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Working Paper No. 11

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[2] School of Economics, The University of Queensland, St. Lucia Campus, Brisbane QLD 4072, Australia Email: c.tisdell@economics.uq.edu.au

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Research for the project *Economics of Giant Clam Mariculture* (Project 8823) is sponsored by the Australian Centre for International Agricultural Research (ACIAR), G.P.O. Box 1571, Canberra, A.C.T. 2601, Australia. The following is a brief outline of the Project:

The technical feasibility of culturing giant clams for food and for restocking tropical reefs was established in an earlier ACIAR project. This project is studying the economics of giant clam mariculture, to determine the potential for an industry. Researchers will evaluate international trade statistics on giant clams, establish whether there is a substantial market for them and where the major overseas markets would be. They will determine the industry prospects for Australia, New Zealand and South Pacific countries, and which countries have property right factors that are most favourable for commercial-scale giant clam mariculture. Estimates will be made of production/cost functions intrinsic in both the nursery and growth phases of clam mariculture, with special attention to such factors as economies of scale and sensitivity of production levels to market prices.

Commissioned Organization: University of Queensland.

Collaborators: James Cook University, Townsville, Queensland; South Pacific Trade Commission, Australia; Ministry of Primary Industries, Fiji; Ministry of Natural Resources and Development, Kiribati; Silliman University, Philippines; Ministry of Agriculture, Fisheries and Forests, Tonga; Forum Fisheries Agency, South Pacific; ICLARM, Manila, Philippines.

For more information write to Professor Clem Tisdell, Project Co-ordinator, Economics of Giant Clam Mariculture, Department of Economics, University of Queensland, St Lucia 4067, Brisbane, Queensland, Australia. Email: c.tisdell@economics.uq.edu.au

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ABSTRACT

The costs of providing giant clam seed in Australia using existing techniques are examined for alternative annual volumes of production. Considerable economies of scale in production are available both in relation to labour costs and non-labour costs (mostly capital costs). In Australia, direct labour costs appear as though they would account for between 40-60 percent of total costs depending on volume and production levels. It is possible that these costs would be lower in some of the less developed countries which could produce clams. The fall in per unit full cost of producing giant clam seed is considerable when annual production is expanded from 100,000 to 500,000 seed clams per year. At 10% rate of interest, full cost for seed clam falls from $1.43-2.01 at a production level of 100,000 to $0.41-0.54 at a production level of 500,000. Operating costs also fall. They decline from $1.01-1.22 to $0.29-0.35. Although lower cost levels may be achieved in the future, and with different techniques in other countries, the cost of clam seed can be expected to be much higher than for oyster spat.

Keywords: Giant Clam Mariculture in Australia, seed production costs, supply and demand, giant clam production techniques.

JEL Classifications: Q57, Q31

An Analysis of the Cost of Producing Giant Clam (*Tridacna Gigas*) Seed in Australia

1. Introduction

Considerable effort has been expended on research directed towards (obtaining the knowledge necessary to allow) successful mariculture of giant clams (*Tridacnidae*) (Braley, 1989). This effort has been rewarded in that all seven species of giant clam have been successfully raised from eggs through to juveniles (Pernetta, 1987). Most effort, however, has been directed towards the mariculture of *T. gigas* and *T. derasa*. A closed breeding cycle has been established for *T. derasa* at the Micronesian Mariculture Demonstration Centre (MMDC) at Palau, (Heslinga and Fitt, 1987). A closed breeding cycle for *T. gigas* has not been established yet because work on this species started later than that for *T. derasa* and, as well, *T. gigas* takes several years longer to sexually mature than *T. derasa*. It seems likely, however, that workers at the James Cook University Research Station at Orpheus Island (JCUOIRS) could have a closed breeding cycle established for *T. gigas* by the mid-1990s.

The work on culturing giant clams has been concentrated on *T. gigas* and *T. derasa* for two reasons. Firstly, these two species are considered to be "... in danger of extinction in many parts of their range" (Munro, 1989). Secondly, these two species are the largest and have the fastest growth rates; therefore, they are considered to have the greatest potential for mariculture by biologists.

This paper examines the costs of producing *T. gigas* seed (i.e. juveniles with a shell length of 2-3 cm) based on Australian experience and cost structures using the current techniques most commonly employed in Australia. To some extent the results are Australian specific. Lucas (1988) considered that *T. gigas* reached this size in about a year. At this size the clams are ready for transferal to ocean based nurseries. There are a number of reasons why seed size should be used as a demarcation point in determining production costs for giant clams. At seed-size the clams can be transferred to ocean nurseries, although continued growth in shore-based facilities is also a possibility (Munro, 1989). If clam seed is to be sold as a product, as occurs in Palau for ocean-staged growth in other areas (Heslinga and Fitt, 1987), then transportation costs must be considered. It seems probable that, because clams at the next stage of culture, which are ready for unprotected ocean growout, are much bigger (approximately 125 times heavier) that transportation of clams as seed stock (as such) will generally occur in the range of 2-3 cm, because of the much lower transport costs involved. In the case of international sales, quarantine restrictions might make the shipment of the larger clams for regrowth impractical.

There are two other important reasons why seed-size (2-3 cm) is a good point for a demarcation in production costs. First the conditions optimal for both shore-based hatchery facilities and ocean- based growth facilities may not occur together. This is because a hatchery requires easy access to clean, clear sea-water, whereas for an ocean-based ocean nursery a wide intertidal area is necessary if the intertidal method of growout is adopted. Clearly the wider the intertidal area the harder it will be to pump sea water to the hatchery. Crawford, Lucas and Nash (1988) considered intertidal ocean nursery growout to be superior to other methods they have tried. Secondly, factors such as availability of technical staff, power supplies and economies of scale may mean that importation of giant clam seed from centralized hatcheries is a sounder economic proposition for clam-growers than growing their own seed. As well as possibly being more economical, centralized hatcheries may well be advantageous from the point of view of conserving natural giant clam stocks. A proliferation of small hatcheries could lead to increased competition for already limited natural broodstock stock.

2. Choosing a Site for a Hatchery

The successful economic production of giant clam seed will depend heavily on the appropriate selection of a site for a giant clam hatchery. Hatcheries using extensive techniques which rely heavily on favourable environmental conditions will be much more vulnerable to the vagaries of nature than those hatcheries using intensive techniques where culture conditions are to a greater extent controlled. A venture is, however, more likely to be successful if environmental conditions are favourable.

Besides environmental considerations, other factors such as the availability of labour, power and supplies must be taken into consideration. A hatchery on a mainland would usually be less expensive to run in terms of labour and transportation costs, and the costs of constructing hatchery facilities are likely to be less. However mainland hatcheries may not be viable due to factors such as poor water quality. Clearly a trade-off between all the various environmental and logistical factors must be made. This of course, would not be easy and would depend very heavily on the expertise of those involved in the project. If production of mature clams at the same site was being considered, then further environmental conditions such as suitability of the intertidal zone would need to be taken into account if intertidal growout is to be used. Since the culture of giant clams becomes more extensive as the clams increase in size, the environmental factors must be more fully respected if ocean growth phases are envisaged.

Ideally the area chosen for a site will have a stable water temperature of around 23-30°C and a salinity of 33-35 ppt (Heslinga et al., 1986). Such conditions prevail around equatorial islands in the Pacific; however access to power, supplies and skilled labour could be a problem. In order to minimise salt water pumping costs, the site should have easy access to clear unpolluted water. The wider the intertidal zone the greater the distance the salt water will have to be pumped. The increased pipe length will add to pipe-laying expenses, as well as increase the frictional forces on the water being pumped and lead to greater fuel usage. The capital and operating cost of the salt water system will depend on both the volume of water to be pumped and the circumstances under which it must be pumped.

Once a site is chosen all the necessary permits required by the various government agencies (depending on the country) must be obtained. The cost of choosing a site and attending to the necessary legal processes may be quite considerable. "Major commitment of time and money may be required to obtain all the necessary permits for a marine or estuarine project" (Huguenin and Colt, 1989).

3. Constructing a Hatchery

The cost of construction of the hatchery will depend heavily on the location of the site. The construction costs of a hatchery on a remote uninhabited island will be much more expensive than the construction of one on a mainland close to urban amenities. Because a hatchery has to have certain basic features, such as brood-stock handling and holding facilities, regardless of its size, it is likely that some economies of scale exist as far as hatchery costs are concerned.

4. Worker Accommodation

The costs of employee accommodation are even more dependent on location than those relating to the hatchery. If the hatchery is located in an isolated area where daily commuting is impractical then full living quarters and amenities will have to be provided for the workers; whereas, in the case of a hatchery located within commuting range for the employees such construction would not be necessary. As with hatchery costs, the cost of construction will also depend heavily on location. It is likely that freshwater needs will have to be met by rainfall. Therefore, large rainwater tanks will be required in most instances to store collected water. The cost of such tanks again increases the cost of employee accommodation.

Economies of scale exist as far as worker accommodation is concerned. For instance the cost of constructing living quarters for 6 workers is likely to be much less than twice the cost of providing accommodation for 3 workers.

5. The Cost of Personnel

The location of a hatchery is a very important factor in determining labour costs; for instance it may be necessary to pay higher wages to employees of an isolated hatchery than one closer to civilization. Also in an isolated area greater dependence on hatchery staff is necessary because of the difficulty in arranging for outside help, this may necessitate a larger staff than would otherwise be the case.

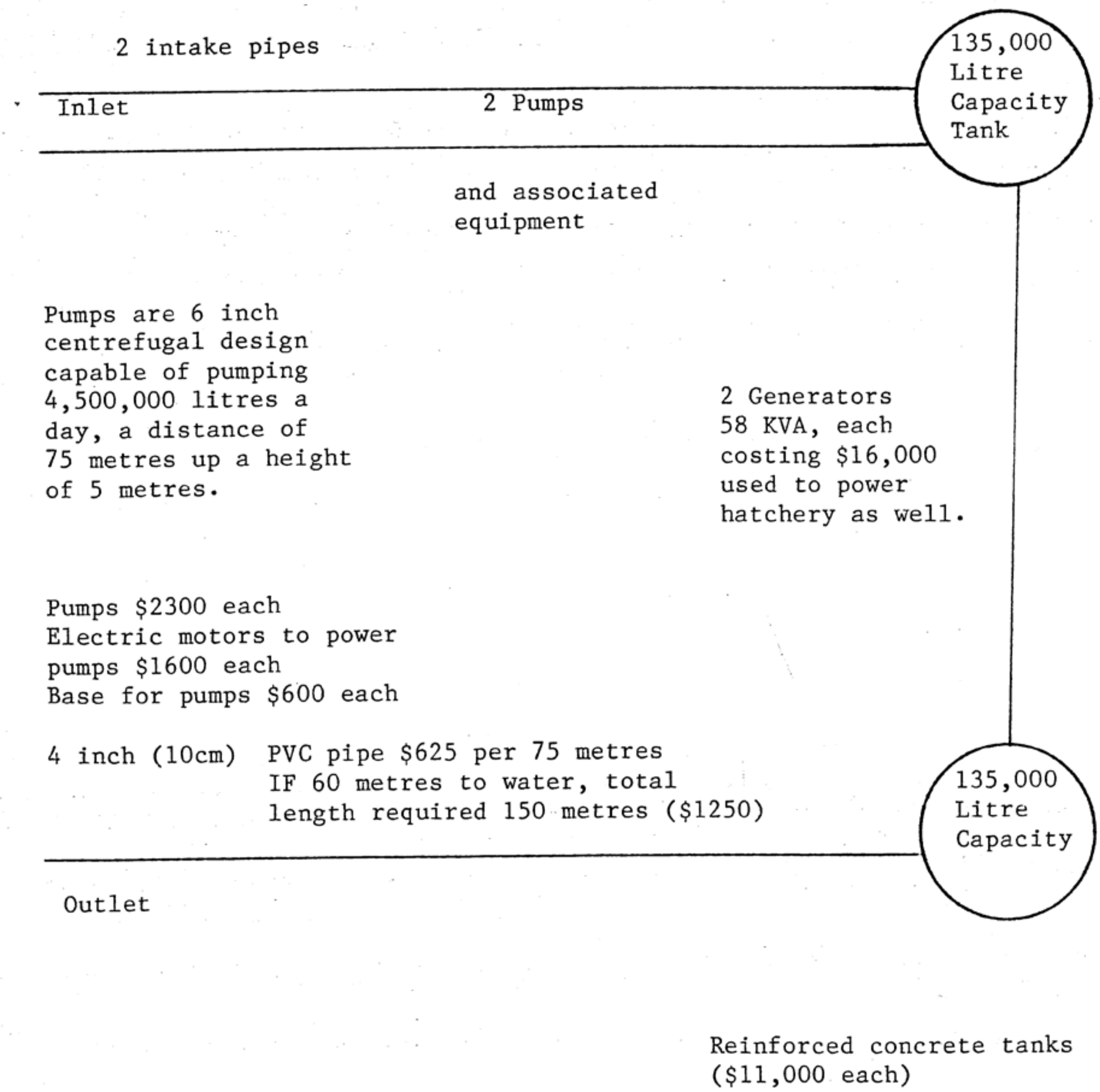
The mix of skills and attributes required by the hatchery staff will depend on the circumstances peculiar to the hatchery itself. Apart from the administrative and managerial skills possessed by the entrepreneur and/or a manager, certain fundamental skills must be possessed by the staff of the hatchery. One employee at least will have to.be thoroughly familiar with the operation and maintenance of seawater pumping systems. If the hatchery has to generate its own power then it would be necessary for one of the staff to be competent in operating and maintaining generators. One staff member will need to be thoroughly familiar with bivalve hatchery techniques and have considerable experience in aquaculture. The degree of task specialization between staff and the number of general assistants required will depend on the scale of operations of the hatchery.

The continuous presence of staff would decrease the effect of a system failure; however the cost of continuous monitoring would be prohibitively costly. It is likely therefore that alarm systems would be set up to activate when equipment failure caused environmental parameters to reach predetermined levels. If the hatchery was situated in a relatively remote area then it would be likely that the presence of an on-site caretaker would be required. It is probable that the key personnel could if given assistance by comparatively inexperienced workers be able to handle a wide range of output. This suggests that considerable economies of scale exist in respect of personnel costs.

6. The Sea-Water Supply System

The cost of the equipment needed to supply sea water to the hatchery facility will depend on the quantity of water required, and the distance and height that the water must be pumped. The cost will also depend on whether new or second hand pumps and generators are used; for the purpose of this paper, however, only new prices will be considered. The location is also important as the cost of laying the pipes will depend on the terrain as well as the distance which equipment and workers must be transported.

It is particularly vital to the operation of the hatchery that a continuous supply of good quality sea water be maintained. In terms of equipment this is best achieved by allowing an excess of capacity to be designed into the system. This allows the equipment to be run at speeds that are best suited to the equipment's smooth running. It is also imperative that backup equipment be installed ready for immediate use should the normal equipment fail. Although having surplus capacity and backup equipment increases running costs it does considerably reduce the risk of complete failure in the production process. Figure 1 shows a simplified seawater circulation system. Figure 1 also gives the cost of the various components of the system based on prices quoted by local Brisbane retailers. The system shown is designed to cope with the requirements of a hatchery producing 1,000,000 seed clam per year where the water is pumped 75 metres up a height of 5 metres. Although smaller capacity pumps and generators would be cheaper, for production targets of 100,000 or 500,000 seed clam per year this system might still be desirable, unless it was certain that no expansion of the hatchery would occur at a later date. Clearly considerable economies of scale exist with respect to the sea-water supply system.



Total $64,000 for major components. Duplication of pumps and generators required as backups. $10,000 should be allowed for miscellaneous expenses such as transportation and the cost of placing the PVC pipes. These miscellaneous expenses will depend heavily on the location of the site and the type of substrate present.

Total Cost approximately $74,000

Figure 1: Sea-water Supply System

7. Tanks Used for Giant Clam Culture

At present fibreglass and concrete tanks and galvanized walls with plastic liners are used for culturing giant clam seed. The relative merits of each type of tank depend on the circumstances peculiar to a given application at a particular location. For example, concrete tanks cost much the same as fibreglass tanks but last much longer and are the cheapest to operate over a long period of time (20-50 years), but they are difficult to reposition once in place. Fibreglass tanks by contrast have considerable mobility. A 10,000 litre fibreglass tank, however, costs around $1400, which makes it a much more expensive capital purchase than the cheap "splasher pools" used at JCUOIRS. However the short lifespan (1 to 2 years) of a 10,000 litre splasher pool and liner costing around $270 make them a less attractive long term proposition.

The commercial giant clam growers near Cairns appear at present to favour fibreglass while workers at JCUOIRS appear to favour low cost "splasher pools". A big advantage of the "splasher pools" is that they are very convenient for shipping e.g. to Pacific Islands, since the galvanized sides roll up, and the plastic liner folds up. A big disadvantage of the galvanized tanks is that they are quite delicate once set up and do not react favourably to careless handling. Fibreglass tanks are also vulnerable to careless handling.

Although concrete tanks would appear to be the best long-term proposition, until such time as methods have been refined and the giant clam industry is proven economically viable, it is likely that commercial growers will continue to use fibreglass tanks because such tanks are easily repositioned and do not have to be replaced yearly. The cheap "splasher pools" do however seem well suited to short term pilot studies where capital costs must be kept low. They allow for flexible adjustment for uncertainty.

It is necessary to facilitate drainage of the tanks by either raising the tanks above surface level or by excavating drainage passages beside the tanks. JCUOIRS has found that raising the tanks above the surface by about 0.5 metres to be convenient. The tanks can be raised by numerous methods, however whichever method is used allowance must be made for the cost of materials and labour used. Estimates given in Table 1 are for the costs of using besser bricks and concrete to retain the fill or line the drainage passages.

8. Weather Protection for Nursery Tanks

Large nursery tanks and the large algal culture tanks are kept in the open and generally require some limited protection from the elements. Generally shade cloth supported by galvanized tubing is used for this purpose. The shade cloth does not adversely affect the growth of young clams as might be expected because of the reduction of light available to the symbiotic zooxanthellae contained within the clam's tissues. "Zooxanthellae in small (1-2 cm long) juvenile *T.gigas*, for example photosynthesize at near maximal rates even at ambient light intensities as low as 500 u $E/m^2/sec$, about one-fourth that of natural above-water noontime intensity on a clear day…" (Heslinga and Fitt, 1987).

The cost of such weather protection is however surprisingly expensive. The cost of materials alone necessary to provide weather protection to sufficient tanks to culture 500,000 seed clam (i.e. 30, four metre diameter) would be about $11,000. The life span of the shade cloth would be about 5 years and tubing would have a life expectancy of about 10 years.

9. Nutrient Enrichment and Algal Control

These two factors are considered together because nutrient enrichment adds to the problem of algal overgrowth and algal overgrowth has been one of the hardest problems for giant clam growers to solve. It has been found both at the JCUOIRS and "Reefarm" that the addition of nitrogenous fertilizers (such as calcium nitrate) to the water, greatly enhances the growth rate of the clams. The cost of nitrogenous supplements for 500,000 seed clams would be around $5,000-$10,000 depending on the fertilizer used.

Nutrient enrichment, however, exacerbates algal overgrowth, which adversely affects the juvenile clams by shading them out. Algal grazing snails (*Trochus niloticus*) have been used to combat the problem of algal overgrowth (Heslinga and Fitt, 1987). These snails, however, do not always manage to keep the algae under control, and also pollute the water with faecal waste. Philippe Dor and Bruce Stevens from "Reefarm" believe that they have found a solution to the problem of filamentous algal overgrowth. They have found that by introducing colonies of amphipods (*Ampithoe* spp.) into the tanks, the 'growth of filamentous algae is very much restricted. The amphipods are detrital feeders and apparently dislodge the filamentous algae in their efforts to obtain the detritus on which they feed. The filamentous algae then floats off and passes through the tank outlet which is positioned at the water surface.

10. Other Major Expenses Incurred in Clam Culture

Most of the other major expenses depend heavily on the particular circumstances of a hatchery. Expenses incurred on the acquisition and maintenance of boats could be very considerable if the hatchery was very isolated and required its own boat for transporting staff and supplies. On the other hand, a hatchery situated on the mainland, which had good road access, could keep boat expenses to a minimum and get by with just small dingies and occasionally hiring larger vessels when required for collecting broodstock.

One item of major expense that would be required in the majority of hatcheries would be a small agricultural tractor. A tractor could be useful to help clear areas to be used for tanks. It would also be needed for moving the brood stock from the sea to the brood tanks when spawning was to be included and for harvesting clams in the intertidal area. An adequate tractor for clam culture would cost around $20,000 new; however a second-hand tractor would generally be quite satisfactory and would cost considerably less. Another major expense would be the cost of a utility for transporting supplies and equipment. Such a vehicle would cost around $15,000.

11. Other Expenses Incurred in a Clam Culture

Many other expenses that are incurred in the culture of giant clams, however, the majority of these are relatively minor (compared with such items as tanks and labour cost). Notwithstanding this, the combined cost of these small expenses mounts up and can add a surprising large amount to the total cost. Items such as microscopes, glassware, antibiotics and permits can be more expensive than originally anticipated. It would also seem a wise policy to allow a reserve fund for items which had not been originally thought of, "Major cost underestimates are more likely to result from necessary but uncounted components and services or increased requirements rather than errors in specific items" (Huguenin and Colt, 1989).

12. Producing the Giant Clam Seed

After obtaining the necessary permits, broodstock are collected from reefs and transferred to holding areas in close proximity to the hatcheries. The broodstock are generally kept sub-tidally as this restricts unauthorized access to them. During the period when clams become ready for spawning (October to March in Australia) some of the broodstock are transferred to shore facilities and kept in a tank. Spawning can be artificially induced; however, it is not clear whether or not such induction leads to the release of less viable eggs (Fitt et al., 1984).

Eggs are collected in plastic bags as they are expelled from the spawning clam. The eggs are then placed in small (50 litre) containers and fertilized with sperm obtained from another clam. The developing eggs sink to the bottom and are syphoned up and transferred to larger tanks (500 litre). Within 24 hours at 28-30 C the fertilized eggs hatch into ciliated trochophore larvae. It has been found that trochophore survival is greatest at densities of less than 5 per millilitre (Fitt et al., 1984). This means that a 500 litre container can accommodate 2,500,000 trochophores comfortably, Sufficient 500 litre containers would be required to accept as many eggs as was required since "A large *T. gigas* is capable of releasing hundreds of millions of microscopic eggs on a single day" (Heslinga and Fitt, 1987).

The trochophores develop into bivalved veligers within two days after fertilization at 28-30 C and can now be placed into large nursery tanks. At three days post-fertilization, the veligers are fed cultured unicellular algae. They are fed until metamorphosis occurs at about nine days post-fertilization. Zooxanthellae are introduced at 7 days post fertilization. The metamorphosed clams appear to obtain all their energy requirements from their symbionts once the. symbiosis is well established. The metamorphosed giant clams can be kept in the large outdoor tanks until they are ready for sale to other growers or transfer into an ocean nursery. Depending on the survival and growth rate, the young giant clams may need to be thinned out into other tanks prior to sale or transfer. At JCUOIRS up to 50,000 six month old clams have been produced from one 10,000 litre tank. Generally (barring total failure) a range of 10,000 to 50,000 can be expected. It should be possible to keep at least 20,000 one year old seed clam in the larger 10,000 litre tanks (surface area 16 square metres) therefore 25 tanks would be required to produce 500,000 one year old seed clams.

13. Estimating the Costs of Giant Clam Seed Production

The cost of setting up and operating a giant clam hatchery will depend on its particular location. A general estimation of such costs is therefore difficult. Estimation of costs is also made difficult by the fact that the commercial giant clam hatcheries in existence, and the

JCUOIRS, have up to this point in time been experimenting with their methods. Notwithstanding these difficulties, an estimation of the cost of producing giant clam seed has been attempted.

Tables 1 and 2 present cost estimates based on the methods used by JCUOIRS and . "Reefarm". The estimates for the cost of building hatchery facilities is based largely on a quote obtained by Richard Braley from the Quantity Surveying Section, Ministry of Works, Cook Islands. Apart from the hatchery the cost estimates shown for capital expenditure have been calculated by the authors by estimating material requirements for the various production targets, prices for these materials were obtained from local suppliers. With regard to operating costs, labour and fuel costs are based largely on extrapolations of information obtained from JCUOIRS and "Reefarm". The cost estimates for repairs and maintenance, however, involve speculations by the authors.

TABLE 1 Estimated Capital Costs Associated with Giant Clam Seed Production Hatchery Capital Equipment in Australian Dollars

Production Target	100,000 seed	500,000 seed	1,000,000 seed
Capital Items		Costs ($A)	
Hatchery*	45,000-100,000	55,000-120,000	60,000-120,000
Worker accommodation and amenities*	For 3 workers 20,000-120,000	For 4 workers 25,000-120,000	For 5 workers 30,000-130,000
Sea-water supply system (see figure 1)	50,000-80,000	50,000-80,000	50,000-80,000
10,000 litre fibreglass nursery tanks* ($1400 each)	7,000	35,000	70,000
Besser bricks and cement for tank bases	2,000	10,000	20,000
Hatchery tanks 500 litre fibreglass ($300 each)	900	3,000	4,500
Broodstock tanks 10,000 litres ($1400 each)	1,400	2,800	4,200
Tractor	20,000	20,000	20,000
Utility truck	15,000	15,000	15,000
Boats*	5,000-50,000	5,000-60,000	5,000-65,000
Shade Cloth	625	2640	5000
Galvanized piping and fittings for shade cloth	2,000	8,300	16,000
Laboratory equipment	4,000	6,000	8,000
Microscopes (2)	2,500	2,500	2,500
Glassware	1,000	2,000	3,000
Plastic piping and fittings	2,000	5,000	8,000
Diving equipment	3,000	3,000	3,000
Air blowers	3,000	6,000	9,000
Miscellaneous Items	10,000	15,000	25,000
TOTAL ($)	194,425-424,425	271,240-516,240	356,800-606,800
Capital Cost per clam ($	1.94-4.24	.52-1.00	.356-.606

* Depends very heavily on local circumstances of the hatchery. See text for a more complete explanation.

TABLE 2 Estimated Annual Operating Costs Associated with Giant Clam Seed Production in Australian Dollars

Production Target	100,000 seed	500,000 seed	1,000,000 seed
Operating Cost		Production Costs	
Labour ($30,000 per employee)	(3) 90,000	(4) 120,000	(5) 150,000
Fuel	5,000-10,000	15,000-20,000	20,000-35,000
Repairs and Maintenance			
Pumps & generators	1,000-4,000	2,000-8,000	3,000-10,000
Boats	2,000-15,000	3,000-20,000	4,000-25,000
Glassware & laboratory consumables	1,000	2,000	3,000
Tractor	2,000	2,500	3,000
Total Operating Cost	101,000-122,000	144,500-172,500	183,000-226,000
Operating Cost per Clam ($)	1.01-1.22	0.29-0.35	.183-.226
Depreciation of worker accommodation and amenities at 2 1/2% per annum	500-3000	625-3000	750-3250
Depreciation of 10% per annum allowed for all capital items	17443-30443	24624-39624	32680-47680
Interest charges (assumption is made that all funds used for capital and operating costs borrowed, and that operating costs expended progressively through the year) assuming a real rate of interest of 10%	24493-48543	34349-60249	44830-71980
TOTAL	142935-200985	203473-272373	260510-345660
Total Cost per clam ($)	1.43-2.01	0.41-0.54	0.26-0.35
If a real rate of interest of 5% is assumed:			
Interest charges are ($):	12246-24271	17175-30125	22415-35990
Total cost is ($):	130689-176714	186299-242249	238095-309670
Total cost per clam is ($)	1.31-1.77	0.37-0.48	0.24-0.31

These cost estimates are summarised in Table 3. Figures 2 and 3 illustrate the relationship between the per unit cost of production of giant clam seed and the volume of production. Figure 2 is constructed on the assumption that the minimum cost estimates prevail and Figure 3 on the basis that maximum cost estimates prevail. Cost curves of the nature suggested by the first estimates have been drawn in freehand. They suggest significant economies of scale in production of seed.

TABLE 3 Summary of Cost of Producing Giant Clam Seed as a Function of Volume of Annual Output ($A)

Cost of Seed Clam	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
Full cost (5% interest)	1.31-1.77	0.37-0.48	0.24-0.31
Full cost (10% interest)	1.43-2.01	0.41-0.54	0.26-0.35

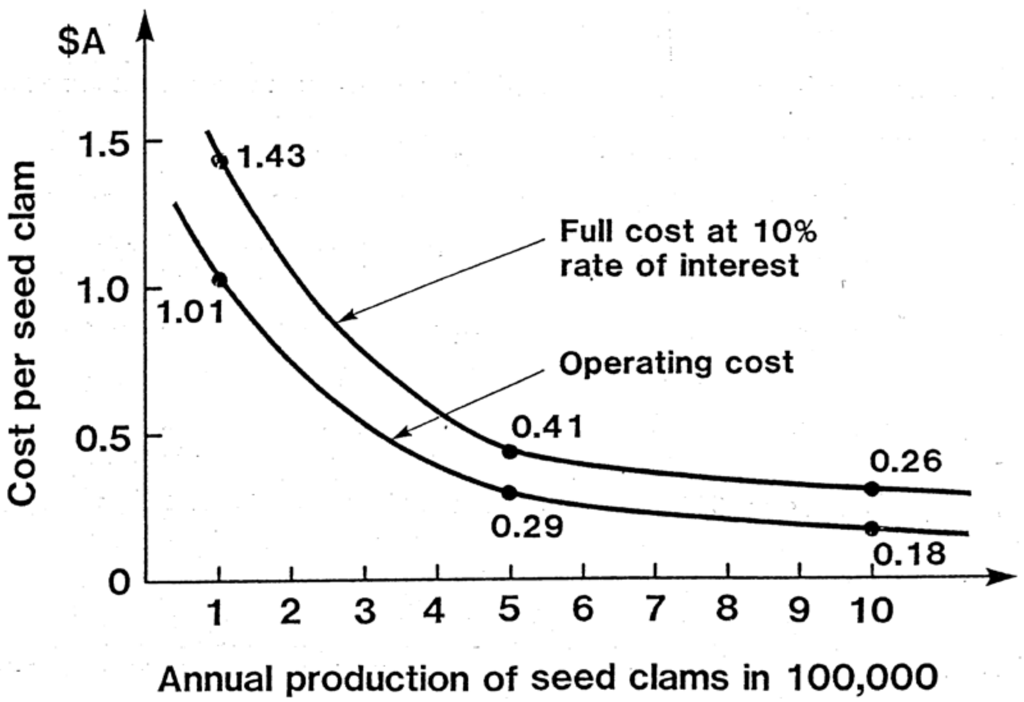


Figure 2: Operating costs and full costs of production for clam seed given minimum predicted costs.

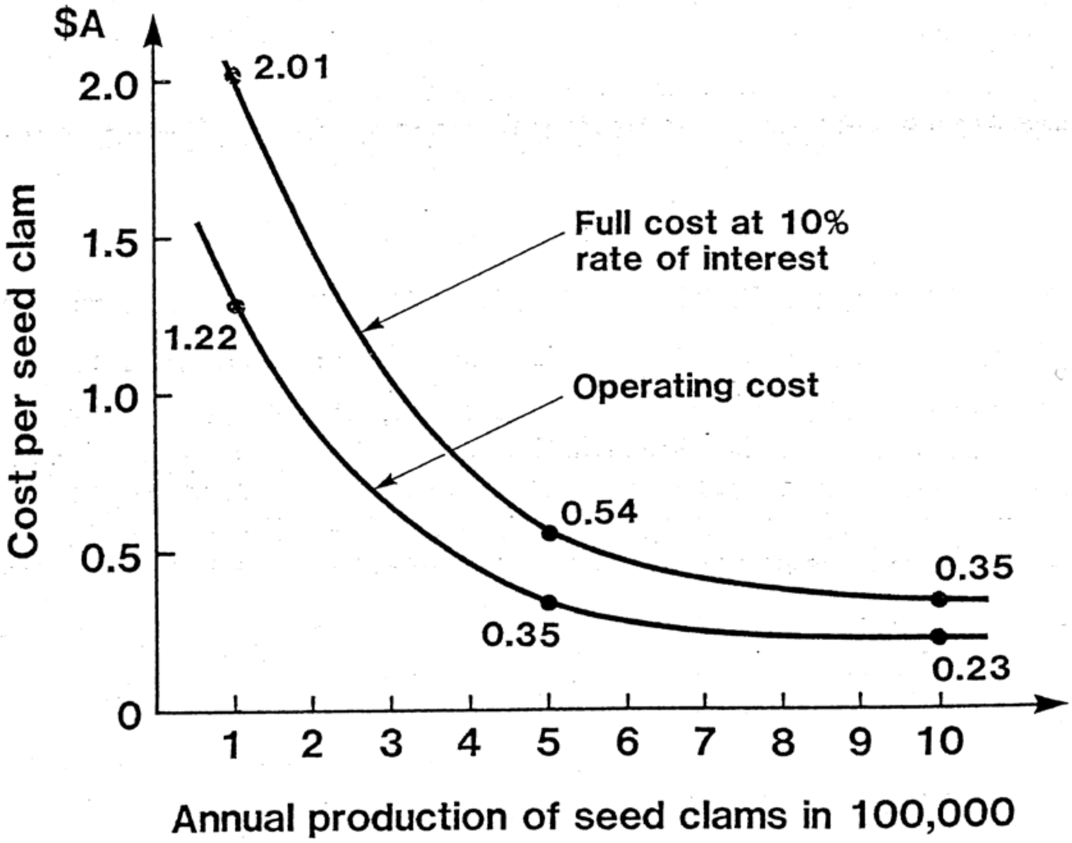


Figure 2: Operating costs and full costs of production for clam seed given maximum predicted costs.

Table 3 indicates that at an output of 100,000 clam seed per year, that at the very minimum a price of $1.00 per clam seed needs to be obtained just to recover operating cost and possibly a price of up to $1.22 per clam is needed. Recovery of full costs assuming a 10% real rate of interest would require a price of $1.43-$2.01 per seed depending upon whether the most optimistic or pessimistic assumption about the level of cost prevail. At a 5% real rate of interest the comparable required prices for breaking even are $1.31-1.77. A commercial hatchery on this scale is unlikely to be economic given that $1.00 per clam seed is likely to be about the maximum that could be attained. However at a higher volume the economic prospects are considerably improved.

At an output of 500,000 clam seed per year operating costs per clam seed lie in the range 29-35 cents. Full costs per seed produced are in the range of 41-54 cents per clam seed given a 10% rate of interest, and at a 5% rate of interest full costs per seed are in the range of 37-48 cents per seed clam. At such volumes, much lower prices are required to break-even or to make a profit compared with an output of 100,000 seed clams per year. Even lower per unit costs occur for an output of 1 million seed clams per year. But even though costs per seed clam appear to decline as the volume of output rises, it does so at a decreasing rate.

Under Australian conditions both labour and capital costs of producing giant clam seed are relatively high. Labour costs are relatively higher as a proportion of total costs at low volumes of production. Table 4 sets out direct labour cost as a percentage of total cost assuming a 10 percent rate of interest. Non-labour costs are principally those associated with the use of durable equipment.

TABLE 4 Breakdown of Direct Labour and Non-Labour Costs of Hatchery Operations as a Percentage of Full Cost

Assumed rate of interest	Number of seed clams					
	100,000		500,000		1,000,000	
	*Min	#Max	Min	Max	Min	Max
5%						
Labour Cost	51	69	50	64	48	63
Non-labour Cost	49	31	50	36	52	37
	100	100	100	100	100	100
10%						
Labour Costs	45	63	44	59	43	58
Non-labour Cost	55	37	56	41	57	42
	100	100	100	100	100	100

* Minimum capital and minimum labour costs.
\# Maximum capital and maximum labour costs. Percentages rounded to nearest whole number.

In less developed countries labour costs may be lower and for techniques different to those considered here it is also possible that costs will be lower especially at lower volumes of output of seed. But this matter still has yet to be investigated.

Note also that no allowance has been made for possible marketing costs and in larger enterprises possibly a separate cost item should be included for administration. However, allowance for these items is unlikely to alter the general conclusion that substantial economies of scale in production exist. Therefore, one of the main constraints, on size of hatcheries is likely to be availability of suitable sites of sufficient size to accommodate large hatcheries, rather than inherent production cost diseconomies.

14. Discussion

From an examination of the estimated cost of producing giant clam seed (see Tables 1, 2 and 3) indicates that there are considerable economies of scale in producing giant clam seed. Although the figures quoted are estimates, the figures do suggest that large hatcheries would produce giant clam seed more cheaply than small hatcheries. This suggests that large centralized hatcheries which supply seed to a network of growers could be more profitable than a proliferation of small hatcheries operated independently by individual growers. Whether a system of centralized hatcheries which supply small growers would be economically more viable than small localised hatcheries will depend on costs associated with the transportation of the giant clam seed. Indications are, however, that the transport of giant clam seed would be a viable proposition (Solis and Heslinga, 1989).

This analysis indicates that the cost of producing giant clam seed is high, compared with oyster spat for instance. Frankish (pers. comm.) calculated that Sydney rock oyster spat (*Saccostrea commercialis*) of 0.6 cm could be produced for under 1 cent, if the scale of operations was in the order of 60,000,000 spat per year. Commercial oyster growers at Yamba N.S.W. sell natural spat (0.5 to 1.5 cm.) for $10.00 per 1,000, that is, at 1 cent each.

The explanation for the relatively high cost of giant clam seed is the fact that once the giant clam veligers have settled they become phototrophs and require unobstructed access to light whereas oysters being filter feeders will grow up to 15 layers thick at a size of 0.5 if sufficient are supplied to them through upwelling devices (Frankish, pers. comm.). Although these cost figures may seem initially discouraging to potential commercial growers, it must be remembered that the growth rates of the larger species of giant clam are rapid relative to oysters once they reach a size of 5-10 cm. It may well be as Yamaguchi (1977) has said, that "conservation and cultivation of giant clams could be practised in the same manner as that applies to trees".

If giant clam farming does not prove to be commercially profitable it is still highly likely that giant clam seed will be required for restocking of reefs. Restocking of reefs is required for two reasons. Firstly the larger of the giant clams species (particularly *T.gigas*) have been made locally extinct or brought to the point of extinction on many reefs. Restocking reefs where local populations have become extinct should be advantageous to the survival of the species. From the point of view of avoiding total extinction restocking of depleted reefs is probably also likely to be advantageous, although the decrease in genetic variability brought about by restocking should be considered carefully. Secondly giant clams have been used as a traditional food source by Pacific Islanders for many centuries and since many of the Pacific Island states are resource poor they cannot afford to lose this food source; particularly since giant clams can be used as a strategic food reserve because of their longevity.

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