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Review Article

Factors influencing the quality of half-pearls (mabé) produced by the winged pearl oyster, *Pteria penguin* (Röding, 1758)

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Abstract

The winged pearl oyster, *Pteria penguin*, is cultured primarily to produce half-pearls (mabé). The mabé quality is influenced by culture techniques, but there is limited information in this field. *P. penguin* with mean (±SE) dorso-ventral height of 250 ± 6.5 mm were used to investigate the influence of culture period and nucleus position on mabé quality. Oysters were relaxed using 1-propylene phenoxetol, and five nuclei were glued at different positions to the inner surfaces of the oyster shells; three on the more concave left valve and two on the right valve. Nucleated oysters were then cultured for 10 months under commercial pearl farming conditions at Savusavu in Fiji. Nacre deposited at the base and top of the nuclei was measured monthly, from the 6th to the 10th months of culture and the different qualities of mabé produced at different positions were scrutinized. Nacre thicknesses at the base and top of the resulting mabé were significantly different at different months ($P < 0.05$) and the rate of nacre deposition was highest during the warmer months. The different positions of nuclei on the valve greatly affected the quality of mabé formed. After a 10-month culture period, around 1 mm of nacre covered the nuclei although the best quality mabé were obtained after 9 months.

Keywords: Pearl oyster, *Pteria penguin*, half-pearl, mabé, pearl quality, nacre

Introduction

Pearl culture is a major source of income for Pacific island countries (Ponia 2010) and has expanded, over recent years, from its traditional base in eastern Polynesia into some countries in the western Pacific such as the Fiji Islands. Although production of round pearls for export is the major focus for Pacific pearl industries (Southgate, Strack, Hart, Wada, Monteforte, Carino, Langy, Lo, Acosta-Salmon & Wang 2008), production of half-pearls has also become important. Unlike round pearls, half-pearls can be made by local people with minimal training. Furthermore, half-pearl production requires around 30% of the culture time required for round pearls (Haws, Ellis & Ellis 2006) and, although they are generally less valuable than round pearls, multiple (up to five) half-pearls can be produced from an individual oyster in contrast to a single round pearl (Gervis & Sims 1992). These benefits have encouraged growing interest in half-pearl culture by pearl farmers and coastal communities throughout the Pacific.

Half-pearls are now generically referred to as 'mabé' regardless of the mollusc species used to produce them; these include pearl oysters from the genera *Pinctada* and *Pteria* (Taylor & Strack 2008) and even abalone (Matlins 1996). However, the term mabé was traditionally referred to half-pearls produced by the winged pearl oyster, *Pteria penguin* (Röding, 1758) or 'mabé gai' (Southgate *et al.* 2008), which is the subject of this study. Mabé are hemispherical cultured pearls produced by adhesion of a nucleus to the inner surface of the oyster shell (Kripa, Abraham, Libini, Velayudhan, Radhakrishnan, Mohamed & Mohan 2008; Taylor & Strack 2008). The nucleus can vary in shape (e.g. hemispherical, heart and tear drop) and polycyanoacrylate glue, commonly referred as super glue, is usually used to attach them to oyster shells (Haws *et al.* 2006; Ruíz-Rubio, Acosta-Salmon, Olivera, Southgate & Rangel-Davalos 2006; Kripa *et al.* 2008).

Pteria penguin is cultured for mabé production in Japan, Australia, Philippines, Indonesia, Thailand, Vietnam and Tonga (Southgate *et al.* 2008). In the South Pacific region, Tonga is recognized as the only country producing mabé (FAO 1997; Southgate *et al.* 2008). However, *P. penguin* is widespread throughout the western Pacific and there is clear opportunity for further development of mabé production in this region. Pearl value is determined by pearl quality and there is little information on factors affecting the quality of mabé produced by *P. penguin*. Such information would provide an important basis for further development of a mabé industry in the Pacific region.

Studies with the related rainbow-lip pearl oyster, *Pteria sterna* (Gould 1851), in Mexico, have reported that nuclei for half-pearl production should be implanted in winter or spring when the seawater temperature is low (Ruíz-Rubio *et al.* 2006). An increase in seawater temperature after nucleus implantation increases the metabolic rate of oysters and stimulates increased nacre deposition onto the nuclei (Gervis & Sims 1992). Generally, a period of 5–12 months produces half-pearls with a commercially acceptable nacre thickness, depending on culture methods, geographical location, and oyster species used (Farn 1986; Ruíz-Rubio *et al.* 2006). The nacre quality of half-pearls produced by *P. sterna* improved with increasing culture period beyond 5 months (Ruíz-Rubio *et al.* 2006). The position within the shell chosen for nucleus adhesion also influences the quality of resulting half-pearls with those implanted close to the adductor muscle producing pearls with no commercial value in *P. sterna* (Ruíz-Rubio *et al.* 2006). The results of Ruíz-Rubio *et al.* (2006) provide a basis for optimizing half-pearl production from *P. sterna* and for maximizing pearl yield and pearl quality. No similar information is available for the more widely cultured *P. penguin*.

This study aimed to determine the influence of nucleus position, cultivation period, and water quality parameters on the quality of mabé produced by *P. penguin*. The results will allow development of a protocol to maximize pearl yield and value, thereby supporting income generation and livelihood opportunities in the Pacific region.

Materials and methods

This experiment was performed at a commercial pearl farm (J. Hunter Pearls) in Savusavu Bay, on the island of Vanua Levu, Fiji Islands (16°49′ 10.96″S, 179°19′56.21″E). The mean depth of water beneath the pearl farm is 25 m. Oysters used for this experiment were wild-collected as spat and cultured on long lines prior to the experiment. Eighty-five oysters were selected for nucleus implantation. They were 3.5 years of age at the start of the experiment with a mean (±SE) dorso-ventral measurement (DVM) of 250 ± 6.5 mm. Typically, the nacre of *P. penguin* shells from Fiji is silver-white in the centre of the shell and is bordered by an area of golden nacre, which is approximately 20 mm wide ventrally, but reduced anteriorly and posteriorly (Fig. 1).

Prior to nucleus implantation, the oysters were cleaned before being placed on their hinges in sunlight in groups of five for approximately 10 min

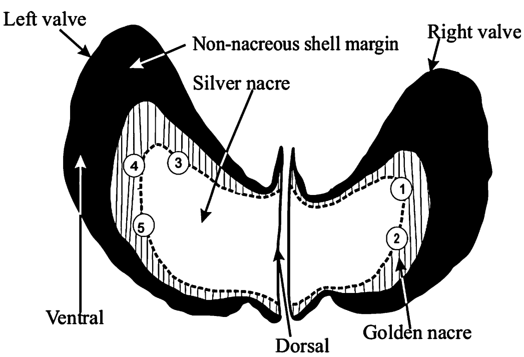

Figure 1 Diagrammatic representation of the inner surfaces of *Pteria penguin* shells showing positions where nuclei were attached and characteristic colouration of nacre within Fijian *P. penguin* shells.

until the shell valves opened slightly. A wooden wedge was then inserted between the shell valves to prevent closure, and the oysters were placed in an anaesthetic solution (1-propylene phenoxetol at 3 mL L^{-1} of seawater) to fully relax them prior to nucleus implantation (Mills, Tlili & Norton 1997). At any point, only five oysters were held in the anaesthetic solution to prevent mortality due to mantle and body collapse that may result from over exposure of pearl oysters to relaxants (Acosta-Salmón, Martínez-Fernández & Southgate 2005; Mamangkey, Acosta-Salmon & Southgate 2009). The mantle tissue of relaxed oysters was probed with forceps to confirm relaxation and oysters were considered to be fully relaxed when there was no reaction to this stimulus, or if shell valves did not close when removed from the relaxant solution (Norton, Dashorst, Lansky & Mayer 1996; Mamangkey & Southgate 2009).

Relaxed oysters were again wedged open carefully so that the shell gape did not exceed 25 mm to avoid potential damage to the adductor muscle. Relaxed and wedged oysters were then placed individually on a stand for nucleus implantation (Taylor & Strack 2008). Their mantle tissues were pushed back using a blunt plastic spatula to expose the nacreous inner shell surface. The oysters used in this study were large enough to accommodate five hemispherical nuclei, which were attached to the shells at the positions shown in Fig. 1. Three nuclei were attached to the inner surface of the left (more convex) shell valve and two others were applied to the right valve (Fig. 1). They were positioned to allow the oysters to be able to close their shells normally (Saucedo, Monteforte & Blanc 1998; Haws *et al.* 2006). The clear plastic nuclei had a diameter of 15 mm and a height of 7 mm. Polycyanoacrylate gel was used to attach nuclei to the shells. Each nucleus was pressed to the inner shell surface for 5–10 s for complete adhesion (Haws *et al.* 2006).

To minimize stress and possible mortality due to desiccation, the implantation process was limited to approximately 3 mins. Following nucleus implanting, oysters were placed into a 30 L aquarium containing freshly aerated seawater to allow recovery. Continuous aeration was maintained with a battery-operated aerator and water in the aquarium was replaced at 30 min intervals. Oysters were considered to have recovered from anaesthesia once they closed their shells in response to mantle stimulation or removal from the water (Norton *et al.* 1996; Mamangkey *et al.* 2009).

Following implantation, oysters were tied to 1.5 m length of ropes (chaplets) and hung back on the long line at a depth of 6 m. Each chaplet contained 10 oysters with the exception of one that contained five. Water temperature was recorded using a multi data-logger every 2 h, while dissolved oxygen (DO) content and salinity were measured weekly using a YSI 85 m and turbidity was measured weekly using a Secchi disc. Oysters were cleaned of fouling at 8-week intervals.

Beginning 6 months after nucleus implantation, four oysters were sacrificed every month until the 10th month of culture, when the experiment was terminated. Mabé from all oysters from each sampling period were cut from the shells using a high-speed diamond-cutting tool. The shells at the base of the mabé were ground to expose the base of the nuclei. The thickness of the nacre covering the nucleus on the top (calculated as the difference between nucleus height and mabé height) and at the base (calculated from difference between nucleus diameter and mabé diameter) (Fig. 2) was measured using a micrometer screw gauge (±0.01 mm). Nacre thickness data were tested for normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene's test). The possible difference of nacre thickness in different months was determined using one-way ANOVA followed by Tukey post hoc test. The analysis was performed using IBM SPSS statistics software version 19 (New York, NY, USA). Mabé were graded for quality using alphabetical nomenclature (Matlins 1996; Ruíz-Rubio *et al.* 2006), which accounted for the following key determinants of pearl quality: lustre, size, shape, surface perfection and nacre thickness. The characteristics used to grade pearls in this study are defined in Table 1.

Results

Of the 85 oysters implanted, 28% (24 oysters) died during the experiment. The majority of these deaths (18 oysters, 78.8%) occurred within 3 weeks of nucleus implantation.

Nacre thickness at the top ($F = 15.39$, $P = 0.00$) and base ($F = 41.54$, $P = 0.00$) of the mabé (Fig. 2) produced during the experiment were significantly different in different months (Table 2). After 6 months, mean nacre thickness

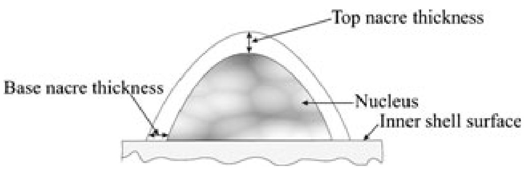

Figure 2 Measurement of nacre thickness at the top and base of mabé during this study.

Table 1 The grading system used to evaluate pearl quality in this study (Matlins 1996; Ruíz-Rubio *et al.* 2006)

Grade	Mabé characteristics
AAA	The highest quality of pearl. Perfect quality, with outstanding lustre, with at least 95% free from any forms of defect. Dark colours and good symmetry
AA	Good quality. At least 75% of the surface does not have any form of defects. Has good lustre with unvarying colours
A	Medium quality. With at least 25% of defects. Varying colours with poorer symmetry and no over-tones
B	Sufficient quality. Uneven surfaces, with a lot of flaws, but having good lustre
C	Pearls with minimal commercial value having poor lustre and imperfect shapes
NC	Pearls with no commercial value. Poorest lustre of all, with virtually all surface imperfections and very thin nacre

on top of the nuclei was 0.48 ± 0.11 mm and this increased to 0.97 ± 0.15 mm after 10 months of culture. Mean nacre thicknesses at the base of the nuclei were 0.50 ± 0.38 mm and 1.04 ± 0.05 mm after 6 and 10 months of culture respectively. The rate of nacre deposition varied over the culture period and was most rapid over the first 6–7 months of culture. Nacre was deposited on the top of nuclei at an average rate of 5.7 ± 0.11 μm day^{-1} and 6.0 ± 0.11 μm day^{-1} after 6 months (August) and 7 months (September) respectively (Fig. 3). The mean rate of nacre deposition slowed to 3.7 ± 0.09 μm day^{-1} after 8 months of culture (October) and slowed even further to 1.0 ± 0.05 μm day^{-1} after 9 months of culture (November) (Fig. 3). The rates of nacre deposition at the base of nuclei were very similar to that at the top of the nuclei and averaged 6.0 ± 0.11 μm day^{-1} and 6.3 ± 0.13 μm day^{-1} after 6 and 7 months of culture, respectively, but declined to 4.0 ± 0.09 μm day^{-1} and 1.3 ± 0.05 μm day^{-1}, after 8 and 9 months respectively.

Table 2 Mean (±SE) nacre thickness (mm) at the top and base of mabé produced by *Pteria penguin* at a depth of 6 m over a 10-month period in Savusavu Bay, Fiji Islands

Month (culture period)	Top	Base
August (6 months)	0.48 ± 0.11^{1}	0.50 ± 0.38^{1}
September (7 months)	0.65 ± 0.25^{1}	0.68 ± 0.16^{1}
October (8 months)	0.83 ± 0.21^{2}	0.87 ± 0.10^{1,2}
November (9 months)	0.94 ± 0.19^{2,3}	0.99 ± 0.07^{3}
December (10 months)	0.97 ± 0.15^{3}	1.04 ± 0.05^{3}

Values in columns with different superscripts are significantly different ($P < 0.05$).

Mabé formed during the culture period varied in their colour and they reflected the nacre colour in the area of the shell to which the nucleus was glued. For example, those formed close to the adductor muscle towards the centre of the shell (position 3, Fig. 1) were mainly metallic grey to silver-white in colour, while those formed more

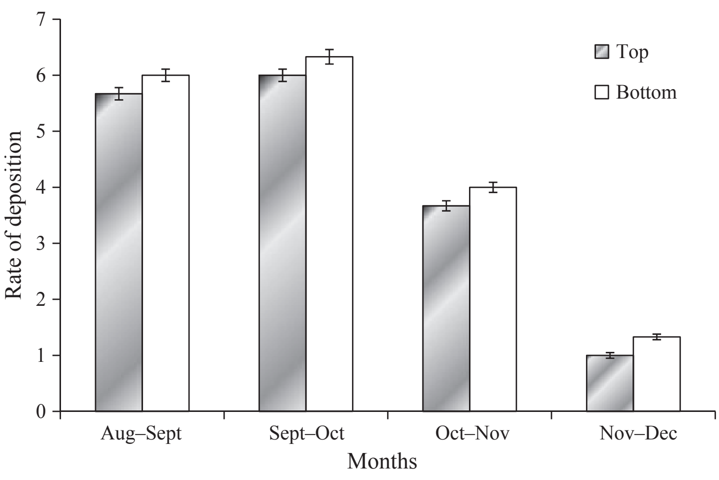

Figure 3 Mean (±SE) rate of nacre deposition (μm per day) at the top and base of mabé produced by *Pteria penguin* between 6 and 7 months (August/September), 7 and 8 months (September/October), 8 and 9 months (October/November) and 9 and 10 months (November/December) of culture.

Figure 4 Mabé formed on the right shell valve of *Pteria penguin*. The pearl in the background had a silver-white colour, while the closer mabé had a golden colour with greenish overtones. The latter was formed close to the ventral edge of the nacre from a nucleus glued onto the golden-coloured nacre band (see Fig 1).

ventrally and closer to the growing nacre edge reflected the more colourful nacre in that area of the shell (Fig. 1). Generally, the resulting mabé ranged in colour from metallic grey to gold and many had greenish, purplish and light bluish overtones.

As well as colour, the positions to which nuclei were applied to the inner surfaces of *P. penguin* shells also influenced the quality of resulting mabé. Those formed at positions 1 and 2 (Fig. 1) shared very similar characteristics; they showed good lustre and all had near-symmetrical round shapes. All mabé formed at these positions were graded as AA (Table 1). In contrast, 82% of mabé formed at position 3 (Fig. 1) was of lower quality, mostly dull white in colour with minimal commercial value that was categorized as C grade. Mabé formed at position 4 (Fig. 1) had very high lustre, good colour and high commercial value. The quality of mabé formed at position 5 was good, with most having a golden colour with green and purple overtone (Fig 4). However, 14.6% of the total mabé sampled from position 4% and 18.9% of those from position 5 had asymmetrical shapes. Mabé formed at positions 4 and 5 were generally graded as AA and A respectively.

Water quality parameters at the culture site varied during the experiment. Water temperature ranged from 26.2°C in August to 28.7°C in March (Table 3). Salinity ranged from a minimum of 31.2‰ in April to a maximum of 33.5‰ in November, while the lowest DO value of 4.88 mg L^{-1} was recorded in March and the highest

Table 3 Variations in water quality parameters recorded at the experimental site during this 10-month study

Month	Temperature (°C)	Salinity (‰)	Dissolve oxygen (mg L^{-1})	Turbidity (m)
1 (March)	28.7	33.2	5.0	7.0
2 (April)	27.5	32.0	5.2	7.0
3 (May)	27.3	32.5	5.0	5.0
4 (June)	27.2	33.7	5.3	5.5
5 (July)	26.0	32.5	5.5	6.0
6 (August)	26.2	32.2	6.0	7.0
7 (September)	26.3	31.7	7.0	7.0
8 (October)	26.5	33.4	5.2	7.0
9 (November)	26.9	33.6	7.0	6.0
10 (December)	26.5	32.9	5.2	4.5

of 7.04 mg L^{-1} in September. A marked increase in turbidity was noticed towards the end of the study in the sampling months of November and December when Secchi depth decreased from 7 m in August, September and October to 6 m in November and 4.5 m in December (Table 3).

Discussion

Nacre thickness is one the main measurable feature used to evaluate half-pearl quality (Ruíz-Rubio *et al.* 2006). This study recorded similar rates of nacre deposition between the 6th and 9th months of culture (August–October, Fig. 3) with improving lustre during this period. Maximum rate of nacre deposition on the top and base of nuclei was between the 7th and 8th months of culture (September–October, Fig. 3) after which, the rate of deposition declined to the 9th and 10th months of culture (November–December) when the rate of nacre deposition was less than one-third to that during the period of maximal nacre deposition (September–October) (Fig. 3). When examining changes in water quality parameters throughout the culture period (Table 3), correlations between these data and the rate of nacre deposition are not clear; however, the lowest rate of nacre deposition recorded in this study occurred during the period of the highest recorded turbidity. This may indicate a link between nacre deposition rate and food availability or the level of suspended particulate matter. A recent study in Australia reported that *P. penguin* is able to tolerate environments with relatively high levels of particulate inorganic matter, possibly as a result of its capacity to derive higher nutrient uptake under these conditions

(Milione & Southgate 2012). The authors concluded that culture sites with relatively high turbidity may promote faster growth of *P. penguin*. However, no prior study has reported the effect of increasing turbidity on nacre deposition rate in any pearl oyster species and this issue requires clarification. Links between high turbidity and round pearl nucleus rejection and mortalities in *Pinctada fucata* in Japan have been reported, as well as a positive relationship between pearl lustre and high turbidity (Lucas 2008).

A nacre thickness of between 0.7 mm and 2.5 mm is usually required for commercial half-pearl culture and this is generally attained over a culture period of 6–12 months (Shirai 1994; Mclaurin, Arizmendi, Farell & Nava 1999; Ruíz-Rubio *et al.* 2006). This study has shown that similar nacre thicknesses can be achieved by *P. penguin* in Fiji waters over a similar culture period. Notably, the quality of mabé continued to improve throughout the culture period and it was not until the 9th and 10th months of culture, when the highest commercial value of mabé was achieved. In a similar study with *P. sterna*, commercial nacre thickness was attained after 5 months, but the commercial value of resulting half-pearls was highest after 9 months of culture (Ruíz-Rubio *et al.* 2006). The term 'lustre' is used to describe the reflective index of a pearl (Taylor & Strack 2008) and is a key characteristic influencing pearl quality. The lustre of mabé from *P. penguin* in this study was adequate when they were first harvested after 6 months although some had uneven surfaces. Lustre quality improved with increasing culture period and the best quality mabé were obtained in the 9th month of culture during a period of relatively low water temperature (June–October). Reduced water temperature is believed to improve the quality of pearls as it results in a slower rate of nacre deposition with a finer finish and better lustre (Taylor & Strack 2008). Indeed, round pearls are commonly harvested at the coolest time of the year to take advantage of this. The results of this study indicate that the timing of nucleation for mabé production by *P. penguin* should consider seasonal changes in water temperature at the culture site to maximize the quality of resulting pearls.

The position at which nuclei were attached to the shells of *P. penguin* was another factor that influenced the quality of resulting mabé. There were no asymmetrical (irregular) mabé formed at positions 1 and 2 in this study, however, most (89%) of the mabé formed at these positions were metallic grey or silver-white in colour reflecting the colour of nacre in the area of the shell to which the nucleus was attached. Our results show that golden-coloured mabé can be obtained if nuclei are attached on (or close to) the golden-coloured area (Fig. 1) of nacre distal to the silver-white nacre of Fijian *P. penguin* shells. All mabé formed at these positions had good lustre; however, 53% and 47% of the mabé formed at positions 4 and 5, respectively, were asymmetrical. Formation of asymmetrical mabé is thought to result from the inability of mantle tissue to completely cover nuclei pasted to the shell (Ruíz-Rubio *et al.* 2006) because the nuclei effectively increase the surface area of the shell valve. Despite their asymmetrical shapes, the more attractive colours and lustre of these mabé assure good commercial value; they are often used to make necklaces or individual jewellery items with unique shapes. A high proportion of mabé formed at position 3 (65%) were dull white with poor lustre. Although the nuclei initially attached at this position were distant from the adductor muscle, after 6 months of culture, the growing adductor muscles had at least partially covered nuclei at position 3 in 75% of the oysters sampled and this coverage increased with the culture period. This result indicates that smaller *P. penguin* will produce poor quality mabé with impaired lustre at position 3. This problem was also reported in *P. sterna* (Ruíz-Rubio *et al.* 2006).

Our results show that 3-year-old *P. penguin* within a size range of 250–300 mm are appropriate for nucleus implantation and can produce mabé of commercial quality within a culture period of around 10 months under Fijian conditions. Furthermore, gluing five nuclei per oyster (three on the left valve and two on the right) presented no difficulty for oysters of this size which were able to open and close their shells freely. However, sufficient space around nucleus is required to maximize the proportion of symmetrical mabé. In addition, pearl 'carvers', artisans and jewellers in the Pacific often enhance mabé by adding carved designs to shell surrounding them (Teitelbaum & Fale 2008). For these reasons, it may be more appropriate to evenly attach only two nuclei per valve to ensure high quality mabé production from *P. penguin*.

The study showed that the positions at which nuclei were attached to *P. penguin* shells influenced the quality of mabé formed. Mabé with high commercial values were produced at positions 1, 2, 4 and 5. While mabé produced at positions 1 and 2 showed greater symmetry, they were not as colourful as those from more ventral positions which generally had greater asymmetry. Our results also showed that mabé sampled after 6 months had sufficient nacre thickness to be commercially viable, and that lustre improved over the culture period. The best quality mabé were obtained in the 9th month of culture suggesting a culture period of 9 months is most appropriate for mabé production in Fiji. The simplicity of mabé culture provides opportunities for alternative livelihoods in rural communities in the South Pacific region. The information generated in this study provides a foundation for such development and will allow mabé producers to maximize pearl quality and value.

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References

Acosta-Salmón H., Martínez-Fernández E. & Southgate P.C. (2005) Use of relaxants to obtain saibo tissue from the blacklip pearl oyster (*Pinctada margaritifera*) and the Akoya pearl oyster (*Pinctada fucata*). *Aquaculture* **246**, 167–172.

FAO (1997) *Potential of Commercial Development of Mabe Pearl Farming in Vava'u Islands, Kingdom of Tonga*, Food and Agricultural Organization of the United Nations, Suva, Fiji.

Farn A.E. (1986) *Pearls Natural Cultural and Imitation*, Butterworth Gem Books, London, England.

Gervis M.H. & Sims A.N. (1992) *The Biology and Culture of Pearl Oysters (Bivalvia: pteriidae)*, International Center for Living Aquatic Resources Management and Reviews 21, Mainila, Philippines.

Haws M., Ellis S. & Ellis E.P. (2006) *Producing Half-Pearls (Mabe)*, Western Indian Ocean Marine Science Association, University of Hawaii, Hilo and the Coastal Resources Center, University of Rhode Island, Hilo, Hawaii.

Kripa V., Abraham K., Libini C., Velayudhan T., Radhakrishnan P., Mohamed K. & Mohan J. (2008) Production of designer mabe pearls in the black-lipped pearl oyster, *Pinctada margaritifera*, and the winged pearl oyster, *Pteria penguin*, from Andaman and Nicobar Islands, India. *Journal of the World Aquaculture Society* **39**, 131–137.

Lucas J. (2008) Environment influences. In: *The Pearl Oyster* (ed. by P.C. Southgate & J.S. Lucas), pp 187–229. Elsevier, Amsterdam, The Netherlands.

Mamangkey N.G.F. & Southgate P.C. (2009) Regeneration of excised mantle tissue by the silver-lip pearl oyster, *Pinctada maxima* (Jameson). *Fish & Shellfish Immunology* **27**, 164–174.

Mamangkey N.G.F., Acosta-Salmon H. & Southgate P.C. (2009) Use of anaesthetics with the silver-lip pearl oyster, *Pinctada maxima* (Jameson). *Aquaculture* **288**, 280–284.

Matlins A.L. (1996) *The Pearl Book: The Definitive Buying Guide*, Gemstone Press, Woodstock, VT, USA.

Mclaurin D., Arizmendi E., Farell S. & Nava M. (1999) Pearls and pearl oysters from the Gulf of California, México, an update. *The Australian Gemmologist* **20**, 239–245.

Milione M. & Southgate P. (2012) Growth of the winged pearl oyster, *Pteria penguin*, at dissimilar sites in Northeastern Australia. *Journal of Shellfish Research* **31**, 13–20.

Mills D., Tlili A. & Norton J.H. (1997) Large-scale anesthesia of the silver-lip pearl oyster, *Pinctada maxima* Jameson. *Journal of Shellfish Research* **16**, 573–574.

Norton J.H., Dashorst M., Lansky T.M. & Mayer R.J. (1996) An evaluation of some relaxants for use with pearl oysters. *Aquaculture* **144**, 39–52.

Ponia B. (2010) *A Review of Aquaculture in the Pacific Islands 1998–2007: Tracking a Decade of Progress through Official and Provisional Statistics*, Secretariat of Pacific Community, Noumea, New Caledonia.

Ruíz-Rubio H., Acosta-Salmon H., Olivera A., Southgate P.C. & Rangel-Davalos C. (2006) The influence of culture method and culture period on quality of half-pearls (mabé) from the winged pearl oyster *Pteria sterna*, Gould, 1851. *Aquaculture* **254**, 269–274.

Saucedo P., Monteforte M. & Blanc F. (1998) Changes in shell dimensions of pearl oysters, *Pinctada mazatlanica* (Hanley 1856) and *Pteria sterna* (Gould 1851), during growth as criteria for Mabé pearl implants. *Aquaculture Research* **29**, 801–814.

Shirai S. (1994) *Pearls and Pearl Oysters of the World*, Marine Planning, Okinawa, Japan.

Southgate C.P., Strack E., Hart A., Wada T.K., Monteforte M., Carino M., Langy S., Lo C., Acosta-Salmon H. & Wang A. (2008) Exploitation and culture of major commercial species. In: *The Pearl Oyster* (ed. by P.C. Southgate, & J.S. Lucas), pp 303–354. Elsevier, Amsterdam, The Netherlands.

Taylor J.J. & Strack E. (2008) Pearl production. In: *The Pearl Oyster* (ed. by P.C. Southgate & J.S. Lucas), pp 273–302. Elsevier, Amsterdam, The Nertherlands.

Teitelbaum A. & Fale P.N. (2008) Support for the Tongan pearl industry. *SPC Pearl Oyster Information Bulletin* **18**, 11–14.

