SEASONAL CHANGES IN RECRUITMENT OF *PTERIA PENGUIN* IN NORTH QUEENSLAND, AUSTRALIA

MICHAEL MILIONE* AND PAUL SOUTHGATE

Pearl Oyster Research Group, School of Marine and Tropical Biology, James Cook University, Qld 4811, Australia

**ABSTRACT** Spat recruitment of the winged pearl oyster *Pteria penguin*, in relation to season, substrate type, and depth was investigated at Orpheus Island in north Queensland for 27 mo, from February 2008 to April 2010. Two substrate types (70% shade cloth and open-weave polypropylene mesh bags) were deployed at 2 depths (4 m and 6 m) and checked every 6 wk for 3 spawning seasons to determine any differences in quantity of spatfall between these factors. No significant difference was found in spat recruitment between substrate types ($P = 0.158$) or depth ($P = 0.349$), although there was a significant seasonal effect on spat recruitment ($P < 0.001$), with a peak in the quantity of spatfall in late summer, from February to March, and no spat collected in the winter to spring (July to October). Maximum settlement of spat was 10.2 spat per mesh bag collector in February 2008. Recruitment was significantly reduced ($P < 0.001$) during the 2010 spawning season as a result of disturbance from severe storms generated by tropical cyclone Olga in late January.

**KEY WORDS:** winged pearl oyster, *Pteria penguin*, spat, reproduction, pearl oyster

**INTRODUCTION**

A reliable supply of spat (wild or cultured) is required for the commercial culture of bivalves. It is therefore useful to investigate the status of natural stocks in an area, the spatial and temporal distribution of spat, and the possible preferences of spat for certain collector materials prior to setting up extensive culture operations (Gosling 2003). Collector materials used for monitoring spat recruitment vary depending on the species to be collected and the traditional methods of collection in specific areas (Gervis & Sims 1992). Apart from their effectiveness as settlement substrate, spat collector materials can also be evaluated in terms of availability, durability, potential for reuse, cost, and the effort required to clean them of fouling (Vakily 1989).

*Pteria penguin* (Röding 1798) is a commercially important pearl oyster species cultivated in southeast Asia and in the west Pacific (Gervis & Sims 1992, Southgate et al. 2008). Natural populations are found along Australia’s northern coastline (Lamprell & Healy 1998), and there is some small-scale culture of this species in several states (O’Sullivan et al. 2007, QDPI 2007). However, little is known about the recruitment patterns and substrate preferences of *P. penguin* in Australian waters. In a year-long study conducted at Orpheus Island in North Queensland, Beer and Southgate (2000) reported that recruitment of *P. penguin* extended from December to June, with a peak in early autumn (March to April); in the Va’va’u Islands in Tonga, Yamamoto and Tanaka (1997) reported that highest recruitment of *P. penguin* occurred in summer, from December to March.

Beer and Southgate (2000) also found that settlement of *P. penguin* spat was significantly higher on spat collectors placed at a 6-m depth compared with 2 m, and that many of the spat recorded were observed to have settled on the outer surface of mesh bags. Gervis and Sims (1992) reported that *P. penguin* spat were often found on the outside, rather than the inside, of collector bags, suggesting a preference for access to free-flowing water. In addition, hatchery trials have indicated that *P. penguin* prefer to settle on dark materials or on the underside of materials, suggesting negative phototaxis at settlement (Gervis & Sims 1992).

This study investigated the timing of recruitment and abundance of *P. penguin* spat throughout successive breeding seasons, because significant variability in yearly recruitment patterns at specific sites has been reported for other pearl oysters, such as *Pteria sterna* (Gould, 1851) (Monteforte & Aldana 1994), *Pinctada imbricata* (Röding, 1798) (O’Connor & Lawler 2004), *Pinctada maxima* (Jameson, 1901) (Hart & Joll 2006), and *Pinctada margaritifera* (Linnaeus, 1758) (Oengpepa et al. 2006). In addition, spat preferences for specific substrate materials have been demonstrated (e.g., for *P. sterna* (Monteforte et al. 1995), *P. maxima* (Taylor et al. 1998), *Pinctada martensii* (Dunker, 1872) (Su et al. 2007), *Pinctada mazatlanica* (Hanley, 1856) (Saucedo et al. 2005), and *P. margaritifera* (Friedman et al. 1998)). Further investigation of the effect of depth on recruitment at Orpheus Island is also useful, as significant differences in levels of recruitment between 1- and 2-m intervals have been reported for *P. sterna* (Caceres-Martinez et al. 1992, Monteforte et al. 1995).

In this article, we report results from a sampling program conducted for 27 mo to assess the temporal variation in abundance of *P. penguin* spat at Orpheus Island. In particular, we focus on the time of year when spat are most abundant throughout 3 successive reproductive cycles, and test the suitability of 2 collector substrate materials (shade cloth and mesh bags) and 2 depths (4 m and 6 m) for collecting spat.

**MATERIALS AND METHODS**

**Study Site**

The study was carried out at James Cook University’s Research Station at Pioneer Bay, Orpheus Island, northeastern Queensland (Fig. 1) for 27 mo, from February 2008 to April 2010. Orpheus Island is situated 80 km north of Townsville and 17 km (8.3 nautical miles) east of the mainland coast. The study was conducted on a floating longline in Pioneer Bay, situated 50 m from a reef flat with a depth underneath of 10–13 m.

**Collection of Spat**

Two collector types were used—40 × 70-cm mesh bags and 40 × 70-cm sheets of 70% shade cloth—with 5 types placed at.
each depth for both treatments. Twenty spat collectors were attached at 2-m intervals along the longline, 10 at each depth of 4 m and 6 m. The collectors were attached to a 7-m length of 12-mm polypropylene rope, which was weighted at the end. The experiment was carried out from February 2008 to April 2010. Spat were harvested from collectors as close as possible to 45-day intervals, corresponding to 8 collection periods yearly: (1) February to March, (2) March to April, (3) May to June, (4) June to July, (5) August to September, (6) September to October, (7) November to December, and (8) December to January. Dorsoventral measurement (DVM) was recorded for spat to the nearest 0.1 mm using calipers. DVM is the greatest dorsoventral distance measured at a right angle to the hinge line (Saucedo & Southgate 2008).

Data Analysis

As a result of insufficient numbers and multiple 0 values for sampling periods when there was no recruitment, the spat recruitment data did not meet the assumptions of heterogeneity of variance and normality required for parametric analysis. Therefore nonparametric tests were used. Mann-Whitney tests were used to examine the variation in abundance of spat in relation to substrate and depth, and the Kruskal-Wallis test was used to examine the variation in abundance of spat in relation to time periods, with the P-value set at ≤ 0.05. For post hoc analyses, Mann Whitney tests were used to identify significant variations between groups, with the P-value set at ≤ 0.017, to correct for the possibility of type I errors (Olejnik et al. 1997). All tests were carried out using SPSS version 16 (IBM, Somers, NY).

RESULTS

A total of 201 Pteria penguin spat were collected during the course of the study. Of these, 101 were collected on shade cloth and 100 on mesh bags; 81 were collected at 4 m and 120 at 6 m. Mean DVM of collected spat was 5.9 ± 1.5 mm, and they ranged in size from 3.3–12.5 mm DVM.

Recruitment of Pteria penguin showed distinct seasonal trends in which the rise and fall of recruitment abundance coincided with changes in monthly water temperature (Fig. 2). Mean recruitment per collector was highest from February to March in 2008 (2.5 ± 0.7) and in 2009 (2.6 ± 0.7). In 2010, there was a smaller recruitment peak (0.9 ± 0.3), which occurred earlier, in December to January. Recruitment differed significantly between the 8 collection periods (Kruskal-Wallis, chi-square = 123.285, n = 360, df = 7, P < 0.001). Post hoc pairwise comparison analysis of collection periods showed that December to January and February to March did not differ significantly (Mann-Whitney, U = 1,154.0, n = 100, P = 0.737), but recruitment during these periods was significantly higher than all other collection periods (Mann-Whitney, P < 0.001 for all tests). Analysis of the 3 successive annual recruitment peaks (February to March 2008, February to March 2009, and December to January 2010) showed there was a significant difference in mean recruitment ranks (Kruskal-Wallis, chi-square = 6.881, n = 60, df = 2, P = 0.032). Post hoc pairwise comparisons showed recruitment in February to March 2009 was significantly greater than in December to January 2010 (Mann-Whitney, U = 107.0, n = 40, P = 0.011).

On the whole, there were no discernable differences in recruitment patterns between the 2 substrate types tested. Overall mean recruitment was 0.6 ± 0.9 for mesh bags and 0.6 ± 0.1 for shade cloth (Fig. 3A). The highest mean recruitment recorded (4.0 ± 1.1) was on mesh bag substrate in February to March 2008, whereas the highest recruitment recorded for shade cloth substrate was 2.8 ± 1.1 in February to March 2009. Differences in recruitment between substrate types were not significant (Mann-Whitney, U = 15,124.5, P = 0.158). Mean recruitment between depths was frequently higher at 6 m than at 4 m (Fig. 3B). Mean recruitment per collector at 6 m was 0.7 ± 0.1, and 0.5 ± 0.1 at 4 m. The highest mean recruitment recorded (3.7 ± 1.0) was at 6 m in February to March 2009, whereas the highest at 4 m (2.3 ± 0.9) was in February to March 2008. Differences in recruitment between depths were not significant (Mann-Whitney, U = 15,487.5, P = 0.349).

DISCUSSION

Overall, our results support previous reports of a distinct recruitment season for Pteria penguin in north Queensland (Beer & Southgate 2000) and in Tonga (Yamamoto & Tanaka 1997) (Table 1). Water temperature and its variation with latitude is
known to have an important influence on the timing of sexual development and spawning in bivalves (Sastry 1979). Pearl oysters in temperate regions generally show more discrete spawning seasons in the warmer summer months, whereas those in the tropics, where there is reduced variation in water temperature throughout the year, generally show multiple spawning peaks of varying intensity during the whole year (Saucedo & Monteforte 2008). A number of studies have shown that intraspecific reproductive cycles become shorter with increasing latitude for a range of pearl oyster species, such as *P. sterna* (Caceres-Martinez et al. 1992, Saucedo & Monteforte 1997, Hernández-Olalde et al. 2007), *Pinctada fucata* (Gould, 1850) (Behzadi et al. 1997, Choi & Chang 2003, O’Connor & Lawler 2004, Wada et al. 1995), *P. maxima* (Rose et al. 1990, Joll 1994, Wada et al. 1995), *Pinctada albina* (Lamarck, 1819) (O’Connor 2002), and *P. mazatlanica* (Garcia-Dominguez et al. 1996, Saucedo & Monteforte 1994).

There is comparatively little published literature on the reproductive activity of *P. penguin*. However, a histological study of the gametogenic cycle showed there were continuous partial spawnings throughout the year for this species in Thailand (Arjarasirikoon et al. 2004). This was attributed to the close proximity of the study site to the equator (7° S), where mean monthly water temperature ranged from 26.8–30°C (Arjarasirikoon et al. 2004). In both this and a prior study (Beer & Southgate 2000), more discrete patterns of spat recruitment were found for *P. penguin* at Orpheus Island (18° S), where annual water temperature ranges from 21–30°C (AIMS 2010). Annual recruitment of *P. penguin* at Orpheus Island extended from November to June, with a peak in late summer (February to March), coinciding with mean water temperatures between 28°C and 29°C. These dates were earlier than those previously reported by Beer and Southgate (2000), in which recruitment commenced in December and peaked in March to April. Overall, these findings support the notion of a shorter reproductive period with increasing latitude. Observations of shorter periods of spat recruitment for *P. fucata* and *P. alba* at Orpheus Island (Beer & Southgate 2000) compared with populations farther north in Torres Strait (10° S) (Tranter 1958, 1959) also provide further support of this hypothesis.

Despite this, there is also ample evidence of spawning activity in pearl oysters continuing throughout the year, at some low level in most species, even in temperate zones (e.g., for *P. sterna* (24° N) (Caceres-Martinez et al. 1992, Monteforte et al. 1995, Saucedo & Monteforte 1997), *P. fucata* (26° N) (Wada et al. 1995, Behzadi et al. 1997), *P. maxima* (18° S) (Rose et al. 1990), and *P. mazatlanica* (24° N) (Garcia-Dominguez et al. 1996, Saucedo & Monteforte 1997)). This also appears to be the case for *P. penguin*. Even though there was no recruitment of spat recorded in the winter-to-spring period (July to October) in this study, small numbers of spat were found on culture nets on the longline during this time. This suggests that the spat collectors may not necessarily reflect small pulses in recruitment. This could probably be addressed by increasing the number of spat collectors in such studies.

Our results also showed that peak spatfall was significantly lower in 2010 and occurred earlier (December to January) than in 2008 to 2009. Two successive recruitment peaks were recorded in February to March 2008 and in February to March 2009, whereas in 2010 a smaller peak was recorded earlier: in December to January. The deviation from the expected pattern of high recruitment in February to March was apparently influenced by severe storms generated by tropical cyclone Olga in late January to early February 2010 (BOM 2010). During this period, inclement weather also affected oyster growth, as mean monthly increase in DVM slumped simultaneously in 3 separate culture populations of *P. penguin* held at Orpheus Island and nearby at Cape Ferguson and Horseshoe Bay at Magnetic Island (Milione and Southgate, unpublished data).

Interrannual variations in the timing and duration of spatfall, and in the total abundance of spat between years have been commonly reported for pearl oysters. The start and duration of the main spatfall season of *P. sterna* at Baha California varied from 1 to another with differences of 1–3 mo (Monteforte et al. 1995). Mean spatfall of *P. imbricata* at Port Stephens, New South Wales, fell from 453 per collector in 1998 to 20 spat per collector the following year (O’Connor & Lawler 2004). Similar variability has also been reported for *P. penguin* in Tonga (Yamamoto & Tanaka 1997), *P. margaritifera* in the Solomon Islands (Oengpepa et al. 2006), *P. maxima* in western Australia (Hart & Joll 2006), and *P. fucata* in Torres Strait (Tranter 1959). These findings highlight the fact that although spat collection studies provide useful information about when peak spat fall is likely to occur, the timing and abundance of spatfall may vary annually as a result of environmental conditions, or other factors such as mortality through predation or inadequate settlement surfaces (Gosling 2003).

The highest mean recruitment per collector we recorded was 4.0 ± 1.1 for mesh bags in February to March 2008, which is
Results have either been inconclusive or are highly specific, so that no universally accepted collection method has emerged from these studies. *P. penguin* are reported to prefer settling on the outside of collector bags (Gervis & Sims 1992, Beer & Southgate 2000), but it is unclear whether this is the result of a preference for the mesh bag substrate or whether it reflects a preference for greater water flow, as has been suggested (Gervis & Sims 1992). Pearl oyster spat have also been observed to settle on adult shells (e.g., *P. maxima*; Takemura & Okutani 1955, Yamamoto & Tanaka 1997). On the other hand, it is also contended that mesh bags tend to become colonized by predators such as xanthid and portunid crabs, cone gastropods, turbellarian flatworms, and spionid polychaetes, leading to higher mortality of spat (Monteforte & Garcia-Gasca 1994, O’Connor 2002). However, during the peak reproductive seasons we observed crabs, flatworms, and amphipods to be present inside the mesh bags, so it is possible that this may have affected the number of spat counted. We also found that pieces of shade cloth were more durable than the mesh bags, which often became frayed and had to be replaced during the course of the experiment. The mesh bags were also more difficult to clean and to inspect for spat than the shade cloth, which we recommend for similar studies. Our results also showed that recruitment did not differ significantly between depths of 4 m and 6 m, despite higher recruitment being earlier reported at this site at the 6-m depth compared with 2 m (Beer & Southgate 2000). Therefore, broadening the range of suspension depth of collectors to commence from 4 m would increase recruitment yield at this site.

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Latitude</th>
<th>Timing of Spatfall</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pteria penguin</em></td>
<td>Orpheus Island, Queensland</td>
<td>18° S</td>
<td>From Dec-Jun, with peak in late summer (Mar–Apr)</td>
<td>(Beer &amp; Southgate 2000)</td>
</tr>
<tr>
<td></td>
<td>Va’vau Islands, Tonga</td>
<td>21° S</td>
<td>Highest in summer (Dec–Mar)</td>
<td>(Yamamoto &amp; Tanaka 1997)</td>
</tr>
<tr>
<td><em>Pteria sterna</em></td>
<td>Baha California, Mexico</td>
<td>24° N</td>
<td>Continuous, with peak in winter (Feb–Mar)</td>
<td>(Caceres-Martinez et al. 1992)</td>
</tr>
<tr>
<td></td>
<td>Orpheus Island, Queensland</td>
<td>18° S</td>
<td>Continuous, with peak in winter (Jun–Aug)</td>
<td>(Beer &amp; Southgate 2000)</td>
</tr>
<tr>
<td></td>
<td>Port Stephens, New South Wales</td>
<td>32° S</td>
<td>Continuous, with peak in winter (Jan–Feb)</td>
<td>(O’Connor 2002)</td>
</tr>
<tr>
<td><em>Pinctada albina</em></td>
<td>Thursday Island, Queensland</td>
<td>10° S</td>
<td>Continuous, with peak in spring–summer (Nov–Jan)</td>
<td>(Tranter 1958)</td>
</tr>
<tr>
<td></td>
<td>Orpheus Island, Queensland</td>
<td>18° S</td>
<td>Over 9 mo, with peak in Aug and Feb</td>
<td>(Beer &amp; Southgate 2000)</td>
</tr>
<tr>
<td></td>
<td>Port Stephens, New South Wales</td>
<td>32° S</td>
<td>Early summer (Nov–Jan)</td>
<td>(Sumpton et al. 1990)</td>
</tr>
<tr>
<td><em>Pinctada fucata</em></td>
<td>Thursday Island, Queensland</td>
<td>10° S</td>
<td>Continuous, with peak in May–Aug and Jan–Mar</td>
<td>(Jiménez et al. 2000)</td>
</tr>
<tr>
<td></td>
<td>Gulf of Cariaco, Venezuela</td>
<td>10° S</td>
<td>Continuous, with peak in May–Aug</td>
<td>(Beer &amp; Southgate 2000)</td>
</tr>
<tr>
<td></td>
<td>Orpheus Island, Queensland</td>
<td>18° S</td>
<td>Over 7 mo, with peak in spring–summer (Nov–Jan)</td>
<td>(Jiménez et al. 2000)</td>
</tr>
<tr>
<td></td>
<td>Hervey Bay, Queensland</td>
<td>23° S</td>
<td>Early summer (Nov–Jan)</td>
<td>(O’Connor &amp; Lawler 2004)</td>
</tr>
<tr>
<td><em>Pinctada margaritifera</em></td>
<td>Gizo, Solomon Islands</td>
<td>8° S</td>
<td>Continuous with peak in late summer (Oct–Nov)</td>
<td>(Okutani 1955)</td>
</tr>
<tr>
<td></td>
<td>Orpheus Island, Queensland</td>
<td>18° S</td>
<td>Continuous with peak in late summer (Nov–Mar)</td>
<td>(Beer &amp; Southgate 2000)</td>
</tr>
</tbody>
</table>

Studies testing different kinds of spat collectors to determine the most effective methods for spat collection have compared substrate materials, including PVC slats, polypropylene rope, and monofilament nylon (Taylor et al. 1998); smooth and rough-textured plastic sheets (Su et al. 2007); shade cloth and plastic strips (Friedman et al. 1998); fishing net, mosquito net, mesh bags, and shade cloth (Sumpton et al. 1990); and chivato bush, palm leaves, and mesh bags (Monteforte et al. 1995). The results have either been inconclusive or are highly specific, so that no universally accepted collection method has emerged from these studies. *P. penguin* are reported to prefer settling on the outside of collector bags (Gervis & Sims 1992, Beer & Southgate 2000), but it is unclear whether this is the result of a preference for the mesh bag substrate or whether it reflects a preference for greater water flow, as has been suggested (Gervis & Sims 1992). Pearl oyster spat have also been observed to settle on adult shells (e.g., *P. maxima*; Takemura & Okutani 1955, Yamamoto & Tanaka 1997). On the other hand, it is also contended that mesh bags tend to become colonized by predators such as xanthid and portunid crabs, cone gastropods, turbellarian flatworms, and spionid polychaetes, leading to higher mortality of spat (Monteforte & Garcia-Gasca 1994, O’Connor 2002). However, during the peak reproductive seasons we observed crabs, flatworms, and amphipods to be present inside the mesh bags, so it is possible that this may have affected the number of spat counted. We also found that pieces of shade cloth were more durable than the mesh bags, which often became frayed and had to be replaced during the course of the experiment. The mesh bags were also more difficult to clean and to inspect for spat than the shade cloth, which we recommend for similar studies. Our results also showed that recruitment did not differ significantly between depths of 4 m and 6 m, despite higher recruitment being earlier reported at this site at the 6-m depth compared with 2 m (Beer & Southgate 2000). Therefore, broadening the range of suspension depth of collectors to commence from 4 m would increase recruitment yield at this site.
In summary, this study has confirmed that Pioneer Bay at Orpheus Island is a reliable place for the collection of *P. penguin* spat. Collection of spat is expected to be most effective between November and April, with a peak in February to March expected in most years. Shade cloth (70%) is an effective and relatively inexpensive substrate material, which is less prone to colonization by predators than mesh bags, and is easier to clean and inspect for spat. Collectors at Orpheus Island should be submersed at a depth of 4 m or more to maximize the yield of spat.

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LITERATURE CITED


