

Successes and failures in reintroducing giant clams in the Indo-Pacific region

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Background

Giant clams (Tridacnidae) are the largest marine bivalves found in coastal areas of the Indo-Pacific region. Eight species of giant clam of varying size and habitat preference have been described (*Tridacna gigas*, *T. derasa*, *T. squamosa*, *T. maxima*, *T. crocea*, *T. tevora*, *Hippopus hippopus* and *H. porcellanus*). In addition to the colourful smaller boring clams, such as *T. maxima* and *T. crocea* that are found within limestone substrates, larger free-living species such as *T. squamosa*, *T. derasa* and *T. gigas* are usually recorded near reefs or over sand. Similarly, *Hippopus* spp. are often found on soft substrata, e.g. in sea-grass beds. These bivalves are unusual in that they host symbiotic zooxanthellae within their mantle tissue and benefit from the products of photosynthesis, which provides part of their nutrition.

Giant clams are a highly prized food source, and both harvesting by subsistence fishers and exports of clam meat have been responsible for stock depletion across their range. The clams are also harvested for their shells and for live export for the marine aquarium trade. Although fishing by foreign vessels (for the adductor muscle) caused much of the depletion of the largest species, giant clams are now mostly under pressure from subsistence and semi-commercial (artisanal) fishers.

Giant clams have been depleted from coral reefs because they are slow growing, non cryptic and generally easily accessible to fishers. Habitat degradation is also responsible for declines in abundance, especially close to larger urban centres. Due to these pressures, and their depletion and slow recovery from overfishing, giant clams are listed under Annex II of CITES (1983), and are considered vulnerable under the IUCN red list of threatened species (1996).

Although there are examples of local extinctions (*T. gigas* in Guam, Mariana Islands, Federated States of Micronesia, New Caledonia, Taiwan, Ryukyu Islands and Vanuatu; *T. derasa* in Vanuatu; and *H. hippopus*

in Fiji, Tonga, Samoa and American Samoa, Guam, Mariana Islands and Taiwan), in most cases giant clams are not eradicated through fishing and habitat change. In general, declines in abundance result in a pronounced constriction of their range and reduced spawning success as giant clams are sessile and cannot actively aggregate for sexual reproduction.

Programmes to re-establish or supplement depleted populations of giant clams have centred around two main activities: (1) protecting and aggregating remaining wild adults to facilitate spawning and fertilisation success and subsequent “downstream” recruitment, and (2) breeding and releasing hatchery-reared clams. In the early 1980s, several government and private institutions throughout the Indo-Pacific region agreed to a joint effort to propagate giant clams and restock the reefs of Pacific Island nations (Bell et al. 2005). The organisations involved in hatchery and early culture research were the Okinawa Prefectural Fisheries Experimental Station, University of Papua New Guinea, Micronesian Mariculture Demonstration Center, Australian Centre for International Agricultural Research, Marine Science Institute at the University of the Philippines, and WorldFish Center (formerly known as ICLARM). Re-establishment and reinforcement of stocks and increased awareness of the plight of giant clams stemmed from these initiatives.

Goals of restocking programmes

The various restocking programmes that took place throughout the region shared three main goals:

- To reinforce giant clam stocks at overfished sites in the Indo-Pacific region. This goal cannot succeed in isolation from improved general management of remaining stocks, which is not covered in this submission.
- To reintroduce giant clam species in places where they have been extinguished, with the aim of re-establishing populations capable of self-replenishment.

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3. A ninth member, *Tridacna rosewateri* has been proposed, although not established as a new species as yet. *T. rosewateri* has been recorded in Mauritius.

- To improve aquaculture technology and early grow-out systems to assist restocking projects that could be monitored and supported through the development of a successful long-term breeding programme.

Main stages in reintroducing giant clams: methods, implementation and post-release monitoring

Feasibility

In some areas of the Indo-Pacific, natural recruitment was thought to be almost impossible (other than through self-fertilisation) as large mature clams were so scattered they were considered to be beyond the threshold density required for successful cross-fertilisation (e.g. Tonga, see Chesher 1995). Trials were carried out to augment stocks through aggregating adult clams to increase the chance of successful external fertilisation and subsequent downstream recruitment. In theory, aggregation of adults in “clam circles” (Chesher 1995) overcomes Allee (Courchamp et al. 1999; Stephens et al. 1999) or depensatory (Liermann and Hilborn 2001) effects (i.e. when a population falls below a certain threshold, its population growth rate may decrease due to factors such as greater difficulty in finding a mate, or dependence on a mating strategy that requires larger numbers). Although there are few quantitative studies showing the success of clam circles, the simplicity and practicality of this low-cost system encouraged their establishment in many countries (Tonga, Fiji, Vanuatu and Solomon Islands). The practice of concentrating clams in “clam gardens”

has long been documented in northern Papua New Guinea (Mitchell 1972).

The availability of spat for reintroduction projects generally relies on hatchery production and early grow-out technology as most Indo-Pacific countries do not have access to sufficient juveniles from the wild. An exception is French Polynesia, where “collectors” are used to settle *T. maxima* spat in atolls with exceptionally large clam populations (Gilbert et al. 2006). Manuals have been produced that document hatchery and culture methods for giant clams (see Fig. 1, Calumpong 1992; Ellis 1998).

Depending on the species and location, it takes between 8 and 14 days after fertilisation for giant clam larvae to settle on the bottom of tanks. They are then held in nursery grow-out facilities (generally land-based raceways) for around 3 to 6 months before first handling, and up to 12 months before being transferred to ocean nurseries.

Usually, simple mesh cages, kept off the bottom, are used to protect the giant clams against large predators such as turtles, rays, octopus and fish (Figs. 2 and 3). Growth rates vary greatly among species (Munro 1993a). Even in this protected environment, predatory gastropods such as *Cymatium* spp. (Fig. 4) and pyramidellid snails can settle into cages as larvae, making predation unpredictable until the giant clams reach a larger “refuge” size when they are less susceptible (Govan 1995). Site selection and juvenile management practices (Fig. 5) have proved to be critical factors in improving survival of cultured clams (Hart et al. 1998, 1999).

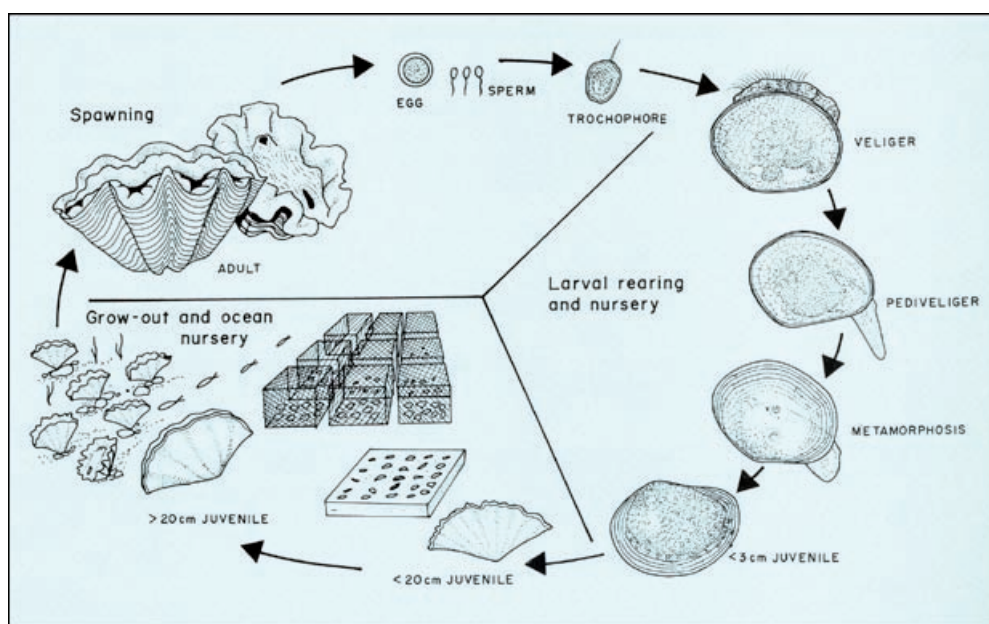


Figure 1. Four basic stages in clam culture, taken from Calumpong (1992).



Figure 2. Giant clam nursery cages near a coastal village in Solomon Islands. (Image: WorldFish Center)

Figure 3. Floating nursery cages used in Solomon Islands. (Image: WorldFish Center)



Figure 4. Predator (*Cymatium muricinum*) on juvenile *T. derasa* in Cook Islands. (Image: A. Teitelbaum)



Figure 5. In situ training on giant clam nursery practices in Solomon Islands. (Image: WorldFish Center)

A range of hatchery and nursery production systems are currently used in over 21 Indo-Pacific countries, but even low-tech operations still require trained personnel and specialised equipment. The process of maintaining large numbers of broodstock for hatchery production also requires holding adult specimens near hatchery sites (Fig. 6). These aggregations of broodstock, in more than 11 countries in the Pacific, also contribute to egg production and downstream settlement of clams.

Implementation

Clam restocking and stock enhancement projects have been carried out at various locations in the Indo-Pacific (Table 1).

Although programmes to aggregate adults have usually operated independently of commercial ventures, projects that rely on hatchery production have generally coupled re-establishment and reinforcement programmes with commercial clam farming activities.

Post-release monitoring

There has been little definitive proof of enhanced recruitment after the establishment of adult clam circles, although quantitative studies have detected increased settlement of *T. derasa* and *T. squamosa* on nearby reefs (Chesher 1995). For example, following establishment of clam circles at Falevai in Tonga's Vava'u Group, monitoring showed that the number of juvenile *T. derasa* (individuals per hour of searching) increased from 0 in 1987 to 1.48 in 1990. The increase was consistent over yearly

assessments, and was even greater for the medium-sized clam, *T. squamosa*. There was no change in the average number of *T. maxima*, which were not aggregated. The real number of new recruits detected after the establishment of clam circles is low, but detection rates for juvenile clams are normally low, and this rate is higher than reported by other surveys of clam recruitment elsewhere in the Pacific (Braley 1988).

An interesting opportunity now exists to detect increased recruitment around *T. gigas* release sites on Australia's Great Barrier Reef. Concentrations of hatchery-reared *T. gigas* were relocated to reefs some distance away from the hatchery, and these clams have now had sufficient time to become egg-producing adults (giant clams mature first as males and later become functional hermaphrodites). It would be interesting to study whether additional recruitment is taking place downstream of these clam concentrations.

For clams returned to the wild at the end of nursery culture, high mortality is a major problem and further husbandry for up to three years is required to maximise survival (Bell et al. 2005). In the Philippines, where more than 75,000 clams have been restocked (Gomez and Mingoa-Licuanan 2006), 10,000 were placed in the Hundred Islands National Park. As many as 7531 remained after 2.5 years, with the last inventory showing that losses were predominantly among the juvenile size classes. Only 2% of sub-adults and 1% of broodstock were lost. Mortalities were attributed to typhoons, fouling, crowding, predation and poaching (Gomez and Mingoa-Licuanan 2006).



Figure 6. WorldFish Center *Tridacna gigas* broodstock at Nusatupe, Solomon Islands. (Image: WorldFish Center)

Table 1. Outline of Indo-Pacific giant clam restocking programmes*

Location	Organisation involved	Start	Species (translocated species in brackets)
American Samoa	Office of Marine and Wildlife Resources	1986	<i>(T. derasa)</i> , <i>(T. gigas)</i>
Australia	James Cook University; ACIAR; Aquasearch (private company)	1984	<i>T. gigas</i> , <i>T. derasa</i>
Cook Islands	Ministry of Marine Resources	1986	<i>T. maxima</i> , <i>T. squamosa</i> , <i>(T. derasa)</i> , <i>(T. gigas)</i> , <i>(H. hippopus)</i>
Fiji	Fiji Fisheries Division	1985	<i>T. maxima</i> , <i>T. derasa</i> , <i>T. squamosa</i> , <i>(T. gigas)</i> , <i>(T. tevorooa)</i> , <i>(H. hippopus)</i>
French Polynesia	Service de la Pêche	2002	<i>T. maxima</i>
Federated States of Micronesia **	National Aquaculture Centre Marine and Environmental Research Institute of Pohnpei	1984	<i>(T. derasa)</i> , <i>(T. gigas)</i> , <i>(H. hippopus)</i>
Guam	Dept of Agriculture	1982	<i>(T. derasa)</i> , <i>(T. gigas)</i> , <i>(T. squamosa)</i>
Japan	Okinawa Prefectural Fisheries Experimental Station; Okinawa Kuruma-ebi Co., Ltd (private company)	1987	<i>T. crocea</i> , <i>T. squamosa</i> , <i>T. maxima</i> , <i>(T. derasa)</i>
Kiribati	Atoll Beauties (private company)	2000	<i>T. maxima</i> , <i>T. squamosa</i>
Marshall Islands	Marshall Islands Marine Resources Authority; Robert Reimers Enterprises & Mili Atoll (private companies)	1985	<i>(T. derasa)</i> , <i>T. gigas</i> , <i>T. squamosa</i> , <i>H. hippopus</i>
New Caledonia	IFREMER	1993	<i>H. hippopus</i> , <i>T. derasa</i> , <i>T. maxima</i> , <i>T. crocea</i> , <i>T. squamosa</i>
Northern Mariana Islands	Dept of Lands and Natural Resources	1986	<i>(T. derasa)</i> , <i>(T. gigas)</i> , <i>(H. hippopus)</i>
Palau	Micronesia Mariculture Demonstration Center	Late 1970s	<i>T. derasa</i> , <i>T. gigas</i> , <i>T. squamosa</i> , <i>T. maxima</i> , <i>T. crocea</i> , <i>H. hippopus</i> , <i>H. porcellanus</i>
Papua New Guinea	UPNG – Motupore Island Research Centre	1983	<i>T. gigas</i> , <i>T. squamosa</i> , <i>T. crocea</i> , <i>H. hippopus</i>
Philippines	University of the Philippines Marine Science Institute	1987	<i>T. maxima</i> , <i>T. squamosa</i> , <i>H. hippopus</i> , <i>(T. derasa)</i> , <i>(T. gigas)</i>
Samoa	Samoa Fisheries Dept SPADP	1988	<i>T. maxima</i> , <i>T. squamosa</i> , <i>(H. hippopus)</i> , <i>(T. derasa)</i> , <i>(T. gigas)</i> , <i>(T. squamosa)</i>
Solomon Islands	WorldFish Center	1989	<i>T. maxima</i> , <i>T. squamosa</i> , <i>T. derasa</i> , <i>H. hippopus</i> , <i>T. gigas</i>
Thailand	Department of Fisheries	1997	<i>T. squamosa</i>
Tonga	Ministry of Lands, Survey and Natural Resources; Japanese International Cooperation Agency (JICA); EarthWatch (private company)	1989	<i>T. maxima</i> , <i>T. squamosa</i> , <i>T. derasa</i> , <i>T. tevorooa</i> , <i>(T. gigas)</i> , <i>(H. hippopus)</i>
Tuvalu	SPC/Tuvalu Fish	1989	<i>(T. derasa)</i>
USA (Hawaii)	Not available	1951	<i>(T. crocea)</i> , <i>(T. squamosa)</i> , <i>(T. gigas)</i>
Vanuatu	Vanuatu Fisheries Dept; JICA; Ringi Te Suh Marine Conservation Reserve, Malekula (Anon. 2000) (private companies)	1998	<i>T. maxima</i> , <i>T. squamosa</i> , <i>T. crocea</i> , <i>H. hippopus</i> , <i>(T. derasa)</i> , <i>(T. gigas)</i>

* Also see Eldredge 1994 and Bell 1999.

** There are separate facilities in Yap, Chuuk, Kosrae and Pohnpei States.

T. gigas imported from Australia into the Philippines became female-phase mature as early as 1995, with second-generation clams being recorded at low density (R. Braley, pers. comm.). Yap is another example where re-establishment has occurred after translocation of hatchery-reared clams. Price (1998) argues that large clams were originally found on Yap but became extinct. The reintroduction of approximately 25,000 *T. derasa* to Yap from neighbouring Palau in 1984 resulted in only ~8% survival of the introduced stock. However, these *T. derasa* matured, reproduced and re-established viable populations on nearby reefs (Lindsay 1995). Surveys conducted by the Secretariat of the Pacific Community (PROC-Fish/C-CoFish programmes) noted the continued presence of *T. derasa* in low numbers in mid-2006.

When smaller boring species (*T. crocea*) were restocked in Japan, survival of clams ranged from 0.3–56% three years after release. Survival was found to be higher when individual clams were settled into pits on *Porites* heads or on to artificial substrates and then released in situ, rather than releasing them directly on to limestone substrates (Masayoshi 1991; Murakoshi 1986). In Australia, predation of *T. gigas* was lower when clams were held in the intertidal zone (Lucas 1994), and in Solomon Islands, *H. hippopus* was held on the bottom but behind suspended cargo netting, to protect medium-sized, hatchery-reared clams from predation by large rays.

Major difficulties faced and lessons learnt

Difficulties

The range of difficulties encountered by various restocking programmes involve biological, technical and human factors.

When placed at sea, survival of juvenile giant clams (<25 mm shell length) is generally low even with protection and husbandry (Heslinga et al. 1984), and therefore clams require approximately nine months in land-based nurseries. Clams only reach a general refuge size at a shell length of around 150 mm. Even then, they are still vulnerable to rays, triggerfish and turtles (Heslinga et al. 1990).

Producing giant clam spat in hatcheries and holding them in early juvenile culture is relatively expensive. Estimates of the cost of raising juveniles till ready for transfer to sea range from USD 0.27 to 0.36 per individual (Hambrey and Gervis 1993; Tisdell et al. 1993). These estimates do not reflect the full capital cost of hatchery development. Furthermore, a variety of skills are needed for spawning giant clams and rearing spat until refuge size and these skills are not always available or funded for long periods, making some operations unsustainable.

Poaching of broodstock from clam circles, and clams from hatchery and restocking areas, has also been a problem. A very recent example of such a loss occurred in January 2008 in French Polynesia, where numerous clams restocked from the Tuamotu Islands to the Faaa site in Tahiti were poached just a few days after they were settled on a reef within a marine reserve (G. Remoissenet, pers. comm.).

From a biological standpoint, genetic diversity of hatchery-reared stock is likely to be lower, or in some cases different from that found in wild populations (Benzie 1993; Munro 1993b). Hatcheries also increase the potential for introduction of pathogens (Eldredge 1994). Although there have been no reports of mortality associated with viruses, *Chlamydia*, *Mycoplasma*, fungi, or neoplasms (Braley 1992), Rickettsia-like organisms have been noted in local and translocated giant clams. Furthermore, mass mortalities of *T. gigas* and *T. derasa* have been recorded on the Great Barrier Reef, although tests were not successful in identifying the pathogen involved (Alder and Braley 1989).

Lessons learnt

Many lessons have been learnt from these programmes over the years and most still apply.

The relatively high cost of producing giant clams suggests that managing wild stocks may be more cost efficient than investing in hatcheries to restock overfished giant clam populations (Bell et al. 2005).

Site selection and early stock husbandry are critical to the survival of giant clams, especially hatchery-reared juveniles. Selection of a site with suitable environmental conditions, and where there is social cohesion within the nearby community, assists the growth and general condition of stocks, while minimising losses to predation and/or poachers.

Stakeholder consultation is an essential part of successful restocking of giant clams. Reaching informed agreement between researchers, government workers and local villagers requires extended periods of awareness raising and information sharing. Special care should be taken to see that programmes respond appropriately to traditional reef tenure systems and encourage direct community and fisher participation in reintroduction and reinforcement programmes.

The original premise of the ICLARM/ACIAR Giant Clam Project initiated in 1984 was that the economic burden of producing large enough clams for restocking could be spread by coupling restocking programmes with commercial farming. This premise has been supported. The technology developed for clam production has in some cases been transferred

to the private sector, and a number of people across the Pacific are employed to produce clams for the marine ornamental trade. A proportion of this production is also available for restocking.

Conclusion: limited success of giant clam restocking programmes

The success of reintroduction and reinforcement programmes aimed at placing clams in coastal environments has varied. Projects have been carried out in Australia (GBR), Asia (Philippines) and the Pacific (notably in Palau, Solomon Islands, Vanuatu, Tonga, Marshall Islands and Cook Islands). However, in general, after more than 20 years of work, most restocking projects can be considered to have been only partially successful. The reasons for these mixed results include:

- the high cost and length of time required to produce “seed” clams have limited the sustainability of many operations. The high mortality of juvenile clams has also lowered success rates.
- lack of social adhesion in communities participating in several of these projects. In some cases, projects were not well matched to the communities’ needs or wants.
- lack of funding for monitoring and the absence of standard protocols for surveys have limited the reporting of successful results from some reintroduction and reinforcement programmes.

Rearing and growing clams have been learning processes for many of the participating countries. In the course of this activity, many countries now have greater knowledge of the clam life cycle and a more realistic awareness of the value of these resources. In some places, this has resulted in increased protection of giant clams at both national and community levels.

A further advantage is that the methods used to rear and grow clams have been adopted, refined and transferred between countries. The successful introduction of simple hatchery and early rearing processes has seen increased capacity development in countries, and local operators are now progressing from clams to more “difficult” species (Friedman and Tekanene 2005). Currently, simple hatchery technology is also being adopted by the private sector in a handful of Pacific Island countries and territories, and giant clam production is seeing another rise, this time to target the marine ornamental trade.

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