

seawater (Fig. 6). It should be mentioned here that the apparent Cd concentration increases in the visceral mass during depuration were attributed to weight loss during spawning and not a net gain in absolute amounts of this metal.

Of the three metals tested, Hg was accumulated by *T. crocea* to the greatest extent. In fact, all edible tissues exhibited a very high affinity for this metal (Fig. 7) and quickly accumulated it to levels often greatly in excess of the NHMRC recommended MPC of 0.5 µg/g wet weight in both treatments. Uptake rates in the gill and visceral mass were not significantly different between high and low treatments suggesting that saturation of external binding sites and/or internal transportation mechanisms had occurred at these levels of exposure.

The enormous increase in renal Hg concentrations, over the exposure period (Fig. 8), indicates that a significant proportion of the total Hg taken up by the edible tissues is readily mobilised to the kidney. The initial sharp decline in Hg levels from the gills, mantle and visceral mass during depuration (Fig. 7) is further evidence for this and, in turn, reflects the existence of regulatory processes. However, the clear indication of a persistent, residual Hg component in the latter tissues also means that clams exposed to severe Hg pollution may require a cleansing period of several months or even years, before they are acceptable for human consumption.

Concluding Remarks

It is clear from the foregoing study, that *T. crocea* possess a marked capacity to confine Zn, Cu, and Pb to a relatively narrow range that is most unlikely to exceed NHMRC food standards even in waters that are substantially enriched by these metals. Brief exposure to elevated Cd concentrations also seem unlikely to affect the quality of edible clam tissues owing to slow accumulation rates for this metal. However, prolonged exposure over a month or more, may require clams to be purged in clean seawater prior to marketing. In contrast, the clam's relatively high affinity for Hg suggests that exposure periods of relatively short duration, even under conditions of mild Hg enrichment, could have potentially disastrous effects on the commercial viability of this bivalve.

Acknowledgments

This work was undertaken within the Department of Marine Biology, at the James Cook University of North Queensland, Australia. The use of facilities provided by the School of Biological Sciences and the technical and

administrative services provided by the university are gratefully acknowledged. G.R.W.D wishes to express his sincere appreciation and thanks to Professor Cyril Burdon-Jones (Retired Head of Department of Marine Biology, JCU), for his role in initiating the program and his unfailing support during the course of the study and throughout this author's stay at JCU. Thanks also go to Professor Howard Choat (Head of Department of Marine Biology, JCU), Dr Joe Baker (Director, Australian Institute of Marine Science, Townsville) and Dr David J.H. Phillips (Acer Consultant Ltd., UK) for their encouragement and continued interest in the program.

The research was supported, in part, by the Water Quality Council of Queensland and Australian Marine Science and Technologies research grants (# 80-0078R and 84/1962)

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Economics of Giant Clam Production in Australia and Fiji and Sensitivity Factors

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THIS paper gives an overview of our main research results relating to the economics of production of giant clams for meat. This research was sponsored by the Australian Centre for Agricultural Research as part of its project 'Economics of Giant Clam Mariculture' (ACIAR Project No. 8823). Results are reported for the mariculture of *Tridacna gigas* in Australia (both for the economics of the hatchery/nursery phase and for the ocean phase) and for Fiji for the ocean phase of mariculture of *Tridacna derasa*.

Results for *Tridacna gigas* in Australia

Australian estimates are based upon the experience of scientific researchers at James Cook University and extrapolation, rather than a time-series for an actual commercial nursery, because of lack of data for the latter. The culture methods developed at the Orpheus Island Research Station of James Cook University (JCUOIRS) were assumed to be used by the hatchery/nursery. Estimates were made for both the operating and full cost of producing clam seed of one year of age in quantities of 100 000, 500 000 and a million seed per year. Full cost includes an allowance for all the funds tied up in clam production. Details of estimation of the costs are set out in Tisdell, Lucas and Thomas (1990) and the results are summarised in Table 1.

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Substantial economies of scale are evident from Table 1. When the commercial volume of production is 100 000 seed at the end of one year and full cost is accounted for at a 5% rate of interest on funds, clam seed on average would be expected to cost about A\$1.50 each. If only operating cost is taken into account, then the average cost per clam seed is about A\$1.10. But cost per seed is much lower when 500 000 clam seed are produced annually. Full cost, at 5% interest, averages A\$0.425 per clam and for a production of 1 million clams annually falls to A\$0.275. Hambrey (1991a) also found, on the basis of experience at the International Centre for Living Aquatic Resources Management (ICLARM) hatchery in Solomon Islands, that economies of scale are important in the production of clam seed.

Returns on the Ocean Phase of Mariculture of *T. gigas*

To determine whether the ocean growout of *Tridacna gigas* could be profitable under Australian conditions, internal rate of return analysis was applied to a hypothetical farm placing 10 000 one-year-old seed in the ocean each year and using the intertidal culture techniques developed at JCU. Data from JCUOIRS on costs was supplemented by information from Reefarm Hatcheries, Cairns (see Tisdell, Barker et al. 1991, Tisdell, Tacconi et al. 1991 for details) and growth and mortality rates were those found at JCUOIRS and by the observation of Munro (1988). Details are available in (Tisdell, Barker et al. 1991). After an initial period (two years) of higher mortality rates, a mortality rate of 5% per annum is assumed to apply.

Table 1. Per unit cost of producing giant clam seed at a function of volume of annual output^a.

Type of cost	Number of seed clams per year		
	100000	500000	1000000
Operating cost	1.01–1.22 (1.115)	0.29–0.35 (0.32)	0.18–0.23 (0.205)
Full cost (5% interest)	1.31–1.77 (1.54)	0.37–0.48 (0.423)	0.24–0.31 (0.275)
Full cost (10% interest)	1.43–2.01 (1.72)	0.41–0.54 (0.47)	0.26–0.35 (0.305)

^aAll dollar values used in this article are Australian dollars. Figures in parenthesis are averages of upper and lower bounds of per unit costs of production.

Seed clams of one year old were assumed to cost A\$0.75 each and the aim of the farm was assumed to be to hold seed clams long enough in the ocean to maximise its internal rate of return on resources employed, that is the profitability of its operations. The end product is assumed to be the clam meat only, although it is possible also that there could be a market for the shell. Clam meat could sell at the alternative prices listed in Table 2 at the farm-gate in Australia. A price of around A\$5 seems highly probable given that clam meat in Australia should retail for A\$10–12 per kilogram, a price comparable to that for fish, according to surveys by Tisdell and Wittenberg (1990a,b and cf. Shang et al. 1991).

The internal rates of return listed in Table 2 are all positive. While this is encouraging from a commercial point of view, the industry will only be truly economic if the rate of return exceeds the rate of interest on funds. The most likely situation of those shown in Table 2 could be that involving a farm-gate price of \$A5 per kg,

a post-harvest drip loss of 40% and an internal rate of return of 11.25%. Therefore, this type of clam farming is likely to be profitable under Australian conditions but not highly profitable.

The number of years which *T. gigas* has to be held in the ocean to maximise returns in supplying the meat market might seem relatively long, e.g. 11 or 14 years in the intermediate price case. However, examination of the internal rate of return function indicates that after the ninth year of the ocean phase only a very slight increase in returns is achieved by holding the clams longer. Thus taking into account cash flow considerations and impatience, harvesting in the ninth year of grow-out is likely to be optimal. The clams would then be 10 years old. Nevertheless, this is a longer period of ocean grow-out than that recommended by Watson and Heslinga (1988) for *T. derasa*. They recommend a grow-out period of five years for one year old *T. derasa*, that is, their harvest at six years old, based on the fact that *T. derasa* has significant decrease in growth at onset of the female phase of reproduction.

Preliminary Estimates of Economic Returns from Ocean Farming of *T. derasa* in Fiji

Prospects for subsistence production and commercial mariculture of giant clams in Fiji, and domestic and export markets for clam meat have been considered (Tacconi and Tisdell 1992 a,b,c). Fiji has had a substantial export market for giant clam meat in the past and there is also a domestic market for the meat. Harvest of natural populations supplied past demand from clam meat, but has led to the near extinction of the larger species.

Subsistence Prospects

Fijian data indicates that giant clam farming at the village level is unlikely to be economic for subsistence purposes. From surveys of villagers, it is clear that they

Table 2. Number of years for which *Tridacna gigas* should be held in ocean phase to maximise economic returns and the resulting internal rate of return (IRR).

Farmgate price/kg of meat in 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

are mainly interested in whether giant clam farming can provide them with cash income rather than means for subsistence (Vuki et al. 1991). Estimates of Tacconi and Tisdell (1992a) indicate that the cost per kilogram of producing giant clam meat by mariculture is likely to exceed the price at the village level of substitutes for clam meat such as fish. Also the capital outlay required for the purchase of seed is comparatively high for a village household (cf. Veitayaki 1990). There are also risk factors to consider, such as loss of clam stocks due to predators or disease.

Commercial Prospects for Fiji and Profitability

T. derasa seed stocks are at present held by the Fijian Fisheries Division and this is likely to be the first species released for commercial farming in Fiji. It will be recommended by the division that giant clams be held for five years in the ocean phase before harvest, the optimal length of time to hold *T. derasa* according to the estimates of Watson and Heslinga (1988).

Taking account of the possible cost of seed (F\$0.50 or F\$1.00) and the cost of protective cages, alternative prices for muscle and other edible meat and different mortality rates, as well as different levels of drip weight loss, internal rates of return are as set out in Table 3. More detail is available in Tacconi and Tisdell (1992a). Hambrey (1991b) points out that a drip weight loss in clam seed of up to 50% is possible.

These estimates should be regarded as upper limits for returns since no allowance for labour cost has been made mainly because no reliable data for these in the Fijian village situation was available. Implicitly they are therefore assumed to be zero but even on an opportunity cost basis, they are likely to be positive in practice. The range of farm-gate prices considered for meat and mantle are believed to be realistic taking into account previous market prices and margins necessary for transport, for processors and for middlemen. Possibly the intermediate set of prices in Table 3 is most likely in the long run but in the short run when supply would still be limited, the higher set of prices would be realistic.

Table 3. Internal rates of return from ocean farming of *T. derasa* in Fiji.

	Farm-gate price/kg		
	Muscle F\$10 Other tissues F\$3	Muscle F\$7 Other tissues F\$2	Muscle F\$5 Other tissues F\$2
Drip loss 5%			
Low mortality (25% first year, 5% afterwards)			
—seed F\$1 each	5.4	Negative	Negative
—seed F\$0.5 each	20.4	11.5	8.9
High mortality (25% first year, 10% afterwards)			
—seed F\$1 each	0.9	Negative	Negative
—seed F\$0.5 each	15.3	6.7	4.2
Drip loss 40%			
Low mortality			
—seed F\$1 each	Negative	Negative	Negative
—seed F\$0.5 each	14.2	5.85	2.6
High mortality			
—seed F\$1 each	Negative	Negative	Negative
—seed F\$0.5 each	9.3	1.3	Negative

Source: Based on Tacconi and Tisdell (1992a).

Table 3 indicates that the rate of return to ocean growout of *T. derasa* is very sensitive to the price of clam seed. If the price for clam seed can be kept to F\$0.50 each, a positive rate of return can be obtained in all the alternative situations highlighted in Table 3, except one. On the other hand, if clam seed costs F\$1 each, a negative rate of return is to be expected in most cases.

A positive rate of return from the farming of *T. derasa* in Fiji under the conditions considered seems to depend on the price of clam seed being kept at low levels, and there being low labour costs at the village level in tending clams. At F\$0.50 each for seed, and given the intermediate price set, returns are all positive but none are exceptionally high.

Concluding Observations

The economic prospects for farming *T. gigas* profitably under Australian conditions seem on the whole to be more favourable (or at least no less so) than those for farming *T. derasa* in Fiji under the conditions specified. This indicates that an efficient Australian industry could be competitive with Fiji despite higher labour costs.

The above assumes that all the edible clam meat is marketed. This usually is the case in the Pacific Islands. In the past, Fiji had a sizeable export market in giant clam meat (see Table 4). It's export peaked at 38.5 tonnes in 1988, after which an export ban was imposed because of depletion of natural stocks. About half of the export was muscle and the remainder, other soft edible tissues such as mantle. The main export destination for muscle was Taiwan and for mantle New Zealand, where it was probably consumed by immigrants from the Pacific Islands. In addition, the 'normal' Fijian domestic market for clam meat is about 13 tonnes annually.

Table 4. Quantity of giant clam meat exported from Fiji, 1984–1988.

Year	Weight (kg)
1984	7276
1985	20794
1986	16806
1987	5490 ^a
1988	38493

^aData available only for the period September–December. Source: Based on Fiji Fisheries Division (1986, 1987). Files of Fiji Fisheries Division.

If peak exports were to be regained by Fiji, 275 000 *T. derasa* of six years old would be needed annually to supply exports, the estimate being based upon volume of muscle needed. Depending upon survival rates, this would require half a million one year old giant clams to be grown out in the ocean each year, and at 600 seed per household, about 800 households being supplied. However, the Fijian Fishery Division hatcheries capacity is about 200 000 eight month old seed per year (Batibasaga and Ledua 1992) so even under very favourable economic conditions, availability of seed may be limiting to expansion of Fijian commercial production. However, Fiji has had a substantial market for clam meat, with its export market being much larger in the past than its domestic market, and could look to recapturing a part of its former export market as a result of clam farming. Tonga has similar prospects but it has never had commercial exports of clam meat on the scale of Fiji (Tacconi and Tisdell 1992c).

Acknowledgments

We wish to thank Jeremy Barker, John Lucas and Bill Thomas for assistance with the Australian data and Esaroma Ledua for help with Fijian data and ACIAR Project No. 8823 for financial support.

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The Economic Potential of Village Based Farming of Giant Clams (*Tridacna gigas*) in Solomon Islands

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INTEREST has been shown throughout the Pacific in the possibility of developing giant clam mariculture as an export industry and it has been suggested that such an industry might be particularly suitable as a part-time activity for Pacific Island villagers.

Much of the research effort has concentrated on the production of large *Tridacna gigas* or *Tridacna derasa* (e.g. Munro 1988, Barker et al. 1988). This paper considers prospects for the farming of large *Tridacna gigas* as a village based industry in Solomon Islands. It is based on two detailed working papers on market value and production costs for *T. gigas* in Solomon Islands (Hambrey 1991a and b). A third working paper on the economic potential of farming smaller giant clams (either young *T. gigas* or smaller species) is in preparation.

Other studies on the economic potential of farming large *T. gigas* or *T. derasa* have been undertaken by Tisdell et al. 1991 (for the Australian mainland) and Tacconi and Tisdell 1992 (for Fiji, Tonga and Western Samoa).

Unless otherwise stated, all costs given below are in Solomon Island dollars (= US\$0.37).

Production Parameters

The production system is still undergoing development and different researchers favour different systems or production strategies. The production parameters are

also still rather poorly defined: the survival in hatchery tanks and floating cages is still highly variable; the effectiveness or otherwise of grading and discard at various stages is poorly established; and there are still very little data available on the survival rates of larger clams on the open reef.

For the purposes of this analysis the production process is assumed to be as follows: four month old hatchery grown spat at 4 mm (unselected) or 6 mm (selected) are stocked in floating ocean nurseries alongside a hatchery. These are grown for six months to a size of around 35 mm and then sold to villagers for grow-out. At village sites they are grown in cages for the first year and net enclosures for the second. Thereafter they are transferred to the open reef (unprotected) for final grow-out to a size of 45 cms +.

The range of production parameters used in the economic models is given in Table 1. For the most important or ill-defined parameters, three values are used in the economic models: worst case, corresponding to a production situation where regular bouts of poor performance are experienced, e.g. as a result of algal fouling in hatchery, flatworm or predatory snail infestation in ocean nursery; most likely case, corresponding to what research staff believe could be consistently achieved with well trained and motivated staff using the best currently available technology and husbandry practices—i.e., rather better than present average performance; and best case, representing what might be possible if the factors resulting in occasional excellent performance in individual tanks or cages could be understood and reproduced consistently.

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Table 1. Production parameters.

(a) Hatchery (production of four month old 4–6 mm spat)	
Yield per tank (10 m ²)	20 000, 40 000, 80 000
Age at harvest	Four months
Production cycles/year	3
Percentage discard	60, 0
Mean size (mm) selected, unselected	6,4
(b) First stage ocean nursery (production of 10-month-old 35 mm seed)	
Harvest/grade after three months; restock and hold for further three months; sell to on-growers.	
Stocking density phase 1	10000/m ²
Stocking density phase 1	2000/m ²
Survival phase 1 (selected)	0.3, 0.5, 0.6
Survival phase 2	0.5, 0.7, 0.8
Survival phase 1 (unselected)	0.2, 0.4, 0.5
Survival phase 2	0.5, 0.5, 0.7
No. of production cycles/cage/year	3
(c) On-growing at village sites (production of seven to nine-year-old 45 cm clams)	
Stocking density phase 1 (cage on trestle)	800/m ²
Stocking density phase 2 (cage on bottom)	200/m ²
Stocking density phase 3 (exclosure)	30/m ²
Stocking density phase 4 (open reef)	5/m ²
Overall survival (%)	15,22,30
Production cycles/year	2
Time to harvest (years)	6,7,8

Cost of hatchery spat (3–6 mm)

Estimates for capital and operating costs of a hatchery based on 300 m² of growing tank space are presented in Table 2. Operating costs are presented in three categories: fixed, which would correspond to the essential overheads for any reasonable sized hatchery; semi-variable, which would vary in approximate proportion to the physical size of the hatchery; and variable, which would vary in approximate proportion to the output from a hatchery. The relatively high fixed and semi-variable costs (between \$109000 and

\$143000 for hatcheries with up to 300 m² of growing tank), imply that spat production costs will be highly sensitive to scale of production (when considering hatchery design) and even more sensitive to the actual output rate for any established hatchery.

The basic hatchery described could produce 1.8–7.2 million ungraded spat of approximately 4 mm (worst and best cases) in size with a most likely production of 3.6 million. Corresponding estimates for cost/spat would be 8.5, 2 and 4 cents. If 60% of these were considered runts and discarded, unit costs for the remaining (ca. 6 mm) spat would be in the range of 5–21 cents, with a most likely value of 11 cents. Figure 1 shows the way in which these values would vary (approximately) with scale of production in terms of hatchery size. Costs would be even more sensitive to the actual output of a hatchery of any given size.

Cost of seed (35 mm) production

The capital and operating costs for a first stage ocean nursery, assuming shared management and overhead costs with a hatchery and growing spat from 4–6 mm to 35 mm in six months in floating cages, are given in Table 3. Costs are again divided into fixed, semi-variable and variable. Spat costs (variable) dominate the production costs for such a nursery (76%). A specialist producer not directly associated with a hatchery and supplying widely dispersed growers would suffer much higher fixed (overhead) costs and would therefore experience important economies of scale. Villagers might be able to undertake this stage themselves but because of the relative unimportance of labour in operating costs, their production costs are unlikely to be significantly lower; indeed it is probable that survival rates would be lower (and spat costs correspondingly higher) than those achieved in a centralised or specialist facility.

Using the most likely cost for selected 6 mm spat (11 cents), unit productions costs for 35 mm seed would vary between 30 and 88 cents with a most likely value of 40. Approximately 10 cents of this is associated with labour, capital (floating cages) and overheads; the highly variable balance is contributed by the spat costs. Assuming that all the hatchery output is kept in Solomon Islands, such a cost would correspond to a total annual Solomon Islands production of 504 000 35 mm seed.

Other researchers have estimated production costs for seed of 25–30 mm direct from the hatchery at A\$ 0.37–0.48 (= SIB \$0.74–0.96) for 500 000 production (Tisdell et al. 1990). The differences derive from the Australians' higher estimates for capital and labour costs and the different production process. Using their

Figure 2. Capital and operating costs for *T. gigas* hatchery.

Capital costs		Operating costs	
Fixed		Fixed	
Land and buildings	77600	Manager	28000
Pumphouse and generator	21000	Assistant/engineer	12000
Intake line	4300	Office	7000
Spawning tanks (2)	1200	Maintenance (7% capital)	12748
Freshwater system	2600	Insurance.(3% capital)	5464
Truck	35000		
Equipment	15420	Capital charge	40977
Misc.	5000		
Installation	20000		
Subtotal	182120	Subtotal	106189
Semi-variable (design variable)		Semi-variable (design variable)	
Tanks (30 at 10 m ²)	18000	Labour/technicians	24600
Pipes, drains, shade	12500	Maintenance/insurance (10% on cap)	7555
Aeration	4000	Capital charge	16999
Pumps	28600	Subtotal	49154
Broodstock	2450	Variable	
Installation	10000	Fuel/lubricants	11500
		Consumables	5570
Subtotal	75550	Subtotal	17070
Total capital costs	257670	Total operating costs	172413

Cost/spat	Yield (spat/m ²)		
	2000	4000	8000
Discard	0	0.09	0.04
	60	0.22	0.11
Hatchery output	1800000	3600000	7200000

Notes: it is assumed that management, workshop and office space is shared with the ocean nursery. Age at harvest would be 4 months; each tank is restocked on average every 4 months; the total growing tank area is 300 m²; and the capital charge = sum (capital cost/life+ 0.1* capital cost).

Table 3. Seed (35 mm) production costs: central specialist facility. Example for 35% overall survival: production 504000.

Capital costs (SIB\$)		Life	Operating costs		SIB\$	Percentage
Variable	Cages	49 140	5	Fixed		
Fixed	Canoe	700	6	Office	4000	2
Fixed	Tools	2000	3	Transport	5000	2
Fixed	Masks	1000	4	Semi-variable		
Fixed	SCUBA	2000	5	Maintenance/insurance ^a	5484	3
Total		54 840		Capital charge	16 745	8
				Variable		
				Spat	162 720	79
				Packaging	230	0
				Labour	12 850	6
				Total	207 029	
				Production cost	0.41/35 mm seed	

Notes: It is assumed that management and overheads are shared with the hatchery. The above assumes a 6-month production cycle in two three-month stages. Clams are stocked and harvested regularly at approximately monthly intervals. The stocking density at stage 1 was 1000/m² and 200/m² at stage 2; survival at stage 1 was 0.5 and at stage 2 was 0.7; runt cull at end of stage 1 was 0; and the spat cost was 0.11.

^aMaintenance/insurance was charged at 10% of capital.

production parameters with CAC estimates for hatchery costs would give a hatchery produced (one year old) seed cost of SIB\$0.6.

The delivered cost of seed to the village grower will be higher according to transportation costs. For sites other than those in the immediate vicinity of the seed producer, these could be anywhere in the range of SIB\$0.01–0.1 per seed clam for Solomon Island growers, according to the location and size of shipment.

Returns to village growers (grow-out to 45 cm+)

Returns to village growers will depend critically on seed costs, survival and growth rates and market value. 'Most likely values' for these are extremely difficult to establish at this stage and deserve some discussion.

The most likely value for seed cost derived above was SIB\$0.40 + delivery costs. It must be remembered that this corresponds to production (and therefore sales) of 500000 seed per annum. Costs would be very much higher at lower rates of output. Such a cost would therefore only be possible once a village based industry was well established and well organised in the Solomon Islands, with a total output of perhaps 150000 45 cm clams, (corresponding to around 33 tonnes of adductor muscle, 247 tonnes of mantle meat and more than 3000

tonnes of shell). Clearly, many years of investment in hatchery production, village extension and market identification, development and supply would be required before this became a reality.

Data from the best performing and longest established village trials in Solomon Islands suggest by extrapolation from current growth rates that a size of 45 cm (average) could be achieved in 6.5–7.5 years (from stocking at 35 mm) using high quality (highly selected) seed. Growth rates quoted for Orpheus Island (Barker et al. 1988) of 5–6 mm per month for sub-tidal cultivation (clams between 30 and 225 mm) tend to confirm these figures. Studies on wild clams in New Guinea and on the Great Barrier Reef (Munro and Gwyther 1981, Munro 1986, 1989, Pearson and Munro 1991) suggest that the age of 45 cm clams averages something in the range of 7–9 years, which corresponds well with the above. For the purposes of this analysis, it is assumed that the average growout from 35 mm–45 cm using moderately selected stock at good sites will take between six and eight years with a most likely value of seven years.

Survival from stocking (using highly selected 10–12-month-old seed) through to around 230 mm after 30 months, at the best and longest established village trials, stands at between 28% and 40%. At more

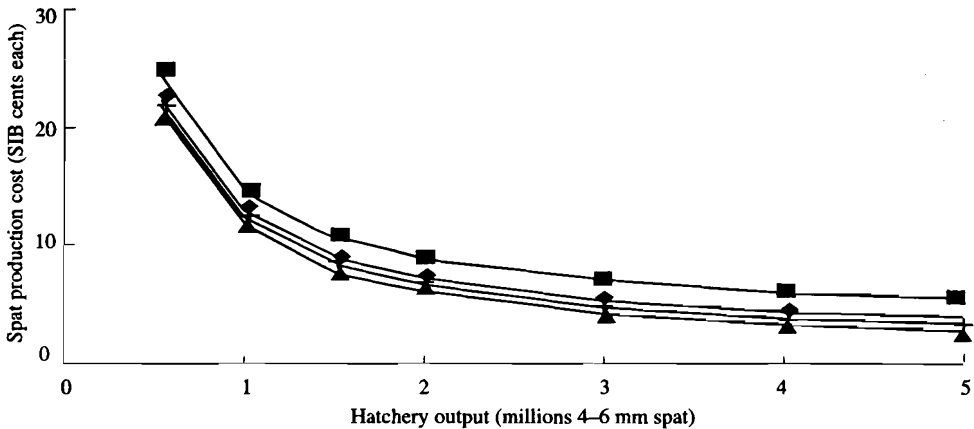


Figure 1. Economies of scale for spat production. ■ = 60% discard; 4000/m²; ◆ = 60% discard; 8000/m²; + = no discard; 4000/m²; and ▲ = no discard; 8000/m².

typical sites neglect and/or serious snail (*Cymatium* spp.) infestation may result in very much worse performance. At Orpheus Island the average survival in 'lines' over a 19 month period from stocking at 11 months was 41% (Barker et al. 1988). For clams of 20 months + the same authors suggest an annual survival rate of >84% and for clams over 30 months more than 90%. Very little data are available on the survival of the large clams on the open reef. The data of Pearson and Munro (1991) for wild *Tridacna gigas* on Michelmas reef show that survival is very variable but in their study the average annual survival rate increased from 0.6 at 20 cm to 0.95 at 45 cm, which would correspond to 45% to 55% overall survival between 20 and 45 cm. On the basis of this rather limited data it is suggested that overall survival between stocking at 35 mm and marketing at 45 cm is likely to lie in the range 15–30% with a most likely value of 22%. Survival in the earlier stages (35–100 mm) might be improved substantially if some effective means of controlling predation, (especially by *Cymatium* snails) can be developed.

Numerous market and processing studies have been undertaken for large giant clam products (Carlton 1984, Dawson 1986, Sanders 1987, Trachet 1989, Phillipson 1989, Tisdell 1989, Tisdell and Wittenberg 1990, Shang et al. 1990, Parry 1990, Cowan 1991) but very few of these have examined collection, processing and exporting costs—the main component in seafood and marine product value, especially for small island nations. Table 4 gives the estimated return for different products from a 45 cm *Tridacna gigas* to a clam farmer

at a typical Solomon Island village site. The adductor muscle is likely to bring a return of no more than SIB\$3.6–4.6 on a 45 cm clam and the return from frozen or processed mantle meat products is likely to be negative or insignificant, apart from some possible pickled products. The shell has not been included because this size (45–50 cm) of shell is not and has never been internationally traded in large volumes and although there is considerable interest in it for a variety of applications in southeast Asian markets, it has so far been impossible to estimate a likely future export value for significant volumes.

For grow-out it is appropriate to use cash flow techniques for the analysis, since cash flow will be crucial for a long term production cycle. An example cash flow over a 15-year period is presented in Table 5. Using a delivered seed cost of 41 cents (i.e. most likely cost + 1 cent distribution costs, corresponding to a relatively accessible and large scale operation or group of growers), overall survival of 22% from stocking at 35 mm to harvest at 45 cm, an average production cycle of seven years and a farm-gate value of SIB\$5/clam (corresponding to sales of adductor + mantle only), the cash flow generates a negative internal rate of return (IRR—labour charged at \$10/day) and a negative return on labour (ROL—cost of labour giving a zero internal rate of return). For a farm-gate value of \$7.5 (i.e. assuming \$4–\$5 for adductor and mantle and \$2–\$3 for the shell), IRR would be 7% and ROL \$14/day and for a farm-gate value of \$10 (i.e. assuming a value of around \$5 for the shell), IRR would be 14%

Table 4. Giant clam (large *T. gigas*) products: potential farm-gate value in the Solomon Islands based on most likely retail, wholesale, or CIF value.

Product/market	retail price	wholesale price	port value	import tax	Clf	freight type	freight cost	FOB Hon	export tax	net of tax	export process cost	process yield %	value raw	less process cost	Internal freight	price/kg to producer	value/ clam \$US	Value/ clam \$SI
1 frozen adductor, 2-300q, Taiwan		17.0	17.0	25.0	13.6	air	4.2	9.4	10.0	8.5	1.4	97.0	8.2	6.8	0.8	6.0	1.3	3.6
2 frozen adductor, 2-300q, Taiwan		16.0	15.0	25.0	11.3	sea	0.5	10.8	10.0	9.7	1.4	97.0	9.4	7.9	0.8	7.1	1.6	4.3
3 frozen adductor, 3-400q, Taiwan		24.0	25.0	25.0	18.8	air	4.2	14.6	10.0	13.1	1.4	97.0	12.7	11.3	0.8	10.5	3.5	9.3
4 frozen adductor, 3-400q, Taiwan		23.0	23.0	25.0	17.3	sea	0.5	16.8	10.0	15.1	1.4	97.0	14.6	13.2	0.8	12.4	4.1	11.0
5 frozen adductor 2-400q, Hong Kong					12.0	air	3.5	8.5	10.0	7.7	1.4	97.0	7.4	6.0	0.8	5.2	1.2	3.2
6 Dried adductor, Hong Kong (Top subst.)					50.0	air	3.5	46.5	10.0	41.9	1.6	18.0	7.5	6.0	0.6	5.4	1.2	3.3
7 Dried adductor, Hong Kong					25.0	air	3.5	21.5	10.0	19.4	1.6	18.0	3.5	1.9	0.6	1.3	0.3	0.8
8 smoked adductor (vacpak, Pac. Isl.)	50.0				20.0	air	2.2	17.8	10.0	16.0	2.1	45.0	7.2	5.1	0.6	4.5	1.0	2.7
9 soft adductor (vacpak, Pa. Isl.)	40.0				16.0	air	2.2	13.8	10.0	12.4	2.0	50.0	6.2	4.2	0.6	3.6	0.8	2.2
10 canned adductor (S E Asia)					7.0		0.2	6.8	10.0	6.1	2.0	45.0	2.8	0.8	0.6	0.2	0.0	0.1
11 whole meat/mantle, Pacific is./NZ	4.0				2.0	air	2.0	0.0	10.0	0.0	1.4	57.0	0.0	-1.4	0.6	-2.0	-3.4	-9.1
12 whole meat/mantle, Australia	6.0				3.0	sea	0.3	2.8	10.0	2.5	1.4	57.0	1.4	-0.0	0.6	-0.6	-1.0	-2.8
13 whole meat/mantle, Australia	6.0				3.0	air	0.6	2.4	10.0	2.2	1.4	57.0	1.2	-0.2	0.6	-0.8	-1.3	-3.6
14 dried mantle, HK/Tokyo					10.0	sea	0.5	9.5	10.0	8.6	1.6	6.5	0.6	-1.0	0.6	-1.6	-2.6	-7.2
15 clam crackers					10.0	sea	0.5	9.5	10.0	8.6	1.7	6.0	0.5	-1.2	0.6	-1.8	-2.9	-7.8
16 pickled mantle (uncooked, japan)	24.0		9.6	15.0	8.2	sea	0.5	7.7	10.0	6.9	2.1	40.0	2.8	0.6	0.6	0.0	0.1	0.2
17 pickled mantle cooked	24.0				9.6	sea	0.5	9.1	10.0	8.2	1.9	17.0	1.4	-0.5	0.6	-1.1	-1.8	-4.8
18 smoked mantle, vacpak	40.0				16.0	sea	0.5	15.5	10.0	14.0	1.9	15.0	2.1	0.2	0.6	-0.4	-0.6	-1.6
19 minced mantle frozen, vacpak					3.0	sea	0.3	2.7	10.0	2.4	2.0	45.0	1.1	-0.9	0.6	-1.5	-2.5	-6.9
20 minced mantle, cooked in brine					3.0		0.5	2.5	10.0	2.3	1.8	18.0	0.4	-1.4	0.8	-2.2	-3.7	-10.0
21 canned mantle					3.0		0.3	2.7	10.0	2.4	1.8	18.0	0.4	-1.4	0.6	-2.0	-3.3	-8.9

Notes:

- 1) a CIF-retail mark-up of 2 is assumed for bulk frozen product, and 2.5 for all other products.
- 2) products 3 and 4 assume a 50 cm (ca 9 yr old) clam.
- 3) Products 2,4 : at present there is no refrigerated delivery, Solomon to Taiwan. Would have to go via Australia (not recommended by exporters) or refrigerated container bought or hired, and delivery costs paid both ways

All values in \$US/kg Unless otherwise stated values/clam refer to a 45cm clam aged approximately 7.5 yrs

Table 5. Cash flow and returns to village grower aiming at annual production of 1000 45 cm clams. Assumes seed cost of SIB\$0.4; survival to market 22%; and farm-gate value \$8/clam.

	year					year					year					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
COSTS																
SEED	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	1,818	
CAGES	185			185			185			185			185			
EXCLOSURES		702			702			702			702			702		
EQUIPMENT+ MEDICINES	500			500			500			500			500			
TOTAL before labour	2,503	2,520	1,818	2,503	2,520	1,818	2,503	2,520*	1,818	2,503	2,520	1,818	2,503	2,520	1,818	
LABOUR	739	739	739	739	739	739	739	739	739	739	739	739	739	739	739	
TOTAL incl. labour	3,241	3,258	2,557	3,241	3,258	2,557	3,241	3,258	2,557	3,241	3,258	2,557	3,241	3,258	2,557	
REVENUE																
							2,000	6,000.00	8,000.00	8,000.00	8,000.00	8,000.00	8,000.00	8,000.00	8,000.00	
MCF before labour and interest	(2,503)	(2,520)	(1,818)	(2,503)	(2,520)	(1,818)	(503)	3,480	6,182	5,497	5,480	6,182	5,497	5,480	6,182	
CNCF before labour and interest	(2,503)	(5,023)	(6,841)	(9,344)	(11,863)	(13,682)	(14,184)	(10,704)	(4,522)	975	6,455	12,637	18,134	23,614	29,796	
INTEREST	(300)	(603)	(821)	(1,121)	(1,424)	(1,642)	(1,702)	(1,284)	(543)	0	0	0	0	0	0	
MCF incl. interest, no labour	(2,803)	(3,122)	(2,639)	(3,624)	(3,945)	(3,460)	(2,205)	2,196	5,639	5,497	5,480	6,182	5,497	5,480	6,182	
CNCF incl. interest, no labour	(2,803)	(5,326)	(8,565)	(12,189)	(16,132)	(19,532)	(21,797)	(19,601)	(13,962)	(8,465)	(2,985)	3,197	8,694	14,175	20,356	
MCF inc. labour, no interest	(3,241)	(3,258)	(2,557)	(3,241)	(3,258)	(2,557)	(1,241)	2,742	5,443	4,759	4,742	5,443	4,759	4,742	5,443	
CNCF incl. labour, no interest	(3,241)	(6,500)	(9,057)	(12,298)	(15,557)	(18,113)	(19,355)	(16,813)	(11,170)	(6,411)	(1,670)	3,773	8,532	13,274	18,717	
MCF incl. labour and interest	(3,542)	(3,861)	(3,378)	(4,363)	(4,682)	(4,199)	(2,944)	1,457	4,901	4,759	4,742	5,443	4,759	4,742	5,443	
CNCF incl. labour and interest	(3,542)	(7,403)	(10,781)	(15,143)	(19,825)	(24,024)	(26,967)	(25,510)	(20,610)	(15,851)	(11,110)	(5,666)	(908)	3,834	9,277	
SUMMARY OF RETURNS																
		VARIABLES				INPUT PARAMETERS				PRODUCTION AND SIZE						
NPV before labour and interest	4,937	Labour (SIB/day)				10.00	cage cost				25.00	seed requirements				4,545
IRR before labour and interest	0.151	delivered seed cost				0.40	tools, masks etc				500	cage requirement				6
NPV incl. labour, no interest	(1,243)	survival to 50m				57	annual production				1,000	buffer				2
IRR incl. labour, no interest = IRR	0.088	survival to 100m				94	time to harvest				7.0 yrs	Enclosure area(sq.m)				67
NPV incl. interest, no labour	(1,297)	survival to market				22	size at harvest				45 cm					
NPV incl. labour and interest	(7,477)	Market value (SIB)				8.0	Stock density 0-6 m				400	labour (days/yr)				74
IRR incl. labour and interest = 0 for ROL	0.038	Discount rate				0.10	Stock density 6-12 m				100					
		Interest rate				0.12	Stock density, excl				30					
							cage inspections/week				3					
							time/cage (mins)				10					
							Enclosure net cleans/month				1					
							Predator checks (hrs/excl/week)				1					

and ROL \$33/day. The accumulated investment requirements (mainly on seed, cages, exclosures) are substantial, rising to around SIB\$22000 in year seven for a village grower aiming at an annual production of 1000 market clams, with a payback period of 11 years (farm-gate value \$10) to 13 years (product value \$7.5). Given the rather low labour requirements for production (around 70 man/days per year for 1000 output), it is evident that giant clam farming is capital rather than labour intensive.

Since likely seed cost and survival during grow-out are so poorly established, it is useful to examine the market value which would be required for different seed costs and survival rates, in order to achieve a 20% rate of return on investment, or a \$20 return on labour. These are shown in Figures 2 and 3 for a seven year grow-out period and permit a rapid assessment of economic potential and sensitivity to production and marketing assumptions. Each line or isobar corresponds to a 20% return on capital or a \$20 return

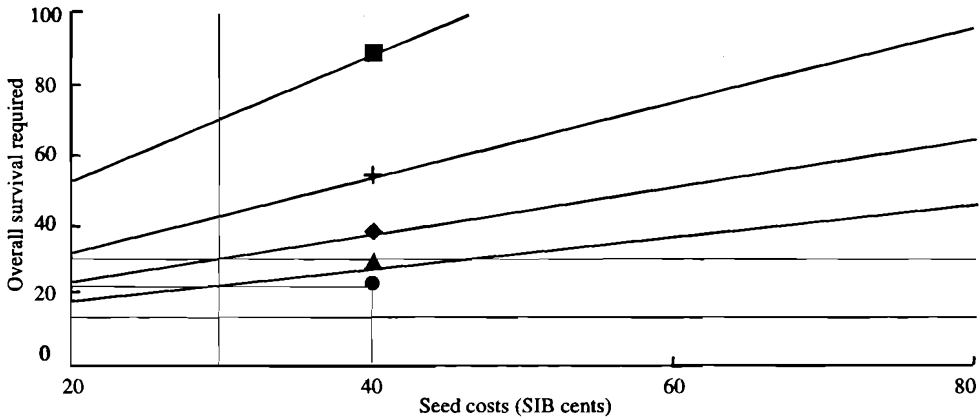


Figure 2. Seed costs and survival rates needed for 20% IRR at a range of 'farm-gate' values. ■ \$5/clam; + \$7/clam; ◆ \$9/clam; and ▲ \$11/clam.

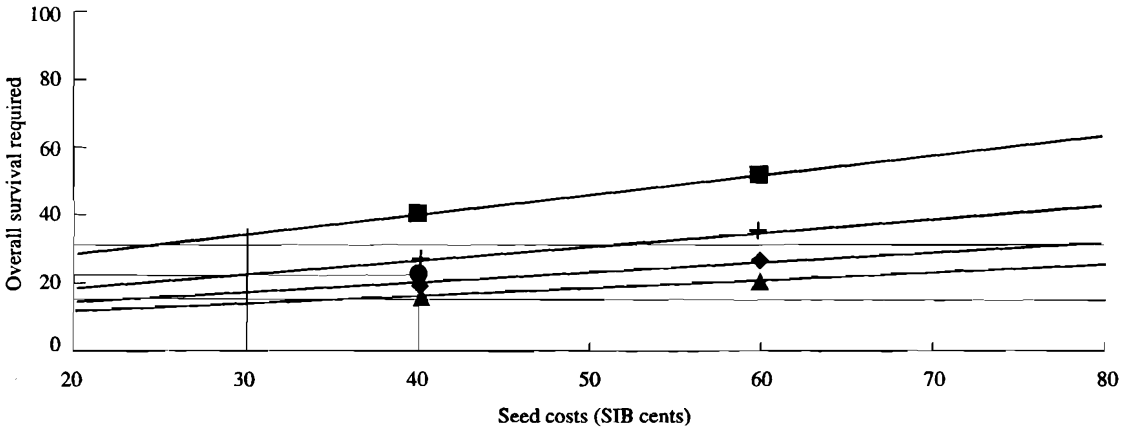


Figure 3. Seed costs and survival rates needed for SIB\$20 ROL for a range of 'farm-gate' values. ■ \$5/clam; + \$7/clam; ◆ \$9/clam; and ▲ \$11/clam.

on labour for a particular market value. The 'likely zone' on the basis of the above discussion is marked and shows that a 20% return on capital would only be possible under optimistic assumptions about seed costs and survival rates, coupled with a farm-gate shell value of at least \$5 (ca. \$0.3/kg). A \$20 return on labour could be achieved under rather less optimistic assumptions.

Conclusions

It is apparent from the foregoing analysis that the adductor muscle and mantle are unlikely to contribute more than half of the farm-gate value which would be required for the financial viability of giant clam

farming (large *Tridacna gigas*) in Solomon Islands and that high value/high volume markets for the shell (at least \$0.3/kg at the village site, for a total Solomon Islands production of around 3000 tonnes), will need to be developed if such farming is to become a viable industry in Solomon Islands.

Unfortunately several features of this potential industry make its suitability as a part-time village based activity highly questionable. These include the high investment requirements (>\$22000 per 1000 clams annual production), the long payback period (11 years or more) and the very high production and marketing risks, which are compounded by the long growout period and the fixed production ratio of meat to shell

(which is likely to lead to a mismatch between supply and demand in any new developing markets).

The production of smaller clams may have greater potential because of the more rapid returns (and associated lower risks); the possibility of selling whole frozen meat to a single market; the larger numbers of seed that would be required for any particular output allowing for greater economies of scale in the hatchery; and the well established international markets in smaller (bowl sized) shells.

In the light of these considerations, it may be appropriate to place at least as much emphasis on the marketability of the shell as on meat yield or growth rate, when considering species choice or optimum market size for future research or development on giant clam mariculture.

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Distribution, Habitat and Culture of the Recently Described Giant Clam *Tridacna tevoroa* in Fiji and Tonga

E. Ledua*, N. Manu†, R. Braley‡

A recently described eighth series of tridacnid clam, *Tridacna tevoroa* Lucas, Ledua, Braley (Lucas et al. 1990, 1991) exhibits interesting characteristics which may change the taxonomy of the family. Few specimens have been found live in Fiji and only recently larger numbers of this species have been found in Tongan waters. The clam first came to the notice of Fiji Fisheries Division officials. This locally known 'tevoru' or 'devil' clam was proposed as a new species at an international meeting in Australia (Lewis and Ledua 1988). It was subsequently described (Lucas et al. 1990) and a more detailed description, together with tissue and shell morphometric comparisons with *T. derasa* were made (Lucas et al. 1991). The shell of *T. tevoroa* was significantly ($p < 0.05$) thinner than *T. derasa* in terms of shell width, umbo thickness and shell weight versus shell length. In the central Ha'apai Group of Tonga this clam is known as the 'vasuva ngesi manifi', translated directly to 'clam shell thin'. Data on the habitat of this new species is sparse, since few have been seen by Fisheries officials or scientists just prior to the description. Lucas et al. (1991) state that '*T. tevoroa*

appears to be along outer slopes of leeward reefs, in very clear, oceanic water at 20–30 m.' More than fifty *T. tevoroa* have been found in Tonga, especially in the central Ha'apai group, allowing us a clear description of the habitat of this rare species.

A concentrated effort was made to collect as many broodstock specimens of this new species in Tonga as possible and to transport these to the hatchery at Sopa, Tongatapu for attempted spawning and larval culture. An account of the first successful spawning and culture of the larvae and juveniles will be described.

Methods

Field collection—habitat

The first *Tridacna tevoroa* was collected in 1986. About 20 individuals were collected in the eastern Lau group of Fiji in 1989, 1990 and 1991. Although most clams were collected by Self-Contained Underwater Breathing Apparatus (SCUBA), a few were gathered by a traditional Pacific islands method. Here, a weight tied to the end of a long rope is lowered into the mantle of the open (and unsuspecting clam) which subsequently closes its valves tightly and is lifted up to the boat at the surface. A fisheries research vessel (20 m length) was used for the collection expeditions. During SCUBA collections, two divers went to areas where this locally named 'tevoru' clam had been spotted and marked by

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local free divers. New areas were surveyed in later collections by the Fisheries division divers for presence of the tevoro clam. Clams were returned in seawater tanks to the Ministry's giant clam hatchery at Makogai Island about 24 steaming hours from the Lau group. They were held in cages on sand at about 13–14 m.

The first *Tridacna tevoroa* were collected in the Ha'apai Group in Tonga in mid-1989 and some clams were transported by ship in seawater tanks to the Fisheries Department's giant clam hatchery at Sopa, Tongatapu Island. Further collections were made in Vava'u and Ha'apai in 1990, 1991 and early 1992 and shipped to the hatchery at Tongatapu where they were held offshore at 18 m. A few tevoro clams were even purchased from a fisherman on Tongatapu Island who was going to sell the clams in the market. All collections were done by SCUBA, except for several specimens collected by free divers in Vava'u and Tongatapu. An 8 m Fisheries Department skiff was used in other cases. In February 1992 two of the authors carried out a two day SCUBA search at reefs in northern Ha'apai to find live tevoro clams in their natural habitat and further detail of the habitat.

Spawning and culture

The first successful attempt to spawn *T. tevoroa* took place at the Tonga Fisheries Department at Sopa on 30 October 1991. Ten mature *T. tevoroa* were placed in a clean, empty cement raceway on their sides for 45–50 minutes to heat up. This temperature shock induction method has worked well with *T. derasa* in Tonga and Fiji in the past. Filtered seawater was then quickly added to the tank to a level just above the shell edge of the clam when standing upright. Sperm was collected in plastic containers and when egg release began, eggs were collected with plastic buckets or bags. About 1 ml concentrated sperm was added per litre of egg water to obtain fertilisation. However, some of the egg water already contained sperm from the spawning tank. Standard protocol development at James Cook University–Orpheus Island for semi-extensive culture were used in the hatching and larval phases of culture (Braley et al. 1988, Braley 1990). During the larval phase a flow-through screen was used to provide the best quality seawater to these larvae. On day 2 (about 40 hours post-fertilisation) the swimming veligers were 'selected' from the hatching tank and placed in the larval-nursery tank. The stocking density was very low (0.05 veligers per ml) due to poor survival of veligers through the hatching phase, despite the use of 7 ppm antibiotic (streptomycin sulfate). Also, it was thought wise to maintain larvae in good quality seawater to increase the chances of a higher production of

juveniles. This required a greater depth of water and a shade cloth cover directly over the cement raceway to approximate the light levels found at greater water depth. Larvae were fed baker's yeast every second day at a rate of 1.4 g of yeast/10000 L seawater. One of the adult tevoro clams was sacrificed to give to the larvae zooxanthellae during their pre-settlement phase. On another day zooxanthellae were provided from a sacrificed *T. derasa*. After settlement, adult *T. tevoroa* were placed on the bottom of the tank to provide the right variety of zooxanthellae to the metamorphosing larvae, through feces.

The fouling algae was first cleaned by siphoning off from the bank bottom at day 90. Juvenile clams were heavy enough to fall to the bottom of a bucket while the algae could be floated off the top of the bucket. Juveniles were measured and examined under a dissecting microscope.

A second attempt at spawning *T. tevoroa* was made at Tonga Fisheries Department's hatchery in January–February 1992. Twelve new broodstock had been collected from Ha'apai in January 1992 and transported to the hatchery at Sopa for induced spawning. Solar heated seawater (to 32°C) and injection of 2 mM serotonin (1.5–2.0 mL dosage) were used. No spawning was observed this time. One of the 12 broodstock died on arrival at the hatchery and was dissected to check gonad condition.

Results

Field collection/habitat

Figure 1 shows a map of the islands where tevoro clams have been collected. The coordinates are listed in Table 1 for the location of collection. Table 1 details the collection of all the known specimens from 1986 through January 1992 associated with the government Fisheries from both Fiji and Tonga. Table 2 lists location and habitat information from discussions with Ha'apai and Tongatapu fishermen who have seen and collected tevoro clams. An estimate of the number of clams found per man hour of search on SCUBA showed that an average of about one clam per man hour was collected in Tonga. The average from Fiji is about 0.26 clams/man hour. It should be noted that the divers doing the searching are particularly fit divers and have an eye for clams in the habitat. About half of the clams in Tonga were found on the leeward and half on the windward side of reefs. However, windward side of reefs were still somewhat protected within barrier islands or reefs. No search has yet been made on outer windward reefs. In Tonga the mean depth for the clams is 26 m, varying from 9–33 m. Table 2 lists a response

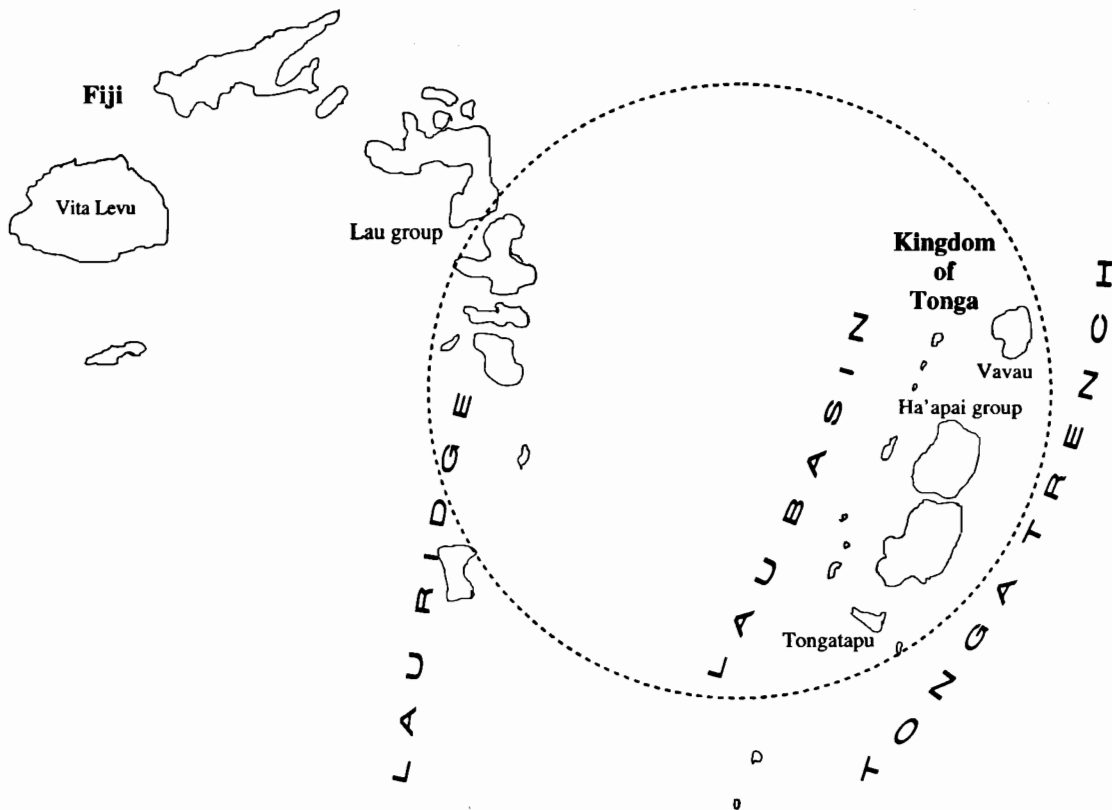


Figure 1. The main island groups of Tonga and the eastern Fiji Lau group of islands showing the known species distribution within the circle of *Tridacna tevoroa*.

from an old diver from Uihā Island, Ha'apai, suggesting that he saw or collected *tevorō* clams in 3 m of water in the 1940s; and clams were seen in small clumps at that time. The mean depth of clams collected in Fiji was 27.4 m, varying from 20–33 m and all were found on the leeward side of reefs and islands. Many of the clams found in Tonga were adjacent to the edge of a sand patch and cradled against rocky outcrops, rubble or bare rock with steep slopes. It is significant that during the SCUBA search in February 1992 in Ha'apai two of the authors found a considerable number of *tevorō* clams on live coral. However, in Fiji these clams have not been found on live coral, possibly because little live coral was found at this depth in the Lau group. Figure 2 shows profiles of the bottom in areas where *tevorō* clams have been found.

Larger, older specimens do not travel as well as younger *tevorō* clams and such deaths were recorded. Other deaths have occurred in Fiji after being held in the ocean nursery for two weeks or longer, or were eaten by turtles. *Tevorō* clams held at the 18 m deep site in Tonga looked healthy.

Spawning and culture

Five of ten clams released eggs, while seven released sperm. However, the number of eggs were small for four clams. A total of 28.2×10^6 eggs were collected. The fertilisation rate determined after 2 hours averaged 90.6%. Only 90 000 veligers were retrieved from the hatching tank. This represents 0.3% survival from fertilised eggs. On day 90 there were about 2000 juvenile *T. tevorō* found live on the bottom of the tank. This is about 2.2% survival from veligers, but only 0.08% survival from fertilised eggs to day 90. Juvenile clams have scutes like the other *Tridacna* species. The mantle does not reach over the edge of the shell in these small juveniles. The average shell length of 100 clams was $6.5 \text{ mm} \pm 1.2 \text{ mm}$ (SD).

The second attempts at spawning *T. tevorō* in January–February 1992 did not result in any successful sperm or egg release, nor any other spawning behaviour other than inflated excurrent siphons in some of the broodstock. The specimen which died on arrival from Ha'apai and was dissected had no gonad visible.

Table 1. Location-habitat description of *Tridacna tevoroa* specimens in Fiji and Tonga.

Collection date	Location coordinates	Depth (m)	Habitat	Number collected	Estimate of clams/man hrs search on SCUBA (m/h)
Early August 1989	Lofanga, Ha'apai 174°33'W and 19°49'S	33	T,L,RO(AA-20)	1	1 clam
Late August 1989	Auhangamea channel, Uiha Is., Ha'apai 174°20'W and 19°52'S	24-30.5	T,L,RO(AA-O adjacent to 40 slope R)	12	2.5 clam
May 1990	Kahefahefa Is., Vava'u 174°03'W and 18°48'S	18	T,W(inside barrier lagoon) on S(AA-O) next to R(AA-70)	5	0.35 clam
February 1991	Kahefahefa Is., Vava'u 174°03'W and 18°48'S	27.5-35	T,W(Inside barrier lagoon), R(AA-30); on S(AA-) next to R(AA-30-70)	6	0.04 clam
June 1991	Kahefahefa Is., Vava'u 174°03'W and 18°48'S	9	T,W(inside barrier lagoon), on S(AA-O) next to C(AA-20)	1	2.0 clam
January 1992	Faka'osi reef, Pangai, Ha'apai 174°26'W & 19°43'S	27.5-30.5	T,L(7 clams),W(inside barrier of isl., 5 n.mi. away; 9 clams), on S(AA-O) next to RO(AA-20-60) & some C	16	0.33 clam
February 1992	Luahoko Is., W & NW sides, Ha'apai 174°28'W & 19°41'S	24.4-27.5	T,L(18 clams)W(3 clams), 2 on S(AA-O)next to C; 19 on C(AA-0-20); clumps of 4,3,2 seen, others singly	21	9.1 clam
January 1986	Cakau Tabu reef, Lau 178°32'W 17°40'S	20	F,L,S slope (AA-30)	1	0.25 clam
November 1989	Vatoka Is., Lau 178°13'W 19°56'S	33	F,L,RO next to R(AA-20-60)	6	0.30 clam
February 1990	Vatoka Is., Lau 178°13'W 19°56'S	0	F,L,RO next to R(AA-20-60)	5	0.20 clam
April 1991	Vatoka Is., Lau 178°13'W 19°56'S	26.6	F,L,RO next to R(AA-20-60)	2	0.30 clam

Notes: F—Fiji, T—Tonga, W—windward reef (forereef), L—leeward reef (backreef or lagoon), S—sandy, R—bare rock, C—live hard coral, RO—rocky outcrops between sand/rubble, AA—approximate angle of the substrate to the horizontal (degrees).

Discussion

Field collection—habitat

The relatively close proximity of the eastern Fiji Lau group and the Tongan Ha'apai group make the species distribution understandable. The presence of the clams both north (Vava'u) and south (Tongatapu) of Ha'apai in Tonga follows, since the ocean bottom topography is

deep only for short distances between the rises of each group. Ha'apai has large areas of suitable reefs and shoals with typical habitat for *T. tevoroa*. It is suggested that this area may be the centre of distribution of this newly-described species and it is probably the largest repository of the species.

The features of *T. tevoroa* typical of both *T. derasa* and *Hippopus hippopus* were discussed in Lucas et al. (1991) and it was suggested that *T. tevoroa* could

Table 2. Location and habitat information on *T. tevoroa* from information from local fishermen.

Name	Village (Island)	Comments
Mr Peni Iketau (31 yr)	Faleloa (Foa Is.)	He has seen/collected about 20 tevero clams since 1982; he often uses SCUBA. Clams 18–27 m), leeward side of reefs; clams scattered, not clumped together, but highest number (7) seen around Luahoko Is., west of Foa Is. Clams are almost always found next to flat sand but touching rocky outcrops or rock slope next to the sand.
Mr Sione Punai Sr and Jr (66 yr and 38 yr)	Uiha (Uiha Is.)	They named three areas good for clams, including <i>T. tevoroa</i> —Hakau Ata reef, Limu Is., Luataua shoal. Elder Sione saw and collected many tevero clams in the 1940s; these were on sand near the reef usually and as shallow as 3 m down to 27 m. They were found in groups in shallower water many years ago. These people told us another Tongan name for the tevero clam, <i>Vasuva ngesi sio ata</i> (window pane shell clam).
Mr Oueni	Tolonga (Tongatapu Is.)	The clams were collected from the reef between Tau and 'Ata islands (the same reef). He sold seven of these to Tonga Fisheries Dept. He collected the clams from 13.7–16.7 m, some on sand and some on coral.
Mr Peni Tuicake	Lau (Vatoo Is.)	He collected tevero clams from 9.1 m, amongst a branching <i>Acropora</i> thicket. This sighting was from 1984 on Vatoo. He and another fisherman also found two tevero clams on a nearby reef (Vuata Vatoo) in shallow water.

represent a transitional stage between the genera *Tridacna* and *Hippopus*. However, without further information, a separate subgeneric or generic status has not been proposed.

It could also be suggested that *T. tevoroa* speciated in this area of its known distribution, perhaps even from a successful hybridisation of *T. derasa* and *H. hippopus* (found in both Fiji and Tonga prior to local extinction 20–30+ years ago). Although this is highly speculative without the support of genetic evidence, it is most interesting to note that seven of the eight members of the family Tridacnidae have their centres of distribution around Indonesian and southern Philippines, as is typical of many Indo-Pacific families of reef vertebrates and invertebrates. The smallest distribution of any tridacnid is that of *T. tevoroa*, located far from the Indo-Pacific 'source' of speciation. This will remain highly speculative until fossil evidence, new records for species distribution and genetic work support or refute this.

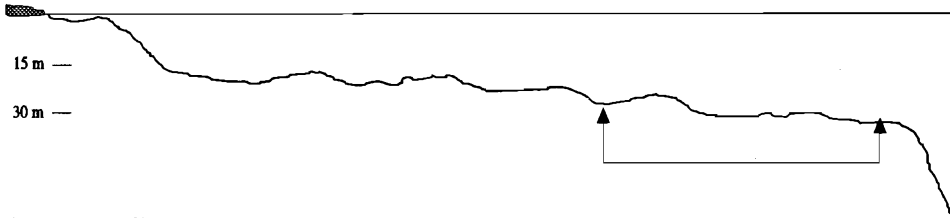
Spatial distribution appears to be very sparse with single individuals being found at most locations. However, clumps of four individuals were seen twice and other smaller clumps were seen in Tonga. These could represent small breeding groups for this species. Evidence of former greater abundance and distribution in shallow water in Ha'apai would indicate that fishing pressure has also contributed to the rarity of this species.

Spawning and culture

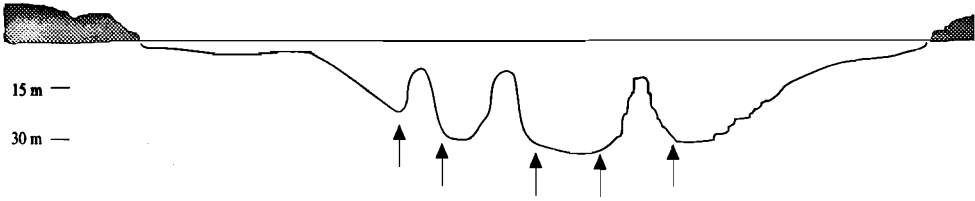
The lack of success in spawning of the *T. tevoroa* broodstock during the latter part of January indicates that this may be the resting period of gametogenesis. This was supported by the dissection of one specimen which died and from a specimen which was killed by Tonga Fisheries staff in December 1991 showing no gonad visible. The successful spawning in late October 1991 indicates that this species has a breeding season not unlike that of *T. derasa*. On the Great Barrier Reef in Australia the breeding season of *T. derasa* is from late winter–early spring to early summer and virtually all are spent by mid-December (Braley 1984, Braley 1988). In Fiji the breeding program for this species is from July to October and in Tonga from September to late November. It must be noted that the examples of the breeding season of *T. derasa* given here are from higher latitudes within the tropics (17°–21°S) while there is evidence from hatchery spawnings that at lower latitudes (Palau, 7°N) this species has an almost full-year breeding season (Heslinga et al. 1984).

The poor success of veligers resulting from the hatching phase may be attributed to polyspermy or self-fertilisation (see Calumpong et al. these Proceedings). Recent quantitative evidence of polyspermy in oysters (Stephano and Gould, 1988) further supports the likeliness of the results in this spawning. Normally, the clam releasing eggs is removed from the spawning tank, rinsed with filtered seawater and placed into

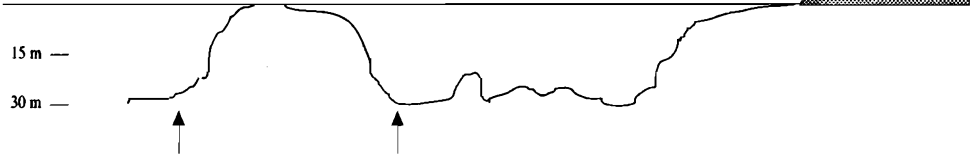
(1) Luahoko Island, Faka'osi reef, Ha'apai group, Tonga



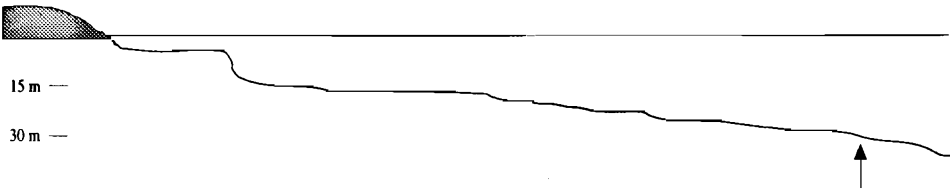
(2) Auhangamea Channel, Uiha Island, Ha'apai group, Tonga



(3) Kahefahefa Island, Vava'u group, Tonga



(4) Lofanga Island, Ha'apai group, Tonga



(5) Vatoa Island, Lau group, Fiji

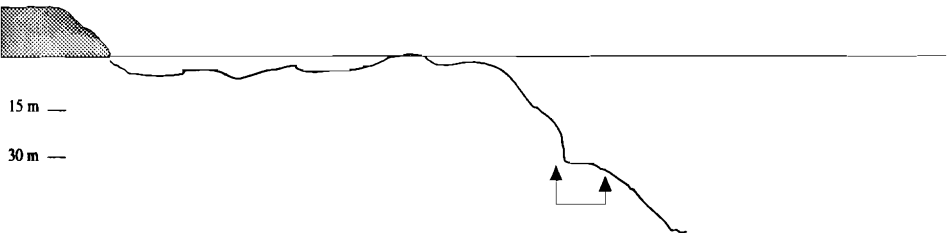


Figure 2. Profiles of sea bottom topography where tevoru clams have been found in Tonga and eastern Fiji. Depth markers for 15 m and 30 m are shown and names of islands or reefs are given where the clams have been found.

successive bins of filtered seawater before sperm is added to effect fertilisation. Here, due to lack of some equipment, the eggs were collected as spawned in the spawning tank plus the addition of the normal amount of sperm. The fertilisation rate was high but number of veligers surviving at 40 hour post-fertilisation was very low. Given the use of antibiotics in the hatching phase, the implication would be polyspermy as a cause. If one considers the sparse distribution and abundance of *T. tevoroa* it would appear that polyspermy could present a problem in the fertilisation of eggs of this species.

Acknowledgments

This research was part of an international project funded by the Australian Centre for International Agricultural Research (Project No. 8733). We thank the Fisheries personnel in Fiji and Tonga and to local divers for assistance with collection.

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Some Responses of the Giant Clam to Elevated Nutrient Levels in Sea Water

C. Belda, C. Cuff, J. Lucas and D. Yellowlees*

THE addition of dissolved inorganic nutrients to sea water during the early stages of growth of cultured tridacnid clams is now common practice. This prompted us to examine the implications on the physiology and morphology of the clam and their symbiotic algae. Our studies revealed that elevated dissolved inorganic nutrients effect many aspects of the structure, biology, physiology and biochemistry of these animals. Some of these changes are beneficial for clam mariculture. However, when applied to wild

stock, as may be the case where anthropogenic input into adjacent waters is significant, then the effects may not be so beneficial. Our results have been submitted to *Marine Biology* in the following two manuscripts:

Belda, C.A., Lucas, J.S., Yellowlees, D. 1993. Nutrient limitation in *Tridacna gigas* symbiosis: Effects of nutrient supplements on growth of the symbiotic partners.

Belda, C.A., Cuff, C., Yellowlees, D. 1993. Modification of shell formation in the giant clam *Tridacna gigas* at elevated nutrient levels in sea water.

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