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The Case History of a Large Natural Cohort of the Giant Clam *Tridacna gigas* (Fam. Tridacnidae) and the Implications for Re-stocking Depauperate Reefs with Maricultured Giant Clams

R.D. BRALEY

AQUASEARCH
6-10 Elena St., Nelly Bay
Magnetic Island, QLD 4819
Australia

F. MUIR

Coastal Management Program
Department of Environment and Heritage
Far Northern Region
Cairns, QLD, Australia

Abstract

A large pulse of recruitment of *Tridacna gigas* was first noticed in January 1987 when juveniles were about 18 months of age. Survival over 5 years was 56% at one site and 9.7% at another site. Shell length increased from a mean of 11.2 cm at about 18 months of age to a mean of 41.8 cm after 5 years (6.5 years from spawning). Juvenile clams of this cohort were close to random in spatial distribition. Preferred settlement and/or survival was found on several substrata such as branching *Acropora* sp. thickets, on filamentous algal covered surfaces, and in coral crevices. An understanding of the survival and growth of this year class of *T. gigas* through long-term monitoring will contribute to the wise management of this resource. These results also indicate that the use of cultured juvenile clams to restock areas depauperate of giant clams in Asia and the Pacific will be successful.

Introduction

In long-lived marine invertebrates such as the giant clam *Tridacna gigas* (F. Tridacnidae) events such as major recruitment of juveniles or major mortalities of adults are rare (Pearson 1977; Yamaguchi 1977; Braley 1984, 1986, 1988; Alder and Braley 1989; Pearson and Munro 1991). Both these events occurred at Lizard Island, northern Great Barrier Reef (Braley 1988; Alder and Braley 1989). Thus, a rare opportunity occurred to monitor growth and survival of the cohort which recruited to this reef. No such large cohort (50% of the original adult standing stock) has been followed over time though average size cohorts had been recorded elsewhere (Braley 1986, 1987; Pearson and Munro 1991). The spatial distribution of juvenile clams at the site is of interest because adults have been shown to be significantly aggregated in distribution (Braley 1986, 1987). Substrate preference or increased survival within branching *Acropora* sp. coral thickets has been shown for adult *T. gigas* (Braley 1986, 1987). Are the juveniles likewise distributed or does clumping enhance survival over time in some way?

In the Indo-Pacific region, there is increasing interest in the use of maricultured giant clams to re-stock marine parks and reserves in which giant clam populations have been drastically reduced by overfishing (Braley, in press; Calumpong and Solis-Duran 1993; S.S.M. Mingoa, pers. comm., 1995; WWF-Indonesia, pers comm., 1995). The comparison of growth and survival achieved by cultured giant clams with this 5-year monitoring of a wild cohort will be useful in making marine park management decisions involving where and how to spatially place cultured giant clams for maximum growth and survival in a re-stocking program.

Materials and Methods

A map of Lizard Island indicates the study site areas at Watson's Bay (WB; 0.55 ha) and Palfrey Island - South Island channel (PS; 0.73 ha) (Fig. 1). Adult clams at these sites were previously mapped and monitored (Braley 1986). Study sites were surveyed for juvenile clam cohorts by repeatedly marking off 5-10 m-wide sections along the length of the reef site and using a zigzag pattern of search. In the initial survey, the shell length (SL) of juvenile *T. gigas* were measured *in situ* with a vernier caliper, and a float with numbered tag was attached near each juvenile clam. In subsequent surveys, SL was measured for each tagged *T. gigas*. Where tags were lost, the clams were measured only if their position could be ascertained from the maps. In the final survey, new floats and tag numbers were placed near surviving clams. There were six surveys as follows: April 1987, July 1987, December 1987, April 1988, September 1988, April 1992.

Substratum Habitat and Spatial Distribution

During the first survey, the substratum type(s) immediately surrounding the clam cohort were recorded. The degree of association with substratum types was analyzed. The seven substratum types were: 1) soft coral, 2) filamentous algal covered surface, 3) branching *Acropora* sp. coral, 4) coral crevice, 5) other hard coral, 6) coral pavement, and 7) sand and rubble.

During the mapping of juvenile clams, it was necessary to assign multiple substrata for clams located within 15 cm of differing substratum types. Thus, the total number of clams associated with all substrata (Y) was greater than the known number of clams in the cohort which recruited to these sites (X). Y was used in chi-square analysis.

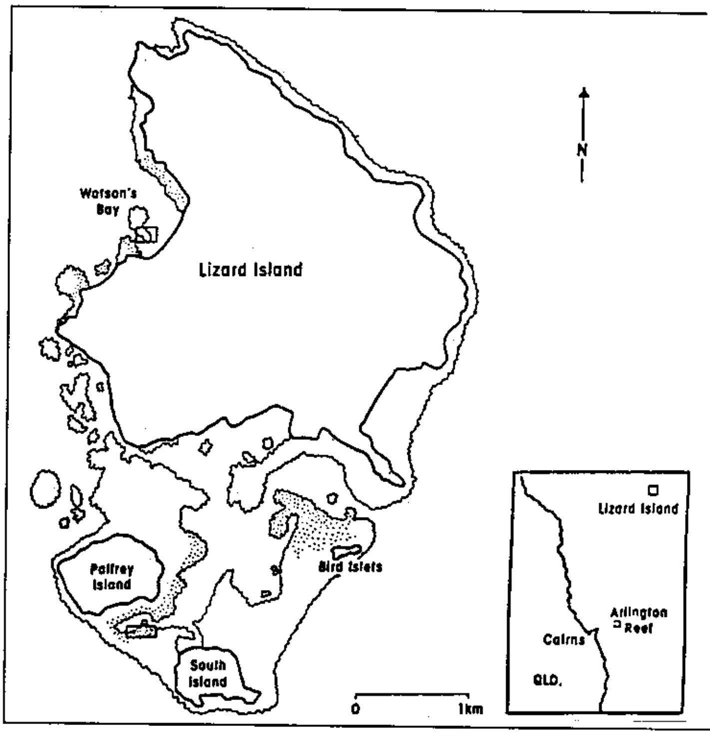

Fig. 1. Lizard Island and lagoon (14°41'S, 145°27'E) showing study sites. Original numbers of adult clams before the mass mortality of 1985 were: site in Watson's Bay (136 *Tridacna gigas*, 29 *T. derasa*); site along the channel between Palfrey and South Islands (79 *T. gigas*, 21 *T. derasa*) (after Alder and Braley 1989).

During the final survey, the nearest neighbor distances were measured between surviving clams within the WB site. The nearest neighbor distances of adult clams at the site had previously been analyzed using the Clark and Evans (1954) method. The results showed significant aggregation (Braley 1986; 1987). The new recruited cohort was similarly analyzed here.

During the final survey, a single day was devoted to survey the reefs and islands in the relative vicinity of Lizard Island to locate and measure all recruited juvenile clams, in order to see if a parallel recruitment was taking place on these reefs surrounding Lizard Island.

Results

Survival and Growth of Recruited Clams

The mean SL (± SD; cm) and a number of cohort clams surviving at each survey are shown in Table 1. The survival of clams at the WB site was higher at each measurement period compared with the PS site. The survival to 5 years [at the final measurement period] was 55.8% at WB, 9.7% at PS and a combined site survival of 40.9%. At the PS site, the number had already dropped to four juveniles (9.7% of the original number) within a year of the initial survey. At the WB site, size-frequency distributions of the cohort are shown for the first

Table 1. Mean shell length and number of *Tridacna gigas* found during each of the six surveys covering a period of 5 years; age of clams shown as approximate number of months from spawning.

Survey date	Approx. age of clams (months)	Mean SL (± SD) in cm and no. of individuals (n)	
		Watson's Bay (WB)	Palfrey-South (PS)
Apr 1987	18+	11.2 ± 3.1 (n=86)	11.5 ± 3.3 (n=41)
Jul 1987	21+	14.1 ± 2.7 (n=66)	13.9 ± 3.6 (n=20)
Dec 1987	26+	16.9 ± 3.4 (n=62)	14.9 ± 2.2 (n=11)
Apr 1988	30+	19.8 ± 4.0 (n=59)	15.6 ± 0.5 (n=4)
Sep 1988	35+	22.4 ± 5.0 (n=50)	- - - - - - - (n=4)
Apr 1992	61+	41.8 ± 4.4 (n=48)	42.2 ± 6.9 (n=4)

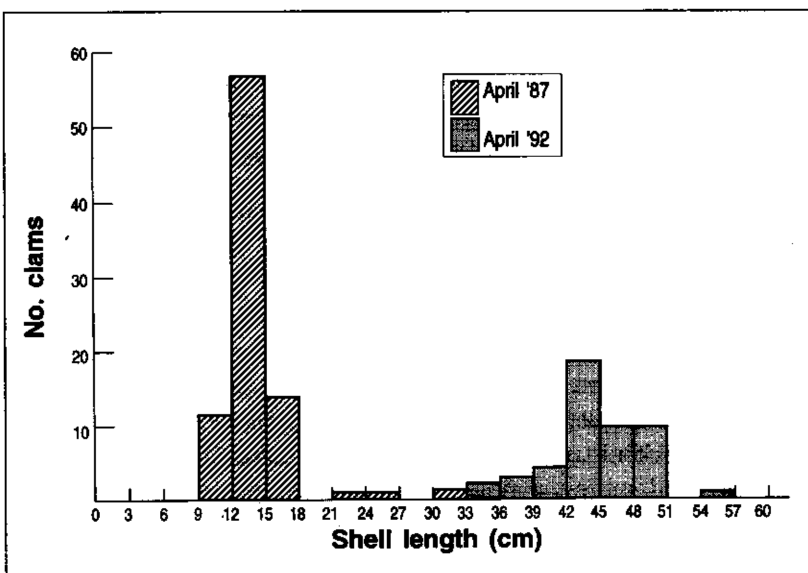

Fig. 2. Size-frequencies of *Tridacna gigas* recruits at Watson's Bay, Lizard Island, Great Barrier Reef, Australia, in April 1987 and April 1992.

survey and 5 years later (Fig. 2). There was no overlap between size of individuals in these two time periods. There was a mean growth of 30.6 cm SL between the first and last periods of measurement. The estimated age from settled larvae of this cohort of giant clams is 6.5 years to the last measurement, with a mean of 6.4 cm growth in SL per year. At WB the mean growth rate between measurement periods was 0.70 ± 0.17 cm per month and the overall growth rate was 0.50 cm per month.

Growth of wild *T. gigas* juveniles at WB is compared with a growth curve derived from a cohort of maricultured *T. gigas* from Lizard Island and from another cohort of this species reared at Seafarm Pty. Ltd. [Innisfail, north

Table 2. Substratum type (and percent of total area) associated with juvenile *Tridacna gigas* recruits at Watson's Bay (WB) and Palfrey Island-South Island channel (PS) sites in April 1987. Expected (E) and observed (O) numbers of clams are shown for each substratum type, and chi-square values and significance are shown for combined sites. When clams were associated with multiple substrata, each substratum was treated as having those clams' association. Total clam recruitment at WB and PS was 85 and 41, respectively, in April 1987. The artificially higher total numbers of clams as a result of the multiple substrata associations was 123 (WB) and 63 (PS).

Substratum type	% of total area	WB		PS		Combined sites	
		E	O	E	O	Chi-square value	P
Soft coral	11.8	14.5	6.0	3.5	0.9	6.9	P<0.05
Algal covered surface	2.1	2.6	19.9	0.8	10.9	242.6	P<0.001
Branching *Acropora* sp. coral	6.0	7.3	30.0	9.0	31.9	128.9	P<0.001
Coral crevice	1.9	2.3	11.9	1.3	1.96	40.4	P<0.001
Other hard coral	25.0	30.7	34.0	11.7	8.97	1.0	P>0.05
Coral pavement	7.0	8.6	13.0	0.8	2.0	4.0	P<0.05
Sand and rubble	46.0	56.6	7.9	35.7	5.9	66.7	P<0.001

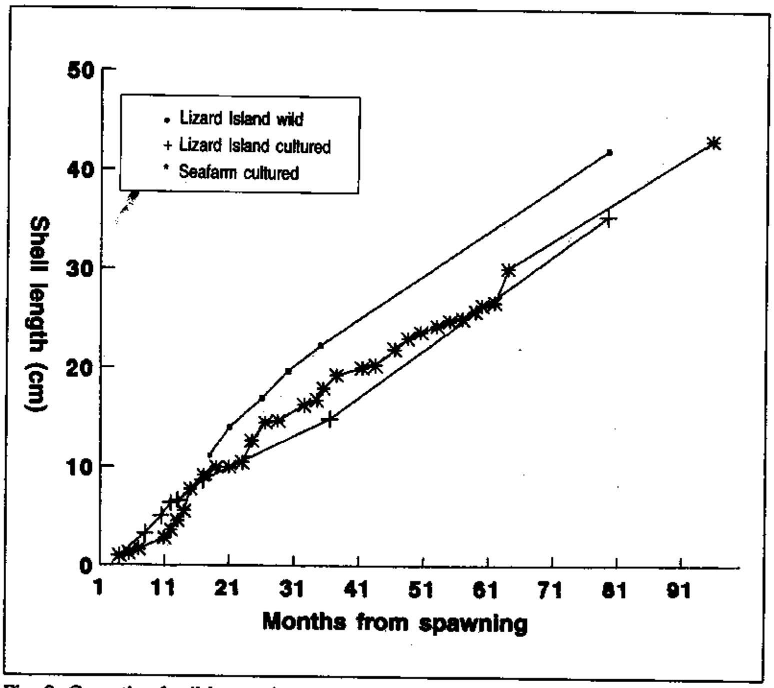

Fig. 3. Growth of wild recruits vs. cultured juvenile *Tridacna gigas* from Lizard Island and Seafarm Pty. Ltd. The cultured juveniles were later reared in the ocean nursery at Orpheus Island, north Queensland, Australia. Cultured juveniles were placed in ocean nurseries at about 8-10 months of age from hatchery/land nursery tanks.

Queensland] and later moved to the James Cook University Orpheus Island Research Station, north Queensland (pers. observations, unpubl.; ACIAR Giant Clam Project, unpubl. data) [Fig. 3]. Size at 17-18 months of age was similar for both wild and cultured clams, but growth from this age to 35 months appears favorable for wild versus cultured clams. After 35-40 months, the growth curves were essentially parallel. The result was that a similar size clam (about 42 cm SL) was produced a year or more earlier in the wild group compared to cultured clams of this species.

Spatial Distribution and Substratum

Nearest neighbor analyses of surviving juveniles in the cohort in April 1992 resulted in an R value of 0.896, showing a very slight tendency toward clumping but approaching a uniform distribution (where $R = 1.0$ in the Clark and Evans [1954] analysis). The probability of a greater difference between the observed and expected value of r was not significant ($P = 0.169$).

Table 2 shows the percentage of total cohort clams associated with the seven substratum types. Chi-square tests resulted in highly significant ($P<0.001$) greater numbers of clams than expected on algal covered surfaces (substratum 2), branching *Acropora* sp. (substratum 3), and coral crevices (substratum 4). Coral pavement (substratum 6) had significantly ($P<0.05$) greater numbers of clams than expected. Conversely, soft corals (substratum 1) and sand and rubble (substratum 7) had a highly significant fewer number of clams than expected ($P<0.05$ and $P<0.001$, respectively). Other hard corals (substratum 5) were not significantly different ($P>0.05$) than expected. Substratum 2 (2.1% of total area) and substratum 3 (6.0% of total area) together accounted for 75% of all the clam associations.

Recruitment at Nearby Islands and Reefs

Four islands or reefs at which spot check surveys were done to confirm recruitment of *T. gigas* varied in distance from 3.0 to 9.4 nautical miles from Lizard Island lagoon. Forty juveniles were found at these sites which were in the >33-50 cm-size class similar to the cohort at Lizard Island. A mean of 65% of the juveniles observed at the four sites were in this size class. The mean SL of juveniles measured at all four reefs were not significantly different from the mean SL of juveniles from the WB site on Lizard Island ($P>0.05$, t-tests).

Discussion

Growth of juvenile *T. gigas* from this large natural recuitment was slightly faster than growth of hatchery-reared juveniles placed in ocean-nursery situations. This may be due to the high density of clams in ocean-nurseries, as shown by Lucas et al. (1992). Survival of these naturally recruited juveniles was clearly lower than the approximately 82% survival from age 20 months for cultured *T. gigas* at Orpheus Island (Barker et al. 1988). The lower survival at the PS site than WB may be due to the dense coral cover present only along a channel in the lagoon at PS between relatively shallow (and somewhat barren) reef flats. The WB site has a greater area of dense coral cover and a much more protected position than the PS site. Whether or not survival is affected by the surrounding substratum type has yet to be tested quantitatively. This may be done with maricultured animals. Braley (1986, 1987) demonstrated substratum preference by young hatchery-reared juveniles as well as adults in the natural habitat. In that work, branching *Acropora* sp. corals and sometimes other hard corals were highly preferred over other substrata, or survival was highest in these 'preferred' substrata.

Previous work at several sites on the Great Barrier Reef have revealed similarly low recruitment levels (Braley 1986, 1988; Pearson and Munro 1991). However, this unusually large recruitment event at Lizard Island followed the major mortality of 1985+ (Alder and Braley 1989). It is of considerable interest that the size of juveniles, when first noticed in January 1987, would place them in an age-group which originated from a spawning in the same year, but after the mortality event. The major mortalities were in June-August 1985, during the cool winter water temperatures. It is most likely that the juveniles originated from the start of the 1985-86 spawning season in October-November. Of the original standing stock of adults, there was a 50% mortality of adults and subsequently, a 50% recruitment of juveniles (Braley 1988). There may be a connection here between large mortalities followed by a large recruitment. This leads to questions regarding the kind of cues and triggers required for *T. gigas* to participate in natural mass spawning events. Some research was initiated (Munro et al. 1983), but the active principal in gonad homogenate still eludes us. Stress is one well-known cause of spawning induction in marine animals. Perhaps this mass spawning was also triggered by the stress of the mass mortality event. It may not be possible to find further evidence for this hypothesis, unless genetic factors can be shown to be similar between this cohort at Lizard Island and the older adult clams at Lizard Island which survived the mass mortality of 1985+.

Maricultured Clams, Management and Re-stocking

Growth and survival of cultured animals are similar to their naturally recruited counterparts. This supports mariculture as a legitimate means to re-stock giant clams in depauperate areas. The potential of genetic dilution must be considered however, unless several batches of clam juveniles from different parents are used in the re-stocking (Benzie 1992) or alternatively, cultured juveniles should be placed in the field with wild stock specimens of the same species. In the Philippines, imported mariculture-produced *T. gigas* have been re-stocked into marine reserve areas (E. Gomez and S.S.M. Mingoa, pers. comm., 1992 and 1995), as Philippine genetic stocks are close to local extinction.

Advice for management on re-stocking of reefs with maricultured clams, based upon the monitoring of this natural cohort, include:

1) Place cultured juveniles (*T. gigas*) in protective mesh cages, allowing light to enter, until they are at least 2.5 years of age (about 18-20 cm SL [true at a latitude similar to this experiment]).
2) When released without protective cages, place them primarily in branching *Acropora* sp. thickets or in coral crevices which are large enough to accommodate their growth. They may be placed in other hard coral areas, but not upon wide open areas of sand or rubble.
3) Attempt to simulate a clumping distribution as is found with adults. This may best be done in branching *Acropora* sp. thickets.
4) Place some wild stock specimens of the same species near the re-stocked maricultured juveniles to improve genetic variability when the cohort becomes reproductively active.

The present information will be useful to marine conservationists deciding where to place aquaculture-reared juvenile clams in order to maintain the highest survival, and to approximate natural conditions when restocking depauperate reef areas.

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