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DEVELOPMENTS IN GIANT CLAM MARICULTURE RELATED TO FRINGING REEFS

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ABSTRACT

Recent new data and the recognition that natural stocks of giant clams are declining dramatically through over-fishing have produced interest in the mariculture of giant clams. Heslinga et al. at the Micronesian Mariculture Demonstration Center have successfully developed extensive methods for rearing Tridacna derasa, including ocean-nursery and grow-out culture in a reef lagoon environment. Research at James Cook University has been concentrated on the mariculture of T. gigas and is based at the University's research station on Orpheus Island. T. gigas is the largestand fastest growing species of giant clam and it occurs naturally on fringing reefs, which are more accessible than reef lagoons in the Great Barrier Reef region. A number of biological problems for mariculture of T. gigas have been overcome, including selection of brood-stock, spawning induction and heavy mortality of the early juveniles during the nursery phase. In a comparison of growth and survival of T. gigas juveniles in four positions for holding them during the ocean-nursery phase, the intertidal benthic position gave near maximum growth rates and very high survival. A protected fringing reef gave much better growth rates than an exposed fringing reef -despite greater turbidity at the former site. Initial testing of the juvenile clams' tolerance of intertidal exposure suggests that they can tolerate 4 hours mean exposure per day without strongly adverse effects. A major research effort is now being made to develop large-scale systems for mariculture of T. gigas in the intertidal fringing reef environment. To date, the only mariculture industry involving fringing coral reefs is with benthic algae and so giant clam mariculture represents a new method of using this environment.

INTRODUCTION

Giant clams (Family Tridacnidae) are the iargest living bivalve molluscs. As such, they would seem to be of intrinsic interest to marine biologists. Yet surprisingly little research., was done on them until quite recently and this allowed some popular misconceptions to prevail. One of these misconceptions is that they are dangerous animals: "killer clams" has'been a popular name. Another misconception is that giant clams are very large because they are very old (Comfort, 1957). In some centres on the Great Barrier Reef, tourists may be shown a very large living specimen of Tridacna gigas that was "here when Captain Cook sailed past". In fact, careful measurements of the growth rates of giant clams have shown that they grow rapidly and that the largest species, T. gigas, grows most rapidly (Munro and Heslinga, 1983). Another recent discovery was the degree to which giant clams, known for some time to contain symbiotic algae, Symbiodinium species (e.g. Yonge, 1936), are effectively phototrophic through their heavy dependence on the algae (Trench, Wethey & Porter, 19.81).

A further impetus.for research on giant clams has been the declining stocks through much of their Pacific distribution, 'including recent extinctions of the larger species, T. derasa' and T. gigas, in some regions (Wells, Pyle and Collins, 1983). This has been partly from excessive fishing of their local'reefs by Pacific peoples, for whom giant clams are part of the traditional diet. It is also from Taiwanese fishermen who have scoured the Pacific in recent decades collecting the adductor muscles from the larger species (Carleton, 1984). The more remote reef. complexes of the Great Barrier Reef were included in this 'Ta,iwanese activity until more effective preventative measures

were implemented (Dawson, 1984, 1986).

The findings regarding rapid growth and autotrophy of giant clams, together with the heavy overfishing of natural stocks led to the realisation that there was potential for the mariculture of giant clams. The demand for giant clam productscouldthen be supplied from farmed clams and depleted natural populations replenished. Mr. Gerry Heslinga at the Micronesian Mariculture Demonstration Center (MMDC), Palau, and Dr. John Munro, at the University of Papua New Guinea and then the International Center for Living Aquatic Resources Management (ICLARM), were two biologists who recognised this potential for mariculture (Munro and Heslinga, 1983). John Munro initiated the International Giant Clam Mariculture Project, an international collaborative program for research on giant clams, which a number 'of institutions in the Pacific region were invited to join.

The successful rearing of the early stages of three species of giant clams by Nancy Beckvar at MMDC was also a crucial step for increasing interest in giant clam mariculture (Beckvar, 1981). Subsequently, at MMDC, Gerry Heslinga developed methods for the spawning and rearing of larvae, juveniles and adults of T. derasa to commercial size (Heslinga and Watson, 1985). Heslinga was able, within a few years, to take giant clam mariculture from the laboratory stage to potentially commercial-scale production. He is now planning for annual productions at MMDC of 100 tonnes whole weight of T. derasa, 6 years of age (Heslinga, Watson and Isamu, 1986). To achieve this production level requires one hectare of shallow reef lagoon.

Heslinga et al. at MMDC have developed low technology methods for the mariculture of T. derasa. They rely on the lunar

pattern of spawning in Palau and, after establishing a large group of broodstock in a shore-based tank, await spontaneous spawning. The fertilized eggs and larvae ar'e then, reared 'extensively. That i's, the eggs are transferred to another tank with coarse-filtered seawater and the resulting larvae rely, for their feeding on natural blooms of algae in the static conditions. Water flow through the tank is resumed after the late-stage larvae have settled onto the tank floor. Unfiltered lagoon water is supplied to the juvenile clams and at five months of age the juvenile clams are removed from the tank floor, cutting their byssal attachments to the tank surface. They are-. transferred to fibreglass trays containing basalt chips. Three. to four months later the trays of 30-40mm shell length juvenile clams are transferred from the seawater system to the ocean-nursery in the field. The trays are covered with plastic mesh to -exclude predators and they are placed at about 5 m depth on a coral sand and rubble substrate in the lagoon adjacent to MMDC. After two years, the juvenile clams, 100-120 mm shell length, are large enough to be virtually free of predation and their protective meshes are removed (Heslinga and Watson, 1985).

MARICULTURE ON FRINGING REEFS

The mariculture technology developed for _T. derasa_ at MMDC, is very appropriate and successful for that species and to the MMDC environment, where 'protected coral reef lagoon conditions adjoin the land-based mariculture facility. Lagoon conditions in the Great Barrier Reef (GBR) are more inaccessible. They , "generally occur behind the reef platforms of mid to outer shelf' patch reefs. This means that, in order to use the reef lagoon conditions in the GBR region, the ocean-nursery and grow-out

phases of giant clam mariculture would generally have to be sited well offshore. This has disadvantages in terms of weather limited accessibility, of security, and of costs in time and fuel for regular maintenance. The land-based phases of giant clam mariculture would be well separated from the ocean phases, probably necessitating two staff units during the long periods of the year when there are concurrent land and ocean-based activities.

These problems are overcome if the ocean-phases of mariculture are conducted on fringing reefs adjacent to a land-based mariculture facility.

The system developed at MMDC is not necessarily applicable to fringing reefs and T. derasa does not occur on fringing reefs in the GBR region. T. derasa seems to require more oceanic conditions than the other five species in the GBR. In extensive observations in the Palm Islands, north of Townsville, T. gigas, T. squamosa, T. maxima, T. crocea and Hippopus hippopus were commonly found on the fringing reefs, but only three specimens of T. derasa were found, although T. derasa is common in the lagoon of Bramble Reef, the nearest patch reef offshore from the. Palms (unpubl. observations, JCU giant clam group).

Another factor against T. derasa is that it grows more slowly than T. gigas (Munro and Heslinga, 1983). While growth rate is not the only criterion in selecting suitability for mariculture, it is obviously an important factor.

RESEARCH AT JAMES COOK UNIVERSITY

Giant clam mariculture research at James Cook University (JCU) is part of an international collaborative project funded by the Australian Centre for International Agricultural Research

(ACIAR). There are four overseas organizations collaborating with JCU and funded by ACIAR: Fisheries Division, Fiji; University of Papua New Guinea; and two Universities in the Philippines, Silliman University on Negros Island and University of the Phillipines at Dilliman. The Project commenced in mid-1984 and is planned to run for three years. Concurrently, ICLARM is involved in the development of a pilot hatchery for giant clams in the Solomon Islands and results from this Project will be implemented at the pilot hatchery.

Giant clam research at JCU has mainly focused on *T. gigas* because, as outlined earlier, it is the fastest growing tridacnid species. However, several other species are being reared and studied for comparative purposes: *T. derasa*, *T.* squamosa and *Hippopus hippopus*. The mariculture research is conducted at the JCU Orpheus Island Research Station, north of Townsville.

The research findings will be outlined under a series of headings below.

Reproduction

Histological studies of *T. gigas* from Great Barrier Reef waters confirm the findings of Braley (1984) of an annual reproductive season with highest proportions of ripe eggs during summer months. It appears that there may be repeated partial spawnings during summer. This leads to spawned-out animals with no evidence of a second onset of gametogenesis during the spawning period. The seasonality of gametogenesis means that induced spawnings of *T. gigas* for mariculture must be conducted during the summer months.

Selection of broodstock is especially important for *T. gigas*. The large size of adults of this species (up to 400 kg and more) and their low densities in the field make it

impractical to collect large numbers of broodstock, 'using the strategy that some of them will be ripe individuals. The development of a gonad biopsy technique, so that individuals with ripe gonads can be identified in the field (Braley, 1984; Crawford, Nash and Lucas, in press), was thus an important step in the mariculture process.

Spawning

At the commencement of this Project, one of the major drawbacks for using *T. gigas* in mariculture was inabilility to induce them to spawn. The only observed spawnings of this species were spontaneous (Munro and Heslinga, 1983).

The breakthrough in spawning induction came from reports of the role of serotonin (a neuro-transmitter substance) in spawning induction in scallops and some other bivalves when injected directly into the gonad (Matsutani and Nomura, 1982). This method was found to work with tridacnids (Braley, 1985; Crawford et al., in press). Brood-stock clams are induced to spawn by an injection of 1mM serotonin solution into the gonad. It appears that the effect of serotonin is to cause the gonad musculature to contract and expel gametes. The. clams engage in normal expulsive contractions as the gametes are released; although the serotonin stimulus for gamete release initially by-passes the central nervous system. The response to serotonin injections is not predictable even in clams with ripe gonads: but, by using this technique on a group of selected clams, it has been possible to regularly obtain eggs and sperm from *T. gigas* brood-stock - a major advance for mariculture of this species.

Giant clams are usually simultaneous hermaphrodites. They shed sperm soon after stimulation and then eggs an hour or so

later (apparently to reduce selfing). In our procedures, the sperm and eggs are collected as they are released: eggs are collected in large'plastic bags placed over the clam's excurrent aperture as it expels the eggs in a dense suspension. The gametes are mixed fo'r cross-fertilization and the numbers of resulting zygotes are estimated. The fertilized eggs are then distributed at known densities to hatchery tanks (Crawford et al., in press).

Hatchery phase

Larvae of *T. gigas* have been cultured using intensive and extensive methods. Intensive methods are those used in commercial bivalve mollusc hatcheries : micro-filtered seawater, daily water changes, feeding with cultured unicellular algae and controlled temperature, etc. Good survival through larval development has been obtained with this method (Crawford et al., in press). It is more reliable than extensive culture,,but it has the disadvantages of requiring much greater inputs of labour and technical facilities. Larvae of *T. gigas* have also been cultured extensively, i.e. large numbers of eggs,are added to outside 3,000 1 tanks with static seawater and essentially left to develop, following similar methods to those at MMDC. The only management used in these extensive cultures is some additions of unicellular algae (*Isochrysis galbana* - Tahitian strain) for food and, a water change if bacteria bloom excessively. Some batches of extensively cultured larvae have been discarded because of virtually total mortality.

The period of larval development-of giant clams (about 8 days) is short compared to other commercial bivalves such as oysters and scallops. This is a distinct advantage for their mariculture, as larval development is the most technically-

demanding phase of the bivalve life-cycle. The larvae have quite modest requirements of algal food. Thus they appear to be good candidates for development of an artificial diet, which would obviate the need for algal culturing facilities. Artificial diets (microencapsulated food particles) have been developed for penaeid larvae, but not yet for bivalve larvae (Langdon and Siegfried, 1984); so the development of a microencapsulated diet for giant clam larvae would be a major breakthrough.

Nursery phase

The late-stage larvae, pediveligers, are transferred to outside tanks from intensive culture or allowed to settle in their hatchery tanks in extensive culture. The newly-settled juvenile clams are 0.2 mm shell length and it is some months before they are visible on the tank surfaces where they have settled. The juvenile clams must commence their symbiotic relationship with zooxanthellae soon after settlement and the recently-metamorphosed juvenile clams are "inoculated" with zooxanthellae obtained from pieces of mantle tissue of adult clams (Crawford et al., in press). This proceedure saves maintaining cultures of zooxanthellae.

In the first batch of T. gigas juveniles reared in early 1985 there was very heavy mortality between settlement and 5 mm shell length (Crawford et al., in press). Less than 1% of the original pediveligers survived this period. The minute size of the juvenile clams compared to the dimensions of the nursery tanks made it impossible to observe the occurrence of this mortality and to identify the causal factors. Overgrowth by benthic algae,' which thrive in'the strong sunlight conditions required by the juvenile clams with their autotrophic

zooxanthellae, was suspected of reducing light and water exchange for the juvenile clams. Some benthic predatory invertebrates may also have been involved in the mortality.

Improving survival through this'nursery phase was another step to be made in developing mariculture techniques for *T. gigas*. This was achieved during the rearing of batches of juveniles in summer 1985/1986 by using prepared substrates and a regular cleaning regime to control the growth of benthic algae. Two substrates were prepared on the bottoms of nursery tanks; a dried lime-sand slurry and a thick layer of Carborundum beads (Mullite) glued with polyester resin to a fibro base. Survival after several months was approximately 17% and 8% on the carborundum bead and lime-sand surfaces, respectively, compared with approximately 5% on an untreated fibreglass tank base (control). This level of survival through early juvenile development achieved on the Carborundum, bead surface'is quite acceptable by the standards of commercial bivalve hatcheries.

Ocean-nursery phase

At approximately 20+ mm shell length the juvenile clams are ready to be transferred from the land-based nursery tanks to the field. At this size they are easy targets for predators and must be held in' protective containers (ocean-nursery phase).' Also, because of their dependence on light they must be held in two-dimensional systems. The usual methods of culturing filter-feeding bivalves in the field, e.g. suspended on lines or stacks of plates, are three-dimensional systems and inappropriate for giant clam juveniles, where only the upper-most individuals would receive enough light. It is also because of this two-dimensional culturing that there is need to conclude the nursery phase as early as possible and to get the juvenile clams into,the field

despite the additional. hazards from predators. As the juvenile clams grow, their requirements for tank space can only be met by the expensive option of adding to the number of tanks in the seawater system, to increase the available surface area; not by the less expensive option of having deeper tanks and increasing the volume.

As described earlier, Heslinga et al. at MMDC, Palau, rear juveniles of T. derasa on the subtidal substrate of a reef lagoon. This is quite successful, but it is the only method of culturing in the ocean-nursery phase that they have tested. For rearing juveniles of T. gigas at Orpheus Island, fringing coral reefs and, adjacent areas were used, and four alternative me'thods for holding the clams were tested in an initial small-scale study. The juvenile clams were placed on granite chip substrates in perforated plastic trays (freezer trays) , 55 x 30 x 9 cm, covered with 26 mm plastic mesh. The four methods of holding the clams in trays were: 1. on frames suspended from floats: 2. on racks 1 m above the bottom; 3. on the bottom subtidally; and 4. on the bottom intertidally. The potentially favourable features of a floating system arethatthe clams are keptnearthe surface in high light levels and away from their benthic predators. Racks have the same advantages ofhigherlightlevelsthanonthe bottom and protection from.predators. The intertidal situation has potential advantages of accessibility without the need for diving (Munro, 1985b) and of high light intensities. However, there are potential disadvantages of intertidal rearing in terms of mortality from exposure and of lowered growth rates as the clams' metabolism is disrupted during exposure.

The floating, rack, subtidal and intertidal (FRSI) study

outlined above was conducted at three locations on the fringing reef in Pioneer Bay, adjacent to the research station. This bay is on the western side of Orpheus Island and faces towards the mainland. It is sheltered from the prevailing easterly winds and thus is more protected but more silty than the environment on the eastern side of the island. Some trays of clams were also established on the fringing reef at the northeastern side of Orpheus Island on the bottom subtidally and intertidally for comparison with those in Pioneer Bay. The clams on the northeastern reef experienced stronger wave action, lower turbidity and, presumably, greater water turnover than those in Pioneer Bay.

The results of the FRSI study revealed that the floating trays, surprisingly, showed poor survival and growth of clams. Racks were best for growth, with mean growth increments of greater than 10 mm per month during the summer months, and they showed good survival of clams. Survival was high in the subtidal benthic trays, but growth rates were lower than on the racks: while growth rates were high, near 10 mm per month, and there was no mortality (excluding equipment failures) in the intertidal benthic trays. The mortality in the floating and rack based trays appeared to be largely from small parasitic gastropods of the family Pyramidellidae. These ectoparasites settle from the plankton onto the clam shells and feed on the clam's blood and tissues by inserting their long proboscis between the valves. Numbers of them can be found on some infected juvenile clams and in these individuals the tissues progressively shrink until they die. The pyramidellids also occurred on similar sized juveniles in the seawater system, but they were not observed on the clams in benthic trays in either the subtidal or intertidal zone. It

appears that small benthic predators', which must be able to pass through the 25 mm mesh covering the trays, normally control the pyramidellids, and that in the seawater system and above the substrate in the field these predators are absent. Gerry Heslinga at MMDC has-also found that pyramidellids do not trouble benthic juvenile clams in the field, but occur on tank-held clams (pers. comm.). It is paradoxical that, in the field situations that seemed potentially free of predators, the clams suffered high mortalities because a predator of their ectoparasites was apparently also absent. Studies of the biology and epidemiology of the pyramidellids are planned.

In addition to their influence on growth and survival, the four methods of holding T. gigas juveniles during the ocean-nursery phase were assessed in terms of their practicability: cost and ease of construction, propensity for equipment failures, ease of maintenance and levels of fouling (affecting the amount of maintenance). The benthic intertidal method was superior in each of these, with the exception of propensity for equipment failures. The one weakness of the intertidal situation was exposure to strong wave action during heavy seas. Thus, when Cyclone Winifred passed north of Orpheus Island in February 1986, causing strong winds into Pioneer Bay from the north, three of the twelve trays in the intertidal zone were torn from their bases and carried away, while none of the subtidal trays were lost (the floating trays were taken out before the cyclone struck). Intertidal systems must be securely fixed to the substrate to resist periods of strong wave action.

Comparing 'growth rate data for the two fringing reef localities, it was found that, despite the lower turbidity and

generally more oceanic conditions at the northeastern fringing reef site, the juvenile clams there were growing substantially slower than those in the equivalent positions in Pioneer Bay. This was especially the case'for the intertidal position on the northeastern reef. The detrimental factor here was disturbance of the clams by wave action, which'was especially strong at the shallower site. It is not clear how disturbance adversely affects the clams, but sensitivity to movement appears to be also implicated in the poor results for growth from the floating position in the FRSI study.

The three intertidal positions of trays in the FRSI study were at approximately 0.6 m tidal height above chart datum and further groups of T. gigas were put out higher in the intertidal zone' of the fringing reef of Pioneer Bay to test their tolerance of exposure. Initial results over the winter months indicate that levels up to 0.8 m tidal height have no, pronounced effect on growth and survival of these juvenile clams: however, clams at approximately 1.2 m tidal height survived but showed no' growth. The difference between 0.8 m and 1.2 m tidal levels in terms of mean daily periods of exposure during the winter months is from approximately.4 to 9 hours, respectively, per 24 hour period or from 3 to 5.5 hours, respectively, during daylight hours. It seems that ocean-nursery phase juveniles of T. gigas can tolerate mean daily periods of exposure up to 4 hours per 24 hour period without strongly deleterious effects on their growth and survival.

'The intertidal zone of protected fringing reefs is obviously,' very suitable for the ocean-nursery culture of T. gigas in the GBR region, both in terms of being a favourable environment for the clams and also in terms of the' logistics of commercial

mariculture. Also, for the development of giant clam mariculture in Pacific countries (the objective of the ACIAR-funded Project), the intertidal zone has obvious advantages where SCUBA facilities are unavailable or inappropriate. Thus, a major research effort is being made at OIRS to develop intertidal systems for the ocean-nursery and later grow-out phase of T. gigas.

Two kinds of large protective containers are being assessed as alternatives to the trays that were used in the initial studies. These are "boxes" and "lines". Boxes are containers 2.3 m X 1.2 m X 0.2 m with a hinged lid made from a sheet of galvanised steel mesh, 6mm diameter steel and 100 mm mesh size, and enclosed with a finer protective mesh. They are being tested both intertidally and subtidally. The protective meshes used on the subtidal boxes include "chicken" and "trellis" galvanised wire meshes, but only plastic meshes are being used in the intertidal zone, because of higher levels of corrosion. Lines are 30 m long containers, 1.1 m wide and 0.2 m high, made from two 30 m rolls of plastic mesh: one roll makes the base and the other the lid. The lines are held in place with metal stakes and subdivided with internal partitions into 2 m long compartments. The reason for compartmentalising the lines is to restrict the movements of any predators that may penetrate into the line.

Grow-out phase

The largest T. gigas juveniles reared are now greater than 100 mm (at age 20 months) and during this 1986/87 summer will be transferred to the grow-out phase, i.e. removed from the protective containers and placed on the surface of the fringing reef in Pioneer Bay. The size at which they are large enough to be virtually free of predators will thus be determined. The

shells of T. gigas in this size range are'thinner and thus more easily crushed than those of T. derasa and this may well require that T. gigas be reared to a larger size before the grow-out phase.,

Recently a permit was obtained from GBRMPA to set up a small ocean-nursery and grow-out site in the lagoon of John Brewer Reef, within the area of the "Reeflink" operation. This will serve for a comparison of growth and survival in the lagoon of a mid-shelf reef versus the fringing reef culture at Orpheus Island. Inspite of all the advantages of fringing reef culture and the apparently good results obtained to date, the possibility exists that fringing reefs are sub-optimal environments for T. gigas compared to reef lagoons and this possibility must be tested.

IN CONCLUSION

As mentioned earlier, T. gigas is not the only giant clam species that inhabits fringing reefs and the techniques being developed at OIRS are not only applicable to T. gigas. In other: parts of- the Pacific region particular giant clam species have economic significance. For example, H. hippopus and especially H . porcellanus are important in the shell trade, in, the Philippines and there is interest in the mariculture of,the smallest giant clam species, T. crocea, in southern Japan'where it is prized as a delicacy (Murakoshi, Aramaki and Hirata, 1984; M. Yamaguchi, pers. comm.) These three'species typically occur in shallow conditions on fringing reefs.

To develop ,the commercial mariculture of giant clams requires more than solving biological problems and efficient' production methods. It involves investigating the existing and

potential markets for giant clam products, research on product 'development, and research on sociological and economic aspects of giant clam mariculture. Such studies have been undertaken or initiated by the Forum Fisheries Agency, ICLARM and ACIAR (e.g. Dawson, 1986; Munro, 1985; Tisdell, 1986).

Development of a mariculture industry for giant clams on fringing coral reefs in the Pacific region would represent a major new mode of use of these reefs. There are currently industries based on culturing benthic algae, e.g. Eucheuma and Caulerpa species, and industries based on culturing animals near fringing reefs, e.g. pearl oysters, Pinctada species; but none yet based on culturing benthic animals on fringing coral reefs.

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