HATCHERY AND EARLY NURSERY CULTURE OF THE BLACKLIP PEARL OYSTER
(PINCTADA MARGARITIFERA L.)

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ABSTRACT This article reports on spawning induction and larval and early nursery culture of the blacklip pearl oyster Pinceptada margaritifera (L.). Spawning was induced using thermal "shock," where water temperature was manipulated from an overnight low of 22°C to a high at spawning of 32–33°C. Larvae were cultured in 500-L tanks in which the water was replaced every 3–4 days (static system) or in 500-L flow-through tanks in which 100% of the tank water was changed every 24 h. There was no significant difference in survival or growth of the larvae in static or flow-through tanks. Mean (±SE) anteroposterior length (APM) on Day 20, when larvae were transferred to settlement tanks, was 214.38 (±3.06) μm and 217.52 (±2.93) μm for static culture and flow-through culture, respectively. Spat held in settlement tanks had a mean (±SE) dorsoventral shell height (DVH) of 1.38 (±0.03) mm at 43 days postfertilization when they were placed in plastic mesh trays and transferred to the sea. At 106 days of age, spat were removed from collectors and graded. The mean (±SE) DVH of 106-day-old spat was 11.2 (±2.7) mm; the largest individual had a DVH of 33 mm, whereas the smallest was less than 2 mm. At grading, 0.2, 8.9, and 67.3% of spat were retained on 15-, 10-, and 5-mm plastic mesh, respectively, and 23.6% fell through the 5-mm mesh. Growth of spat in plastic trays and pearl nets was assessed at densities of 10, 50, and 100 per tray and at densities of 20, 50, 100, 150, and 200 per net over a 19-wk growth trial. DVH was significantly greater in pearl oysters held in plastic trays at a density of 100 per tray (40.48 ± 0.9 mm). Oysters held at this density also had the greatest APM (39.68 ± 0.9 mm) and wet weight (7.44 ± 0.4 g). Pearl oysters held in pearl nets showed the greatest DVH (39.22 ± 0.6 mm), APM (38.36 ± 0.6 mm), hinge length (34.47 ± 0.5 mm), and wet weight (6.84 ± 0.8 g) at the lowest density of 20 per net. These values did not differ significantly from those of juveniles held at a density of 50 per net. Growth of juveniles held at densities of 20 and 50 per net was significantly greater than that of juveniles held at densities of 100, 150, and 200 per net. The presence of leatherjackets (Paramonacanthus japonicus) in trays and nets significantly affected growth rates of the spat.

KEY WORDS: pearl oyster, spawning, larvae, spat, growth, survival

INTRODUCTION

Pearl culture has traditionally relied on the collection of pearl oysters from the wild. Oysters are either collected as adults or collected as spat that are on-grown to a size suitable for pearl production. In the Pacific, the blacklip pearl oyster (Pinceptada margaritifera L.) supports well-established cultured pearl industries in French Polynesia and the Cook Islands. The former generated an estimated income of US $135.3 million in 1994, while the value of the Cook Islands industry was estimated US $4.5 million in 1993 (Fassler 1995). Not surprisingly, there is considerable interest from other Pacific nations in developing similar cultured pearl industries. In a number of countries, however, such development is prevented by low natural stocks of pearl oysters (Southgate 1995, Southgate 1996). Clearly, for countries with low stocks of adult pearl oysters, the opportunity to develop a cultured pearl industry based on wild spat collection is very limited and development is only likely using hatchery-produced seed. Recent years have seen the development of hatchery techniques for pearl oysters (Alagarswami et al. 1983, Alagarswami et al. 1989, Rose and Baker 1994) and an increasing use of hatchery-produced seed in culture operations (Gervis and Sims 1992). Hatchery production of P. margaritifera seed is limited, and difficulties have been encountered (Coeroli et al. 1984). Nevertheless, Alagarswami et al. (1989) reported successful experimental hatchery production of P. margaritifera in India, and commercial seed production now occurs in French Polynesia and Okinawa (Sims 1993) and in Hawaii (Clarke et al. 1996).

Information on the hatchery rearing of pearl oysters is limited, although the techniques used are similar to those developed for other bivalves. Larvae are usually reared in static culture tanks with periodic water changes (Alagarswami et al. 1989, Gervis and Sims 1992, Rose and Baker 1994). Southgate and Ito (in press) recently described a flow-through larval culture system used successfully for P. margaritifera; however, this system has not yet been evaluated against a conventional static culture system. Although suitable hatchery techniques are becoming established and experimentally evaluated for P. margaritifera, very little information is available on appropriate methods for nursery culture of hatchery-produced spat. This results primarily from the traditional use of wild-collected P. margaritifera spat as the basis for cultured pearl industries in the Pacific (Coeroli et al. 1984, Gervis and Sims 1992, Friedman and Bell 1996). Spat collected in this manner are generally left on collectors for approximately 6 mo before being transferred to juvenile culture systems (Gervis and Sims 1992). As such, until the relatively recent interest in hatchery production of P. margaritifera, there has been no incentive to establish nursery culture techniques for young spat and juveniles. This article reports on the successful production of P. margaritifera seed in Australia and on the evaluation of novel hatchery and nursery techniques.

MATERIALS AND METHODS

Spawning Induction

Adult P. margaritifera were held in eight-pocket panel nets (Gervis and Sims 1992) suspended from a longline at a depth of 3–4 m at Pioneer Bay, Orpheus Island, North Queensland, Australia (latitude, 18°35'S; longitude, 146°29'E). Broodstock were removed from the longline, scrubbed, and washed with filtered (1-μm-pore-size filter) seawater (FSW) to remove sediment and fouling organisms. Cleaned broodstock were placed upright in plastic aquaria containing a minimum volume of FSW and held overnight in an air-conditioned room with an air temperature of
22°C. The following morning, broodstock were placed into a shallow raceway containing only sufficient FSW to just cover the oysters. Spawning was induced by thermal stimulation; before the introduction of broodstock to the raceway, the temperature of the raceway water was raised to around 30–32°C with water heaters or by the addition of heated FSW. Spawning oysters were removed from the raceway into individual containers and allowed to complete spawning. Fertilized eggs were collected on a 25-μm-pore-size mesh screen and washed briefly with FSW. Eggs were incubated in gently aerated 500-L tanks containing FSW at a density of 30–50 mL⁻¹ (Southgate et al., in press). After 24 h, D-stage veliger larvae were removed from the incubation tank onto a 25-μm-pore-size mesh screen, counted, and placed into larval rearing tanks.

**Larval Rearing**

Six outdoor 500-L tanks were filled with FSW, and each was stocked (on Day 1) with 1-day-old *P. margaritifera* veligers at a density of 2 mL⁻¹. Three of the tanks were run using static culture conditions and were provided with gentle aeration. Static tanks were drained, washed, and refilled with clean FSW on Days 4, 7, 11, 14, and 17. Larvae from each tank were removed onto a mesh screen and held in a 20-L bucket containing fresh seawater before being returned to the tanks. The remaining three tanks were set up as flow-through tanks as described by Southgate and Ito (in press). Each tank was provided with a central standpipe to which a mesh cone and float were attached (Fig. 1). The mesh allowed a throughflow of water but prevented escape of the larvae. The pore size of the mesh was increased from 37 μm to 53 μm and finally to 74 μm, on Days 8 and 15, respectively. Water passed through the flow-through tanks for 12 h/day at a flow rate sufficient to replace 100% of the tank volume during this period. The flow-through tanks were completely drained and washed on Days 8 and 15, and the larvae were retained as described above. Water temperature was measured in each tank at 09:00 and 21:00 each day. Water samples were removed on Days 7 and 20 from both static and flow-through tanks for analysis of ammonia and nitrite content by the methods outlined by Franson (1995). Water samples from static-culture tanks were removed immediately before water change. Water temperature in the static and flow-through tanks ranged from 26.3 to 30.1°C and from 26.5 to 30.1°C, respectively, during the larval culture period.

Larvae were fed a mixed diet of cultured microalgae consisting of *Isochrysis* aff. galbana clone T-ISO (CS 177), *Chaetoceros* simplex (CS 251), and *Pavlova salina* (CS 49). All three species are well suited for use in tropical conditions (Jeffrey et al. 1992). Starter cultures were obtained from the CSIRO Fisheries Division in Hobart, Tasmania, and the codes above refer to CSIRO catalogue codes. Microalgae were initially cultured in 3- to 5-L glass flasks in filtered (0.45 μm pore size) and ultraviolet-treated seawater with the nutrient medium described by Southgate and Ito (in press). Larger culture volumes were maintained in 30-L plastic tubs. All algae were fed to larvae and spat during the exponential growth phase. The feeding rate for larvae is shown in Table 1.

**Settlement and Nursery Culture**

On Day 20, eyed larvae large enough to be retained on a 150-μm-pore-size mesh screen were removed from the larval culture tanks and placed into 500-L settlement tanks. Each settlement tank contained FSW vigorously aerated with five air lines. Seventy-five spat collectors were suspended in each settlement tank. Each collector measured approximately 30 × 15 cm and consisted of an outer “onion” bag filled with approximately 0.5 m² of 50% woven shade cloth.

Cultured microalgae were added to the settlement tanks at the rates shown in Table 1. Water in the settlement tanks was completely exchanged on a daily basis using a flow-through system, and water temperature ranged from 26.5 to 30.1°C during the study. On Day 43, spat collectors were removed from the settle-

![Figure 1. Apparatus placed onto central stand pipe in “flow-through” culture tanks used for *P. margaritifera* larvae. A = float, B = mesh cone, and C = flexible aeration tubing.](image-url)
ment tanks and placed inside plastic mesh trays (55 x 30 x 10 cm) with lids; four collectors were tied into each tray, and trays were then weighted and suspended from a surface longline at a depth of 6 m. On Day 106, 63 days after being placed into the sea, spat were removed from the collectors and graded through plastic mesh screens. Spat that passed through a 15-mm-pore-size (square) mesh and were retained on a 10-mm-pore-size mesh were placed into the same plastic mesh trays used for housing spat collectors at densities of 10, 50, and 100 per tray, and plastic mesh lids were placed onto the trays. Three replicate trays of each stocking density were then suspended from a surface longline at a depth of 4 m. Spat that passed through the 10-mm-pore-size mesh but were retained on a 5-mm-pore-size mesh were placed into square-based pyramidal pearl nets (see Gervis and Sims 1992) made of 7-mm-pore-size nylon mesh; the sides of the base of the nets were 35 cm. Spat were stocked into pearl nets at densities of 20, 50, 100, 150, and 200 per net. Five replicates of each density were suspended from the longline at a depth of 4 m. At the start of the nursery growth trial, the mean (±SE) dorsoventral height (DVH) of individuals in crates and pearl nets was 13.9 ± 0.28 and 9.8 ± 0.24 mm, respectively.

Trays and pearl nets were brushed in situ approximately every 4 wk to reduce fouling. After 19 wk, juveniles were removed from the trays and pearl nets and counted; shell growth was measured as DVH, anteroposterior measurement (APM), and hinge length (HL) (see Fig. 2). All remaining juveniles in the 10, 20, and 50 treatments were weighed and measured, and 50 randomly selected juveniles were measured from the 100, 150, and 200 treatments. Survival data (%) were arcsin transformed before analysis. Data were analyzed using one-way analysis of variance, and significant differences between means were identified using the Tukey test (Zar 1984).

RESULTS

Larval Development

Fertilized eggs had a mean diameter of 61.03 ± 1.04 μm (±SE, n = 30). Development of P. margaritifera larvae was similar to that described by Alagarswami et al. (1989) and to that described for Pinna nobilis by Rose and Baker (1994). Changes in mean APM of P. margaritifera larvae cultured in static and flow-through culture tanks are shown in Figure 3. Larvae had reached the D-stage by 20–24 h after fertilization and had a mean APM of 82.09 ± 1.37 μm. Umbonal larvae were first seen on Day 9; however, the majority of the larvae were umboval on Day 11 when the mean APM was 138.28 ± 2.31 μm. Growth rates were similar in both the static and the flow-through systems (Fig. 3). On Day 20, larvae from the static and flow-through systems had mean APM of 214.38 ± 0.06 and 217.52 ± 2.93 μm, respectively. The relationship between APM (y) and DVH (x) is described by the equation: 

\[ y = 1.017x + 13.712 \]

There was no significant difference between treatment in survival to Day 20 (p = 0.842). Mean (±SE, n = 3) survival to Day 20 was 4.33% (±2.1) and 5.75% (±3.8) in the static and flow-through tanks, respectively. Survival was very variable between replicate tanks of the same treatment and, for example, ranged from 1.9 to 6.9% in flow-through tanks. The mean proportion of the total number of larvae surviving to Day 20 that were large enough to be caught on a 150-μm-pore-size sieve mesh was 52.1 ± 3.5% in the static tanks and 63.0 ± 7.7% in the flow-through tanks. These values did not differ significantly (p = 0.328).

Water Chemistry

Ammonia and nitrite levels in the static and flow-through tanks are shown in Table 2. There was no significant difference in the levels of ammonia or nitrite between static and flow-through tanks on Day 7. On Day 20, mean ammonia and nitrite levels were higher in both static and flow-through tanks than on Day 7; the

![Figure 2](image2.png)

**Figure 2.** Dimensions used for measurement of P. margaritifera spat and juveniles.

![Figure 3](image3.png)

**Figure 3.** Changes in mean (±SE) anteroposterior shell length of P. margaritifera larvae cultured in flow-through (■) and static (●) tanks.
TABLE 2.
Ammonia and nitrite contents (mg L\(^{-1}\)) in seawater from static and 
flow-through larval culture tanks.

<table>
<thead>
<tr>
<th>Day</th>
<th>Ammonia</th>
<th>Nitrite</th>
<th>Ammonia</th>
<th>Nitrite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow-Through Tanks</td>
<td>Static Tanks</td>
<td>Flow-Through Tanks</td>
<td>Static Tanks</td>
</tr>
<tr>
<td>7</td>
<td>13.23*</td>
<td>1.73*</td>
<td>15.57*</td>
<td>2.17*</td>
</tr>
<tr>
<td></td>
<td>(±0.69)</td>
<td>(±0.38)</td>
<td>(±0.87)</td>
<td>(±0.18)</td>
</tr>
<tr>
<td>20</td>
<td>18.73*</td>
<td>1.90*</td>
<td>27.20*</td>
<td>2.23*</td>
</tr>
<tr>
<td></td>
<td>(±0.18)</td>
<td>(±1.0)</td>
<td>(±1.3)</td>
<td>(±0.18)</td>
</tr>
</tbody>
</table>

Values are mean (±SE) from three determination (one from each replicate tank). Means for the same parameter within the same row with the same superscript are not significantly different (p > 0.05).

Mean ammonia level in static culture tanks was 27.2 ± 1.3 mg L\(^{-1}\), and this was significantly higher than the mean ammonia level in the flow-through tanks of 18.7 ± 0.2 mg L\(^{-1}\) (p = 0.018). The mean nitrite level in static culture tanks was 2.2 ± 0.2 mg L\(^{-1}\) on Day 20, which was higher than the mean nitrite level in flow-through tanks of 1.9 ± 1.0 mg L\(^{-1}\); however, this difference was not significant (p = 0.22).

Spat Growth

Mean (±SE, n = 50) DVH of spat removed from the settlement tanks 43 days after fertilization was 1.37 ± 0.1 mm. Mortality of larvae and spat in the settlement tanks was relatively high, and approximately 17% of the larvae placed into settlement tanks on Day 20 survived to Day 43. Mean monthly water temperature during the nursery study ranged from 28.4 (±0.3)°C at the start of the experiment in December to 23.7 (±0.3)°C at the end of the experiment in June; however, the highest water temperature of 29.8 (±0.2)°C was reached in February (Fig. 4). Growth of spat to grading at 106 days is shown in Figure 5.

The development of growth processes on the shell was evident in spat with DVH greater than 3 mm. Spat growth was rapid, and 106-day-old spat had a mean DVH and HL of 11.2 ± 2.1 mm and 11.7 ± 2.7 mm, respectively. The proportion of 106-day-old spat in each of four size categories, after removal from the settlement media and grading, is presented in Table 3. The majority of spat (67.3%) passed through the 10-mm-pore-size mesh and were retained on the 5-mm-pore-size mesh. Nine percent of the spat were retained on the 10-mm-pore-size mesh, and 0.2% were retained on the 15-mm-pore-size mesh. Almost 24% of the juveniles passed through the 5-mm-pore-size mesh. The largest individual measured at 106 days had a DVH of 23 mm, while the smallest was less than 2 mm. Survival of spat between transfer to the sea on Day 43 and grading on Day 106 was 38.9%. The relationships between DVH, APM, HL, and wet weight for *P. margaritifera* spat are described in Table 4.

Spat at all densities in both trays and pearl nets tended to aggregate and form clumps composed of many individuals. The number of spat in the clumps increased with increasing stocking density. Survival, wet weight (WW), and shell dimensions of spat held at different densities in trays are shown in Table 5. Survival of pearl oyster juveniles in plastic trays was high and varied be-

**Figure 4.** Changes in mean (±SE) monthly water temperature (°C) at Pioneer Bay, Orpheus Island, during the nursery experiment.

**Figure 5.** Changes in mean DVH of *P. margaritifera* spat during early nursery culture up to grading at 106 days old.

**TABLE 3.**
Percentage of *P. margaritifera* spat in each of four size classes when graded at 106 days of age.

<table>
<thead>
<tr>
<th>Pore Size of Mesh (mm)*</th>
<th>Diagonal Measure (mm)</th>
<th>Juveniles Retained (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>23</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>8.9</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>67.3</td>
</tr>
<tr>
<td>≤5</td>
<td>23.6</td>
<td></td>
</tr>
</tbody>
</table>

* Three pore sizes were used for grading: 15, 10, and 5 mm, which had diagonal measurements of 23, 15, and 7 mm, respectively.
between 76.6 and 88%. The majority of trays, including all replicates
stocked with 10 oysters, two replicates stocked with 50 oysters,
and one stocked with 100 oysters, became populated by leather-
jackets (*Paramonacanthus japonicus* during the study. These fish
trimmed the dorsal shell margin and growth processes of spat
shells and may also have ingested mantle tissue. The data pre-
sented in Table 5 include replicates affected by *P. japonicus*.
DVH, APM, and WW were all higher at a density of 100 than at
densities of 50 or 10 individuals per tray. Individuals held at a
density of 100 per tray had significantly greater DVH, APM, HL,
and WW than individuals held at a density of 50 per tray; however,
there were no significant differences in DVH, APM, HL, or WW
between oysters held at 100 per tray and those held at 10 per tray.
Survival, WW, and shell dimensions of spat held at different
densities in pearl nets are shown in Table 6. Survival of individuals
held in pearl nets was lower than that for pearl oysters held in trays
and ranged from 68 to 74.8%. One of the pearl nets stocked with
20 oysters contained *P. japonicus*, and this replicate was not in-
cluded in the data presented in Table 6. Pearl oysters held at a
density of 20 per pearl net had greater DVH, APM, HL, and WW
than those held at any of the other four densities; however, there
were no significant differences for any of these parameters be-
tween oysters held at 20 per net and those held at 50 per net. There
was a progressive decline in mean DVH, APM, HL, and WW with
increasing stocking density, and spat held at densities of 20 and 50
per net had significantly greater DVH, APM, HL, and WW than
those held at higher densities. The presence of *P. japonicus*
significantly affected shell growth of juvenile oysters. For example,
mean DVH, APM, HL, and WW of juveniles held at a density of
20 per pearl net were 36.77 (±0.73) mm, 36.26 (±0.68) mm, 32.96
(±0.56) mm, and 5.96 (±0.29) g, respectively, when the fish-
affected replicate was included. However, when this replicate was
omitted, mean values for DVH, APM, HL, and WW were 39.22
(±0.65) mm, 38.36 (±0.63) mm, 34.46 (±0.54) mm, and 6.84
(±0.80) g, respectively.

### TABLE 4.

Morphometric relationships for *P. margaritifera* spat following log
transformation of values for DVH, APM, HL, and WW.

<table>
<thead>
<tr>
<th></th>
<th>x</th>
<th>y</th>
<th>Regression Equation</th>
<th>r²</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVH(mm)</td>
<td>y</td>
<td>x</td>
<td>0.9944x - 0.0175</td>
<td>0.985</td>
<td>1,067</td>
</tr>
<tr>
<td>DVH(mm)</td>
<td>y</td>
<td>x</td>
<td>0.8543x - 0.386</td>
<td>0.967</td>
<td>1,117</td>
</tr>
<tr>
<td>DVH(cm)</td>
<td>y</td>
<td>x</td>
<td>3.0294x - 9.288</td>
<td>0.983</td>
<td>1,117</td>
</tr>
</tbody>
</table>

**Discussion**

There is a paucity of information on successful spawning in-
duction of *P. margaritifera*. In this study, cleaned broodstock
were held overnight in a minimum volume of seawater in an air-
conditioned room (ca. 22°C) before spawning induction. Spawning
was readily induced the following morning, when broodstock
were returned to ambient or heated (to a maximum of 32°C) seawater.
At Orpheus Island, this method has been used successfully be-
tween September and May and has consistently resulted in the
production of high-quality gametes. *P. margaritifera* at Orpheus
Island experience an annual water temperature range of 20.1 to
31.2°C (B. Willis unpubl.); as such, the minimum temperature
experienced by broodstock before spawning induction is within the
range normally experienced in the wild. However, in regions
where the natural temperature range of seawater is narrower than
that experienced by the *P. margaritifera* used in this study, the
minimum water temperature reached during "cold conditioning,"
before spawning induction, should be modified accordingly.
It should also be noted that *P. margaritifera* broodstock often spawn
spontaneously after transport to the hatchery or in response to
cleaning.

The flow-through larval culture system was initially investi-
gated as a means of simplifying hatchery procedure (Southgate
1995). Southgate and Ito (in press) suggested that a flow-through
larval rearing system not only offered a simpler method of larval
rearing but, because of more frequent water exchanges, would
result in better water quality compared with that in conventional
static culture systems. Although there were favorable and signif-
cantly different differences between water-quality parameters in the
flow-through and static culture tanks, these did not promote signif-
cantly improved larval growth or survival. However, the flow-
through tanks required only two complete water changes during
the larval culture period compared with the five water changes
performed on static-culture tanks. Clearly, one of the major poten-
tial benefits of a flow-through larval culture system is reduced
labor input. This is likely to be particularly advantageous in small
island nations of the Pacific, where the availability of skilled or
experienced hatchery staff is extremely limited.

Large variation in the growth rates of juvenile *P. maxima* and
*P. margaritifera* cohorts has been reported for both wild (Scoones
1990) and hatchery cultured juveniles (Alagarswami et al. 1989,
Rose 1990, Rose and Baker 1994). Similar variation in spat size
was also recorded in this study. At 106 days of age, the largest
individuals had a DVH greater than 20 mm, while the smallest had
DVH measurements of less than 2 mm; approximately 9% of spat
at this age were retained on a 10-mm-pore-size mesh, while 23.6%

### TABLE 5.

Mean (±SE) survival, DVH, APM, HL, and WW of *P. margaritifera* spat held at three densities in plastic trays for 19 weeks.

<table>
<thead>
<tr>
<th>Density</th>
<th>Survival (%)</th>
<th>DVH (mm)</th>
<th>APM (mm)</th>
<th>HL (mm)</th>
<th>WW (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>76.67 ± 3.33</td>
<td>37.39 ± 1.47</td>
<td>38.57 ± 1.64</td>
<td>35.70 ± 1.56</td>
<td>7.19 ± 0.61</td>
</tr>
<tr>
<td>50</td>
<td>88.00 ± 5.29</td>
<td>35.70 ± 0.66</td>
<td>35.32 ± 0.73</td>
<td>32.17 ± 0.67</td>
<td>5.46 ± 0.28</td>
</tr>
<tr>
<td>100</td>
<td>87.00 ± 1.15</td>
<td>40.48 ± 0.91</td>
<td>39.68 ± 0.93</td>
<td>35.44 ± 0.84</td>
<td>7.44 ± 0.43</td>
</tr>
</tbody>
</table>

Ranges are shown in parentheses. Means in columns with the same superscript are not significantly different (p > 0.05).
TABLE 6.
Mean (±SE) survival, DVH, APM, HL and WW of P. margaritifera spat held at five densities in pearl nets for 19 weeks.

<table>
<thead>
<tr>
<th>Density</th>
<th>Survival (%)</th>
<th>DVH (mm)</th>
<th>APM (mm)</th>
<th>HL (mm)</th>
<th>WW (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>73.7±5±7.74</td>
<td>39.22±0.65</td>
<td>38.36±0.63</td>
<td>34.47±0.54</td>
<td>6.84±0.80</td>
</tr>
<tr>
<td></td>
<td>(25-47)</td>
<td>(25-46)</td>
<td>(25-42)</td>
<td>(2.2-11.2)</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>74.80±2.42</td>
<td>37.30±0.41</td>
<td>36.69±0.43</td>
<td>32.66±0.40</td>
<td>6.02±0.18</td>
</tr>
<tr>
<td></td>
<td>(24-49)</td>
<td>(22-50)</td>
<td>(18-47)</td>
<td>(1.1-12)</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>70.40±4.85</td>
<td>34.28±0.58</td>
<td>32.50±0.57</td>
<td>30.08±0.56</td>
<td>4.40±0.18</td>
</tr>
<tr>
<td></td>
<td>(9-48)</td>
<td>(10-46)</td>
<td>(11-44)</td>
<td>(0.1-10.6)</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>68.60±2.89</td>
<td>30.63±0.55</td>
<td>28.75±0.54</td>
<td>26.59±0.49</td>
<td>3.11±0.17</td>
</tr>
<tr>
<td></td>
<td>(10-53)</td>
<td>(10-53)</td>
<td>(11-43)</td>
<td>(0.1-12.3)</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>68.30±2.49</td>
<td>29.77±0.58</td>
<td>28.40±0.58</td>
<td>26.21±0.50</td>
<td>3.24±0.17</td>
</tr>
<tr>
<td></td>
<td>(12-49)</td>
<td>(13-51)</td>
<td>(12-42)</td>
<td>(0.1-11.3)</td>
<td></td>
</tr>
</tbody>
</table>

Means in columns with the same superscript are not significantly different (p > 0.05). Ranges are shown in parentheses. Means were calculated from five replicates per treatment, except at a density of 20 oysters per net, where data were calculated from four replicates.

fell through a 5-mm-pore-size mesh. To maintain the highest growth rates during nursery culture, regular grading is required to allow spat to be placed in growout apparatus with the largest suitable mesh pore sizes. The use of the crates and pearl nets in this study was related to the variation in size of the spat at first grading (106 days) as well as the desire to explore the value of different nursery culture techniques. The range of sizes at grading and the requirement for the largest mesh pore size to suit the juveniles led to the use of the two types of rearing systems. Continual grading during nursery culture ensures optimized growing conditions. At each grading, the pore size of the container is increased to match increasing juvenile size; this reduces fouling and ensures adequate water flow rates, which provide an adequate food supply and oxygen, and remove waste products (Gervis and Sims 1992). Achieving maximum growth rates in the nursery phase of pearl oyster culture reduces the time required to reach operable size for pearl production. Scoones (1990) reported that slower growing P. maxima juveniles in Western Australia required 30 mo to reach commercial size compared with 18 mo for the rapid growers. Smaller or slower growing pearl oyster juveniles require more frequent maintenance and have a longer nonproductive culture period.

It is interesting to note that at the end of the nursery trials, the largest pearl oysters held in pearl nets were of similar size and weight to those of the largest pearl oysters held in plastic trays. However, the pearl oysters stocked into plastic trays were those retained by a 10-mm-pore-size mesh during grading, whereas oysters used to stock pearl nets were those retained by a 5-mm-pore-size mesh. Although this may reflect differences in growth rates between oysters held in the trays and pearl nets, it is more likely to result from the effects of P. japonicus, which were far more common in trays than in pearl nets.

The P. margaritifera spat produced in this study showed growth rates similar to those reported for P. margaritifera in other studies. Alagarwsswani et al. (1989) reported a daily DVH growth rate of 0.4 mm/day for hatchery-reared P. margaritifera spat on transfer to the ocean; these animals had a mean DVH of 14.2 mm (range, 8.2-21.1 mm) 99 days after settlement. Growth data are also available for wild-collected P. margaritifera spat from French Polynesia. Coeroli et al. (1984) reported that spat held in suspended culture at 3 m reached a DVH of 8-10 mm after 3 mo and 40-50 mm after 6 mo. In the Solomon Islands, Friedman and Bell (1996) reported that P. margaritifera spat removed from collectors that had been in the sea for 6 mo had a mean DVH of 32.4 ± 1.7 mm (range, 8-71 mm). The mean size of spat reported by Friedman and Bell (1996) is comparable to that in this study; when the nursery trial was terminated, spat were almost 7.5 mo old and had a mean DVH of approximately 40 mm. However, this is considerably smaller than the largest spat recorded by Friedman and Bell (1996), which had a DVH of 71 mm.

Survival of juvenile P. margaritifera between transfer to the sea and termination of the nursery trial ranged from 29.6 to 34.2% for juveniles held in trays and from 26.5 to 29.1% for juveniles held in pearl nets. This is relatively high compared with survival reported for P. margaritifera in India. Alagarwsswani et al. (1989) reared hatchery-produced P. margaritifera spat in pearl nets (triangular base with 35-cm sides) at a density of 600 per net. Forty-five days after transfer to the sea, survival was 15.1-17.4%; however, 50 days after transfer, survival had declined to almost zero (Alagarwsswani et al. 1989). This low survival may have resulted from the extremely high densities of spat in the pearl nets, although the authors stated that P. margaritifera does not occur naturally in the coastal waters of India, where their growth trials were conducted. In contrast, mortality of 6- to 12-mo-old P. margaritifera spat in French Polynesia has been reported at approximately 30% (Coeroli et al. 1984).

The gregarious behavior of P. margaritifera spat and their tendency to form clumps are consistent with the findings of previous studies. Crossland (1957) reported that P. margaritifera grew in mesh-covered boxes in the Red Sea readily formed “clusters,” which if not broken-up, resulted in stunting or mortality of the innermost individuals. Similar behavior has been reported for spat of the Japanese pearl oyster, Pinctada fucata (Gervis and Sims 1992) and the silverlip pearl oyster P. maxima (Taylor et al. 1997). Taylor et al. (1997) reported that early juvenile P. maxima moved together to form large groups of up to 25 individuals when held at high stocking densities. This behavior resulted in reductions in shell growth, survival, and WW and an increase in the prevalence of growth deformities (Taylor et al. 1997).

Sims (1994) reported “fish grazing” as a cause of non-necareous shell loss in P. margaritifera juveniles in the Cook Islands. Similar damage was caused to juveniles in this study by leatherjackets (P. japonicus; family Aluteridae). Groups of these fish took up residence in some of the trays and nets used in this
study and trimmed the non-nacreous shell margin, growth processes, and possibly some mantle tissue from juvenile oysters. The actions of these fish caused significant reduction in juvenile growth. The trays and nets used in this study were brushed on the outside to remove fouling but not inspected internally during the study. The presence of P. japonicus could have been prevented by regular and thorough inspection of culture apparatus. Many of the fish found at the end of the nursery trial were too large to escape through the mesh of the trays and nets and were trapped within them. Fish, primarily of the family Balistidae, have been recorded as predators of juvenile P. margaritifera in the Solomon Islands (Friedman and Bell 1996) and as a source of mortality of P. margaritifera in the Red Sea (Crossland 1957). Other recorded predators of P. margaritifera spat and juveniles include crabs and gastropods such as Murex spp. and Cymatium spp. (Crossland 1957, Southgate and Beer 1996, Friedman and Bell 1996). Although predation by Cymatium is a major problem for bivalve culture in other parts of the Pacific (Gowan 1995, Friedman and Bell 1996), they are rarely encountered on suspended culture apparatus used at Orpheus Island.

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LITERATURE CITED


