ENVIRONMENTAL CONDITIONS AND CULTURE METHOD EFFECTS ON GROWTH AND SURVIVAL OF JUVENILE WINGED PEARL OYSTER, *PTERIA PENGUIN*

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**ABSTRACT**  
Juvenile winged pearl oysters, *Pteria penguin*, were cultured for 6 mo in three commonly used culture units (panel nets, plastic mesh trays, and pyramidal pearl nets) at two dissimilar sites—Pioneer Bay (a coral reef environment in which *P. penguin* are naturally present) and Cape Ferguson (a coastal semiestuarine environment with high levels of silt deposition)—to determine the effects of site and culture method on growth, survival, and fouling. Mean growth increases were recorded for the dorsoventral measurement (DVM), anteroposterior measurement (APM), shell thickness, and whole weight. At Pioneer Bay, five replicates for each of the three culture unit types were suspended at 3 m and at 6 m, and mean initial DVM was 28.0 ± 0.6 mm (*n* = 190). At Cape Ferguson, there were five replicates for each culture unit at 3 m only, and mean initial DVM was 28.0 ± 0.6 mm (*n* = 86). Mean growth increase at the end of the experiment for oysters at Pioneer Bay and Cape Ferguson, respectively, were 26.6 ± 1.0 mm and 32.6 ± 2.4 mm DVM, 29.6 ± 1.2 mm and 34.0 ± 2.9 mm APM, 6.7 ± 0.3 mm and 9.7 ± 0.5 mm shell thickness, and 16.5 ± 0.7 g and 23.0 ± 2.1 g whole weight. For all growth parameters, mean increase was significantly higher under high-turbidity conditions at Cape Ferguson (*P* < 0.05). Culture unit also affected growth, with oysters held in mesh trays showing significantly more growth at both sites (*P* < 0.05). Mean survival of oysters at Cape Ferguson (96.5%) was significantly higher than at Pioneer Bay (79.4%). Depth had no significant effect on growth, survival, or fouling. The results indicate that site selection and culture unit are important parameters for optimizing growth and survival during nursery phase culture of *P. penguin*.

**KEY WORDS:** pearl oyster, environment, nursery culture, fouling, survival

**INTRODUCTION**

Pearl oysters (*Pinctada* spp. and *Pteria* spp.) are commonly collected from the wild using spat collectors, and are then placed into nursery culture units with the appropriate-size mesh to retain the spat and protect them from predators during the juvenile phase (Wada 1991, Southgate & Beer 2000). Developing optimal culture methods that maximize growth and survival rates in juvenile pearl oysters reduces the time required for them to reach operable size for pearl production. A range of environmental factors influence pearl oyster growth and survival, including water temperature, food availability, salinity, and biofouling (DeNys & Ison 2008, Lucas 2008). Fouling organisms and the accumulation of silt and detritus gradually limit water flow through culture units by blocking the surface perforations over time, and water flow influences growth because it is linked to food availability and the removal of wastes (Wilson 1987, Brown & Hartwick 1988). In addition, the fouling organisms are often filter feeders themselves and thus compete with the oysters for food and reduce the level of available oxygen (Wallace & Reinsnes 1985, Claereboudt et al. 1994). Growth and survival of juvenile pearl oysters may also be influenced by site conditions (Nasr 1984, Pouvreau & Prasul 2001), culture unit (Southgate & Beer 2000), suspension depth (Smitasiri et al. 1994, Lodeiros et al. 2002, Kanjanachatree et al. 2003), cleaning regimen (Friedman & Southgate 1999, Monteforte & Morales-Mulia 2000), and stocking density (Monteforte et al. 2005).

*Pteria penguin* (Röding 1798) is a commercially important species of pearl oyster that is cultivated across southeast Asia and the western Pacific for the production of half-pearls or mabé (Southgate et al. 2008). Utilization of *P. penguin* for pearl production offers both opportunities for diversification within existing pearling industries and as a means of income generation for coastal communities, because mabé pearl production is less technically demanding than round pearl production (Southgate et al. 2006, Taylor & Strack 2008). Despite the rapid increase in pearl culture from this species in recent years, very little is known of the culture requirements of *P. penguin* and, until recently, pearl production from this species was dependant on wild-collected adult oysters (Southgate et al. 2008). This study investigates the efficacy of several nursery culture methods for promoting growth and survival of juvenile *P. penguin*. In particular, two dissimilar sites (an offshore coral reef and a coastal mud flat zone) were compared, as well as three commonly used culture unit types (plastic mesh trays, pocket panel nets, and pyramidal pearl nets) and two suspension depths (3 m and 6 m).

**MATERIALS AND METHODS**

**Study Sites**

This study was conducted at two sites in north Queensland, Australia (Fig. 1). The first was James Cook University’s Research Station at Pioneer Bay, with a natural habitat of *P. penguin* on the leeward side of Orpheus Island. The study was conducted on a long-line situated 50 m from the edge of a fringing coral reef with a depth beneath of 10–13 m and a coral and rubble substrate. The second site was the wharf at the Australian Institute of Marine Science at Cape Ferguson, situated in a sheltered bay on the coast, 50 km south of Townsville. Water depth at the wharf is between 3 m and 6 m. Cape Ferguson sits within Bowling Green Bay, an extensive area of coastal mangroves and mudflats, with high levels of active silt deposition from terrestrial discharges, particularly during periods of intense rainfall in the summer, from November to May (QPWS 2000).
Experimental Design

Juvenile oysters used in this research naturally recruited to spat collectors and ropes on the long-line at Pioneer Bay. The experiment was conducted over 6 mo, from May to October 2009. Oysters were held in 3 culture unit types commonly used in the cultured pearl industry: (1) pocket panel nets (1-cm² mesh), (2) perforated plastic trays (1-cm² mesh), and (3) pyramidal pearl nets (0.5-cm² mesh) (Southgate 2008). Oysters at Pioneer Bay were suspended at 2 depths (3 m and 6 m), and oysters at Cape Ferguson were suspended at 3 m only. During the experiment, all oysters at both sites were cleaned, and growth and survival rates were recorded after 3 mo, and again at the end of the experiment after 6 mo. Fouling organisms were removed from the shells, which were brushed clean. A total of 276 oysters were randomly divided into 2 groups; 190 were used at Pioneer Bay and 86 at Cape Ferguson. At Pioneer Bay there were 10 replicates (5 at each depth) for each of the 3 culture unit types (panel nets, trays, and pearl nets), with 5–7 oysters per replicate. The mean initial dorsoventral measurement (DVM) was 28.0 ± 0.6 mm ($n = 190$). Similarly, at Cape Ferguson, 5 replicates for each culture unit contained 5–7 oysters, with a mean initial DVM of 28.0 ± 0.6 mm ($n = 86$).

Oysters were measured with calipers to the nearest 0.1 mm to record mean growth increase during the experiment for 3 commonly used shell growth parameters: (1) DVM, (2) anteroposterior measurement (APM), and (3) shell thickness (ST) (Hynd 1955) (Fig. 2). Mean increase in whole weight (WW) of oysters to the nearest 0.1 g was also recorded. Fouling (including living organisms as well as accumulated silt and detritus) was recorded by weighing each culture unit before the experiment and again after 3 mo, and at the end of the experiment. Culture units were weighed after oyster removal and after they had dried in the sun. As a result of the variation in size and shape of the various culture units, fouling was expressed on the basis of dry weight per unit surface area (i.e., in milligrams per square centimeter). Water temperature data at Pioneer Bay recorded during the experiment period was provided by The Australian Institute of Marine Science (AIMS 2011).

Data Analyses

Multiple ANOVAs were performed to determine the significance of culture unit, depth, and site on growth, survival, and level of fouling. For Pioneer Bay data, differences in growth of oysters between culture units and depths, and differences in fouling and survival between culture units and depths was tested with 2-way ANOVAs. Tukey’s post hoc test was used to determine significant differences between culture units. All data were checked for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene’s test) prior to running ANOVAs. Survival percentage data at Pioneer Bay was arcsin-square root transformed to achieve normality. Survival data from Cape Ferguson did not meet the assumptions of normality and homogeneity of variance; therefore, nonparametric Kruskal-Wallis analysis was used to test for differences between mean ranks of survival. All statistical analyses were undertaken in SPSS (SPSS Inc., version 19) with $P = 0.05$.

RESULTS

Growth

For oysters at Pioneer Bay, overall mean DVM increase at the end of the experiment was 26.6 ± 0.9 mm, whereas at Cape Ferguson...
significantly, but both were significantly greater than the mean decreases for all parameters were significantly higher at Cape Ferguson—DVM: \( F = 15.652, df = 1, P < 0.001; \) APM: \( F = 5.811, df = 1, P < 0.001; \) ST: \( F = 47.155, df = 1, P < 0.001; \) WW: \( F = 20.650, df = 1, P < 0.001.\)

At Pioneer Bay, mean DVM increase of oysters held in trays (30.1 ± 0.9 mm) and pearl nets (28.6 ± 1.2 mm) did not differ significantly, but both were significantly greater than the mean DVM increase of oysters held in panel nets (21.4 ± 1.0 mm; \( F = 10.957, df = 2, P < 0.001; \)) (Fig. 3A). Mean APM increase of oysters in trays and pearl nets was significantly higher than that of oysters in panel nets (\( F = 14.825, df = 2, P < 0.001, \)) and APM increase of oysters in trays was significantly higher than oysters in pearl nets (Tukey, \( P < 0.05 \)). Culture units had no effect on ST and WW, and depth had no effect on any of the growth parameters.

At Cape Ferguson, culture unit had a significant effect on increases in all growth parameters—DVM: \( F = 65.917, df = 2, P < 0.001; \) APM: \( F = 25.290, df = 2, P < 0.001; \) ST: \( F = 11.363, df = 2, P < 0.01; \) WW: \( F = 25.612, df = 2, P < 0.001 \) (Fig. 3B). Growth increases for all parameters were significantly higher for oysters in trays compared with those in pearl nets and panel nets, whereas DVM and APM increases were significantly higher in oysters held in pearl nets than those in panel nets (Tukey, \( P < 0.05 \)). Oysters held in trays at Cape Ferguson had significantly higher increases in DVM, APM, ST, and WW than oysters in trays at Pioneer Bay (\( P < 0.001, \)) but there were no significant differences for these variables between sites in panel nets, whereas oysters held in pearl nets between sites differed only in ST (\( F = 19.990, df = 1, P < 0.01 \)). At both sites, the migration of oysters in the panel nets caused some to become wedged between the net fibers and their shells were deformed as a result, an many of the oysters held loosely in trays and pearl nets had aligned themselves into aggregations.

**Survival**

Mean survival of oysters at Pioneer Bay was 79.4% (76.3% ± 5.7 at 3 m and 82.5% ± 4.7 at 6 m), compared with 96.5% at Cape Ferguson, and was significantly higher at the latter (Kruskal-Wallis test, \( \lambda = 9.387, df = 1, P < 0.05 \)). There were no significant differences in survival at Pioneer Bay between culture units (2-way ANOVA, \( F = 0.600, df = 2, P > 0.05 \)) or depths (2-way ANOVA, \( F = 0.993, df = 1, P > 0.05 \)). Similarly, differences in survival between culture units at Cape Ferguson were not significant (Kruskal-Wallis, \( \lambda = 1.267, df = 2, P > 0.05 \)).

**Fouling**

At Pioneer Bay, fouling organisms included red algae, *Laurencia* sp., boring sponges (*Cliona* sp.), bivalve spat (predominantly *Electroma* sp.), feather stars (*Comaster* sp.), brittle stars, bryoozoans, annelid worms, polychaetes, sea urchins, and flatworms. The 3-dimensional culture units (trays and panel nets) also contained xanthid crabs, fishes, mantis shrimp, and gastropods (*Conus* sp.). By comparison, fouling at Cape Ferguson consisted mainly of fine silt and detritus, with some bryozone infestation. Thus, the culture units and the oysters at this site were much easier to clean. Fouling at Pioneer Bay averaged 32.7 ± 2.1 mg dry weight/cm\(^2\) for all combined treatments, compared with 27.8 ± 1.9 mg dry weight/cm\(^2\) at Cape Ferguson (Table 2). Two-way ANOVA showed culture units at Pioneer Bay had an effect on fouling (\( F = 7.780, df = 2, P < 0.01 \)). Fouling on trays (41.6 ± 6.7 mg dry weight/cm\(^2\)) was significantly higher than on pearl nets (30.4 ± 5.6 mg dry weight/cm\(^2\)) and panel nets (26.0 ± 4.8 mg dry weight/cm\(^2\)) (Tukey, \( P < 0.05 \)), whereas fouling on pearl nets and panel nets did not differ significantly. Fouling was greater at 3 m (35.4 ± 3.5 mg dry weight/cm\(^2\)) compared with 6 m (29.9 ± 2.4 mg dry weight/cm\(^2\)), although the difference was not significant (\( F = 2.764, df = 1, P > 0.05 \)). At Cape Ferguson, culture unit had no effect on fouling (1-way ANOVA, \( F = 0.770, df = 2, P > 0.05 \)), and site did not affect fouling in pearl nets and panel nets (\( P > 0.05 \)). However, fouling in trays at Pioneer Bay (49.9 ± 4.2 mg dry weight/cm\(^2\)) was significantly higher than that in trays at Cape Ferguson (26.9 ± 1.9 mg dry weight/cm\(^2\)) (1-way ANOVA, \( F = 17.383, df = 1, P < 0.01 \)).

**DISCUSSION**

The results of this study show that site conditions and culture units affected growth and survival in *P. penguin*. Oysters held in panel nets displayed significantly lower growth rates at both sites, although there were some differences in the results between the sites. At Pioneer Bay, increases in DVM and APM were significantly higher for oysters held in trays and pearl nets compared with panel nets, whereas at Cape Ferguson, all growth parameters measured were significantly higher for oysters held in trays than for those in panel nets and pearl nets. Lower growth increases for oysters in panel nets appeared to be caused by an interaction between fouling and culture unit type. The

<table>
<thead>
<tr>
<th>Site</th>
<th>Period</th>
<th>DVM (mm)</th>
<th>APM (mm)</th>
<th>ST (mm)</th>
<th>WW (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pioneer Bay</strong></td>
<td>May–July</td>
<td>12.0 ± 0.9</td>
<td>15.4 ± 1.0</td>
<td>2.5 ± 0.3</td>
<td>6.3 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>August–October</td>
<td>13.7 ± 0.7</td>
<td>13.0 ± 1.0</td>
<td>3.7 ± 0.2</td>
<td>9.7 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>26.6 ± 1.0</td>
<td>29.6 ± 1.2</td>
<td>6.7 ± 0.3</td>
<td>16.5 ± 0.7</td>
</tr>
<tr>
<td><strong>Cape Ferguson</strong></td>
<td>May–July</td>
<td>14.3 ± 1.0</td>
<td>14.4 ± 1.1</td>
<td>4.3 ± 0.3</td>
<td>9.1 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>August–October</td>
<td>18.2 ± 1.8</td>
<td>19.9 ± 2.5</td>
<td>5.5 ± 0.4</td>
<td>14.1 ± 2.0</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>32.6 ± 2.4</td>
<td>34.0 ± 2.9</td>
<td>9.7 ± 0.5</td>
<td>23.0 ± 2.1</td>
</tr>
</tbody>
</table>
growth of fouling organisms and the accumulation of silt and detritus on the culture units gradually limited water flow through them over time. Fouling levels were higher in trays than in panel nets; however, the negative impacts of fouling were mitigated by the structure of the culture unit. In panel nets, the 2 flat sides of the net eventually became fastened together by the buildup of fouling, which prevented the oysters' capacity to open their shell valves, and thus to feed. Fouling in panel nets could be reduced by more frequent cleaning; however, this increases labor costs and there is also a higher risk of mortality in juvenile oysters that are exposed to frequent handling as a result of the stresses associated with severing the byssus attachment, brushing of the shell, and exposure to the air (Taylor et al. 1997, Monteforte & Morales-Mulia 2000). Movement of oysters in the culture units also affected growth. Active mobility and the tendency to form aggregations are commonly observed in juvenile bivalves (Sastry 1979, Mackie 1984). Some oysters in the panel nets had deformed shells after becoming wedged in the net fibers while migrating, whereas oysters in the trays and pearl nets aligned themselves into aggregations and were not restricted in their ability to feed, because their shell valves were not held tightly together, as in the panel nets.

There were significantly higher growth increases for oysters held in trays at both sites in the study, even though fouling levels in these culture units were relatively high at both sites as well. Structural differences between the three culture unit types appeared to have affected water flow through them. Trays had larger surface perforations (1 cm²) and greater internal volume (15.3 L) than pearl nets (0.5 cm² and 7.9 L, respectively). Smaller mesh size in the pearl nets restricted water flow more quickly by fouling, and as a result, less food was available to oysters in those culture units. Fouling in trays at Cape Ferguson was significantly lower than in trays at Pioneer Bay, and increases in DVM, APM, ST, and WW were greater for oysters in trays at Cape Ferguson, indicating that growth of oysters in trays is further improved if fouling is minimized by appropriate site selection.

Figure 3. (A, B) Mean (± 1 SE) increases in dorsoventral measurement (DVM, measured in millimeters), anteroposterior measurement (APM, measured in millimeters), shell thickness (ST, measured in millimeters), and whole weight (WW, measured in grams) of juvenile *Pteria penguin* cultured over 6 mo (May to October 2009) in northeastern Australia at Pioneer Bay (A) and Cape Ferguson (B). Different letters above columns denote significant differences in growth between culture units.
CULTURE OF JUVENILE PTERIA PENGUIN

TABLE 2.
Mean survival (percent) and fouling (milligrams per square centimeter) for Pteria penguin juveniles held in three culture units over 6 mo at two sites.

<table>
<thead>
<tr>
<th></th>
<th>Site</th>
<th>Variable</th>
<th>Depth (m)</th>
<th>Panel Nets</th>
<th>Trays</th>
<th>Pearl Nets</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pioneer Bay</td>
<td>Survival (%)</td>
<td>3</td>
<td>71.5 ± 5.8 (57.1–85.7)</td>
<td>74.7 ± 15.5 (16.7–100)</td>
<td>82.7 ± 7.0 (57.1–100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fouling (mg/cm²)</td>
<td>3</td>
<td>25.7 ± 2.6 (18.6–31.5)</td>
<td>49.9 ± 4.2 (39.8–64.5)</td>
<td>30.7 ± 3.8 (22.2–45.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cape Ferguson</td>
<td>Survival (%)</td>
<td>3</td>
<td>93.8 ± 6.3 (75.0–100)</td>
<td>100 ± 0.0 (100)</td>
<td>95.3 ± 4.7 (86.0–100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fouling (mg/cm²)</td>
<td>3</td>
<td>26.2 ± 4.4 (17.6–39.9)</td>
<td>33.3 ± 2.0 (29.7–41.8)</td>
<td>30.1 ± 4.6 (15.7–42.7)</td>
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</tr>
</tbody>
</table>

All means shown with ±1 SE, and range in parentheses.

Growth of juvenile P. penguin recorded in this study ranged from 4.4–5.4 mm DVM/mo, which is within the range reported for Pteria in other studies, although lower than that reported by Beer (1999) of 5.9 mm DVM/mo for juvenile P. penguin at Pioneer Bay (Table 3). Variability in reported growth rates of pearl oysters is not uncommon and may be attributable to genetic potential or variability in environmental factors, such as water temperature and food availability (Lucas 2008, Saucedo & Southgate 2008). Hart & Joll (2006) for example, reported exceptional growth of juvenile Pinctada maxima (Jameson, 1901) in 1995 (42 mm average DVM increment) compared with 19½–36 mm in other years. The results reported here almost certainly represent seasonally reduced growth rates for P. penguin, because this study was conducted in autumn/winter, when the mean water temperature at Pioneer Bay was 23.3°C (range, 21.0–26.3°C) (AIMS 2011). In a pilot study at Pioneer Bay conducted in the spring/summer prior to this study, mean water temperature was 28.4°C (range, 26.2–29.3°C) (AIMS 2011) and mean DVM increase of juvenile P. penguin was 5.5 mm/mo (unpubl. data). This difference in growth rate also reflects the effect of seasonal variation in food availability, because food concentrations in the form of chlorophyll a and suspended particulate matter are highest in this region during the summer months, and can decrease by as much as 50% in the winter (De’ath 2007).

Pteria penguin is locally abundant at Pioneer Bay, but is not found at Bowling Green Bay (Dayton et al. 1989), and environmental conditions at the two sites differ markedly. At Cape Ferguson, river inputs and wind-driven wave action over the shallow waters generate high levels of suspended particulate matter (Yukihiira et al. 1999). At Pioneer Bay water quality conditions are relatively oligotrophic; it is an offshore coral reef site and it is protected by the island topography from prevailing ocean winds (Yukihiira et al. 2006). Studies show that there is generally significantly less recruitment of pearl oyster spat at in-shore sites compared with offshore sites because of higher runoff from land (Friedman & Southgate 1999).

In a study similar to this with the pearl oysters Pinctada maxima and Pinctada margaritifera (Linnaeus, 1758) (Yukihiira et al. 2006), juvenile P. margaritifera had significantly lower growth and survival at Cape Ferguson compared with those grown at Pioneer Bay, whereas P. maxima juveniles grew at similar rates at both sites, showing that high levels of suspended particulate matter did not negatively impact growth in P. maxima. Oysters may not be able to establish themselves at Cape Ferguson because there is a lack of suitable substrate for settlement, and/or the turbulent wave action and high turbidity levels prevent survival during the larval stage. The results of this study show, however, that if P. penguin spat from Pioneer Bay are transplanted to Cape Ferguson, they can grow well under turbid water conditions, and they actually had higher growth rates at this site compared with Pioneer Bay, which was unexpected considering that this species is not naturally present at Cape Ferguson.

Although bivalve molluscs feed primarily on phytoplankton, they may also exploit a range of nutrient sources, including bacteria, fungi, flagellates, suspended fine organic detritus, and inorganic material (Bricelj & Shumway 1991, Gosling 2003). The ability to select and retain particles of higher nutritional quality varies considerably between species (Bayne & Newell 1983, Dame 1996). In some bivalves, suspended silt in the water column can increase the assimilation of ingested algae, or

TABLE 3.
Mean monthly growth rates of juvenile Pteria spp.

<table>
<thead>
<tr>
<th>Species</th>
<th>Initial DVM (mm)</th>
<th>Duration (mo)</th>
<th>Final DVM (mm)</th>
<th>Growth (mm/mo)</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pteria sterna (Gould, 1851)</td>
<td>13.4</td>
<td>5</td>
<td>42.2</td>
<td>5.8</td>
<td>Bahia de la Paz Mexico, Gulf of California, Mexico</td>
<td>Farell et al. (1994), Monteforte and Aldana (1994)</td>
</tr>
<tr>
<td></td>
<td>6.6</td>
<td>4</td>
<td>45.6</td>
<td>9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pteria penguin (Röding 1798)</td>
<td>12.0</td>
<td>15</td>
<td>100.0</td>
<td>5.9</td>
<td>Queensland, Australia</td>
<td>Beer (1999)</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>17</td>
<td>83.3</td>
<td>4.7</td>
<td>Hainan, China</td>
<td>Gu et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>18.8</td>
<td>10</td>
<td>69.8</td>
<td>4.2</td>
<td>Guandong, China</td>
<td>Liang et al. (2001), this study</td>
</tr>
<tr>
<td></td>
<td>28.0</td>
<td>6</td>
<td>60.3</td>
<td>5.4</td>
<td>Queensland, Australia</td>
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</tr>
</tbody>
</table>
organic material in the silt may provide an important food source (Bayne & Newell 1983). Laboratory studies have shown that the addition of silt to algal diets can significantly increase growth and survival in some bivalve species (Winter 1975, Kiørboe & Møhlenberg 1981).

The results of this study show that *P. penguin* had significantly higher growth and survival rates at Cape Ferguson during the autumn/winter; however, it remains to be seen whether conditions at Cape Ferguson would favor growth and survival in this species year-round. During the spring/summer, the period of major rainfall in this region, there are wide fluctuations in salinity levels at Cape Ferguson as a result of freshwater inputs from local rivers and creeks (QPWS 2000, Lucas 2008).

In summary, several findings in this research are relevant for assessing nursery culture methods for juvenile *P. penguin*. Shallow-water coastal sites with high levels of suspended particulate matter do not appear to have detrimental effects during the dry season, and may in fact be nutritionally beneficial for fast growth. In addition, juvenile *P. penguin* should be loosely held in 3-dimensional culture units with 1-cm² perforations (or greater) to maximize water flow, and cultured at sites where fouling organisms are less prevalent.

**LITERATURE CITED**


