

NURSING OF GIANT CLAM *TRIDACNA SQUAMOSA* IN CAGES

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ABSTRACT

Nursing of young giant clam (*Tridacna squamosa*) was carried out from November 1998 to May 1999 in net cages on a reef flat and a reef slope at Ko Mannai, Gulf of Thailand. Three size classes (3-5, 5-7 and 7-9 cm shell length) were selected from a hatchery and nursed in cages. Survival rate and growth of giant clam were studied in cages without net cover, in cages with net cover opened after 2 months of nursing, in cages with net cover opened after 4 months and in cages closed with a net during the experimental period of 6 months. Giant clams survived significantly different depending on size class and treatment. The shell increment was highest of 3-5 cm clams while 7-9 cm clams had the lowest value.

INTRODUCTION

Giant clams are among the biggest bivalves in the world. They inhabit coral reef areas in shallow water. They are filter feeders but benefit from symbiotic microalgae (zooxanthellae) present in the mantle. When exposed to light the clams can get food and oxygen from the algae via the photosynthesis. Zooxanthellae vary in abundance and location within the tissue resulting in various colour patterns and beautiful appearance. Giant clams are distributed in coastal zones of the tropical Indian and Pacific Oceans. There are seven species of giant clams in these regions (Fig.1, after Braley 1992). Five species have been recorded in Thai waters, but only three species are extant today, namely *Tridacna crocea*, *T. sq-*

uamosa and *T. maxima* (Nugranad *et al.* 1997).

Giant clams are edible and their shells can be used as ornamental objects, so their stocks have rapidly become reduced. Without control the clams may go extinct from Thai waters. For this reason the Department

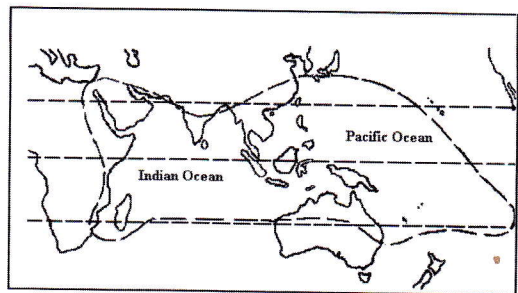


Fig. 1. World distribution of giant clam *Tridacna squamosa*.

of Fisheries has taken action formulating a giant clam conservation policy. The giant clams are now strictly protected species according to the Royal Act of Wild Life Conservation 1991. Besides, the Department of Fisheries is conducting a culture project to compensate and increase the natural populations by release of seed to natural habitats. Since 1992 the Prachuap Khiri Khan Coastal Aquaculture Development Center has succeeded in propagation and larval rearing of the giant clam *T. squamosa*. The clams can be cultivated until adult stage inside the hatchery (Nugranad *et al.* 1997).

Hatchery treatment, however, consumes a great deal of budget, time, and care to get success in the culture. Sea farming of the

clams should be a way to reduce the operation costs. In addition, the exposure treatment could acclimatize the clams to the natural environment before final release. Objectives of this study were to determine survival and growth of the giant clams on a coral reef flat and a coral reef slope, and compare data with hatchery culture.

MATERIALS AND METHODS

Juvenile stocks

The cage culture was conducted in November 1998 and lasted for six months. Rearing sites were located in a coral reef area north-west of the Mannai Island, Rayong Province (Fig. 2). Juveniles of giant clams were obtained from the Prachuap Khiri Khan Coastal Aquaculture Development Center. Clams were divided into three size groups: 3-5, 5-7, and 7-9 cm. The clams were then transferred by car from the Center to the

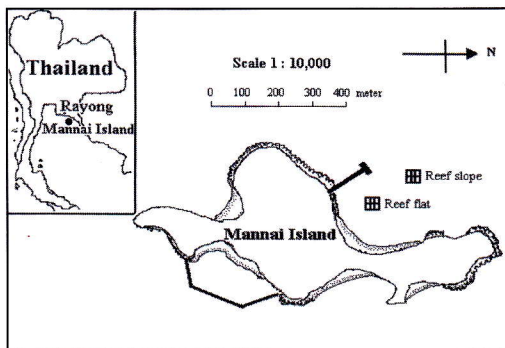


Fig. 2. Location of the two study sites at Ko Mannai, the Gulf of Thailand.

Mannai Sea Turtle Conservation Station, Rayong. During the transfer, the clams were wrapped in wet cotton fibers and kept in foam containers, which were iced to maintain low temperature.

Cage design

Each cage measured 120 x 90 x 20 cm (length, width, height). The frame was made of iron wire, 1.0 cm diameter, coated with anti-rust stain. The frame was wrapped with black plastic net (20 mm mesh size). On top

of the cage there was also a net cover, which could be opened and closed. Each cage was divided into two equal chambers provided with broken coral rubble to yield substrates for the juveniles.

Experimental design

Two areas were selected as rearing sites, one located on a reef flat and the other on a reef slope. The 3 size classes of giant clam juveniles were exposed to 4 treatments as follows:

T1. Cages were opened until the end of experiment.

T2. Cages were opened after 2 months.

T3. Cages were opened after for 4 months.

T4. Cages were closed until the end of experiment.

Table 1. Experimental design of giant clam nursing in cages at Mannai Island, Rayong Province. T1 = cages were open during the whole experiment. T2 = cages were opened after 2 months. T3 = cages were opened after 4 months. T4 = cages were closed during the whole experiment.

Treatment	T1	T2	T3	T4
	<i>Set 1</i>	<i>Set 2</i>	<i>Set 3</i>	<i>Set 4</i>
Shell length	S1 T1	S1 T2	S1 T3	S1 T4
3-5 cm (S1)	S1 T1	S1 T2	S1 T3	S1 T4
	<i>Set 5</i>	<i>Set 6</i>	<i>Set 7</i>	<i>Set 8</i>
Shell length	S2 T1	S2 T2	S2 T3	S2 T4
5-7 cm (S2)	S2 T1	S2 T2	S2 T3	S2 T4
	<i>Set 9</i>	<i>Set 10</i>	<i>Set 11</i>	<i>Set 12</i>
Shell length	S3 T1	S3 T2	S3 T3	S3 T4
7-9 cm (S3)	S3 T1	S3 T2	S3 T3	S3 T4

All 3 size classes received 4 treatments each with 3 replications. So in total 36 experimental units or rearing cages were set on each study site for observations. Each cage contained 40 individuals. The cages were randomly arranged at two sites (Table 1).

Data analysis

Survival rates were estimated by counts of the living clams and data from replications

were averaged. Shell lengths of each set were recorded once a month until the experiment ended. The mean lengths were calculated, and growth rate determined.

The average survival rates obtained from 12 experiment sets were tested statistically by two way analysis of variance and

Newman-Keuls test (S-N-K test) (Aryuthaka 1993).

RESULTS

THE REEF FLAT

Survival rates

Table 2 shows numbers and averages of sur-

Table 2. Survival of giant clam *Tridacna squamosa* reared in cages on a reef flat (6 months). The Table shows average number of surviving individuals (ind.) and the calculated percentage survival (%) for 4 treatments (T1-T4) and 3 size classes (S1-S3)

	T1		T2		T3		T4	
	ind.	%	ind.	%	ind.	%	ind.	%
3-5 cm (S1)	17.7	44.2	35.0	87.5	36.0	90.0	36.3	90.8
5-7 cm (S2)	10.7	26.7	36.0	90.0	36.0	90.0	38.3	95.8
7-9 cm (S3)	28.0	70.0	38.0	95.0	38.3	95.8	37.7	94.2

Table 3. Increment of shell length \pm SD (cm) of *Tridacna squamosa* (3-5 cm size class) reared on the reef flat for 6 months. Four treatments (T1-T4) and the number of measured specimens (n) are shown.

	T1		T2		T3		T4	
	ind.	n	ind.	n	ind.	n	ind.	n
Month 0	4.9 \pm 0.4	120	4.8 \pm 0.4	120	4.8 \pm 0.4	120	4.8 \pm 0.4	120
Month 1	5.5 \pm 0.5	75	5.6 \pm 0.4	30	5.8 \pm 0.4	30	5.9 \pm 0.3	28
Month 2	6.2 \pm 0.5	59	6.5 \pm 0.5	119	6.5 \pm 0.4	29	6.7 \pm 0.4	28
Month 3	6.6 \pm 0.6	59	7.0 \pm 0.5	109	7.3 \pm 0.4	29	7.5 \pm 0.4	27
Month 4	7.8 \pm 0.5	54	7.8 \pm 0.5	108	7.9 \pm 0.5	115	8.1 \pm 0.5	26
Month 5	8.5 \pm 0.5	54	8.5 \pm 0.5	108	8.6 \pm 0.5	114	8.8 \pm 0.6	26
Month 6	8.8 \pm 0.5	53	8.8 \pm 0.6	105	8.9 \pm 0.5	108	8.7 \pm 0.8	109
Increment	3.9		4.0		4.1		3.9	

Table 4. Increment of shell length \pm SD (cm) of *Tridacna squamosa* (5-7 cm size class) reared on the reef flat for 6 months. Four treatments (T1-T4) and the number of measured specimens (n) are shown.

	T1		T2		T3		T4	
	ind.	n	ind.	n	ind.	n	ind.	n
Month 0	6.2 \pm 0.5	120	6.1 \pm 0.5	120	6.7 \pm 0.5	120	6.3 \pm 0.5	120
Month 1	6.9 \pm 0.6	68	6.9 \pm 0.5	29	7.0 \pm 0.6	28	7.2 \pm 0.5	29
Month 2	7.3 \pm 0.5	39	7.7 \pm 0.5	116	7.6 \pm 0.6	28	7.7 \pm 0.5	28
Month 3	8.0 \pm 0.6	35	8.3 \pm 0.5	112	8.4 \pm 0.6	28	8.5 \pm 0.5	28
Month 4	8.8 \pm 0.5	33	9.0 \pm 0.6	111	9.1 \pm 0.6	112	9.1 \pm 0.6	27
Month 5	9.5 \pm 0.6	33	9.8 \pm 0.6	109	9.8 \pm 0.6	112	9.8 \pm 0.7	28
Month 6	9.9 \pm 0.7	32	10.1 \pm 0.7	108	10.1 \pm 0.6	108	9.9 \pm 0.7	115
Increment	3.7		4.0		3.4		3.6	

Table 5. Increment of shell length \pm SD (cm) of *Tridacna squamosa* (7-9 cm size class) reared on the reef flat for 6 months. Four treatments (T1-T4) and the number of measured specimens (n) are shown.

	T1	n	T2	n	T3	n	T4	n
Month 0	7.8 \pm 0.5	120	7.8 \pm 0.5	120	7.7 \pm 0.5	120	7.8 \pm 0.5	120
Month 1	8.5 \pm 0.6	96	8.7 \pm 0.5	29	8.6 \pm 0.6	30	8.4 \pm 0.6	29
Month 2	9.1 \pm 0.6	84	9.2 \pm 0.6	118	9.1 \pm 0.6	28	8.9 \pm 0.6	30
Month 3	9.3 \pm 0.5	81	9.7 \pm 0.6	116	9.8 \pm 0.6	28	9.6 \pm 0.6	30
Month 4	10.4 \pm 0.6	84	10.4 \pm 0.6	114	10.3 \pm 0.6	118	10.2 \pm 0.7	30
Month 5	11.0 \pm 0.6	83	11.0 \pm 0.6	114	11.0 \pm 0.6	118	10.9 \pm 0.7	29
Month 6	11.3 \pm 0.7	84	11.3 \pm 0.7	114	11.3 \pm 0.7	115	11.1 \pm 0.7	113
Increment	3.5		3.5		3.6		3.3	

viving giant clams reared on the reef flat after six months. The survival rates of some groups differed from each other significantly. Maximum survival of 38.3 individuals (95.8 % survival) was recorded in the 7-9 cm size class in cages, which had the cover opened after four months (T₃), and the 5-7 cm size class reared under closed cover throughout the experiment (T₄). On the other hand, the 5-7 cm size class reared without cover (T₁) had the lowest survival of 10.7 individuals (26.7% survival).

The S-N-K Test showed that the survival rates could be divided into two groups:

One group with more than 70% survival. These clams were all in the 7-9 cm size class, or in the 3-5 and the 5-7 cm size classes reared under covers for 2, 4 and 6 months (T₂, T₃ and T₄).

One group with less than 70% survival. These clams were the 3-5 and the 5-7 cm size classes reared under closed cover throughout the experiment (T₁).

Growth rates

Clams of similar size had different shell increments depending on the treatment:

The 3-5 cm size class (treatment T₁, T₂, T₃ and T₄) attained final shell lengths of 8.8 \pm 0.5, 8.8 \pm 0.6, 8.9 \pm 0.5, and 8.7 \pm 0.8 cm respectively. During the 6 months their shells increased 3.9, 4.0, 4.1, and 3.9 cm in length respectively (Table 3).

The 5-7 cm size class (treatment T₁, T₂, T₃ and T₄) attained final shell lengths of 9.9 \pm 0.7, 10.1 \pm 0.7, 10.1 \pm 0.6, and 9.9 \pm 0.7 respectively. During the 6 months their shells increased 3.7, 4.0, 3.4, and 3.6 cm in length respectively (Table 4).

The 7-9 cm size class (treatment T₁, T₂, T₃ and T₄) attained final shell lengths of 11.3 \pm 0.7, 11.3 \pm 0.7, 11.3 \pm 0.7 and 11.1 \pm 0.8 cm respectively. During the 6 months their shells increased 3.5, 3.5, 3.6, and 3.3 cm in length respectively (Table 5).

THE REEF SLOPE

Survival rates

Table 6 shows number of surviving giant clams reared on the reef slope. Survival rates of the 7-9 cm size class, which had the cover opened after 4 months (T₃) showed maximum survival rate of 38.0 individuals or 95.0 %. On the other hand, not a single clam survived in the 3-5 cm size class when reared without a cover (T₁). The S-N-K Test showed that survival rates could be divided into two groups:

One group with more than 70% survival. These clams were all in the 7-9 cm size class, or in the 5-7 cm class reared in cages with covers opened after 2, 4 and 6 months (T₂, T₃ and T₄), and the 3-5 cm class reared by opening covers after 4 and 6 months (T₃ and T₄).

Table 6. Survival of giant clam *Tridacna squamosa* reared in cages on a reef flat (6 months). The Table shows average number of surviving individuals (ind.) and the calculated percentage survival (%) for 4 treatments (T1-T4) and 3 size classes (S1-S3)

	T1		T2		T3		T4	
	ind.	%	ind.	%	ind.	%	ind.	%
3-5 cm (S1)	0	0	12.7	31.7	28.7	71.7	31.0	77.5
5-7 cm (S2)	8.7	21.7	28.7	71.7	34.7	87.0	37.7	94.2
7-9 cm (S3)	31.3	78.3	38.0	95.0	38.0	95.0	37.7	94.2

Table 7. Increment of shell length \pm SD (cm) of *Tridacna squamosa* (3-5 cm size class) reared on the reef slope for 6 months. Four treatments (T1-T4) and the number of measured specimens (n) are shown.

	T1		T2		T3		T4	
	ind.	n	ind.	n	ind.	n	ind.	n
Month 0	5.0 \pm 0.5	120	4.8 \pm 0.4	120	4.7 \pm 0.5	120	5.1 \pm 0.9	120
Month 1	5.4 \pm 0.5	70	5.7 \pm 0.5	29	5.7 \pm 0.5	30	5.3 \pm 0.6	28
Month 2	6.4 \pm 0.2	4	6.5 \pm 0.5	114	6.5 \pm 0.4	28	6.2 \pm 0.6	28
Month 3	-	0	7.6 \pm 0.5	51	7.4 \pm 0.4	27	7.0 \pm 0.6	28
Month 4	-	0	8.3 \pm 0.5	38	8.1 \pm 0.7	107	7.5 \pm 0.7	26
Month 5	-	0	8.7 \pm 0.4	38	8.7 \pm 0.7	90	8.1 \pm 0.8	27
Month 6	-	0	8.9 \pm 0.5	38	8.9 \pm 0.7	86	8.5 \pm 0.8	93
Increment	-		4.1		4.2		3.4	

Table 8. Increment of shell length \pm SD (cm) of *Tridacna squamosa* (5-7 cm size class) reared on the reef slope for 6 months. Four treatments (T1-T4) and the number of measured specimens (n) are shown.

	T1		T2		T3		T4	
	ind.	n	ind.	n	ind.	n	ind.	n
Month 0	6.1 \pm 0.5	120	6.1 \pm 0.5	120	6.0 \pm 0.5	120	6.3 \pm 0.5	120
Month 1	6.9 \pm 0.6	86	6.9 \pm 0.5	27	6.7 \pm 0.4	28	7.3 \pm 0.7	30
Month 2	7.6 \pm 0.6	41	7.8 \pm 0.7	114	7.6 \pm 0.5	27	8.0 \pm 0.7	30
Month 3	8.5 \pm 0.5	32	8.6 \pm 0.6	94	8.3 \pm 0.4	27	8.7 \pm 0.8	29
Month 4	9.1 \pm 0.6	28	9.1 \pm 0.6	88	9.2 \pm 0.8	110	9.2 \pm 0.8	30
Month 5	9.6 \pm 0.7	28	9.7 \pm 0.7	85	9.8 \pm 0.8	106	9.9 \pm 0.9	29
Month 6	9.9 \pm 0.8	26	9.9 \pm 0.7	86	9.9 \pm 0.8	104	10.1 \pm 0.9	113
Increment	3.8		3.8		3.9		3.8	

One group with less than 70% survival. These clams were in the 3-5 cm size class reared without covers for six months (T₁), or in cages with covers opened after two months (T₂), and also the 5-7 cm class reared without cover (T₁).

Growth rates

Clams of similar size had different shell increments depending on the treatment: In the 3-5 cm size class of giant clams of the T₁ were all dead after 2 months while clams in treatment T₂, T₃ and T₄ attained final

Table 9. Increment of shell length \pm SD (cm) of *Tridacna squamosa* (7-9 cm size class) reared on the reef slope for 6 months. Four treatments (T1-T4) and the number of measured specimens (n) are shown.

	T1	n	T2	n	T3	n	T4	n
Month 0	8.0 \pm 0.5	120	7.9 \pm 0.5	120	8.0 \pm 0.5	120	7.9 \pm 0.5	120
Month 1	8.6 \pm 0.6	105	8.8 \pm 0.6	29	8.7 \pm 0.6	29	8.6 \pm 0.5	29
Month 2	9.2 \pm 0.6	98	9.2 \pm 0.9	118	9.4 \pm 0.5	29	9.1 \pm 0.6	30
Month 3	9.8 \pm 0.6	97	9.9 \pm 0.6	116	10.0 \pm 0.5	28	9.8 \pm 0.7	30
Month 4	10.3 \pm 0.6	93	10.4 \pm 0.6	114	10.3 \pm 0.7	116	10.2 \pm 0.8	30
Month 5	10.8 \pm 0.7	93	10.6 \pm 0.7	114	10.7 \pm 0.8	116	10.7 \pm 1.0	29
Month 6	11.0 \pm 0.7	94	10.7 \pm 0.8	114	10.7 \pm 0.8	114	10.7 \pm 1.0	113
Increment	3.0		2.8		2.7		2.8	

shell lengths of 8.9 \pm 0.5, 8.9 \pm 0.7 and 8.5 \pm 0.8 respectively. Their growth rates are observed 4.1, 4.2, and 3.4 cm, respectively (Table 7).

The 5-7 cm size class (treatment T₁, T₂, T₃ and T₄) attained final shell lengths of 9.9 \pm 0.8, 9.9 \pm 0.7, 9.9 \pm 0.8, and 10.1 \pm 0.9 cm respectively. During the 6 months their shells increased 3.8, 3.8, 3.9, and 3.8 cm in length respectively (Table 8).

The 7-9 cm size class (treatment T₁, T₂, T₃ and T₄) attained final shell lengths of 11.0 \pm 0.7, 10.7 \pm 0.8, 10.7 \pm 0.8, and 10.7 \pm 1.0 cm respectively. During the 6 months their shells increased 3.0, 2.8, 2.7, and 2.8 cm in length respectively (Table 9).

DISCUSSION

FACTORS INFLUENCING SURVIVAL AND GROWTH

Rearing

The larger clams have stronger shells that are more tolerant to water turbulence (rolling over) and also more resistant to attack by predators. However, high mortality was found in all three sized classes during the first two month of rearing. Thereafter mortality decreased until the mortality was almost none. In first two months clams must adapt to the new environment, which could

result in the dead rate observed, whereas after month 3-6 the clams were adapted and the dead rate reduced.

Survival

The rearing sites influenced survival rates, especially for the small-sized clams. The 3-5 cm size class showed diminished survival on the reef slope compared to the reef flat. When the cover was permanently open all clams died within 3 months on the slope. When the cover was closed during the first two months, the clams still had lower survival rate. On the reef flat, survival rate was low when the cover was permanently open, but clams survived better when covers were closed during the first two months. The survival rates of the 5-7 cm and 7-9 cm size classes were not different among the two rearing sites. The subtidal reef slope is exposed to strong water currents, and many predator are present on the slope. In comparison there are fewer predators on the reef flat (Phongsuwan *et al.* 1993). This indicates that the cover prevents fish or crab from eating the clams since closing of cages during the first 2 months enhanced survival rate of all size classes.

Growth rate

Growth rates did not differ significantly among the four treatments of clams with

Table 10. Overview. Shell increment (cm) of giant clam *Tridacna squamosa* nursed for 6 months in cages at reef flat and reef slope, compared with increments of the same species in the hatchery of Prachuap Khiri Khan Coastal Aquaculture Development Center. Four treatments (T1-T4) and 3 size classes (S1-S3) are shown.

Shell length	T1		T2		T3		T4		Hatchery	
	flat (cm)	slope (cm)	flat (cm)	slope (cm)	flat (cm)	slope (cm)	flat (cm)	slope (cm)	exp. 1 (cm)	exp. 2 (cm)
3-5 cm	3.9	-	4.0	4.1	4.1	4.2	3.9	3.4	1.9	1.5
5-7 cm	3.7	3.8	4.0	3.8	3.4	3.9	3.6	3.8	1.9	1.9
7-9 cm	3.5	3.0	3.5	2.8	3.6	2.7	3.3	2.8	1.9	1.7

same starting sizes when reared on the reef flat, although smaller clams had a bit greater growth rates than the larger ones. However, on the slope, growth rates of the 3-5 cm and the 5-7 cm size classes were higher than those of the 7-9 cm class. Light is more limited on the slope than on the flat because of water depth. This may limit the photosynthesis of the zooxanthellae. If light is limited the zooxanthellae of smaller clams could carry out photosynthesis more efficiently than zooxanthellae of larger clams because of shading effects (Fitt 1988). I therefore suggest that this could cause lower growth rates in the 7-9 cm class than in the 3-5 cm and 5-7 cm size classes.

COMPARISON OF GROWTH RATES

Table 10 shows the results of the present cage culture carried out by the Mannai Station compared with laboratory culture conducted by the Prachuap Coastal Aquaculture Development Center (Nugranad, personal contact).

The laboratory reared clams of the three size classes had similar growth rates: The 3-5 cm size class increased $1.9 \text{ cm} \pm 1.5 \text{ cm}$ in length, the 5-7 cm class $1.9 \text{ cm} \pm 1.9 \text{ cm}$, and the 7-9 cm class $1.9 \text{ cm} \pm 1.7 \text{ cm}$. These increments were lower than found in the present cage culture. In the hatchery, water circulation system is limited, and the clams received their food regularly in both in terms of food quality and amounts. In nature, light

conditions are presumably better and the clams could obtain a variety phytoplankton.

In terms of investment, the cost for cage culture was less expensive than the hatchery-reared clams. After 2-3 months in permanently closed cages on the reef flat, the 3-5 and the 5-7 cm size classes, showed shell length increments of the same order as clams reared for 6 months in the hatchery. After 4 months the 7-9 cm size class also obtained the same size as achieved after 6 months in the hatchery

CONCLUSIONS REGARDING CAGE CULTURE

Before permanent release to nature the clams they should receive nursing care for some time in order to let them acclimatize to the new environment. This study showed that the 3-5 cm size class is the most feasible size for cage culture. During culture, the clams get stronger and adapted to natural conditions and stress. The nursing period should depend on nursing sites. If the clams are on reef flats with gentle current conditions, the nursing should take about 2 months in closed cages (87 % survival). But if the clams are on reef slopes where strong current conditions prevail and many predators are present, the nursing period should take at least 4 months in closed cages (> 70 % survival).

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