GROWTH OF GIANT CLAM, *TRIDACNA SQUAMOSA* LAMARCK UNDER LABORATORY AND NATURAL CONDITIONS

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ABSTRACT

The giant clam, *Tridacna squamosa* Lamarck, 1819, is the most important species of tridacnid clam being cultured in Thailand. Growth of juvenile *T. squamosa* was studied under laboratory (outdoors) and natural conditions for 14 months at Phuket Marine Biological Center, Thailand. The initial mean size was 73.1 mm in both groups. The clams obtained a mean increment of 43.6 and 67.2 mm shell length yr^{-1} under laboratory and natural conditions respectively. Growth conformed to the von Bertalanffy equation assuming $L\infty$ = 400 mm. The curvature parameter (k) of clams was significantly different between the two groups. The k-parameter values were 0.01165 and 0.023694 in the laboratory and the nature group respectively. The clams grew better under natural conditions than under laboratory conditions.

INTRODUCTION

Giant clams (Tridacnidae) inhabit shallow clear waters of coral reefs in tropical and subtropical areas in the Indo-Pacific region (Rosewater 1965; Shokita *et al.* 1991; Braley 1992; Calumpong 1992). There are eight known species of living giant clams which can be identified by their shape, shell characteristics (presence or absence of scales), relative sizes and the growth habitat of adult clams on reefs. The largest species, *Tridacna gigas* (Linnaeus, 1758), can reach a shell length of more than 100 cm and a weight ranging from 200 to 500 kg. The smallest species, *Tridacna crocea* Lamarck, 1819, can reach only about 15 cm in shell length.

Three species of giant clams; *T. squamosa, Tridacna maxima* (Röding, 1798), and *T. crocea* are commonly found along the coasts of Thailand. The clams are harvested mainly for ornamental use and for consumption (Chantrapornsyl *et al.* 1996). The shells of *T. squamosa* are important in the shell trade. Small specimens of both *T. crocea* and *T. maxima* are in demand for decoration of aquaria (Braley 1992; Calumpong 1992). At Lee-Pae Island, on the southwest coast of Thailand, giant clams are collected by villagers and the dried meat marketed at a price of 180-200 baht kg^{-1} while the shells are sent to shell shops (Adulyanukosol, unpubl.). Presently, international trade is prohibited because giant clams are over-exploited. Therefore, culture of giant clams has been initiated in Thailand. *T. squamosa* is considered to be the species with the highest culture potential due to its elaborate shell ornamentation.

Giant clams harbour symbiotic algae, zooxanthellae, which use sunlight for photosynthesis, so penetration of sunlight into the water column is a limiting factor for the growth of clams (Svane 1996). Braley (1992) and Calumpong (1992) recommended that the water visibility should be around 3-7 m and a rearing density (2 year old clams) of about 30-45 specimens m^{-2} (or less than 70 % of the surface area). In Thailand, hatching and culturing of giant clams has been done at Prachuap-Kirikhan Coastal Aquaculture Development Center. The average egg, larva, and settlement size of *T. squamosa* are 100-105 µm, 150 µm and 200 µm respectively (Nugranad, unpublished data). Beckvar (1981) cultured small sets of *Tridacna derasa* (Röding, 1798), *T. gigas* and *T. squamosa* in a laboratory for 5 months, 10 months and 24 months respectively. The mean length of *T. derasa*, *T. gigas* and *T. sq-*

Table 1. Number of clams in each tray under both laboratory and natural conditions. Numbers in parentheses show the number of clams under natural conditions which were separated into half of the initial stocking density after November 1995.

Tray No.	Laboratory			Tray no.	Nature		
	Feb-95	Nov-95	Mar-96		Feb-95	Nov-95	Mar-96
7	11	1	11	1	11	11 (5,6)	10 (5,5)
8	11	11	11	2	11	9 (4,5)	9 (4,5)
9	12	12	12	3	12	12 (6,6)	12 (6,6)
10	12	9	9	4	12	12 (6,6)	12 (6,6)
11	12	12	12	5	12	10 (5,5)	10 (5,5)
12	12	12	12	6	12	12 (6,6)	12 (6,6)
13	10	10	10	-	-	-	-
Total	80	77	77	-	70	66	65
Density (ind. m^{-2})	63-76	57-76	57-76	-	69-76	25-38	25-38

uamosa were 1.1 cm, 2.6 cm and 6.7 cm respectively. The author estimated the growth rate of the clams (12-25 cm long) to be 3-6 cm yr^{-1} for *T. derasa*, 8-12 cm yr^{-1} for *T. gigas*, 3-5 cm yr^{-1} for *H. hippopus*, and 2-4 cm yr^{-1} for *T. squamosa*.

Muricid snails and parrot fishes are predators of giant clams (Chantrapornsyl, unpublished data).

MATERIALS AND METHODS

The juvenile clams used in this study were hatched and nursed at Prachuap-Kirikhan Coastal Aquaculture Development Center. They spawned in August 1993 and were 17.6 months old at the beginning of this study in February 1995. The initial mean shell length of the clams for this experiment was 73.1 mm. They were placed in 35 x 45 x 19 cm plastic trays, containing a layer of coral rubble for byssus attachment. The experiment was carried out in two groups. The first group consisted of seven trays which were placed in outdoor tanks, 120 cm in diameter (laboratory condition). Four trays were placed in one tank and three trays in another two tanks. The second group, consisting of six trays, were placed close together by metal stakes on the reef flat in front of the Center (natural condition).

Ten to twelve juveniles were placed in each tray, making an initial density of 63.5-76.0 specimens m^{-2} (Tab. 1). Salinity was measured with mini STD Serial SD-200 (Limtragulvong, unpublished data); transparancy and sedimentation (Tab. 2) were recorded by Phongsuwan (1991) and Phongsuwan *et al.* (1992). The total number of clams used was 150 specimens (80 specimens in laboratory tanks and 70 specimens in the sea). The shells were measured and individually tagged using Scotch labelling tape and Bosny cement glue on their shells. The mean shell length and width in the laboratory group were 73.1 mm and 44.0 mm respectively while the group under natural conditions measured 73.1 mm and 51.4 mm respectively (Tab. 3).

The laboratory tanks were exposed directly to sunlight, had a water depth of 0.8 m and sea water was circulated for 24 hours (1-2 litre min^{-1}). The temperature was monitored by a maximum-minimum thermometer. Water depth of the reef flat, where the second group was placed, ranged from 3 to 5 m at high tide and 0.5 to 1 m at low tide. The experiment tanks and trays were cleaned twice a week by brushing off algae and other organisms. Sea weeds and other floating objects were removed. The epibionts growing on the shells and trays under natural conditions were brushed off, the predators removed and the stock counted. Shell width and shell length were measured every month during February 1995 to March 1996, using Vernier callipers.

RESULTS

Physical parameters recorded during the study period are shown in Tab. 1. The maxi-

Table 2. Physical parameters under laboratory and natural conditions.

Physical parameters	Laboratory	Natural
Water temp. (°C)	25.5-35.5	26.59-30.25
Salinity (‰)	-	32.15-33.04
Transparency (m)	-	1-4
Sedimentation rate (g^{-2} m^{-2} d^{-1})	-	100-1000

mum water temperature in the laboratory was about 5 °C higher than the temperature under natural conditions. The sea water used in the laboratory experiment was pumped 500 m from the sea to the experiment, so salinity was approximately similar.

The initial mean length of clams was not significantly different between laboratory and natural condition. The monthly mean shell length and shell width increments from both sites were examined by the von Bertalanffy growth equation, and other growth evaluations were made on the assumption of two different treatments: laboratory group and natural group.

Monthly mean of shell length and shell width from February 1995 to March 1996 are shown in Tab. 3. After 3 months the average shell size was significantly different ($P< 0.05$) between the laboratory and natural conditions in both shell length and width. Within 13 months, the average increment of shell length and width varied between 45.3 mm and 32.7 mm respectively under laboratory conditions, and 72.4 mm and 51.7 mm respectively under natural conditions.

At the end of the experiment in March 1996, most of the reared clams in the natural group (about 80 %) had reached the size class 140-170 mm, while most in the laboratory group were smaller; in the size class of 110-140 mm (Fig. 1).

The growth equations of Gulland and Holt, Ford Walford and von Bertalanffy were applied to the clam growth curves and the von Bartalanffy was chosen as the appropriate equation. The von Bertalanffy growth equation was fitted under the condition of $L\infty$ = 400 mm (equivalent to maximun growth of *T. squamosa*: cited from Braley 1992; Calumpong 1992 and Shokita *et al.* 1991) as follows:

$$-\ln(1-L(t)/L\infty) = -kt_0 + kt$$

k = curvature parameter

$L\infty$ = asymptotic length

The k-value defines the growth efficiency of clams. Determination of growth rate of clams between laboratory and natural condition by the von Bertalanffy growth equation was made in two periods. First period was from February 1995 to November 1995 at equal densities (about 63.5-76.0 specimens m^{-2}) and the second period was from November 1995 to March 1996 at different densities (laboratory: natural = 2:1, see Tab. 1). The value in the last column in Tab. 4 is the result of the whole experiment from February 1995 to March 1996. The curvature parameter (k) from all three columns indicate that growth of the natural group is significantly faster than in the laboratory group, especially in the second period in which there was a difference in density between the two groups (*t*-test; $P< 0.05$).

DISCUSSION

This study showed that despite low light intensity and high sedimentation rate in the sea, the growth of *T. squamosa* under natural conditions was significantly higher than under laboratory conditions.

High water temperature and high light intensity in the laboratory tanks in summer may inhibit growth of zooxanthellae in the mantle tissues. In the late April 1995, the water temperature in the rearing tanks reached 35.5 °C and the strong sunlight caused 50 % of the clams to bleach. To protect the water from strong sunlight and high heat, a shading screen was hung over the tanks until the clams recovered (almost 2 months). This event caused the death of

Table 3. The mean shell length and shell width (mm) of *T. squamosa* under laboratory and natural conditions from February 1995 to March 1996 (-: no data; *: P< 0.05).

Date	Age (month)	Mean length		P value	Mean width		P value
		Lab	Nat		Lab	Nat	
Feb-95	17.6	73.1	73.1	ns	44.0	51.4	ns
Mar-95	18.5	82.3	82.1	ns	50.6	59.2	ns
Apr-95	19.6	89.1	89.4	ns	55.5	67.7	ns
May-95	20.6	92.5	95.6	*	58.0	74.8	*
Jun-95	21.6	94.1	-	-	59.4	-	-
Jul-95	22.6	96.5	109.9	*	61.4	82.0	*
Aug-95	23.6	100.9	112.1	*	63.4	83.0	*
Sep-95	24.7	104.7	116.5	*	66.2	87.6	*
Oct-95	25.7	107.9	-	-	68.8	-	-
Nov-95	26.7	109.7	125.0	*	71.2	89.9	*
Dec-95	27.7	112.4	128.9	*	72.5	90.9	*
Jan-96	28.7	115.0	135.5	*	73.9	94.7	*
Feb-96	29.8	116.7	140.3	*	75.2	99.3	*
Mar-96	30.7	118.4	145.5	*	76.7	103.1	*

Table 4. *t*-Test of the curvature parameter (k) of *T. squamosa* under laboratory and natural conditions (two samples assuming unequal variances).

	Feb-95 to k-Lab	Nov-95 k-Nat	Nov-95 to k-Lab	Mar-96 k-Nat	Feb-95 to k-Lab	Mar-96 k-Nat
Mean	0.012002	0.019045	0.008367	0.02195	0.011650	0.023694
Variance	9.15E-06	5.89E-06	5.14E-05	0.000223	0.000115	0.000949
Observations	77	-	77	-	77	65
T Stat	15.38964		6.712393		3.002691	
P(T<=t) two-tail	6.68E-32		1.73E-09		0.003608	
t Critical two-tail	1.977055		1.986978		1.991257	

three clams (tray no. 10), one in June 1995 and the other two in July 1995. No bleached clams were observed under natural conditions, but some coral colonies in the same area were found bleached. The bleached clams among the laboratory group finally died. However, the present study material is too sparse to judge the precise effect of temperature and strong sunlight on growth of *T. squamosa*.

The rearing density of clams is an important limiting factor for growth. Initial densities of clams under laboratory and natural conditions were 63 and 76 ind. m^{-2}. Due to overcrowding in the trays of the natural group, the clam density was reduced to half

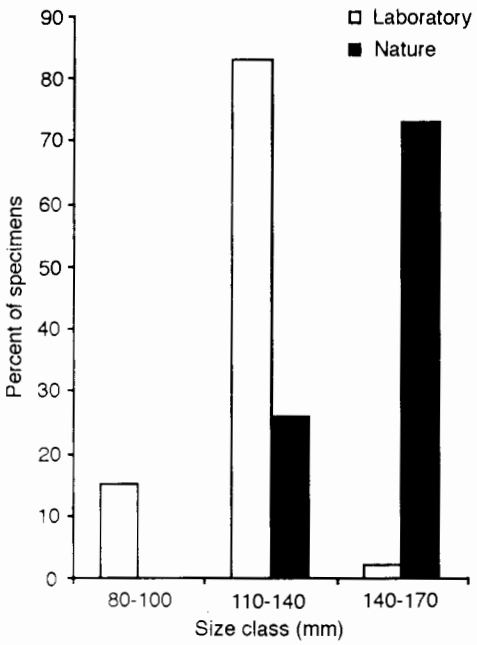

Figure 1. Percentage of specimens of *T. squamosa* in three size classes, at the end of the experiment in March 1996 under laboratory and natural conditions.

in November 1995. This was not done in the laboratory group because of limited availability of tanks. Thus, after November 1995 the density of clams under laboratory conditions was two times higher than clams under natural conditions. Braley (1992) and Calumpong (1992) recommended that clams should be reared with sufficient space and each clam should be able to fully open without touching neighbours (30-45 specimens m^{-2}). In this study, the initial density of clams under both laboratory and natural conditions was above the maximum recommended for rearing. But after November 1995 the density of clams under natural conditions was 25-38 ind. m^{-2} which falls within the range recommended by Braley (1992) and Calumpong (1992).

The growth rate of clams under natural conditions was significantly higher than under laboratory conditions, especially after November 1995 (Tab. 3). Thus, the growth rate of clams under laboratory conditions might be inhibited either by bleaching and/or high density of clams.

The survival rate of clams under laboratory conditions was 96.3 % compared to 100 % in the sea. The growth rate of *T. squamosa* in this experiment was greater than that obtained by Beckvar (1981) who obtained a growth rate of 2-4 cm $year^{-1}$. In this study a growth rate of 4.3 cm $year^{-1}$ under laboratory conditions and 6.7 cm $year^{-1}$ under natural conditions was recorded. Under natural conditions the clams attained a size of 164 mm at the age of 30 months.

During rough sea conditions severe damage to the delicate shell structures occurred when clams were washed against each other and against the tray walls. Thus, the shells of clam reared in laboratory tanks had undamaged scales compared to those reared in the sea. Associated organisms such as polychaetes, chitons, and tunicates were found on the outside of the clams in the laboratory group. Sponges, bryozoans, soft corals, and tunicates were found on the shells of the natural group. Fewer fouling organisms were present in the laboratory group than in the natural group.

Caulerpa racemosa was the only species of seaweed which grew on the clam-trays placed in outdoor tanks and no seaweed was observed in trays under natural condition. Almost all the clams at both sites produced byssus, adhering to the coral fragment substrate within the first three months. However, some were without byssus till the end of the experiment.

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REFERENCES

Braley, R.D. 1992. The giant clams: Hatchery and nursery culture manual. - ACIAR Monograph Series. No. **15.** 144 pp.

Beckvar, N. 1981. Cultivation, spawning, and growth of the giant clams *Tridacna gigas*, *T. derasa*, and *T. squamosa* in Palau Pall, Caroline Islands. - Aquaculture **24**: 21-30.

Calumpong, H.P. 1992. The giant clam: an ocean culture manual. - ACIAR Monograph Series. No. **16**, 68 pp.

Chantrapornsyl, S., K. Kittiwattanawong & K. Adulyanukosol. 1996. Distribution and abundance of giant clam around Lee-Pae Island, The Andaman Sea, Thailand. - Phuket Marine Biological Center Special Publication **16**: 195-200.

Phongsuwan, N. 1991. Recolonization of a coral reef damaged by a storm on Phuket Island, Thailand. - Phuket Marine Biological Center Research Bulletin **56**: 75-83.

Phongsuwan, N., U. Satapoomin & H. Chansang. 1992. The study on effect of sedimentation from offshore mining to coral reefs at the east west areas of Phuket Island. - Technical report presented to the Offshore-mining Organization. (in Thai).

Rosewater, J. 1965. The family Tridacnidae in the Indo-Pacific. - Indo-Pacific Mollusca **1**(6): 347-396.

Shokita, S., K. Kakazu, A. Tomori & T. Toma (eds.). 1991. Aquaculture in Tropical Area. - Midori hobo, Tokyo, Japan. Pp. 257-272.

Svane, I. 1996. Some recent advances in studies on the biology of giant clams (Tridacnidae). - Phuket Marine Biological Center Special Publication **16**: 221-241.

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