

of the foot, and muscular flicking motions of the palps, also free the mucus strings.

Dense sand grains in the food bolus are rotated and come into contact with the inner surfaces of the outer palps several times before being centrifuged off and rejected as pseudofaeces. At this stage of development there are no ciliary sorting areas on the palp, but physical sorting ensures that the particle size ingested does not often exceed 50 μm . Occasionally the foot is reflexed and the propodium stuffs the food bolus into the oesophagus.

This feeding cycle may be repeated as often as 50 times over a period of 10 min. King (1986) remarks that 'Propodial food collection occupies much of the total behaviour of juveniles and is a stereotypical pattern which cannot be confused with burrowing.' Where there is adequate deposit material mixed with the mineral substrate particles the juveniles remain in the same area, excavating the surface. If there is no suitable food, or if the clams are on a hard surface, they move rapidly. For up to 12 weeks of postmetamorphic juvenile existence individuals are byssally attached to sand grains, but the byssus threads can be extended up to 10 cm, or released, so they do not hinder feeding behaviour.

In the early byssal plantigrade the ctenidial filaments are pectinate and have no food-collecting ability. At about 5 weeks into this stage the filaments reflex and grow ventrally, forming a ciliated food-groove at their tips. By this time they are sufficiently developed to divide the posterior mantle cavity into supra- and infrabranchial chambers, and to establish a weak, posterior inhalant flow. At 11-12 weeks after metamorphosis the siphons, gills and labial palps have developed sufficiently to form an 'adult' suspension-feeding apparatus.

King (1986) finds that in the early juvenile plantigrade, which burrows only occasionally and uses pedal-palp feeding, growth is greatest in animals raised in coarse sediment with deposit material. It is next best where suspended algae are provided in containers without a mineral substrate, and worst in fine sediments. He interprets this to mean that for most efficient nutrition the substrate particle size and the availability of deposited organic matter, are both important. Aeration in a coarse substrate may also be significant.

Tridacnidae

As with all other aquacultured bivalves, Tridacnidae have high mortality rates between spawning and the late juvenile stage (summarised by Fitt et al. 1984). Trochophore and pediveliger biology has been studied in some detail, with an emphasis on the acquisition of symbiotic zooxanthellae (Fitt and Trench 1980, 1981; Fitt et

al. 1984). Symbiont transmission is not holobiotic and the larvae will metamorphose in the absence of suitable symbionts. Where the latter are available they become established in the siphonal tissues of *Tridacna squamosa* 2-9 days after metamorphosis (Fitt and Trench 1981). Heslinga et al. (1984) report that symbionts are clearly visible in the siphonal tissues of *T. gigas* 11 days after metamorphosis.

As Fitt et al. (1984) point out, exogenous nutrients encourage growth and survival of pediveligers and are likely necessary for the juveniles. Late juveniles can survive for 6 months in micropore-filtered seawater (Fitt and Trench 1980), and Beckvar (1981) showed growth variations in *T. squamosa* commensurate with available sunlight. Therefore the portion of the life-cycle to which general observations on bivalve pedal feeding might be relevant would be from metamorphosis to whatever juvenile stage can be totally sustained by symbiosis: perhaps only a short but crucial period of no more than a week or so. Fitt et al. (1984) conclude that high mortality at the transition from pediveliger to juvenile is likely due to changes in the mode of acquiring nutrition, and the nutritional requirements at this stage 'would not be expected to be very different from that of nonsymbiotic clams.'

Observations on the byssate and late juveniles of tridacnids have probably been numerous but casual. Yonge (1980) notes that crawling behaviour in 5-mm *T. crocea* juveniles resembles that of *Mytilus edulis*, with intermittent byssal attachment and roaming by pedal locomotion. These individuals have an adult form except for the long, mobile foot. This species may continue to move for 6 months before becoming permanently attached. Heslinga et al. (1984) note similar behaviour in *T. squamosa*.

It is significant that most observations and experiments involving pediveligers and early juveniles have been conducted in glass vessels. Moreover mass culture procedures pay no regard to substrate quality at the early juvenile stage (Heslinga et al. 1984). If tridacnids, like most other bivalves, employ pedal-palp feeding immediately after metamorphosis, they would require a particulate substrate with physical properties consistent with their feeding behaviour: indeed such behaviour might not be observable under any other circumstances. If pedal feeding does occur, physical properties of the substrate particles such as size, density, aeration and cohesion with natural and synthetic food particles would require consideration. Here is a possible opportunity for the use of appropriately designed, sedimentary microcapsules. Yamaguchi (1977) concluded that a breakthrough in the handling of early juveniles was required for final success in large-scale aquacultural methods for tridacnids. We present one such hypothetical 'handling' alternative.

Acknowledgments

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Role of Zooxanthellae in the Mariculture of Giant Clams

William K. Fitt*

Abstract

Interest in the mariculture of giant clams (family Tridacnidae) has blossomed over the last 15 years, initially due to discoveries concerning their reproductive and developmental physiology. Recent progress in the application of mariculture techniques has outstripped our knowledge of the basic physiology of tridacnids, especially understanding the process occurring between the symbiotic zooxanthellae and the clam host. In this presentation aspects concerning the physiology of zooxanthellae symbiosis that have relevance to mariculture of giant clams are reviewed.

Establishment of a Symbiosis

SINCE tridacnids do not pass their symbionts to the next generation via the egg (LaBarbera 1975; Jameson 1976; Fitt and Trench 1981), each baby clam must acquire zooxanthellae from its environment. During 'infection' of veliger and juvenile clams, motile zooxanthellae are apparently attracted to their potential hosts by dissolved nitrogen compounds, such as ammonium or certain amino acids (Fitt 1984, 1985a). Unlike phytoplankton food species, zooxanthellae taken into the stomachs of veliger clams remain there for days, suggesting that they are not digested by the clams (Fitt et al. 1986). Larval clams fed freshly isolated zooxanthellae before metamorphosis have higher growth and survival rates through metamorphosis than starved clams, showing that they derive nutrients from the zooxanthellae in their stomach (Fitt et al. 1986). The presence of zooxanthellae in the stomachs of veligers before metamorphosis facilitates establishment of a symbiosis (entry and growth of the zooxanthellae in the mantle tissues) and increased growth after metamorphosis (Fitt et al. 1986).

Photosynthesis and Photoadaptation

Zooxanthellae in the clam respond to light, giving classic photosynthesis vs light intensity (PI) curves (Fisher et al. 1985). However this response is dependent on the size of the clam: while small clams reach maximal photosynthetic rates at one-quarter of maximum sunlight intensities in air, larger clams never reach their maximal photosynthetic rates because of the extensive shading of many of their zooxanthellae by both clam tissue and other zooxanthellae. Therefore small clams in mariculture may be kept in shaded land-based nurseries or in oceanic habitats with lower light intensities without reducing their maximal growth rates, while larger clams need maximum exposure to sunlight to achieve their maximum potential growth rates. Photoadaptation of zooxanthellae in clams to low light (Mingoa, This Monograph), by increasing numbers of zooxanthellae per clam or the amount of light-harvesting pigments per zooxanthella, is effective in maximising photosynthesis (and therefore clam growth) in small clams in low-light habitats, but probably not very effective in large clams because of the extensive shading of many of the zooxanthellae.

Differences in Zooxanthellae

Genetically distinct species of zooxanthellae of the genus *Symbiodinium* have recently been described

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(Blank and Trench 1985). While all types of *Symbiodinium* are capable of establishing a symbiosis with tridacnids, symbiosis with some zooxanthellae leads to higher growth and survival rates than others (Fitt and Trench 1981; Fitt 1985b). Selection of optimal zooxanthellae for mariculture of specific tridacnid species in particular environments is currently being investigated. Preliminary evidence indicates that fast-growing types of zooxanthellae (in the host) also give faster growth rates of the clams (Fitt 1985b). Introduction of 'optimal' zooxanthellae into larval tanks before metamorphosis is the preferred method of clam acquisition of zooxanthellae in mariculture. Manipulation of type of zooxanthellae living in symbiosis with tridacnids may be achieved by expulsion of 'suboptimal' zooxanthellae by treating clams with warm water, and subsequent reintroduction of 'optimal' zooxanthellae.

Nutrients

Zooxanthellae in tridacnids may be nutrient-limited. Introduction of dissolved inorganic nutrients such as nitrogen (ammonium or nitrate) (see Wilkerson and Trench 1986), phosphate, and sulfate may increase either photosynthetic rates or numbers of zooxanthellae (or both), thereby increasing the amount of photosynthate available to the host for growth (see Alcalá, This Monograph).

Conclusion

Since one of the major constraints in the mass culture of tridacnids is space in the land-based nursery phase, optimising growth and survival of the larvae and juveniles by taking advantage of physiologically optimal conditions of the zooxanthellae symbiosis is one way of efficiently utilising available space and maximising production.



Chapter 6

Culture Techniques

Testing an Antifouling Treatment for Ocean-Nursery Meshes

J.S. Lucas*

Abstract

Controlling the fouling of protective meshes during the ocean-nursery phase of giant clam mariculture can be a time-consuming process. This study tested the effectiveness of coating meshes over trays of juvenile *Tridacna gigas* with Flexgard, a commercial antifouling preparation. Flexgard did not cause clam mortality, nor was there evidence of sublethal effects in terms of reduced clam tissue or shell growth. After 1 month of immersion, Flexgard-coated meshes at a subtidal site were substantially less fouled than uncoated meshes and similar to scrubbed meshes. After 3 months all meshes, scrubbed, untreated and Flexgard-coated, were similarly lightly fouled. By this stage the Flexgard coatings were partly detached from the mesh surfaces and algae were growing directly on the coating. Thus, Flexgard is not suitable for use on these protective meshes as antifouling is required for a year or more, the duration of the ocean-nursery phase. The most economic method of controlling fouling is drying the meshes by removing them from the sea or by using intertidal sites.

WHEN juvenile clams are about 20 mm shell length at 6+ months of age they are transferred to the field in mesh enclosures, a stage of culture which has been called the ocean-nursery phase and which lasts for a year or more (Crawford et al. 1987). The mesh enclosures are necessary to protect the small, thin-shelled clams from a variety of predators, e.g. fishes, crabs, octopods and gastropods. Several different kinds of mesh enclosures have been tested (Barker et al., This Monograph) as well as plastic and wire meshes.

One not-unexpected problem with the meshes is their progressive accumulation of fouling organisms, especially algae. This results in reduced light and reduced circulation of water to the enclosed juvenile clams, both of which are inimical to growth. Heavy fouling of plastic meshes on boxes containing juvenile *Tridacna gigas* at about 5 m depth at Orpheus Island Research Station (OIRS),

Great Barrier Reef, resulted in heavy mortality of these clams during winter 1985 (unpublished data). This was apparently because light levels within the boxes, already reduced by silty water and depth, were reduced to lethal levels by the fouling.

The meshes may be regularly scrubbed to control fouling. This has been done routinely at the Micronesian Mariculture Demonstration Center (MMDC), Palau, and at OIRS. However, it becomes a very time-consuming activity as the ocean-nursery holdings increase. At MMDC the meshes are now changed at 4–6-month intervals and the fouled meshes dried before reuse (Heslinga et al. 1986). At OIRS the ocean-nursery phase of giant clam culture has been developed in the intertidal zone because of the antifouling effect of regular exposure of meshes to air (Lucas 1987; Crawford et al. 1987).

Another potentially economical method of controlling fouling is to treat the meshes with an antifouling coating. Many of the commercially available antifouling coatings are not suited for application to flexible, synthetic surfaces such as the plastic meshes used for the clam enclosures.

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However, Flexgard (manufactured by Flexabar Corporation, 140 Walnut St., Northvale, NJ 07647, USA) is an antifouling coating that is a waterbased latex. It is flexible and, according to the manufacturer, has 'excellent adhesion to synthetic and natural fibers.' The active constituent of Flexgard is not indicated in the manufacturer's literature. It is recommended by the manufacturers for use with pound and trap nets, but not specifically for heavier meshes such as are used for protective coverings of juvenile clams.

This paper describes a study to test (1) the effectiveness of Flexgard in controlling fouling on ocean-nursery meshes, and (2) the toxicity of Flexgard to juvenile giant clams.

Materials and Methods

The study was conducted with juvenile *Tridacna gigas* obtained from a spawning at OIRS in October 1985. They were 1 year old and mostly had shell lengths within the range 30–40 mm at the commencement of the study. The clams were individually tagged using small pieces of plastic tape of various colours and having single letters or numbers on them. The tags were stuck onto one valve using an underwater epoxy adhesive.

Plastic trays covered with 26 mm plastic meshes and attached to wire mesh substrates were used. Each contained initially 25 tagged clams on a substrate of gravel chips. This is the same unit as used in other ocean-nursery studies at OIRS (e.g. Crawford et al. 1988, see Fig. 1). Two different treatments and a control were used: (1) mesh coated with Flexgard, without scrubbing; trays containing clams; (2) mesh uncoated, but with twice-weekly scrubbing; trays containing clams; and (3) control — mesh uncoated and not scrubbed; no clams in trays.

The effect of fouling on light transmittance through the meshes was measured in situ using an integrating quantum radiometer with underwater sensor and expressing the light reading below the mesh as a percentage of the ambient level. The Control meshes showed the degree of fouling and hence light reduction where no antifouling measures were taken. (No clams were used in the controls because it was anticipated that they would all die, at least at the subtidal site.) Treatment 2 served as a comparison of the effectiveness of scrubbing versus Flexgard (Treatment 1) in reducing fouling and as a control for the survival level of clams in the trays with Flexgard. Thus, greater mortality in Treatment 1 (Flexgard), especially early in the study before fouling levels could affect survival, would indicate that Flexgard is toxic to juvenile giant clams.

Two trays were used for each treatment and

controls, and the experiment was repeated at two sites in Pioneer Bay in front of OIRS. One site was subtidal and the other intertidal (the same sites as used in Barker et al., This Monograph). Thus, the experiment consisted of two sites \times two treatments (+ controls) \times two trays at each treatment (+ controls) \times 25 clams per tray (= 200 clams).

Flexgard was painted onto the Nylex meshes, which consisted of high-density polyethylene. It took two coatings to get a complete coverage of the outer surfaces of the meshes.

The shell length and wet weight (including tag) of each clam were measured at the commencement of the study (November 1986) and again at the end of the study (February 1987).

Results

There was very little fouling of the control meshes at the intertidal sites after the first month (Fig. 1), such that light transmittance was 74% compared to the initial level of 70%. Thus, no effect of either Flexgard treatment or scrubbing on fouling or light transmittance could be observed. The apparent slight increases in light transmittance through the meshes at this site, compared to the original values, must be an artifact of some irregularity in the response of the underwater radiometer. This does not negate the validity of the relative readings of the two treatments compared to the control.

After a month at the subtidal site the control meshes showed a marked reduction in light transmittance, down to 48%, due to fouling (Fig. 1). There was little change in light transmittance through the Flexgard-treated and scrubbed meshes, because they had little fouling. This showed the initial effectiveness of Flexgard as an antifouling coating.

After 3 months of exposure, however, all meshes at both sites had low levels of fouling and light transmittance levels were all within the range 60–70% and not significantly different (two-way ANOVA: treatment effect $P > 0.1$; locality effect $P > 0.1$). Thus, no antifouling effect of the

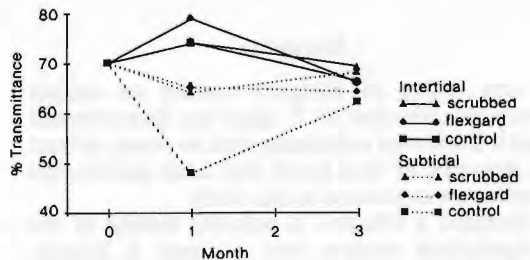


Fig. 1. Variation in percent light transmittance through ocean-nursery meshes versus period of exposure.

TABLE 1. Percent survival and growth of juvenile clams after 3 months under meshes with Flexgard coating or scrubbing. Values in parentheses are standard deviations.

	Intertidal	Subtidal
Flexgard treated meshes		
Percent survival	94	98
Growth increment:		
Shell length (mm)	27.20(3.50)	23.12(5.00)
Wet weight (g)	20.61(5.34)	15.66(5.85)
Cleaned meshes		
Percent survival	100	84
Growth increment:		
Shell length (mm)	29.22(4.05)	20.74(6.23)
Wet weight (g)	20.37(6.39)	11.63(5.12)

Flexgard coating was evident at this stage. The coating would need to be very effective in reducing fouling to have significantly affected light transmittance compared to the low-fouled controls.

General observations of the Flexgard coatings after 3 months showed that they had partly detached from the mesh surface in many places and that there were algae growing directly on the coatings. The experiment was terminated at this point because of the deterioration of the Flexgard coatings.

Survival and growth of the juvenile clams in the two treatments are shown in Table 1. There was no evidence of any toxicity of Flexgard to the juvenile clams under these conditions. The survival rates in the Flexgard treatments were slightly higher than in the scrubbed mesh treatments. Furthermore, there was no evidence of sublethal toxicity in terms of retarded growth. In two-way ANOVA analyses there were no significant effects of Flexgard vs scrubbing treatment on shell length increment ($P > 0.1$); while wet weight increments were significantly greater for the Flexgard treatment compared to scrubbing ($P < 0.05$). The significant effect of Flexgard treatment on wet weight increment was mainly at the subtidal site (Table 1). There were also highly significant intertidal vs subtidal effects (shell length increment $P < 0.001$; wet weight increment $P < 0.001$).

Discussion

This testing of Flexgard coating on meshes protecting juveniles of *T. gigas* has demonstrated that it is not even sublethally toxic to clams, at least as measured by shell length and tissue growth, the parameters considered in this study.

Flexgard is effective in reducing fouling of the polyethylene meshes over at least a month.

However, the deterioration of the Flexgard coating after 3 months and algal growth directly on the coating after this period suggest that Flexgard's antifouling properties are limited in the long term. The period of ocean-nursery culture is a year or more and so an effective antifouling treatment would need to give much longer protection than afforded by Flexgard in this test.

Flexgard could be used on meshes that are exchanged after several months use in the ocean-nursery, as at MMDC. In this way the period between mesh changes could be prolonged. However, the deterioration of the Flexgard coating on the polyethylene mesh means that the coating would have to be renewed before the meshes were reused. This would involve cleaning dried fouling off the meshes before renewing the Flexgard coating and it would be a time-consuming and therefore probably uneconomical procedure.

At this stage, the most economic method of controlling excessive fouling of ocean-nursery meshes is to regularly dry the meshes to kill the fouling. This is done either by removing them from the sea (MMDC) or by using intertidal sites where the meshes dry out at low tides (OIRS).

Two points arise as sidelines of this study. One is the greater growth rates obtained in intertidal culture compared to subtidal culture (Table 1). This confirms the observations made of growth differences between these two sites at OIRS for juvenile clams cultured in larger protective containers (Barker et al., This Monograph). The major difference appears to result from the effects of depth in reducing the light intensity, especially in these relatively silty conditions. The other point is that there appear to be seasonal or temporal differences in net fouling rates at OIRS. While in winter 1985 similar plastic meshes at the subtidal site were heavily fouled, to the point that there was substantial mortality of the juvenile clams beneath the meshes (unpublished data), during the summer period of this study the untreated meshes recovered from early fouling and were lightly fouled after 3 months of immersion. These temporal differences must result from relative changes in rates of grazing on the fouling organisms (e.g. by grazing fishes) versus rate of growth and recruitment of fouling organisms.

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Sea Transport of *Tridacna gigas* Broodstock in Solomon Islands

Hugh Govan*

Abstract

The methods used to transport 35 large giant clams, *Tridacna gigas*, to the ICLARM Coastal Aquaculture Center by sea are described. Transport of these clams is feasible over distances of 200 km and probably up to 500 km using small cargo ships and fibreglass tanks filled with seawater. Possible causes for mortality are discussed. A compilation of local names for tridacnid clams in the South Pacific is also included.

In June 1987 broodstock giant clams *Tridacna gigas* were required for the International Center for Living Aquatic Resources Management (ICLARM) Coastal Aquaculture Center (CAC), which is being established on the north/west coast of Guadalcanal, Solomon Islands. No large *T. gigas* had been reported within close range of the CAC, so it was necessary to look to some of the other islands in the archipelago for supplies of broodstock. The nearest reliably reported stocks of *T. gigas* were on the islands of Ysabel and New Georgia more than 200 km away and therefore the collection of broodstock would involve a fairly arduous sea voyage. No record was found in the scientific literature of large clams being transported over long distances by sea, although Beckvar (1981) transported *T. gigas* broodstock for short distances in baitwells filled with seawater in Palau.

The locations chosen for the collection of broodstock, Furona on Ysabel and the Marovo lagoon in New Georgia, were both serviced by small interisland cargo ships of about 400 t gross weight and 40 m in length, which normally transport copra and trochus. The first collection trip took place in June 1987, to Furona, and in the light of results from the first trip, a second one was organised to the Marovo lagoon on a larger scale in July 1987.

Materials and Methods

Potential broodstock *T. gigas* were moved, using

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a rope sling and sturdy poles, into dugout canoes and then kept in areas of shallow reef to await the arrival of the ship. Clams larger than 65 cm in shell length (SL) generally required three or four people to lift and were difficult to get on board the ship.

The clams were placed in two circular fibreglass tanks (1.85 m in diameter by 0.5 m deep) which were made fast on deck as far aft as possible, close to the ship's superstructure, in order to be near the ship's centre of gravity and thus minimise the effects of the ship's motion on the clams.

The tanks were covered with securely fastened tarpaulins to keep out rainwater, to prevent excessive heating and cooling and to minimise the amount of seawater lost due to spillage during rough weather.

On the first trip the ship's fire pump was relied on to supply fresh seawater whenever required, but due to its frequent failure a 2-inch (5-cm) diesel back-up pump was carried on the second trip enabling very rapid filling of the tanks when the ship was not making way.

On arrival of the ships in Honiara, the nation's capital and the nearest port to the CAC, the broodstock were transferred in the same tanks on a flat-bed truck which was driven slowly out to the CAC (26 km).

Results

First Trip

The voyage from Furona covered 210 km and took 36 hours mainly due to the large number of stops that were made to load cargo. Fourteen clams

were transported; 6 larger than 65 cm SL and 8 between 40 and 65 cm SL.

Heavy rain was experienced on the voyage and some managed to enter the tanks. For the last 100 km, out of the shelter of Ysabel, force 4–5 winds and moderately rough seas were encountered, which caused the water level in the tanks to fall to around 35 cm.

The ship's fire pump broke down several times but four complete water changes were made in each tank during the course of the voyage. The water temperature inside the tanks stayed between 27.5 and 29.5°C.

On arrival at the CAC one clam was dead, another died within 24 hours and a third clam showed signs of stress but later recovered. All three were larger than 65 cm SL.

Second Trip

The voyage from the Marovo lagoon covered 240 km but only took 18 hours because only one stop was made. Twenty-three clams were transported: 2 larger than 65 cm SL and 21 between 40 and 65 cm SL, although only three of these were smaller than 50 cm SL.

Most of the voyage was across the open ocean and for the first 100 km winds of force 6–8 and extremely rough seas were experienced which caused some damage to the ship and half-emptied the broodstock tanks. However, it did not rain.

The tanks were refilled in the Russell Islands, which was the only time that the water was changed. The water temperature in the tanks stayed between 26.0 and 30.0°C.

On arrival at the CAC only one clam 71 cm SL showed any signs of stress and it recovered within a week.

Discussion

It appears that transport of broodstock *T. gigas* by sea is feasible over distances of at least 240 km and probably up to 500 km as the duration of the voyage appears to be more important than the distance involved.

The mortalities incurred during the first trip probably resulted from the long duration of the trip coupled with the small influx of fresh water during rainstorms.

Clams over 65 cm SL seem to suffer most, probably because they are more susceptible to mechanical stresses due to the ship's motion, particularly when the water level inside the tanks is low, and partly because the larger clams are more difficult to handle and thus receive rougher treatment.

Rough seas do not seem to be a problem provided that the tanks are securely fastened as near to the ship's centre of gravity as possible and tightly covered with tarpaulins to prevent excessive water loss.

Temperature and water quality do not seem to be a problem provided that an autonomous water supply is available occasionally.

The methods used are satisfactory for the transport of clams between 40 and 65 cm SL. The optimum broodstock size for the CAC is probably between 60 and 75 cm SL (Usher and Munro, This Monograph) because of ease of handling and their adequate egg production. Transport of these larger clams could probably be improved by using slightly deeper tanks (e.g. 0.75 m) and improving handling methods.

Acknowledgments

I wish to thank the people of Furona and the Marovo lagoon for their enthusiastic help and support and most of all for their patience.

Appendix

A Compilation of Local Names for Tridacnid Clams in the South Pacific.

Country	Language	<i>Tridacna gigas</i>	<i>Tridacna derasa</i>	<i>Tridacna squamosa</i>	<i>Tridacna maxima</i>	<i>Tridacna crocea</i>	<i>Hippopus hippopus</i>
American Samoa	Samoan	-	-	Faisua	Faisua	-	-
Cook Islands	Cook Islands Maori (Northern group)	-	-	Paua	Paua	-	-
	(Southern group)	-	-	Pa'ua	Pa'ua	-	-
F.S.M.							
Yap							
main island	Yapese	Fasuw (+)	-	Fasuw	Fasuw	Fasuw	Fasuw, Kim
outer island	Woleai (Carolinian)	Hamwe (+)	-	Toh	Toh	Toh	Sum
Pohnpei	Ponapean	Pahsu (+)	-	Sile	Sile	Sile	?
Kosrae	Kosraean	-	Netula	Netula	Netula	Netula	Netula
Kapingamarangi	Kapingamarangian	?	-	Baahua	Baahua	Baahua?	Kima
Truk	Trukese	Amwei (+)	-	To	To	To	Sim
Nukuoroa	Nukuoroan	?	-	Baasua	Baasua	Baasua?	Gima
Fiji	Fijian	Vasua mataua (+)	Vasua dina	Cega	Katavatu	-	-
French Polynesia	Polynesian	-	-	-	Pahua	-	-
Guam	Chamorro	-	-	-	Hima	-	-
Kiribati	I-kiribati	Te kima	-	Te were matai	Te were	-	Te nei toro
Marshall Islands	Marshallese	Tangale	-	Mejannoa	Kabajna	-	Dimuj
Nauru	?	?	?	?	?	?	?
New Caledonia	French ¹	-	Bénitier tahitien	Bénitier à ongles	Bénitier à ongles	-	Bénitier rouleur
	e.g. Nenema	-	Fiu	Fiu	Fiu	-	?
Northern Marianas	Chamorro	-	-	-	Hima	-	-
	Carolinian	-	-	-	Toh?	-	-
Palau	Palauan	Otkang	Kism	Ribkungl	Melibs	Orwer	Duadeb
Papua New Guinea	Pidgin ¹	Gramsel	Gramsel	Gramsel	Gramsel	Gramsel	Gramsel
	e.g. Tolai	Korokorot	Korokorot	Korokorot	Korokorot	Korokorot	Korokorot
Solomon Islands	Pijin ¹	Klamsel	Klamsel	Klamsel	Klamsel	Klamsel	Klamsel
	e.g. 'Are'are	Piawa	Sisikeni	Sisimane	Taura	Unupanu	Apuri
	e.g. Ghari	Ghima	-	Inuvitasi	Kapichi	Kapichi	Kwa kwa
Tokelau	Polynesian	-	-	Fahua ²	Fahua ²	-	-
Tonga	Tongan	-	Vasua mole mole	Mata hele	Kaku kuku	-	-
Tuvalu	Tuvaluan	Fasua ²	Fasua? ²	Fasua ²	Fasau ²	-	Fasau ²
Vanuatu	Bislama ¹	-	Natalai?	Natalai	Natalai	Natalai	Natalai
	e.g. Erakor	-	Kram?	Kram	Kram	Kram	Lisan
Wallis and Futuna	Polynesian	?	-	Fasua?	Fasua?	-	?
Western Samoa	Samoan	-	-	Faisua	Faisua	-	-

- Species not known.

? Name not available or uncertain.

+ Extinct

¹ The melanesian countries have many local languages (New Caledonia: 28, Papua New Guinea: 600-700, Solomon Islands: 87, and Vanuatu: 115) so only the names in the lingua franca are given and a few examples of local languages.

² Large clams are known as 'fahua taka' in Tokelau or 'fasua taka' in Tuvalu.



Chapter 7
Growth

Growth of Giant Clams in Bolinao, Philippines

E.D. Gomez and C.A. Belda*

Abstract

Growth of five species of giant clams (*Tridacna derasa*, *T. gigas*, *Hippopus hippopus*, *T. squamosa* and *T. maxima*) was studied in Bolinao, Pangasinan.

Tridacna derasa juveniles reared in silty water conditions had poor growth and survival but improved remarkably when transferred to relatively clear water. *Hippopus hippopus* juveniles performed the same way but were more tolerant to high sediment load in the water in terms of survival. A second cohort of *H. hippopus* juveniles grew very fast in the field with a growth rate only slightly lower than that of *T. gigas*. This is indicative of the good mariculture potential of this species. *Tridacna gigas* grew in the field three times faster than in the raceway indicating that open water is essential for optimum growth of this species. *Tridacna squamosa* also grew better in the field than in the raceway but with poor survival. *Tridacna maxima* juveniles exhibited good growth and survival in spite of the fact that they were set out in the field at a relatively small size (11.2 mm). Two size-classes of wildstock subadults of the last two species were monitored. Growth rates for the smaller clams (75–100 mm) were slightly greater than those for the larger clams (101–125 mm).

At the start of the ACIAR-supported project the Marine Science Institute was faced with the problem of not having any clams for growth studies.

An initial step taken to resolve the problem was to import *Tridacna derasa* from the Micronesian Mariculture Demonstration Center (MMDC) in Palau. The next sets of juvenile clams for our studies were *T. maxima* and *Hippopus hippopus* that were produced by the Silliman University Marine Laboratory. Wildstock juveniles of *T. squamosa* and *T. maxima* were collected from the reefs of Bolinao, mostly by local fishermen who provided them to us. Fortunately, efforts at inducing some wildstock clams to spawn and rearing the juveniles have been successful such that the majority of juvenile clams for our growth studies are now produced in our own laboratory. These belong to the species *T. squamosa*, *T. maxima* and *H. hippopus*. Presently, however, the most exciting juveniles because of their fast growth are the *T.*

gigas that were imported from James Cook University (JCU) of North Queensland.

A number of studies on the growth of giant clams have been undertaken in various countries as reported in the published literature. Noteworthy were the initial efforts at Motupore Island, Papua New Guinea (Munro and Gwyther 1981). Munro and Heslinga (1983) presented a tabulation of available data on the growth of five tridacnid clams (*T. gigas*, *T. derasa*, *H. hippopus*, *T. squamosa* and *T. maxima*). It is interesting to note that the oldest reference they cited was McMichael (1975) on *T. maxima*. Ten years earlier Bonham (1965) had indicated that *T. gigas* was probably the fastest-growing bivalve based on studies of growth rings. Studies in Palau have been of a more recent date in relation to the mariculture efforts there. To complement the tabulation of Munro and Heslinga mentioned above, the growth rates of *T. crocea* are provided by Hamner and Jones (1976) who note an initial 2.0 cm for the first year, 1.5 cm for each of the next 2 years, and a rapid decline thereafter. This is similar to Murakoshi's (1986) finding that juvenile

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T. crocea grew from 0.48 to 6.61 cm in 4 years, that is, approximately 1.5 cm/year. Data on the growth of the seventh species, the China clam *H. porcellanus*, are yet to be published since the studies were initiated only recently at Silliman University where this species was first successfully induced to spawn (Alcazar et al. 1987).

Materials and Methods

As indicated earlier, the clams for the growth studies at the Marine Science Institute have come from various sources. Imported clams were routinely quarantined for 6 months according to the agreed protocol of the project. This was done at the Bolinao Marine Laboratory of the Institute. Following quarantine, the clams were treated in the same way as local clams.

In the raceway, clams were maintained in a seawater system with running seawater during the day. At night, the flow was stopped. Mean daytime temperature of the raceways ranged from 26.7 to 30.2°C. Water depth averaged 0.7 m.

Initial field sites were on opposite sides of the channel between Santiago Island and the mainland, that is, in Tomasa and Guiguiwanen (Fig. 1). The water was not very clear in the channel. The experimental sites had depths of 4–5 m.

Currently, all field growth studies are carried out in the ocean nursery north of Silaqui Islet on the extensive reef flat north of Santiago Island (Fig. 1). The water here is clear and the depth is about 3 m. The juvenile clams are mostly raised in bamboo

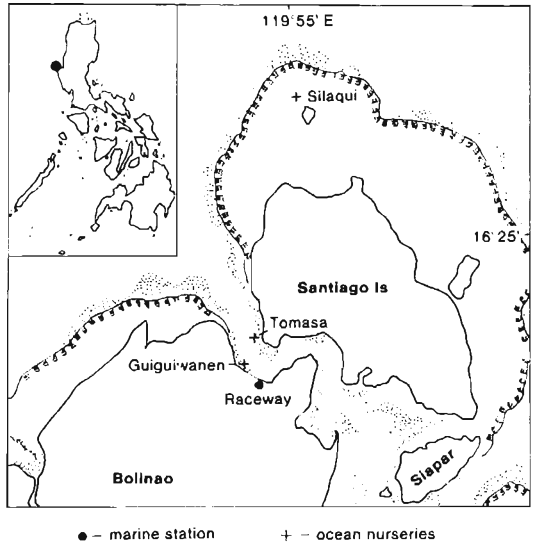


Fig. 1. The study sites in Bolinao, Philippines.

cages about 0.6 m above the seagrass/sand substrate. Measurements were done at intervals of 1 month or longer.

Results

Source and other data concerning the experimental animals are presented in Table 1. Table

TABLE 1. Giant clams used in growth studies.

Species	Source	Spawning date	Age upon arrival/start of experiment	Quarantine period
A. Cultured clams				
<i>T. derasa</i>	Palau	3/84	9 months (N = 293)	12/84–3/85 (4 months)
<i>T. gigas</i>	JCU	10/85	14 months (N = 328)	2/87–7/87 (5 months)
<i>H. hippopus</i>	SU	8/85	10 months (N = 95)	7/86–10/86 (4 months)
	MSI	2/87	6½ months (N = 200)	–
<i>T. squamosa</i>	MSI	6/86	4 months (N = 200)	–
<i>T. maxima</i>	MSI	2/87	6½ months (N = 200)	–
B. Wildstock clams				
Subadult <i>T. maxima</i> and <i>T. squamosa</i> were collected from the reefs around Bolinao, Pangasinan at various times over the past several years. These were tagged and measured periodically in the nursery. Although there are now some 61 <i>T. maxima</i> and 96 <i>T. squamosa</i> , a smaller number was included in this paper, representing those held in the nursery for the longest period.				

JCU, James Cook University; MSI, Marine Science Institute; SU, Silliman University.

2 contains a summary of the growth of various cohorts of giant clams. Survival data were tabulated for all the cultured clams (Table 3). The survival rates of the wildstock clams, however, were not included in the table in as much as the clams comprising this group were acquired at various times. Finally, some environmental parameters measured at the study sites are presented in Table 4.

Discussion

The *T. derasa* juveniles reared in Tomasa grew more slowly than those in Guiguivanen with growth rates of 1.8 and 2.4 mm/month, respectively.

Survival was likewise lower in the former (7%) than in the latter (14%). These differences in growth and survival of the clams correlated with and may be attributed to the higher sedimentation rate in Tomasa (4.20 g/cm²/month) compared with Guiguivanen (2.4 g/cm²/month). Upon transfer to Silaqui, growth rates picked up for both cohorts to 3.3 and 3.6 mm/month, respectively. Survival likewise remarkably improved and is now maintained at 100% for both cohorts. This improvement is attributed to the relatively clear water in Silaqui with an average sedimentation rate of only 0.15 g/cm²/month. The improved growth rates of *T. derasa* are close to the MMDC's

TABLE 2. Summary of growth of giant clams in the raceway and ocean-based nurseries.

Species	Spawning date	Nursery site	Duration in nursery	Initial mean length (mm)	Final mean length (mm)	Total length increment (mm)	Growth rate (mm/mo)
A. Cultured clams							
<i>T. derasa</i>	3/84	Tomasa	4/6/85-18/10/86 (502 days)	64.5	94.2	29.7	1.8
		Guiguivanen	4/6/85-18/10/86 (502 days)	60.9	100.5	39.6	2.4
		Tomasa to Silaqui	18/10/86-16/2/88 (486 days)	94.2	147.1	52.9	3.3
		Guiguivanen to Silaqui	18/10/86-16/2/88 (486 days)	100.5	158.9	58.4	3.6
<i>T. gigas</i>	10/85	Raceway	13/7/87-16/2/88 (218 days)	76.6	90.8	14.2	2.0
		Silaqui	13/7/87-16/2/88 (218 days)	75.6	126.4	50.8	7.0
<i>H. hippopus</i>	8/85	Raceway	29/10/86-19/12/87 (416 days)	56.9	81.9	25.0	1.8
		Silaqui	29/10/86-19/12/87 (416 days)	59.5	99.3	39.8	2.9
		Tomasa	29/10/86-18/2/87 (112 days)	60.0	61.8	1.8	0.5
		Tomasa to Silaqui	18/2/87-19/12/87 (304 days)	61.8	84.1	22.3	2.2
	2/87	Raceway	11/8/87-15/1/88 (157 days)	15.7	38.3	22.6	4.3
		Silaqui	11/8/87-15/1/88 (157 days)	15.9	49.6	33.7	6.4
<i>T. squamosa</i>	6/86	Raceway	29/10/86-15/6/87 (259 days)	12.2	21.4	9.2	1.1
		Silaqui	29/10/86-17/2/88 (476 days)	12.7	48.8	36.1	2.3
<i>T. maxima</i>	2/87	Raceway	11/8/87-15/1/88 (157 days)	11.2	22.0	10.8	2.1
		Silaqui	11/8/87-15/1/88 (157 days)	10.2	23.7	13.5	2.6
B. Wildstock clams							
		Size class (mm)					
<i>T. squamosa</i>	75-100	Silaqui	2/87-3/88 (420 days)	90.6	120.6	30.0	2.1
	101-125	Silaqui		115.6	142.1	26.5	1.9
<i>T. maxima</i>	75-100	Silaqui	2/87-3/88	91.6	114.9	23.3	1.7
	101-125	Silaqui	(420 days)	113.0	132.1	19.1	1.4

projected growth of 3.8 mm/month (Beckvar 1981). These findings indicate that relatively sediment-free water is essential for good growth and survival of *T. derasa*.

The *T. gigas* juveniles in Silaqui grew more than three times (7.0 mm/month) the rate of the raceway cohort (2.0 mm/month) with the same survival rate of 99%. Open water seems to be a prerequisite for

good growth of this species. The growth rate in Silaqui is lower but not far from the value obtained in a benthic subtidal site in Pioneer Bay (7.9 mm/month) by the JCU group (ACIAR 1986) and the projected growth rate for this species at 8.3 mm/month (Beckvar 1981). Our lower value may be attributed to the fact that the clams suffered from severe bleaching during quarantine which may

TABLE 3. Summary of survival of giant clams in the land- and ocean-based nurseries.

Species	Spawning date	Nursery site	Duration in nursery	Initial number	Final number	Survival %
<i>T. derasa</i>	3/84	Tomasa	4/6/85-18/10/86 (502 days)	243	18	7.4
		Guiguiwanen	4/6/85-18/10/86 (502 days)	50	7	14.0
		Tomasa to Silaqui	18/10/86-16/2/88 (486 days)	18	18	100.0
		Guiguiwanen to Silaqui	18/10/86-16/2/88 (486 days)	7	7	100.0
<i>T. gigas</i>	10/85	Raceway	13/7/87-16/2/88 (218 days)	83	82	98.8
		Silaqui	13/7/87-16/2/88 (218 days)	85	84	98.8
<i>H. hippopus</i>	8/85	Raceway	29/10/86-19/12/87 (416 days)	34	32	94.1
		Silaqui	29/10/86-19/12/87 (416 days)	31	29	93.5
		Tomasa	29/10/86-18/2/87 (112 days)	30	21	70.0
		Tomasa to Silaqui	18/2/87-19/12/87 (304 days)	21	20	95.2
	2/87	Raceway	11/8/87-15/1/88 (157 days)	100	92	92.0
		Silaqui	11/8/87-15/1/88 (157 days)	100	99	99.0
<i>T. squamosa</i>	6/86	Raceway	29/10/86-15/6/87 (259 days)	100	43	43.0
		Silaqui	29/10/86-17/2/88 (476 days)	100	10	10.0
<i>T. maxima</i>	2/87	Raceway	11/8/87-15/1/88 (157 days)	100	67	67.0
		Silaqui	11/8/87-15/1/88 (157 days)	100	92	92.0

TABLE 4. Environmental parameters measured in the different study sites.

Study site	Temperature (°C)		Salinity (ppt)		Light intensity (μE/m ² /sec)			Sedimentation (g/cm ² /mo)		
	Range	Mean	Range	Mean	Atm	OC	IC	Range	Mean	Period covered
Tomasa	28.0-30.8	29.4	31.0-35.0	33.5	1400	300	165	0-24.60	4.20	23/2/85-16/10/86
Guiguiwanen	-	-	29.0-33.0	31.0	-	-	-	0-15.00	2.40	23/2/85-16/10/86
Silaqui	28.0-33.8	30.1	32.0-36.0	33.7	2323 ^b 643 ^c	1196 ^b 287 ^a	1189 ^b 124 ^c	0-0.24	0.15	1/87-12/87
Raceway	26.7-30.2	28.7	33.4-37.0	35.8	2488 1876 ^d	1350	-	-	-	-

^a Atm — atmospheric reading; OC — underwater outside cage; IC — underwater inside cage. ^b Clear sky; ^c cloudy sky; ^d under net cover.

have hampered their growth. They are expected to further improve as they have been in Silaqui for only 8 months.

The *H. hippopus* (batch 8/85) reared in Tomasa were stunted exhibiting a growth rate of only 0.5 mm/month with a survival rate of 70%. Upon transfer to Silaqui, they caught up with their raceway siblings. These cohorts exhibited growth rates of 2.2 and 1.8 mm/month, respectively. On the other hand, the growth rate of the clams in Silaqui (2.9 mm/month) was only slightly less than the projected 3.3 mm/month growth rate for this species (Beckvar 1981). It seems that *H. hippopus* was more tolerant of the silty conditions in Tomasa than was *T. derasa* as reflected in its higher survival.

It is interesting to note that the *H. hippopus* (batch 2/87) juveniles fared well in the ocean nursery. Their growth rate (6.4 mm/month) is about twice their projected growth rate of 3.3 mm/month as mentioned above. The growth rate of the raceway cohort (4.3 mm/month), although lower than the Silaqui cohort, still exceeds the projected growth rate for this species. This seems to be a very good batch as its growth rate approaches that of *T. gigas*. This indicates that, aside from *T. gigas*, *H. hippopus* could be another good candidate for mariculture.

The *T. squamosa* juveniles reared in Silaqui grew twice as fast as those in the raceway with growth rates of 2.3 and 1.1 mm/month, respectively. The growth rate of the Silaqui cohort is considerably less than that of the *T. squamosa* reared by the University of Papua New Guinea (UPNG) group which had a growth rate of 6.0 mm/month (ACIAR 1986). Furthermore, survival of this species was low at 43% for the raceway cohort after 259 days and 10% for the Silaqui cohort after 476 days. This very low survival cannot be explained at this point and needs further investigation.

The *T. maxima* juveniles reared in Silaqui grew faster than those reared in the raceway exhibiting growth rates of 2.6 and 2.1 mm/month, respectively. The Silaqui cohort also had a high survival rate of 92%. This is interesting since the juveniles were put out in the field at a relatively small mean size of 11.2 mm. This demonstrates that *T. maxima* can be transplanted early in the field so long as they are provided with a suitable substrate where they can firmly attach. In our case, we provided them with coral rubble.

The wildstock clams belonging to the 75–100-mm size-class exhibited slightly greater growth rates (2.1 mm/month for *T. squamosa* and 1.7 mm/month for *T. maxima*) compared with those in the 101–125-mm size-class (1.9 mm/month for *T. squamosa* and 1.4 mm/month for *T. maxima*).

The above results are a subset of the studies undertaken in the project. The results of other experiments will be published elsewhere.

Acknowledgments

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Growth and Mortality of Juvenile Giant Clams (*Tridacna gigas*) in Relation to Tidal Emersion on a Reef Flat

W.J. Nash*

Abstract

Growth and mortality rates of juvenile *Tridacna gigas* were investigated in relation to tidal elevation in Pioneer Bay, Orpheus Island, North Queensland. Clams were placed on adjacent platforms at five different elevations: 0, 50, 80, 105 and 120 cm above tidal datum respectively. Both 1+ and 2+ year-classes were used, with two trays of each age-class/level and 20 clams/tray. The experiment ran from October 1986 to August 1987. Shell lengths were measured at approximately 2-month intervals.

For the 1+ clams, mortality was very low or zero at the lowest three levels, and total at the highest two levels. The 2+ clams experienced very low or zero mortality at all five levels, except for one tray at the middle level (80 cm above datum), where mortality was 70%, and one tray at the second highest level (105 cm above datum), which was lost in rough weather.

Growth of the 1+ clams was similar at all three levels at which they survived. Growth of the 2+ clams at the lowest three levels was also similar, but was much faster than at the highest two levels. It was concluded that there is an emersion threshold somewhere between those found at elevations 3 and 4 — that is, between 3.75 and 6.4 hours mean daily emersion — beyond which growth slows greatly. Combining the results of this experiment with others from James Cook University this threshold lies between 5.0 and 6.4 hours total daily emersion.

An analysis of growth rates in relation to water temperature and mean daily emersion indicated that at low levels of emersion (≤ 3.75 hours/day), growth rate is positively correlated with temperature, while at higher emersion levels, growth and temperature are negatively correlated, presumably because emersion is more stressful at higher temperatures.

In a comparison of growth and survival of juvenile *Tridacna gigas* in four ocean-nursery culture methods, Crawford et al. (1988) found that high levels of growth and survival were attained in the low intertidal zone. In a subsequent study to determine the level of aerial exposure this species could tolerate, it was found that there is a threshold somewhere between 5 and 10 hours average daily exposure at which growth is greatly retarded (Lucas

et al. in prep.). In the latter study, different elevations of the clam cages in relation to tide height were achieved by placing the cages across the very wide, gently sloping intertidal reef flat in Pioneer Bay, Orpheus Island, on the Great Barrier Reef. The lowest and highest cages were some 300 m apart.

The present study is an extension of that described by Lucas et al. (in prep.) and was designed to determine more precisely the level of exposure *T. gigas* can tolerate without suffering significant retardation of growth or increase in mortality. In addition, since the clams in the study of Lucas et al. (in prep.) were spread over a wide area of reef flat, it was possible, though not likely, that the observed

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differences in growth rate were site-related, not tidal height-related. This possibility was precluded in the present study by placing all experimental clam cages at a single site. Growth patterns were consistent with those found in the previous study (Lucas et al. in prep.).

Methods

The experiment was situated at the northern end of Pioneer Bay, Orpheus Island, in the vicinity of other giant clam experiments. The site was chosen because of its sheltered position from all but northerly and northwesterly swells, as well as its remoteness from tourist traffic to and from the research station. The area was near the outer edge of the reef flat, where microatolls of the massive hard coral *Porites lutea* predominated. Substrate was otherwise bare or alga-covered coral rock, or other robust growth forms of hard corals.

The standard experimental unit was the same as that of Crawford et al. (1988) and Lucas et al. (in prep.): a perforated plastic tray, 550 × 300 × 90 mm. Four trays were placed on each level of a structure resembling a staircase of five levels. The structure consisted of sheets of 100 × 60 mm galvanised steel mesh wired in a horizontal position to steel pegs driven vertically into the substrate. The trays were secured to these mesh bases, four trays/level, and a layer of 15–20 mm sized road gravel (crushed basalt) added. Each tray was covered with a removable 26 mm plastic mesh lid. Twenty juvenile *T. gigas* were placed in each tray. Two trays of each set of four contained *T. gigas* spawned in February 1985 (hereafter called 2+ clams), and two contained *T. gigas* spawned in October 1985 (1+ clams). Thus, there were 80 clams on each of the five levels for a total of 400 clams.

The five levels (levels 1 to 5 respectively) were at 0, 50, 80, 105 and 120 cm above datum for Lucinda, the nearest port for which tidal information was available. Chart datum for Lucinda was indicated at the southern point of Pioneer Bay from a previous study (Parnell 1986).

Using the tidal information, it was possible to calculate the duration of emersion of the clams at each level of the staircase, using a computer program in MBASIC prepared by Dr J.D. Collins. Emersion time was calculated as a proportion of the total time, for the entire period between measurements. Emersion time was also calculated as a proportion of daytime (6 am to 6 pm) and proportion of nighttime (6 pm to 6 am).

Water temperature was recorded continuously in the research station seawater system. The daily temperature range in this system may have been slightly greater than in the adjacent bay, due to the influence of land temperature; the median daily

temperature was therefore used as the representative daily water temperature.

All clams were drained by inverting them for about 10 min, weighed to 0.01 g, and maximum shell length measured to 0.1 mm. The 200 clams in each age-class were divided between 10 trays such that the means and standard deviations of their lengths were approximately equal. This was done to facilitate subsequent statistical analysis. The clams were individually labelled with a numbered plastic strip glued with epoxy resin to the shell after cleaning and drying an area of the shell to minimise the chance of tag loss.

The experiment was commenced on 29 October 1986, and terminated ten months later on 26 August 1987. Lengths of all clams were measured at approximately 2-month intervals. Measurement dates were as follows: in 1986, 29 October and 26 December; and in 1987, 18 February, 15 April, 5 June and 26 August.

Frequent reference is made throughout the text to the intervals between these dates. These are as follows: Interval 1: 29 October to 26 December 1986; Interval 2: 26 December 1986 to 18 February 1987; Interval 3: 18 February to 15 April; Interval 4: 15 April to 5 June; and Interval 5: 5 June to 26 August. The clams were inspected approximately every 2 weeks. Scrubbing of the lids to remove fouling algae was generally not necessary, as found earlier (Crawford et al. 1988). At the conclusion of the experiment, all surviving clams were reweighed and a final measurement of shell lengths and weights made.

Growth variation was analysed in two ways: firstly, by a comparison of the length measurements; and secondly, by comparing relative growth rates, expressed as the percentage change in length between two successive measurements, and standardised as the incremental increase for a 28-day period:

$$G_R = 100 \times ((L_{t+1} - L_t)/L_t) \times 28/\Delta t,$$

where G_R is relative growth rate, L_t and L_{t+1} are length measurements at successive times t and $t+1$, and Δt is the time interval (in days) between these measurements. Since G_R is a measure of relative growth, changes in water temperature or daily emersion times between measurement periods will be more closely reflected in G_R than in the length increments alone, which will also be dependent on the size at the previous measurement.

Results

At the second remeasurement (4 months after the experiment began), it was apparent that the 2+ clams had grown to a size at which overcrowding was occurring. Clams were removed at random with respect to size until there were 10/tray. This was

TABLE 1. Survival rates (%) of juvenile *Tridacna gigas* during the course of the experiment, for 1+ and 2+ clams, shown for each tray at each level.

	Tray level									
	Level 1		Level 2		Level 3		Level 4		Level 5	
	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2	Tray 1	Tray 2
1+ clams	95	100	100	85	95	90	0	0	0	0
2+ clams	100	100	95	95	95	30	85	- ^a	100	95

^a Lid washed off and clams lost, presumably through wave action and/or predation.

done because it has been found that overcrowding induces shell deformation and inhibits linear growth (unpublished observations).

Mortality

Between the start of the experiment and the first remeasurement 2 months later, all 1+ clams in the two most elevated levels (levels 4 and 5) were dead. They were unable to survive the stressful conditions. Some time between the first and second remeasurements, one tray on the second highest level (level 4) was lost, presumably through wave action.

Survival rates of clams at each level are summarised in Table 1. The loss of a tray from level 4 was not treated as part of this, because it was not caused by the emersion factors that this experiment was trying to assess. In most cases, the two trays containing clams of the same age at each level experienced similar survival rates. Exceptions to this were the 2+ clams at level 3, where one tray experienced substantial losses, whereas the other did not (Table 1). Similarly, there was substantial mortality in one tray of 2+ clams at level 4 at the first remeasurement. There is no record of these losses at the time of remeasurement, so no explanation for the high mortalities can be offered.

Growth

For both the 1+ and 2+ clams, the growth rates at the lowest three levels (levels 1-3) are very similar within age-groups (Fig. 1,2). Similarly, growth rates of 2+ clams at levels 4 and 5 are similar. The difference in growth rates of 2+ clams between levels 1-3 and levels 4-5, however, is great (Fig. 1). Clams at 105 and 120 cm above datum (levels 4 and 5) grew much more slowly than those at or below 80 cm above datum (levels 1-3). Thus, the threshold above which there is a substantial decrease in growth rate by juvenile *T. gigas* lies between 80 and 105 cm above chart datum — that is, between 3.75 and 6.4 hours mean total daily emersion.

At levels 4 and 5, mean sizes of the 2+ clams actually decreased between the start of the experiment and the first remeasurement (Fig. 2). It is noteworthy that at the end of the experiment the

1+ clams from levels 1-3 had grown much more rapidly than the 2+ clams from levels 4 and 5 and were almost the same shell length (Fig. 1, 2).

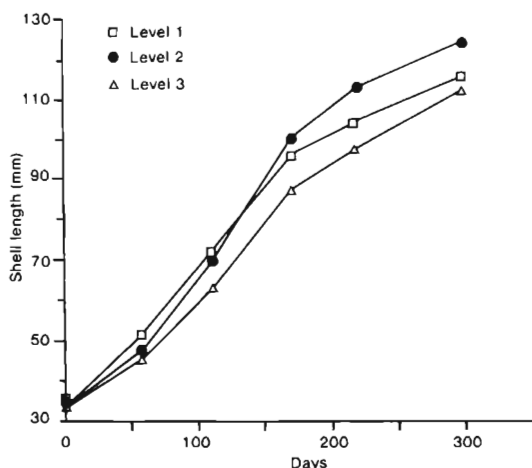


Fig. 1. Growth of 1+ *Tridacna gigas* at emersion levels 1-3 between October 1986 and August 1987.

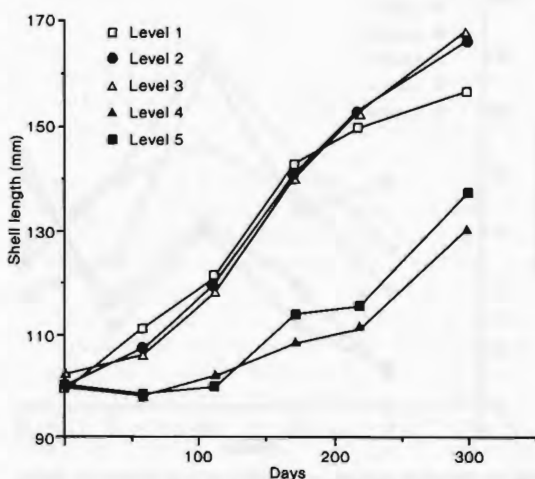


Fig. 2. Growth of 2+ *Tridacna gigas* at five emersion levels between October 1986 and August 1987.