative methods of culture. This chapter reports results on the economics of production of *T. gigas* for the main system of culture developed by Dr John Lucas and his team at James Cook University in northern Queensland. Their aquaculture facilities were located north of Townsville on Orpheus Island, a continental island in the Great Barrier Reef region, and their research was supported by the Australian Centre for International Agricultural Research. Comparisons will be made between results obtained from this culture and those obtained for the U.S.-affiliated territories by Leung, Shang, Wanitpraha and Xijun Tian, bearing in mind that differences in location and techniques can influence productivity considerably.

As will be apparent from the previous chapter, various production techniques have been adopted by economic units engaged in giant clam mariculture. In the early phases of the development of a new industry, such diversity seems to be normal (Metcalf and Gibbons 1989). As an industry develops, techniques are assessed and the least economic ones discarded. An evolutionary selective process involving learning by experimentation is a part of industrial development.

Consider the range of production techniques being used for giant clam mariculture by productive units. As Usher and Munro (1988, p. 108) have stated, the production of giant clam seed can involve use of intensive or extensive methods. This choice can occur at the hatchery stage, e.g. high-tech methods may be used similar to those used by oyster hatcheries, or low-tech extensive methods can be used in which the fertilised eggs are allowed to develop naturally in raceways. The latter technique was used by the Micronesian Mariculture Demonstration Center (MMDC), whereas James Cook University (JCU) adopted the former technique. The raising of seed in the hatchery stage may occur in land-based raceways or in tanks (as is the practice at MMDC and was the practice at JCU) or in marine floating cages, as practiced by the International Center for Living Aquatic Resource Management (ICLARM) at its South Pacific Aquaculture Centre near Honiara in Solomon Islands, the latter in combination with a relatively short nursery period on land. Attempts have also been made to base both the hatchery and nursery phases of giant clam mariculture entirely on floating culture, e.g. by the Pacific Clam company which had its headquarters in Cairns in northern Australia.

In the ocean phase of giant clam culture, a variety of methods is also being used or tried. Intertidal and subtidal methods are in use. The appropriate choice will be influenced to some extent by the species being cultured. Some species, e.g. *T. gigas* and *H. hippopus*, are well adjusted to the intertidal zone whereas others, e.g. *T. derasa*, are best suited ecologically to the subtidal zone. Cultural factors can also influence choice; e.g. members of some South Pacific communities do not like to dive so it would be culturally inappropriate for them to select a species to be grown subtidally. There are many other variations. For example, the clams may be grown on raised platforms rather than on the ocean floor and they may be provided protection from outside predators by means of cages or boxes, net enclosures, and so on, constructed from a variety of materials.

The range of production methods is even greater than indicated above. In the hatchery-nursery phase, different possibilities exist, for example, for nutrition, lighting, and temperature control. In addition, at present there is no universal agreement about the species best suited to commercial culture. Biologists in Western countries favoured the culture of *T. derasa* and *T. gigas*, mainly on the basis that these accumulate more meat biomass than giant clams of smaller size, such as *T. crocea*. The former species were preferred in the programs fostered by MMDC, ACIAR and ICLARM. On the other hand, researchers into giant clam mariculture in Japan concentrated on *T. crocea*, a species well adjusted to environmental conditions in the far south of Japan and with meat of a quality sought after by Okinawans.

As is well known, gain in biomass is not an adequate basis for economic choice of a species to culture. The cost of culturing alternative species must be taken into account, as must the relative demands of consumers for them. This demand will depend not only on the quantity of the product involved but also on its characteristics.

The results reported here are for the economics of culturing *T. gigas* for meat, assuming use of the cultural methods developed at the Orpheus Island Marine Research Station of JCU. These methods involve land-based, semi-intensive production of seed, and intertidal culture of giant clams (Lucas et al. 1988). Giant clams spend the first 10 months or so in a land-based, hatchery-nursery stage. They are then transferred to an intertidal area such as a rock platform where they are placed on the substratum and protected either by galvanised steel-mesh cages or arranged in 'lines' covered by plastic meshing for protection (Figures 19.1–19.3). This is sometimes called the ocean-nursery phase and is the first of the ocean phases. The next phase involves growout on the ocean floor, either without protection (Figure 19.4) or using floating netting fences as enclosures.

We will consider first the cost of seed production, then the economic returns which may be earned from growing-out giant clams.

The cost of production of giant clam seed

The cost of production of one-year-old giant clam seed was estimated using data from Orpheus Island Marine Research Station. The costs may be somewhat higher than one would expect under commercial conditions because the station was involved in research rather than commercial operations. Furthermore, one year may be a slightly longer period than needed for holding seed. Nevertheless, the results do provide useful indications of the likely magnitude of commercial costs.

The costs of production of seed have been estimated for nurseries/hatcheries producing 100000, 500000 and 1 million seed annually. Costs were divided into capital costs and operating costs.

Capital costs included the cost of the hatchery, accommodation and amenities for workers, the seawater supply system, fibreglass nursery tanks, hatchery and broodstock tanks and other equipment needed. Operating costs consisted of wages, fuel costs and outlays for repairs and maintenance of equipment. Depreciation was allowed for on all capital items, at a rate of 2.5% workers' accommodation and amenities and at 10% per annum on all other items, using the straight line method of depreciation. Details of cost estimates given by Tisdell et al. (1993a) are summarised in Table 19.1.

Interest on funds needed to finance annual operations is taken into account. Interest was allowed for both on capital and operating costs. Operating costs were assumed to be incurred evenly throughout the year. Clearly, such an allowance would be appropriate if the nursery borrowed all its funds. However, even if this is



Figure 19.1 Seed clams in a land-based pool at Orpheus Island in a fish tray. These are ready to transfer from the nursery to the ocean phase (C. Tisdell).



Figure 19.2 Giant clams transferred to the ocean nursery phase at Pioneer Bay, Orpheus Island. These have been protected by steel mesh cases (visible) and are located in the intertidal zone on a rock platform (C. Tisdell).



Figure 19.3 Giant clams arranged in rows and protected by plastic meshing or 'lines' on the rock platform at Pioneer Bay, Orpheus Island. This is an alternative form of protection (to steel cages) for the giant clams in the early ocean phase (C. Tisdell).



Figure 19.4 In due course, *T. gigas* can be grown out on the intertidal zone without protection. This is a naturally occurring *T. gigas* exposed at low tide at Orpheus Island (C. Tisdell).

Table 19.1 Estimated annual costs associated with giant clam seed production (A\$).

Production target	100000 seed	500000 seed	1000000 seed
Labour (\$30000/employee)	90000 (3)	120000 (4)	125000 (5)
Fuel	5000–10000	15000–20000	20000–35000
Repairs and maintenance			
Pumps and generators	1000–4000	2000–8000	3000–10000
Boats	2000–15000	3000–20000	4000–25000
Glassware and laboratory			
Consumables	1000	2000	3000
Tractor	2000	2500	3000
(a) Total operating cost	101000–122000	144500–172500	183000–226000
Operating cost per clam	1.01–1.00	0.29–0.35	0.783–0.226
(b) Depreciation of worker accommodation and amenities at 2.5% per annum	500–3000	625–3000	750–3250
(c) Depreciation at 10% per annum allowed for all capital items	17443–30443	24624–39624	32660–47660
(d) Interest charges ^a assuming a real rate of interest of 10%	24493–48543	34349–60249	44830–71980
Total (a+b+c+d)	142936–203986	204098–275373	261260–348910
Total cost per clam	1.43–2.04	0.41–0.55	0.26–0.35
If real rate of interest of 5% is assumed: Interest charges	12246–24271	17175–30125	22415–35990
Total	131389–179714	186934–245249	238845–312920
Total cost per clam	1.31–1.79	0.37–0.49	0.24–0.31

^aAssumption is made that all funds used for capital and operating costs are borrowed, and that operating costs expended progressively through the years.

not the case, interest should be allowed for in the costing because an opportunity is foregone by investing funds in the business rather than investing them elsewhere to earn interest, for example in government bonds. Costs are estimated on the basis of two alternative real rates of interest, 5% and 10%.

Table 19.2 summarises the cost of producing *T. gigas* one-year-old seed given the above assumptions and on the basis of costs in Australia in 1990. Note that a range is given for each estimate in this table. This is because there is some room for variation in the cost components.

It is evident from Table 19.2 that significant economies of scale exist in the production of giant clam seed because the per unit costs of production of seed fall substantially as the annual volume of production increases. Full, operating and fixed costs for seed produced all fall as volume of output increases.

Table 19.2 Per-unit cost (A\$) of producing giant clam seed as a function of volume of annual output

Type of cost	Number of seed clams		
	100 000	500 000	1 000 000
Operating cost	1.01–1.22	0.29–0.35	0.18–0.23
Total cost (5% interest)	1.31–1.79	0.37–0.49	0.24–0.31
Total cost (10% interest)	1.43–2.04	0.41–0.55	0.26–0.35

Given the techniques considered here, small hatcheries producing about 100 000 seed clams per year would need to charge around \$A1.50 (that is, in 1990, US\$1.10 each) per seed to make a profit. However, nurseries/hatcheries producing 500 000 seed per year would make a worthwhile profit if seed sold for \$A0.50 each and, at a million seed clams a year, a price of \$A0.30 could be sufficient to ensure profitability.

The significant economies of scale in production of giant clam seed indicate that it is likely to be advantageous from an economic point of view to have a few large producers of seeds rather than many small producers. Transport costs, however, are likely to influence the extent to which advantage can be taken of economies of volume in production at a single site. Costs will be influenced by choice of site (Tisdell 1993).

Economics of ocean growout

Ocean growout of giant clams can be considered as a separate economic activity to seed production. As the aquaculture of giant clams develops, some firms may specialise in seed production and others in ocean growout, though some firms may also engage in both activities. Here, the economics of ocean growout is estimated independently of seed production.

An ocean growout company is assumed to place in the ocean each year 100 000 seed clams of about one year in age. Each batch of clams is assumed to be held by the firm for the period that maximises the internal rate of return on the funds it employs (cf. Gittinger 1982; Shang 1981). Then the problem is to estimate

the optimal length of time to hold each batch of clams and the maximum rate of return achieved on funds employed (for further details see Tisdell et al. 1993b). To do this, account must be taken of the cost of holding and caring for clams, as well as the revenue to be expected from their sales.

To estimate the costs of the ocean phase of the culture of *T. gigas* we obtained data from the Orpheus Island Marine Research Station of JCU which has had extensive experience in this activity (Tisdell et al. 1991a; 1991b, 1993b). This was supplemented by information from a commercial giant clam farm, Reefarm Hatcheries, Cairns in an effort to obtain realistic cost estimates (Tisdell et al. 1993b).

As in the case of seed production, total costs were divided into capital costs and annual operating costs. Capital costs included outlays for a worker's house, tractor, boats, generator, lines and enclosures. Operating costs included the expenses for clam seed, wages, insurance, fuel, repairs and maintenance, and miscellaneous costs such as office expenses and leasing fees for the farming area. These costs are set out in Table 19.3. Depreciation on the house was allowed for at 2.5% per annum and on all other capital items at 10% per annum using the straight line method of depreciation (see Tisdell et al. 1993).

Table 19.3 Annual operating costs (A\$) for ocean phase of giant clam farm^a

Clam seeds (100000 @ 75c)		75000
Wages:		
1 full-time worker	30000	
Casual work	5000	35000
Insurance		9000
Fuel		1800
Repairs and maintenance:		
House	800	
Tractor	200	
Boats	250	
Generator	50	1300
Lease fees		800
Miscellaneous expenditures (e.g. office costs)		6100
Total		129000

^aIn addition to the costs shown in Tables 1 and 2, an initial advertising cost of \$2000 is needed. This is allowed for in calculations of IRR.

Apart from costs, revenues have to be predicted. To do this it is necessary to estimate quantities of production of clam meat and per kilogram prices to be expected for it. Production estimates were based on biological data on growth and mortality rates for *T. gigas* suggested by experience at Orpheus Island Marine Research Station and the observations of Munro (1988, 1989). Details of the biological data used are given in Tisdell et al. (1993b). A mortality rate of 5% per annum is assumed to apply after an initial 2-year period of higher mortality rates.

A range of possible market prices for giant clam meat from \$A3 to \$A7 at the farmgate is assumed. Market surveys by Tisdell and Wittenberg (1990a,b; 1993a,b) indicated that a retail price for giant clam meat of \$A10–12/kg would be quite acceptable to potential consumers in Australia. Shang et al. (1991 and Chapter 4 this Volume) also provide price estimates for *T. gigas* meat, mostly muscle, in Taiwan.

Giant clam meat can show considerable drip loss when transported or stored for marketing (Hambrey 1991). Internal rates of return estimated for this case allow for the possibility of a 40% drip loss in the weight of the meat.

In relation to sales of *T. gigas*, the possibility of their sale for the aquarium trade and for the high-priced sashimi and sushi market is ignored. The meat of *T. gigas* does not appear to be very suitable for sashimi or sushi, but sale of *T. gigas* shells could provide extra revenue for a giant clam farm if the meat were removed from the shell prior to sale.

The estimated internal rates of return for ocean growout of *T. gigas* for meat are set out in Table 19.4. The giant clam farm is assumed to buy one-year-old seed for \$0.75 each. The alternative returns are shown for a range of farmgate prices for giant clam meat and for a situation without and with postharvest drip loss.

The situation in which the meat sells for \$5.00/kg at the farmgate and a 40% drip loss occurs is possibly not over-optimistic. For this situation, a maximum internal rate of return of 11.25% could be achieved by holding giant clams in ocean growout for 14 years. After 11 years of growout, a return of 10.5% would be earned. This implies for this situation that ocean growout of giant clams for meat would be profitable if the rate of interest were less than the internal rates of return mentioned. If, for example, the rate of interest were 10%, ocean growout of *T. gigas* for meat would be profitable but the amount of pure profit (profit after allowance for interest) would be small.

Table 19.5 summarises the maximum rates of return based on the seed clam costs given in Table 19.2. These rates of return would be higher if the price of giant clam seed were lower. If seed sold at \$0.50 each, the rates of return would be 2–3% higher.

It thus appears that, under Australian conditions and given Australian data, the ocean growout of *T. gigas* could be profitable for meat, but only marginally so. This is so if one takes the 'middle' scenario, which does not seem overly optimistic. The

Table 19.4 Internal rate of return for ocean farming of *Tridacna gigas*

Year of growout	Price of meat at farmgate					
	\$3/kg	\$3/kg	\$5/kg	\$5/kg	\$7/kg	\$7/kg
		-40%DP		-40%DP		-40%DP
8	6.10	0.00	16.30	6.10	23.10	12.80
9	8.40	0.00	17.50	8.40	23.50	14.40
10	9.60	1.30	47.90	9.60	23.30	15.00
11	10.50	3.00	18.00	10.50	22.90	15.40
12	11.00	4.00	17.80	11.00	22.20	15.50
13	11.20	4.80	17.50	11.20	21.60	15.30
14	11.25	5.30	17.00	11.25	20.80	15.05
15	11.21	5.70	16.57	11.21	20.10	14.75
16	11.05	5.87	16.05	11.05	19.30	14.35
17	10.86	6.03	15.57	10.86	18.60	13.96
18	10.60	6.00	15.05	10.60	17.90	13.55

Legend: DP = postharvest drip loss

Table 19.5 Number of years for which *Tridacna gigas* should be held in ocean phase to maximise economic returns and the resulting internal rate of return

Farm-gate price/kg of meat (A\$)	Without drip loss		With 40% drip loss	
	No. of years to hold	IRR(%)	No. of years to hold	IRR(%)
3	14	11.25	17	6.03
5	11	18.00	14	11.25
7	9	23.50	12	15.40

clams would have to be held in ocean growout for a comparatively long time (e.g. 14 years) to maximise returns, but in most cases the penalty in terms of profit foregone by holding for a somewhat smaller number of years is not large. Profitability of production of giant clams for meat is significantly influenced by post-harvest drip loss from the meat. Returns will be improved if this loss can be reduced.

Discussion and comparisons

This study indicates that strong economies of scale are inherent in the production of giant clam seed by nurseries/hatcheries. While this can disadvantage smaller-scale producers of clam seed, we have only considered enterprises producing a single product, giant clam seed. A nursery may, through other products which jointly use its overhead facilities, e.g. seawater systems, be able to offset diseconomies in producing a small volume of giant clam seed. Examples of such diversification were given in Chapter 17. They can yield economies and reduce business risks. Tourists are a valuable commercial sideline for some nurseries. Furthermore, a nursery may use its facilities to grow clams for the aquarium trade.

Economies of scale were not specifically studied in relation to ocean growout of giant clams. Some such economies are likely to be present, although not as significant as for nurseries. The costs of overheads such as housing and boats suggest that some economies of scale are possible. However, once again a business venture need not devote itself entirely to the production of just giant clams. By producing multiple items the enterprise can spread the cost of its overheads between them if their production makes use of joint facilities.

It is interesting to compare the results based on Australian data with those obtained for U.S.-affiliated territories. In 1991, the cost of a one-year-old clam in Palau was estimated (see Table 18.1) to be US\$0.82 and in American Samoa, US\$0.76. At that time, the farmgate price of one-year-old giant clams was US\$1.00 from MMDC in Palau. In Australian dollars (assuming that \$A1 = US\$0.75, as was approximately so in 1990 and 1991) these respective costs/prices are \$1.09, \$1.01 and \$1.33. Taking into account the costs shown in Table 19.2, Australian production would be more costly for a venture producing 100000 giant clam seed per year, but would be well below that of Palau and American Samoa for production of 500000 or more seeds annually.

From Figure 18.4, it can be seen that salaries plus wages account for 42% of the annual costs of the combined nursery operations at MMDC, Palau. Wages and salaries are also the biggest component of annual costs in Australia (Table 19.1) assuming a 10% rate of interest. It is estimated that under Australian conditions, wages and salaries would account for 44–63% of total costs for the production of 100000 clam seeds annually, falling to 43–59% for 500000 clam seeds annually. The percentage of total costs accounted for by fuel and utilities is slightly less in Australia whereas the interest charge as a proportion of total costs is slightly larger. On the whole, there are no major differences in the proportion of costs accounted for by the different components of total annual costs for the hatchery/nursery, except that the wage component is higher in Australia.

From Table 19.3, it can be seen that the cost of giant clam seeds is likely to be the major annual outlay involved in the ocean growout of giant clams. In the case shown, they account for 58% of total annual outlays. Labour is the next largest outlay accounting for 27% of annual total operating expenditure. The percentage

shares of the major items are set out in Table 19.6. This table can be compared with Table A18.6a for the Marshall Islands. Stocking cost is the major component of outlays in this case, accounting for about two-thirds of outlays if the small allowances for interest and depreciation are excluded. Allowances for these were not included in Table 19.3 because outlays were being estimated to compute internal rates of return. The proportion of total outlay accounted for by wages is much lower in the Marshall Islands than in Australia, being only 13–14% of total outlays, and reflects lower wage rates there.

Table 19.6 Percentage of total outlay of major components of annual outlay for giant clam growout based on Table 19.3.

Item	%
Clam seeds	58.1
Wages	27.2
Insurance	7.0
Fuel	1.4
Repairs and maintenance	1.0
Leasing fees	0.6
Miscellaneous expenditure	4.7
	100.0

As regards optimal harvesting time, the model used in Chapter 18 is slightly different to that used in this chapter. The model used in this chapter is designed to determine the growout period that maximises the internal rate of return of the farm. The model employed in Chapter 18 resulted in optimal growout periods for *T. derasa* ranging from 6.5 to 12.3 years depending upon the assumptions made and the product assumed to be saleable. The model considered in this chapter and for the situations dealt with (see Table 19.5) suggests an optimal growout period varying from 9 to 17 years depending upon circumstances. The length of growout for the maximum internal rate of return is, on the whole, longer for this case than that in Chapter 18. Partly, this may be because *T. derasa* reaches maturity earlier than *T. gigas* and therefore has a ‘shorter’ growth curve in comparison to *T. gigas*. While the model in Chapter 18 allows for a variety of saleable products, the one used here does not. However, neither model examines the economics of production for the aquarium trade or production for the sashimi or sushi markets.

While single-product or restricted-product models are useful for providing initial insights into the economics of production of giant clams, it is clear that more complex production and market possibilities exist than have been captured by the models considered here. Giant clams may be harvested, for example, at different ages for different markets, or they may be produced in conjunction with other

aquacultured products. Even if this does not involve a form of polyculture, it still has significant implications for the economics of production.

Future research needs

The research results which have been reported in this monograph are but an introduction to the complexities of markets for giant clam products and the economics of the aquaculture of giant clams. Clearly, it would be an advantage to have a wider range of product models, covering a greater variety of species, a larger number of possible end-products and allowing for the production of multiple products.

Concerning markets for giant clam products, considerable research has already been done, but if commercial markets for aquacultured giant clam products grow, they will yield valuable new data which can be analysed to provide new market priorities. At present, there is a need for much more research into markets for shells and the economics of marketing them. Table 18.6 indicates that sale of shells may account for more than half the net present value of saleable products from aquacultured giant clams. It is therefore a very important component. While the cost of transport of shells is high, they have the advantage, unlike the meat, that they are not perishable, an advantage in regions which lack adequate preservation facilities.

Another area of importance as far as markets are concerned and for the development of clam mariculture is the operation of restrictions on trade, especially restrictions on international trade. For example, the Convention on International Trade in Endangered Species (CITES) applies to tridacnids. Has this restricted the development of giant clam mariculture and, if so, in what ways? Other constraints can include health regulations; for example, the attitude of the U.S. Food and Drug Administration (FDA) to imported giant clams and the hurdles involved in satisfying these regulations. These may reduce market possibilities and undoubtedly add to market transaction costs. However, such market transaction costs are not limited to international markets. As observed, for example, in Chapter 13, licensing requirements in Queensland for the sale of giant clams in the aquarium trade restrict the market for cultured giant clams.

Another important issue that needs to be addressed is the cost of preparing giant clam products for the market. If, for example, meat needs to be removed from the shell at or near the farm site and chilled or frozen, the cost of such preparation must be taken into account. In many cases, such operations would not, however, be carried out at the farm. The giant clam may be delivered in the shell to a 'food processor' with a coldstore and prepared there in a basic fashion as, for example, was done by Feeders in Fiji. Of course, it will be an advantage if such facilities are not distant from the farm. The use of such central facilities would result in economies for all growers of giant clams.

Concluding comments

Commercially, the giant clam is a very versatile animal. Virtually every part of it can be used. It does, however, have relatively specific ecological requirements which limit it to tropical and subtropical areas under natural conditions and it requires saline water which is not subject to significant freshwater surges. This makes it ideal for non-estuarine marine areas and tropical/subtropical islands, especially coral atolls. Using aquaculture, however, its range can be extended by means of land-based facilities but at a cost, e.g. winter heating may be required in some areas.

Biological obstacles to the aquaculture of giant clams have been overcome, though improvements in techniques for its mariculture will no doubt continue to be made. The spread of development of the industry of giant clam aquaculture now depends only on entrepreneurship and the economics of production.

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