Effects of Rearing Methods on Boring Giant Clam

*T. crocea*

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Abstract: We investigated the growth and survival of boring giant clam (*T. crocea*) individuals with shell lengths of around 30 mm. In total, 484 clams were reared; four groups of 87 specimens were reared outdoors under relative light intensities of 4.8, 23.1, 51.5 and 100% for 739 days, and four groups of 34 specimens were reared indoors under fluorescent lighting on a 12 h light and 12 h dark cycle for 520 days with an underwater photosynthetic photon flux density (PPFD) of 126, 169, 330 and 458 μmol/m²/s. As a result, specimens reared under 23.1% and 51.5% relative light intensity in the outdoor experiment showed faster growth (80.6 ± 6.2 mm and 76.1 ± 5.9 mm, respectively; mean ± SD) than control specimens reared under a non-shaded condition (71.7 ± 6.9 mm). There was no difference in survival rate except for the specimens reared under the weakest light intensity (4.8% relative light intensity). In the indoor fluorescent light experiment, the specimens in the slightly weak PPFD group (330 μmol/m²/s) grew to 71.0 ± 5.3 mm and had a faster growth than those in the strongest PPFD group (458 μmol/m²/s), which grew to only 65.9 ± 5.8 mm. All PPFD groups had a survival rate of 100%. The present findings revealed that appropriate shading is needed under natural lighting conditions, and in the case of underwater lighting, 200–400 μmol/m²/s PPFD should be used for farming boring giant clam to optimize growth.

Key words: Boring giant clam *T. crocea*; Growth; Light intensity; Light-shielding

The boring giant clam lives on reefs extending from the east Indian Ocean to the west Pacific Ocean, and being considered the most delicious of the giant clams species (Bivalvia: Tridacnidae) makes it one of the commercially important marine species consumed as sushi and sashimi in Okinawa, Japan. However, since the clam bores into substrates comprised of limestone and the dead parts of massive coral colonies (e.g., *Porites* spp., *Favia* spp.) in coastal areas that are readily occupied by people, it tends to be overfished, with the quantity of this natural resource steadily declining such that the number of clams being caught was at its lowest level in 1981 (Murakoshi 1991). Thus, technology for mass producing the seeds of this clam species was developed in 1987 to restore landing of the clam, which has been sluggish in recent years, while the Ishigaki Branch of the Okinawa Prefectural Fisheries and Ocean Research Center, with the aim of resource recovery, has recently been shipping about 100,000–300,000 seeds a year for restocking and aquaculture purposes (Inoue and Kubo 2008). However, restocking and aquaculture requires a great deal of effort since holes must first be drilled with an air drill into the bedrock under the sea. The seeds are then placed in holes and are covered with a net for about 1 month to prevent damage. Moreover,
after restocking, it takes about 4 years for the seeds to grow to a shell length of 8 cm, which is the appropriate harvest size (Kakuma 1989). The development of a simpler restocking and aquaculture technique is thus needed.

The clam takes up symbiotic algae during its early life stage, and once symbiosis is established, the clam grows under suitable light conditions and does not require artificial feeding. Therefore, to enable effective examination of a rearing method that would accelerate the growth of the boring giant clam, seeds were cultivated on non-perforated concrete plates under varying light conditions, and growth under natural and artificial light was compared. The knowledge acquired from this study will be useful for cultivating the boring giant clam in outdoor and indoor land-based water tanks for edible and ornamental use.

Materials and Methods

Test clam

The experiment used seeds produced by the Ishigaki Branch of the Okinawa Prefecture Fisheries and Ocean Research Center on 17 June 2006. Shells with lengths of up to approximately 10 mm were bred at the Ishigaki Branch and transported to the Okinawa Prefectural Fisheries and Ocean Research Center (hereafter referred to as the Fisheries and Ocean Research Center), which is in Itoman City, Okinawa, Japan (26°8.05'N, 127°39.92'E), on 28 May 2007.

Preparation of the experiment

In its natural environment, the boring giant clam bores into substrates of limestone but can be grown normally for more than 2 years on undrilled concrete plates, and this growth is actually faster than that of clams growing in holes (Yamamoto and Nakamura 2009). Moreover, if seeds are placed directly onto the concrete plate, the shells will move off the concrete plate or will aggregate together to form a patch. Since growth and survival deteriorate when the aggregated shells come into contact with each other, contact between shells should be avoided by attaching the byssus of dispersed shells to a concrete substrate. For this purpose, a 16-mm thick rubber sheet with 15-mm diameter holes at regular intervals was prepared to distribute and attach the shells.

Four plastic water tanks (70 × 115 × 20 cm) were set up at a non-shady area of the Fisheries and Ocean Research Center. A concrete plate (1:3 ratio of Portland Cement:sand; 40 × 60 × 3 cm) to be used for Experiment 1 and one (20 × 30 × 3 cm) to be used for Experiment 2 were placed into the water tanks. On top of these concrete plates, a rubber sheet (40 × 60 × 1.6 cm) with 87 holes at 5 cm intervals and a rubber sheet (20 × 30 × 1.6 cm) with 34 holes at 3.5 cm intervals were respectively placed. On 8 June 2007, random attachment of 484 boring giant clam seeds to the holes in all 4 tanks was started. The concrete plates were installed such that their surface was 6 cm below the water surface. The rearing seawater was sand-filtered and was injected from the bottom of one side of the tank and drained from the top of the other side. The water exchange rate was 20 revolutions per h, and the rubber sheets were removed after 2 weeks, at which time the attachment of the boring giant clams was seen as still insufficient and many seeds had moved. Thus, two sizes of polyvinyl chloride (PVC) pipe (20/26 mm, and 31/38 mm, inner/outer diameter, respectively) were cut into 15-mm lengths and used to entrap individual boring giant clams. The clams were reared in a non-shaded setting until September 3 when most of them had completely attached and did not move anymore. After the rubber sheets were removed, 30 top shells (Trochus niloticus), with a shell diameter of 10 mm and whose seeds were produced by the Okinawa Prefectural Sea Farming Center, were placed in each of the tanks to remove algae growing on the concrete plate.

Rearing management and measurement

The rearing water was sand-filtered seawater, with a water exchange rate of 20 revolutions per h for Experiment 1 and 5.5 revolutions per h for Experiment 2. The water was injected at the bottom and drained at the top of the tanks.
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remove algae from the concrete plates where the boring giant clam seeds were attached, top shells with a shell diameter of 15 mm were placed in each water tank, with 20 shells for Experiment 1 and 10 shells for Experiment 2 allocated to each tank. When the number of top shells decreased due to death, an appropriate number of new shells were added to the water tanks. The temperature of the rearing water was measured daily at 9 am, and shell length was measured once every 2 months for Experiment 1 and once every 1 month for Experiment 2. All clams were measured using a digital caliper with a precision of up to 0.01 mm. If a clam was found to be in contact with another during measurement because of growth, its byssus was cut with a scalpel, and the clam was entrapped inside one of three PVC pipes (31/38 mm, 44/48 mm and 56/60 mm, inner/outer diameter, respectively) were cut into 10–15 mm lengths to prevent further contact with other shells. The ring was removed after the shell attached. When algae proliferated, the external part of the shell and the concrete plate were cleaned with a toothbrush.

Experiment 1: Outdoor experiment

The boring giant clams were reared for 739 days in 1 non-shaded experimental group and 3 experimental groups under light conditions varied by light-shielding net for a total of 4 experimental groups, and their growth and survival were subsequently determined. There were two concrete plates in the water tank for attaching the boring giant clams. After removing the smaller plate for Experiment 2, the remaining concrete plate with 87 attached boring giant clams was placed 6 cm below the water surface in the central area of the tank (Fig. 1a). The non-shaded group (Group A) and the 3 experimental groups, where the intensity of the light was weakened using 3 kinds of commercial light-shielding nets for a total of 4 experimental groups of progressively varying light conditions were set up (Group A, shell length of 31.1 ± 2.7 mm; Group B, shell length of 29.9 ± 2.2 mm; Group C, shell length of 30.1 ± 2.3 mm; Group D, shell length of 29.7 ± 2.4 mm; all measurements average value ± standard deviation). Group A was not covered with a net, Group B was covered and shaded with the 2-mm bore black polyethylene (PE) windbreak net (Dionet windbreak net #111, Dio Chemicals, Ltd., Tokyo, Japan), Group C was covered and shaded with the 1-mm bore black PE windbreak net (Dionet windbreak net #130, Dio Chemicals, Ltd.), and Group D was covered and shaded with a 90–95% black PE light-shielding net (Diosheet #14, Dio Chemicals, Ltd.). The relative light intensity (light transmission rate) of each net was derived from the lux value measured at 10-min intervals using two photo recorders (TRL-10, Espec Mic Co., Aichi, Japan). First, two sensors of two illuminometers were placed side-by-side in an area where they did not form a shadow. The corrected value was determined from the difference of the total illuminance measured for 3 full days.

Fig. 1. Two types of water tanks for rearing boring giant clams (a, tank for Experiment 1; b, tank for Experiment 2).
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to ensure that the total illuminance of the 2 illuminometers would be the same. Next, the sensor of one of the illuminometers was placed on the concrete plate inside the plastic water tank while the sensor of the other illuminometer was placed where it would not receive shade. Thus, there were 3 types of net covering the top of the water tanks and each was measured for illuminance for 3 full days using the 2 illuminometers. The relative light intensity of each of the nets was derived after a correction was performed using the previously determined corrected value. Measurements were performed twice—in February and August, 2009—and the average values from both sessions were used to calculate the relative light intensity of each net (Table 1).

The experimental period was 739 days (3 September 2007 to 11 September 2009). On day 366 of the experiment, the space between the shells had narrowed, so 3 additional water tanks were set up. Half of the shells from Group A, Group B and Group C were distributed to the new water tanks. From the start of the experiment until day 505, the terrestrial photosynthetic photon flux density (PPFD, μmol/m²/s) was measured at 10-min intervals using a data logger (GreenKit 202, Yamatake Corp., Tokyo, Japan) with a quantum sensor (PAR-01, Prede Co., Ltd. Tokyo, Japan) that was installed at the Okinawa Prefectural Agricultural Research Center, which is 3.5 km south-south east from the Fisheries and Ocean Research Center. From day 506, the PPFD was measured at 5-min intervals using a data logger (LI-1400, LI-COR Inc., Lincoln, NE) with a quantum sensor (LI-190SA, LI-COR Inc.) that was installed at the Fisheries and Ocean Research Center. The PPFD value measured in 10-min intervals was multiplied by 600 to obtain the 5-min interval data, and the daily integrated PPFD (mol/m²/day) was derived by integrating the data collected for 1 day (n=288).

**Experiment 2: Indoor experiment**

A growth tank with a lighting device developed by Masuda et al. (2007) was installed indoors, and experimental groups under 4 different kinds of artificial light conditions were set up. The growth and survival of the boring giant clams were studied for 520 days from 3 September 2007 until 4 February 2009. Inside each water tank (40 × 60 × 40 cm), 34 boring giant clam seeds were housed and attached to the concrete plate (Fig. 1b). Group E (shell length of 32.9 ± 2.5 mm) used 4 fluorescent lamps, and the brightness of the lamps was adjusted to maximum by using a dimming light controller. The concrete plate was installed 7 cm below the water surface, which was directly below the fluorescent lamp to ensure that the light would illuminate the top of the concrete plate. Group F (shell length of 32.6 ± 2.5 mm) used 4 fluorescent lamps, and the light controller was adjusted to minimum. Here, the concrete plate was installed 7 cm below the water surface, which was directly below the fluorescent lamp. Group G (shell length of 31.5 ± 2.9 mm) used 4 fluorescent lamps, and the light controller was adjusted to minimum. For this experimental group, all the fluorescent lamps were covered entirely with paper for shading, and the concrete plate was installed 14 cm below the water surface, which was directly below the fluorescent lamp. Group H (shell length of 31.0 ± 2.1 mm) used 2 fluorescent lamps, and the light controller was adjusted to minimum. Here, the concrete plate was installed 14 cm below the water surface, which was directly below the fluorescent lamp.

The fluorescent lamp (National twin fluorescent lamp, Twin 1, FPL55EX-N, 55 W, rated lifespan 9,000 h, Panasonic Electric Works Co., Ltd., Osaka, Japan), which has been used for about 500 h, was used as the light source with illumination only from above with a light-dark cycle of 12 h.

Table 1. Relative light intensity (RLI) values of the materials employed in Experiment 1 as a shield screen

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RLI (%)</th>
<th>Material</th>
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<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>Non-shaded</td>
</tr>
<tr>
<td>B</td>
<td>51.5</td>
<td>2 mm bore black PE windbreak net</td>
</tr>
<tr>
<td>C</td>
<td>23.1</td>
<td>1 mm bore black PE windbreak net</td>
</tr>
<tr>
<td>D</td>
<td>4.8</td>
<td>90~95% black PE light-shielding net</td>
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</tbody>
</table>
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Light and 12 h dark. The fluorescent lamps were replaced after they had been used for 4,100 h since their first use. The underwater PPFD was measured after the new replacement lamps had been used for 2,200 h, 2 cm above the concrete plate top. The measurement was performed 3 times using an underwater planar sensor at each of the 4 corners and at the center of the concrete plate, for a total of 5 measurement locations. The resulting average value was used. The underwater PPFD for each of the experimental groups was calculated as the average of 3 data points, which were the average measured values from the long sides of the concrete plate (a point to b point, and d point to e point) and the measured value from the center (c point) (Table 2). A light meter (LI-250, LI-COR Inc.) with an underwater quantum sensor (LI-192SA, LI-COR Inc.) was used for the measurement of the underwater PPFD.

To investigate whether the observed differences in the growth of the clams were due to the differences in light intensity, the 1% significance level was tested using the Tukey-Kramer method. R version 2.12.2 for Windows was used for the statistical analysis (R Development Core Team 2011).

Results

Experiment 1: Outdoor experiment

The growth and survival of the boring giant clams, which were reared for 739 days, along with changes in water temperature and variation in the daily integrated PPFD (mol/m²/day) of 10 days average during the experimental period are shown in Fig. 2. The water temperature during the period was 17.6–31.2°C and the 10-day average daily integrated PPFD was 10.2–53.0 (mol/m²/day), with a 5.2-fold maximum variation observed. Group C (23.1% relative light intensity) had the fastest growth, with a shell length of 47.9 ± 3.6 mm after 242 days, 66.1 ± 4.7 mm after 490 days and 80.6 ± 6.2 mm after 739 days. Group B (51.5% relative light intensity) had the second fastest growth, with a shell length of 47.0 ± 3.7 mm after 242 days, 64.8 ± 5.0 mm after 490 days and 76.1 ± 5.9 mm after 739 days. Group A (non-shaded) had the third fastest growth, with a shell length of 45.1 ± 4.2 mm after 242 days, 61.7 ± 5.5 mm after 490 days and 71.7 ± 6.9 mm after 739 days. Group D (4.8% relative light intensity) had the slowest growth, with a shell length of 32.7 ± 2.7 mm after 242 days and 35.7 ± 4.7 mm after 490 days, showing that the shells barely grew. The moderately shaded Groups B and C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Measurement point</th>
<th>Average</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
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<tbody>
<tr>
<td>E</td>
<td></td>
<td></td>
<td>407.5</td>
<td>439.3</td>
<td>503.1</td>
<td>459.5</td>
<td>434.9</td>
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<tr>
<td>F</td>
<td></td>
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<td>301.4</td>
<td>363.2</td>
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<td>320.5</td>
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<tr>
<td>G</td>
<td></td>
<td></td>
<td>160.8</td>
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<td>205.9</td>
<td>131.9</td>
<td>139.6</td>
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<tr>
<td>H</td>
<td></td>
<td></td>
<td>115.6</td>
<td>126.0</td>
<td>157.1</td>
<td>100.5</td>
<td>98.0</td>
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</table>

Table 2. Measured values of the underwater photosynthetic photon flux density (μmol/m²/s) in Experiment 2

a and b, each corner of one long side of the rectangular concrete plate; e and d, diagonal of a and b, respectively; c, center of the rectangle.

Fig. 2. Water temperature during the experiment period (a), daily integrated photosynthetic photon flux density (PPFD) of ten days average (b), growth curves (c), and survival rates (d) of T. crocea reared in four plastic tanks. Vertical lines in b show standard deviation. Values of shell length are expressed as mean ± standard deviation. △, group A (100% RLI, n = 77–87); ●, group B (51.5% RLI, n = 82–87); □, group C (23.1% RLI, n = 79–87); ▲, group D (4.8% RLI, n = 0–87).
had faster growth than the non-shaded group (Group A) throughout the experimental period after day 60 at the time of the second measurement until the end of the experiment.

Looking at the growth of the 4 experimental groups, it was only in Group D, which had the weakest light intensity, that significant mortality was observed from 183 days to 305 days from the start of clam rearing. After 490 days, the survival rate was 25.3% and all the clams had died by 548 days. The survival rate for the 3 other groups at the end of the experiment was 88.5% for Group A, 94.3% for Group B and 90.8% for Group C, with no significant differences in the mortality trend and survival rates observed.

**Experiment 2: Indoor experiment**

The growth and survival of the 4 experimental groups of boring giant clams, which were reared for 520 days in a growth tank with a lighting device, along with changes in water temperature, are shown in Fig. 3. The water temperature during the experimental period was 17.8–30.1°C. Looking at the growth, Group F (330 µmol/m²/s PPFD) had the fastest growth, with a shell length of 50.4 ± 4.3 mm after 242 days, 62.8 ± 5.2 mm after 366 days and 71.0 ± 5.3 mm after 520 days. Group G (169 µmol/m²/s PPFD) had the second fastest growth, with a shell length of 49.3 ± 4.9 mm after 242 days, 60.7 ± 5.6 mm after 366 days and 68.1 ± 6.9 mm after 520 days. Group E (458 µmol/m²/s PPFD) had a shell length of 47.2 ± 4.7 mm after 242 days, 59.5 ± 5.6 mm after 366 days and 65.9 ± 5.8 mm after 520 days. Lastly, Group H (126 µmol/m²/s PPFD) had a shell length of 47.2 ± 4.1 mm after 242 days, 57.4 ± 5.5 mm after 366 days and 66.0 ± 7.3 mm after 520 days. Throughout the whole experimental period after day 32 at the time of the second measurement until the end of the experiment, Group F, which had a light intensity slightly less than that of Group E, had faster growth than Group E, which had the strongest light intensity.

From day 60–93 of the experiment, three boring giant clams became detached and fell from the concrete plate of Group E into the bottom of the water tank. Consequently, they were excluded and the experiment was continued. These three clams were excluded from Group E due to problems experienced during the initial stages of the experiment; however, no deaths were subsequently observed. In addition, after day 93, we checked almost every day whether clams had fallen off the concrete plate. If a clam was found on the bottom of the water tank, the clam was immediately returned to the concrete plate. The survival rate in all 4 experimental groups was 100%.

When multiple comparisons were performed on the difference of the average shell length at the end of the experiment, it was found that the growth in Group F were significantly faster (P < 0.01) than those in Group E and Group H, while Group G did not show any significant difference in growth when compared to each of the other groups. Moreover, there was no significant difference between Group E and Group H with respect to growth (Fig. 4).
Discussion

Boring giant clams have a symbiotic relationship with algae, so light is essential for their survival. Thus, if the light intensity is lower than that of Group D (4.8% relative light intensity) in Experiment 1, growth and survival will deteriorate. However, this does not mean that a stronger light intensity will accelerate growth because, as seen in Experiment 1, clams reared in an environment that was 50–75% shaded grew faster than those reared in a non-shaded setting. In Experiment 2, Group F (330 $\mu$mol/m²/s PPFD) had slightly dimmer lighting conditions than Group E (458 $\mu$mol/m²/s PPFD), which had the maximum possible light intensity that could be created by an artificial lighting device. Under these conditions, Group F also had a faster growth than Group E. Moreover, in the rearing experiment done by Yamamoto and Nakamura (2009) using a cage installed on a 2 m deep seabed in Kabira Bay, Ishigaki City, Okinawa, there were slight variations in the internal structure of the cages, which were covered with 2 types of Netlon nets (32% and 44% light-shielding effect) to reduce damage from feeding; however, the boring giant clams inside the cage with a higher degree of shielding were reported to have had a faster growth similar to the results of Experiment 1. The relationship between light intensity and the growth of the boring giant clam suggests that moderate light intensity, neither too strong nor too weak, increases shell length. Since each experiment in this study was not repeated, the possibility that factors other than light intensity might have contributed to differences in the shell length for each of the experimental groups cannot be negated. However, the rearing environment during the experimental period was stable, and for Experiment 1, there was no significant difference in survival rate in the other three experimental groups, except in Group D, which received the lowest intensity of light. Moreover, the clams in all experimental groups showed a faster growth rate than natural clams, except in Group D (Table 3). Given these facts, the difference in shell length between

![Fig. 4. Relationship between photosynthetic photon flux density (PPFD) values and shell length at the end of Experiment 2. Values of shell length are expressed as mean ± standard deviation. ●, group E (458 $\mu$mol/m²/s PPFD, $n=31–34$); □, group F (330 $\mu$mol/m²/s PPFD, $n=34$); ○, group G (169 $\mu$mol/m²/s PPFD, $n=34$); △, group H (126 $\mu$mol/m²/s PPFD, $n=34$). Values with the same letters are not significantly different (Tukey-Kramer multiple comparison test; $P \geq 0.01$).](image)

<table>
<thead>
<tr>
<th>Group</th>
<th>Growth rate (mm/year)</th>
<th>Range of growth (mm)</th>
<th>Yearly survival rate (%)</th>
<th>Size of rearing tank$^1$</th>
<th>Location$^2$</th>
<th>Reference</th>
</tr>
</thead>
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<tr>
<td>A (100% RLI, non-shaded)</td>
<td>24.28</td>
<td>31.06–55.35</td>
<td>95.4</td>
<td>a</td>
<td>O</td>
<td>This study</td>
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<td>B (51.5% RLI)</td>
<td>27.76</td>
<td>29.91–57.67</td>
<td>99.9</td>
<td>a</td>
<td>O</td>
<td>This study</td>
</tr>
<tr>
<td>C (23.1% RLI)</td>
<td>31.08</td>
<td>30.09–61.17</td>
<td>99.9</td>
<td>a</td>
<td>O</td>
<td>This study</td>
</tr>
<tr>
<td>D (4.8% RLI)</td>
<td>5.26</td>
<td>29.66–59.49</td>
<td>27.6</td>
<td>a</td>
<td>O</td>
<td>This study</td>
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<td>E (458 $\mu$mol/m²/s PPFD)</td>
<td>26.59</td>
<td>32.90–59.49</td>
<td>100</td>
<td>b</td>
<td>O</td>
<td>This study</td>
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<tr>
<td>F (330 $\mu$mol/m²/s PPFD)</td>
<td>30.21</td>
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<td>100</td>
<td>b</td>
<td>O</td>
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<td>G (169 $\mu$mol/m²/s PPFD)</td>
<td>29.23</td>
<td>31.48–60.71</td>
<td>100</td>
<td>b</td>
<td>O</td>
<td>This study</td>
</tr>
<tr>
<td>H (126 $\mu$mol/m²/s PPFD)</td>
<td>26.42</td>
<td>31.01–57.43</td>
<td>100</td>
<td>b</td>
<td>O</td>
<td>This study</td>
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<tr>
<td>Wild (non-shaded)</td>
<td>18.44</td>
<td>29.74–48.18$^*$</td>
<td>100</td>
<td>b</td>
<td>I</td>
<td>Murakoshi (1994)</td>
</tr>
</tbody>
</table>

RLI, relative light intensity; PPFD, photosynthetic photon flux density.

$^1$a, 70 × 115 × 20 cm; b, 40 × 60 × 40 cm.

$^2$O, Okinawa Is.; I, Ishigaki Is.

$^*$Estimated value: Based on the growth curve in the report by Murakoshi (1994; Fig. 5).
the experimental groups is presumed to be associated with the difference in light intensity between groups. With regard to the underwater PPFD, which accelerates growth, we have not yet determined its effective range because the set underwater PPFD in Experiment 2 was not appropriate. We would therefore like to conduct a more detailed rearing experiment in the future to determine adequate underwater PPFD (Fig. 4).

Ishikura et al. (1997) examined the relationship between photosynthesis and light intensity using symbiotic algae isolated from *T. crocea* and reported that oxygen production was highest at 200–500 \( \mu \text{mol/m}^2/\text{s} \) PPFD, with photoinhibition observed at 2,900 \( \mu \text{mol/m}^2/\text{s} \) PPFD. Fisher et al. (1985) examined the relationship between photosynthesis and light intensity using symbiotic algae isolated from *T. gigas* and reported that some degree of decrease in gross photosynthesis was observed at 3,000 \( \mu \text{mol/m}^2/\text{s} \) PPFD; however, photoinhibition was not observed at less than 2,000 \( \mu \text{mol/m}^2/\text{s} \) PPFD, which is considered normal maximum light intensity. Moreover, when the relationship between photosynthesis and light intensity was examined using samples of *T. gigas* shells of varying sizes, it was reported that growth is faster when the clams are protected from intense light in their juvenile stage. For the larger clams, it was reported that the stronger the light intensity, the faster the growth, as long as it does not exceed the normal maximum light intensity value (2,000 \( \mu \text{mol/m}^2/\text{s} \) PPFD). Klumpp and Griffiths (1994) studied the relationship of photosynthesis and light intensity in 4 kinds of immature clams, namely *T. gigas*, *T. crocea*, *T. squamosa* and *H. hippopus*, and reported that oxygen production increased asymptotically at a light intensity of less than 1,000 \( \mu \text{mol/m}^2/\text{s} \). Meanwhile, Jantzen et al. (2008) examined the relationship of photosynthesis and light intensity in mature *T. maxima* and *T. squamosa* reported that the electron transport rate (ETR) decreased slightly in both species at a light intensity of 3,889 \( \mu \text{mol/m}^2/\text{s} \). However, photoinhibition was not observed at a light intensity of less than 2,500 \( \mu \text{mol/m}^2/\text{s} \), which exceeds that of the normal maximum light intensity, and the ETR asymptotically increased in line with the increase in light intensity. It is difficult to explain why the boring giant clam shows a faster growth at moderate light intensities from the point of view of photoinhibition, therefore, further research should be done to examine the effect of the difference in the degree of shell opening, the difference in mantle extension, the number of symbiotic algae in the mantle, and the difference in the chlorophyll content of the symbiotic algae on the growth of the clams. It is interesting to note that Jantzen et al. (2008) reared adult *T. maxima* and *T. squamosa* shells with and without shade, and reported that the shaded experimental group for both species showed a significant increase in the chlorophyll a of the symbiotic algae.

Natural clams in Kabira Bay, Ishigaki City, Okinawa, take 3.5 years to grow from a shell length of 3 cm to 8 cm (Murakoshi 1994), while in this study, clams that were reared in an outdoor terrestrial water tank at 77% shade grew to 8 cm in 2 years, which is a significantly faster rate (Fig. 2). With regards to the rearing method of boring giant clams, appropriate shading is needed under natural lighting conditions, and in the case of underwater lighting, 200–400 \( \mu \text{mol/m}^2/\text{s} \) PPFD should be used (Fig. 4).

**Acknowledgments**

The growth tank with a lighting device used in Experiment 2 was from Dr. Atsunori Masuda of Yanmar Corp. In addition, the outdoor PPFD data were provided by Mr. Satoshi Onda and Mr. Maro Tamaki of the Okinawa Prefectural Agricultural Research Center. We extend our deepest gratitude to these people.

**References**


Effects of Rearing Methods on Boring Giant Clam


ヒメジャコ *Tridacna crocea* の成長に及ぼす飼育方法の検討

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30 mm サイズのヒメジャコ種苗を、屋外で相対光強度が4.8, 23.1, 51.5および100%の条件でそれぞれ87個体を739日間飼育し、また、屋内の人工照明下で水中の光合成有効光量子密度（PPFD）が126, 169, 330および458 μmol/m²/s, 明暗12時間ずつの条件で、それぞれ34個体を520日間飼育し成長と生殖を調べた。その結果、試験終了時には屋外試験では無遮光区で平均殻長71.7±6.9 mm となったのに比べ、相対光強度23.1%区では80.6±6.2 mm, 51.5%区では76.1±5.9 mm となり、遮光区の成長が早かった。生殖状況は強く遮光した4.8%区を除いて差は無かった。屋内試験では水中 PPFD が一番強い458 μmol/m²/s 区の65.9±5.8 mm に比べ、少し暗くなった330 μmol/m²/s 区は71.0±5.3 mm と成長が早くなった。生殖率は各区とも100%であった。ヒメジャコの飼育方法としては、自然光を使う場合は適切な遮光を、人工照明で飼育する場合は水中光強度を200～400 μmol/m²/s PPFD にするべきであろう。