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Final report

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prepared by	Prof. Paul Southgate, School of Marine & Tropical Biology, James Cook University, Townsville, Australia
co-authors/ contributors/ collaborators	Mr Poasi Ngaluafe, Aquaculture Manager Ministry of Agriculture and Food, Forests and Fisheries (MAFFF), Tonga
approved by	Dr Chris Barlow, ACIAR Research Program Manager, Fisheries
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1 Acknowledgments

First and foremost, we acknowledge collaboration of the Tonga Pearl Growers Association in Vava'u, for their willing and open engagement with the project, their input into project planning and, in the case of some farms, hosting project research activities. We also acknowledge technical support from Andrew Beer, Jamie Whitford, and two Australian Youth Ambassadors for Development (AYAD), Scott Mactier and Richard Warner. We also acknowledge support of this project by AusAID through the AYAD program.

2 Executive summary

The winged pearl oyster, *Pteria penguin,* is used traditionally for production of half-pearls ('mabe') in Tonga, for which there are export markets in Japan and elsewhere. However, poor recruitment of spat (i.e. oyster supply) has become a major problem for the industry over recent years and an impediment to sustainable pearl production. In addressing this problem, this project investigated the feasibility of hatchery production of *Pteria penguin* and optimised ocean-based culture methods for this species. Annual hatchery production of *Pteria penguin* in Tonga was achieved in 2008, 2009, 2010 and 2011, using methods developed for another species of pearl oyster in a prior ACIAR project (FIS/1997/31). It was successful in supplying a large quantity of oyster juveniles to Tongan pearl farmers.

Another major output of the hatchery research was successful use of commercially available micro-algae concentrates to feed pearl oyster larvae. Larvae were reared to settlement on these products demonstrating that live micro-algae culture is not obligatory for successful culture of pearl oyster larvae. This has major benefits for hatchery culture of pearl oysters (and potentially other invertebrates) in the region, including reduced reliance on dedicated hatchery infrastructure, reduced hatchery establishment and running costs and elimination of the need for specialised algae-culture skills. Large-scale hatchery production was supported by laboratory-scale experiments to determine the optimal culture requirements of *Pteria penguin* larvae. The results were used to fine-tune hatchery techniques and to develop a standard hatchery protocol for this species.

Pearl oyster juveniles resulting from hatchery research in 2008 and 2009 were used in experiments to determine survival and growth of *Pteria penguin* in different culture units, and the influence of depth and site. The type of culture unit had a significant effect on growth rate and survival of oysters and different culture units were found to be optimal for different sizes of oysters. The results allowed a standard culture protocol to be developed for pearl farmers in Tonga. Results of the growth trials showed that hatchery produced *Pteria penguin* required more than 2 years to reach a size suitable for half-pearl production (ca. 170 mm dorso-ventral shell height).

Approximately 50,000 of the hatchery cultured juvenile oysters produced by the Project were provided to the oyster industry to alleviate oyster stock shortage. Tonga Fisheries staff were involved with the regular maintenance of these oysters at farm sites, to generate additional growth rate data to complement that from Project growth trials (i.e. additional sites), and to facilitate training and capacity building. Pearl farmers and locals involved in making pearl handicrafts met with Project staff (both JCU and Tonga Fisheries) on a regular basis.

Regular supply of pearl oyster juveniles to pearl farmers in Tonga has stabilised current levels of pearl farming and prevented industry collapse, and stimulated renewed confidence in the industry. This has resulted in:

- disengaged pearl farmers returning to the industry;
- new farmers entering the industry;
- enquiries about establishing pearl farming in new areas (e.g. Tongatapu); and
- an expanding and more pro-active Pearl Growers Association.

The Project was extended to June 2011. A larger, follow-on project (FIS/2009/057)[1] is being developed to begin in 2012 and will include further research to assist expansion of cultured pearl production in Tonga.

[1] *FIS/2009/057 'Pearl industry development in the Western Pacific'.*

3 Background

The winged pearl oyster, *Pteria penguin,* is used traditionally for production of half-pearls ('mabe') in Tonga, for which there are export markets in Japan and elsewhere. *P. penguin* was introduced to Tonga in 1975 by the Tasaki Pearl Company of Japan (Fa'anunu and Manu, 1996). Subsequent research conducted by the Ministry of Fisheries in Tonga and supported by FAO-SPADP), attracted the interest of local investors and there were twenty-five small pearl farms in Tonga at the end of 2000 with a value of approximately $10,000 in 1996 (Finau, 2005). The current value of the industry is not known as the majority of pearls are sold locally. But the industry, although small, is well organised and is represented by the Pearl Growers' Association (PGA).

The Tongan pearl industry is centred in Vava'u island group and has relied on natural spat collection. Spat are collected from the wild, using spat collectors and grown to a size where they can be used for half-pearl production. Half-pearl culture is attractive because it uses relatively simple and affordable techniques for catching spat, for grow-out and pearl production. Most significantly half-pearl production does not require a specialised technician and can be achieved by local people with minimal training/experience. Japanese specialists visiting Vava'u in the mid 1990's estimated that an area of approximately 850 hectares (ha) in the Vava'u island group could be farmed for half-pearl production, supporting annual production of around 750,000 pearls with approximately 30 percent of these being first grade. Assuming a value of US $30 each for first grade half-pearls, they estimated potential annual revenue from an area of 85 ha to be around US $7.5 million (Finau, 2005). On the basis of this potential, and associated livelihood opportunities, mabe pearl production is the highest ranking aquaculture commodity in the Tonga Aquaculture Commodity Development Plan 2010 to 2014.

A major impediment to the sustainability and expansion of the Tongan pearl industry is a reliable and adequate supply of oysters. Over recent years poor recruitment of spat has resulted in the harvesting of adult oysters from the wild, which has further impacted on recruitment, and natural spat fall of *P. penguin* in Vava'u is now extremely limited. This project focused on the development of appropriate hatchery culture techniques for *P. penguin* and provision of hatchery propagated oysters to pearl farmers to address this problem.

Further development of the pearl industry in Tonga is hindered by a lack of knowledge of the culture requirements of *P. penguin* and methods for optimising pearl production from this species. For example, only one preliminary study has reported on hatchery or nursery culture of *P. penguin* (Beer and Southgate, 1999) and, while limited information is available relating to half-pearl production from the related *P. sterna* (Acosta-Salmon et al., 2006), similar information is not yet available for *P. penguin.* Research is required to optimise culture methodology and pearl production from *P. penguin*, as a basis of sustainable industry development.

Production of high quality half-pearls from *P. penguin* in Tonga has been clearly demonstrated and existing pearl farming expertise in Tonga provides considerable opportunity for this project to have an immediate impact. Half-pearls produced by *Pteria penguin* in Tonga differ from pearls produced in other Pacific nations (i.e. round pearls from the black-lip pearl oyster *Pinctada margaritifera).* Markets for the two types of pearls are separate and this provides an opportunity for Tonga to develop and supply a niche market, independent of pearl production from other countries in the Pacific region.

4 Objectives

The overall aim of this project was to provide a sustainable basis for the continued production and expansion of the Tongan half-pearl industry.

The specific objectives were to:

- Develop hatchery culture techniques for the production of *Pteria penguin* spat;
- Develop appropriate nursery and grow-out techniques for hatchery cultured *P. penguin* spat;
- Optimise the quality of half-pearls produced from *Pteria penguin*; and
- Enhance technical and research skills of Tonga Fisheries and Pearl Growers' Association personnel.

5 Methodology

Objective 1: Develop hatchery culture techniques for production of *Pteria penguin* spat

Reliable hatchery culture methods for pearl oysters have been developed for *Pinctada* spp. (e.g. Rose and Baker, 1994; Southgate and Beer, 1997; Doroudi and Southgate, 1999). Such development has relied on research to determine optimal levels of parameters, such as stocking density of eggs and larvae, feeding ration, nutritional value of various species of micro-algae as a food source, settlement substrate, optimal temperature and salinity etc. This project used a similar approach and conducted a number of experiments to identify optimal culture conditions for embryos and larvae of *Pteria penguin.* The experimental protocols used were based on those used for the black lip pearl oyster, *Pinctada margaritifera* (e.g. Southgate and Beer, 1997; Doroudi and Southgate, 1999; Martinez-Fernandez et al., 2006).

Objective 2: Develop appropriate nursery and grow-out techniques for hatchery cultured *Pteria penguin* spat

Research with other species of pearl oysters has determined that growth and survival during nursery and grow-out stages are influenced by factors such as culture method (i.e. depth, type of culture unit) and water quality conditions (e.g. site). Hatchery produced *Pteria penguin* juveniles were used in experiments that determined the effects of varying culture conditions on growth rate and survival. Oysters were cultured in various culture units (e.g. panel nets, pearl nets) and the experimental methodology generally followed that described by Southgate and Beer (2000), who determined culture conditions for black-lip pearl oyster (*Pinctada margaritifera*) juveniles. Experimental culture apparatus were cleaned on a monthly basis and growth of oysters was determined by measurement of the dorso-ventral shell height.

Objective 3: Optimise the quality of half-pearls from *Pteria penguin*

Recent research has shown that the quality, and therefore value, of half-pearls produced by *Pteria sterna* is influenced by a number of factors including duration of pearl production, position of half-pearl nuclei within the shell (Acosta-Salmon et al., 2006) and depth/method of oyster culture. There is also anecdotal suggestion that the type of fixative used to secure pearl nuclei to the inside of oyster shells may affect nacre secretion and pearl quality. This study aimed to assess the impacts of all these factors. The methods used for half-pearl production are well established (e.g. Acosta-Salmon et al., 2006). Briefly, oysters are selected for half-pearl production on the basis of good nacre colour and quality. Selected oysters are anaesthetised (Acosta-Salmon and Southgate, 2005) and commercially available plastic hemispherical nuclei are then glued to the inside surface of the shells. Multiple nuclei can be applied to each shell surface (Ruiz-Rubio et al., 2006). Oysters are then placed into clean sea water to recover from anaesthesia and, once recovered, placed into culture nets and removed to the pearl farm. A nacre thickness of around one millimetre is considered commercially acceptable and while the rate of nacre secretion over the nucleus varies according to culture conditions and water temperature, a period of between 6-10 months is normally required for half-pearl production. After this period, half-pearls are drilled from the shell. They are assessed for quality, primarily using a visual index which includes qualitative assessment of colour, lustre and surface blemishes according to standard pearl quality assessment (Matlins, 1996). Nacre thickness is determined at the base, apex and sides of the resulting half-pearls using vernacular callipers following sectioning (Ruiz-Rubio et al., 2006).

Objective 4: Enhanced technical and research skills of Tonga Fisheries and Pearl Growers' Association personnel

This project involved considerable training through in-country activities, with a planned workshop in the final year of the project. Personnel from the MAFFF (Aquaculture) and the PGA received training in the following areas of pearl oyster culture: brood-stock selection, spawning induction, larval rearing, micro-algae culture, nursery culture and grow-out. Planned training in pearl 'seeding' and pearl production were unable to be undertaken because of insufficient numbers of appropriately sized oysters, during the life of the project.

This project also involved training of two Australian postgraduate (PhD) students that worked within the project to address specific project milestones. One conducted research related to hatchery culture of *Pteria penguin*, and this work involved two visits to the MAFFF hatchery facility in Tonga for collaborative research with Tongan project staff. The project also involved training of a Tongan national (Mr Martin Finau) who worked within the project to complete his Masters degree, as a recipient of an ACIAR/ University of the South Pacific scholarship.

Technical and research capacity of MAFFF and PGA personnel was also enhanced through placement of two Australian Youth Ambassador for Development (AYAD) scientists within the Aquaculture section of MAFFF during the project.

6 Achievements against activities and outputs/milestones

Objective 1: To develop hatchery culture techniques for production of Pteria penguin spat

no.	activity	outputs/ milestones	completion date	comments
1.1	Re-establish hatchery facility at Sopu, Tonga	Completion of hatchery and use for first hatchery run	March 2008	Project inception meeting was conducted in Tonga in February 2008 and plans were initiated for renovation of existing hatchery to a useable state. An inventory of equipment was also made and replacements and omissions ordered. The hatchery renovation was complete in March 2008 for the planned hatchery run in May 2008 in accordance with the project timeline. A new hatchery facility funded by Tonga Fisheries was completed in May 2009. Project staffs were involved with the design and final fit-out. It was used for the first time in May 2009 for the second hatchery run for this Project and again in Mar/April, 2010 and 2011.

1.2	Undertake lab experiments to determine optimal culture parameters for larvae (e.g. temperature, density, ration)	Successful completion of experiments	May 2011	Preliminary research conducted in Tonga addressed optimal culture temperature for larvae, larval density and food type. Results showed that a water temperature above 20^{o}C is required to optimise larval growth and survival and a larval culture density of 2-5/mL is optimal. More focussed laboratory experiments were begun in February 2008 in Australia and continued through to 2009. They were generally unsuccessful because of smaller than anticipated numbers of eggs and larvae and low survival. In response, a JCU PhD student (Matt Wassnig) conducted laboratory experiments in Tonga in Mar/April 2010 coincident with the large-scale hatchery runs (see Activity 1.3). Results showed that egg density affected the proportion of successfully hatching larvae and that this was positively affected by the use of antibiotics during the egg incubation period. Larval density and ration significantly affected larval growth and survival. These results were used to develop a 'standard' methodology for egg incubation and larval rearing of *Pteria penguin*. Subsequent small-scale experiments conducted in Feb/March, 2011 determined the optimal feeding ration of commercially available micro-algae concentrates for *Pteria penguin* larvae and investigated the potential of chemical settlement cues in *Pteria penguin* hatchery culture. Optimal ration was dependant on larval stocking density and larval age. The results allowed fine tuning of larval culture methodology for *Pteria penguin*. Larval settlement was enhanced when exposed to serotonin (10^{-3} M) or KCl (20 mM) and settlement was also enhanced when an artificial substrate was provided in the presence of settlement cues. Research in Tonga (Activities 1.2 and 1.3) showed that *Pteria penguin* larvae can be reared successfully on a diet of commercially available micro-algae concentrates. This has now been demonstrated in four large-scale hatchery runs in Tonga in 2008, 2009, 2010 and 2011. This finding has major implications for hatchery culture of pearl oysters (and other invertebrates) in the region. It means that hatchery culture can be contemplated in the absence of live micro-algae culture facilities and expertise.

1.3	Undertake large scale hatchery production in Australia and Tonga	Successful production	May 2011	Broodstock oysters were provided by a commercial pearl farm and large scale hatchery production was begun in Tonga in late May 2008 and occurred annually in 2008, 2009, 2010 and 2011. Spawning induction was readily achieved on multiple occasions and large numbers of eggs and larvae were obtained for hatchery culture. Successful larval culture resulted in ~30,000 juveniles in 2008 and around 50,000 juveniles were produced from the hatchery between 2008 and 2011. Spawnings were undertaken with more difficulty in Australia in February 2008 and between Jan-April, 2009 and Nov-Jan 2009/10. Large scale hatchery culture of larvae did not produce any spat. Attempts at large-scale culture of *Pteria penguin* in Australia were abandoned in 2010, in favour of a focussed effort on hatchery production in Tonga. Hatchery activity is limited given the apparently restricted spawning periodicity of *Pteria penguin*. Conditioning of broodstock to enable extended spawning activity will be an important factor in future hatchery-based research with this species. Research undertaken in Australia assessed the feasibility of conditioning *Pteria penguin* broodstock with commercially available micro-algae concentrates. It showed that *Pteria penguin* showed increased clearance rate with increasing food availability up to the maximum ration tested of 50 x 10^3 cells/mL. Pearl oysters are generally considered to have among the highest clearance rates in bivalves and *Pteria penguin* has the highest clearance rate so far reported for pearl oysters. Results indicated that gonad condition of broodstock could be improved when fed a continuously high ration of concentrated micro-algae. However logistical issues relating to provision of high ration and maintenance of water quality are issues requiring further research. It is interesting to note that hatchery culture of *Pteria penguin* in Tonga in 2010 and 2011 used oysters resulting from the hatchery run in 2008 as broodstock. Hatchery culture of pearl oysters using F1 progeny as broodstock has rarely been reported and clearly indicates potential for development of selective breeding programs for this species. A major constraint to hatchery production is predation of spat following transfer from the hatchery to the ocean. Predation intensity and predator type are site specific and vary temporally, and further research is required to optimise early nursery culture of hatchery cultured *Pteria penguin* spat.

1.4	Determine reproductive seasonality of *Pteria penguin* in Tonga	Determination of times of peak reproductive activity.	April 2010	Some samples were taken in Tonga to determine reproductive seasonality however, this method is destructive and sample numbers were considerably limited by low numbers of available natural oysters and their high value for pearl production. Methods to determine reproductive seasonality were modified to non-destructive methods of spat collection data and the response of oysters to spawning stimuli. Detailed study of the reproductive cycle of *Pteria penguin* in north Queensland, Australia, was undertaken by a PhD student associated with this project (Michael Milione). Results were confirmed with studies on spat collection. Major spawning peaks occurred from November to March with a primary spawning peak in December, followed by a secondary peak in March.

PC = partner country, A = Australia

Objective 2: To develop appropriate nursery and grow-out techniques for hatchery cultured Pteria penguin spat

no.	activity	outputs/ milestones	completion date	comments
2.1	Implement nursery culture experiments in Australia and Tonga to determine optimal culture parameters	Successful completion of experiments	June 2011	First nursery culture experiments in Tonga were begun in September 2008 using spat (<25 mm) resulting from the May 2008 hatchery run (see Activity 1.3). The first experiment assessed three different culture units at two sites (Vava'u and Sopu). Results showed that plastic mesh trays were the best of the three culture units at both sites supporting greatest growth rates and survival. Growth rates at Sopu were greater than those at Vava'u. A second experiment was begun in February 2009 with larger oysters. It assessed two different culture units held at two depths at Vava'u and Sopu. It also included two additional culture sites in Vava'u (commercial pearl farms). This provided more information relating to site selection and the influence of water quality parameters on growth and survival of oysters. It also involved commercial pearl farmers in Project research activities and facilitated extension activities (oysters at farms sites are regularly services by Fisheries staff). This experiment was completed in June 2009. Nursery culture experiments in Tonga were conducted by Martin Finau, from the Aquaculture section at MAFFF an ACIAR/USP scholarship holder who conducted his MSc research, during the project.

				Nursery experiments were established in Australia using natural *Pteria penguin* spat in April 2008, December 2008 and February, 2009. They investigated the influence of net type on growth and survival. Later experiments were established at three dissimilar sites at two depths with water quality data loggers to provide information on the influence of water quality parameters on growth and survival of *Pteria penguin* which will be beneficial in site selection. Interestingly, growth rates of *Pteria penguin* were significantly higher in in-shore areas of relatively high turbidity when compared to a mid-shelf coral reef environment. The results indicate that *Pteria penguin* is able to tolerate relatively high levels of turbidity. Culture units also affected growth rates, with oysters held in mesh trays showing greater growth rates than those held in pocket (panel) nets and pyramidal pearl nets. Depth (3 metres and 6 metres) had no significant effect on growth rate, survival or fouling of culture apparatus. Data generated for growth of *Pteria penguin* in Tonga and Australia was modelled and provides the first comprehensive growth rate data for this species. Results from Tonga indicate that this species is capable of reaching (~120 mm) within one year of age. However, growth rate then slows. The smallest oysters used by pearl farmers in Tonga for half pearl production have a dorso-ventral shell height of >170 mm. Results show that oysters require >2 years to reach this size. Growth trials in Australia showed that monthly growth rates were more rapid in smaller oysters (60-70 mm) in the spring and summer and lower in larger oysters (105-110 mm) during spring. At three culture sites studied (coral reef, mid-shelf and semi-estuarine) the time required for *Pteria penguin* to reach a shell size of 120 mm, varied between 1.74 and 1.9 years.

2.2	Implement grow-out experiments in Australia and Tonga to determine optimal culture parameters	Successful completion of experiments	June 2011	In Tonga, these experiments relied on hatchery-produced *Pteria penguin* juveniles that were not available until August 2009 when grow-out experiments began with oysters (~120 mm) cultured in plastic trays and by ear-hanging at sites in Vava'u and Sopu. Similar experiments were established at three dissimilar sites near Townsville Australia with water quality data loggers. They will be completed during 2010 and provide information on the influence of water quality parameters on growth and survival of *Pteria penguin* which will be beneficial in site selection. Results obtained during Activities 2.1 and 2.2 allowed culture protocols for *Pteria penguin* to be revised for growth under Australian and Tongan conditions.

PC = partner country, A = Australia

Objective 3: To optimise the quality of half-pearls from Pteria penguin

no.	activity	outputs/ milestones	completion date	comments
3.1	Implement grow-out experiments in Tonga to determine optimal parameters for half pearl production	Production of high quality half-pearls	Not completed	The availability of oysters to the project, of an appropriate size for pearl seeding, was very limited. Oysters of an appropriate size held by collaborating pearl farmers at the start of the project were already seeded for pearl production. Wild oysters were rare and obtaining them for project research was impractical. It was anticipated that hatchery produced oysters of an appropriate size for pearl seeding (~170 mm), and in large enough numbers, would be available for pearl seeding in 2009. This was not the case. The largest hatchery produced oysters had reached a size of ~120-150 mm by September 2009 (prior to project extension) when they were around 18 months of age. Despite rapid initial growth rates, those of older oysters slowed considerably (see comments for activity 2.2). Because of this, sufficient numbers of oysters of an appropriate size for pearl seeding were unavailable throughout the regular duration of this project and research towards this objective in Tonga was postponed when an opportunity to conduct similar research in Fiji arose. Preliminary research to assess factors influencing pearl quality from *Pteria penguin* was conducted in a related ACIAR project (FIS/2006/138) in Fiji where greater numbers of large *Pteria penguin* were available. This research was conducted by an ACIAR/USP scholarship holder (Pranesh Kishore). Nacre deposition rate was greater during the warmer months of the year. The positions of pearl nucleii was an important influence on pearl quality with those closer to the adductor muscle generally producing pearls of lower quality. The best quality pearls were obtained after nine months of culture and four nuclei per pearl oyster was found to be optimal. This aspect requires further study in Tonga and will be a major component of the follow-on project (FIS/2009/057 'Pearl Industry Development in the Western Pacific').

Objective 4: Enhanced technical and research skills of Tonga Fisheries and Pearl Growers' Association personnel

no.	activity	outputs/ milestones	completion date	comments
4.1	Undertake hatchery culture in Tonga to include training.	Successful completion of three hatchery runs	April 2011	Training relating to hatchery lay-out and set-up and use of hatchery equipment was conducted during refurbishment of the hatchery in 2008. Further training was conducted in assisting Tonga Fisheries equip and set-up the new hatchery facility following its completion in early 2009, in preparation for hatchery activity and in subsequent trouble-shooting and fine-tuning. Hatchery runs in 2008, 2009, 2010 and 2011 included detailed training of Tongan Fisheries personnel in all aspects of hatchery culture of pearl oysters including hatchery hygiene, broodstock husbandry, spawning induction, egg incubation, larval culture, larval development, feeding, settlement and early nursery culture and transfer of spat collectors to the sea. The hatchery run in Mar/April 2010 was funded through FIS/2006/138 as a mini-project (MS1002 Support of pearl oyster *Pteria penguin* hatchery production in Tonga) to maintain Project momentum, prior to extension. Australian hatchery expert, Andrew Beer, assisted hatchery runs in Tonga in 2009 and 2010 and his input provided a broader range of hatchery techniques and experiences for Tongan Fisheries personnel. An AYAD placement was made to the Aquaculture section of Tonga Fisheries in February 2009. The JCU trained Aquaculture graduate (Scott Mactier) provided support to Tonga Fisheries Aquaculture staff in hatchery techniques. AYAD funding ceased in March 2010 but Mr. Mactier was retained by the Project through the FIS/2006/138 mini-project (MS1002 Support of pearl oyster *Pteria penguin* hatchery production in Tonga) to June 2010 and subsequently to June 2011, through the project extension. A second AYAD placement (Richard Warner) began in 2010 and both Scott and Richard provided considerable and ongoing training relating to hatchery culture, during their placements. Mr Matt Wassnig (PhD student, JCU), undertook hatchery based research in Tonga, during the scheduled hatchery runs in 2010 and 2011. Tonga Fisheries personnel assisted Mr Wassnig in

				experimental set-up, experimental design and data collection, which further broadened their training in this field. In June 2011 the Tonga Fisheries Hatchery was visited by Jamie Whitford, Senior Project Scientist for the ACIAR/PARDI Pearl Project. He reviewed the current Tonga Pearl Hatchery set up and made recommendations to facilitate an increase in hatchery capacity, to support growing industry demand. Tonga Fisheries (Aquaculture) staff worked with Mr Whitford during this process.
4.2	Undertake nursery culture in Tonga to include training.	Successful completion of training; transfer of technology to stakeholders.	June 2011	Training in nursery culture methods began in September 2008 with establishment of the first nursery experiment. Training included aspects of experimental design, infrastructure establishment (long-lines etc) and culture apparatus. Training was reinforced when the second nursery experiment was established in February 2009 and a third in August 2009. Training in data collection and analysis was provided when experiments were begun and when the three experiments were terminated. Training was strengthened through synchrony of Project activities with those of the ACIAR-funded mini-project (MS 0807 Improved husbandry methods for culture of juvenile winged pearl oyster, *Pteria penguin*, in Tonga) funded through FIS/2006/138. This project was undertaken by ACIAR/USP Scholarship holder, Martin Finau of Tonga Fisheries (Aquaculture), whose research in Tonga nested within the activities of this Project. Training of MAFFF staff in Tonga, in nursery culture methods was also strengthened through the involvement of two AYAD positions, during the project (see comments under 4.1).

4.3	Undertake training workshop in Tonga	Successful completion of workshop, successful training and transfer of technology	Not completed	A workshop was to be undertaken in late 2009. However, pearl seeding was to be a major component of this training and this was not able to be conducted (see comments for Activity 3.1). Training in general culture methods and oyster husbandry were conducted with farmers directly (see Activity 2.1)
4.4	Enhanced technical and research capacity in pearl culture in Tonga	Improved pearl oyster and pearl production	Ongoing	Ongoing and cumulative through duration of project (see above)

7 Key results and discussion

- Hatchery culture methods were developed for *Pteria penguin* and regular (annual) hatchery production of oyster juveniles has occurred in Tonga since 2008.
- Regular supply of pearl oyster juveniles to pearl farmers in Tonga has stabilised current levels of pearl farming and prevented industry collapse, and stimulated renewed confidence in the industry. This has resulted in: (1) disengaged pearl farmers returning to the industry; (2) new farmers entering the industry; (3) enquiries about establishing pearl farming in new areas (e.g. Tongatapu); and (4) an expanding and more pro-active Pearl Growers Association. This project has resulted directly in a 40% increase in the number of pearl farmers in Vava'u.
- Technical constraints to live micro-algae production forced evaluation of commercially produced micro-algae concentrates as a food source for *Pteria penguin* larvae during hatchery culture. 'Instant Algae'® (Reed Mariculture, USA) supported good rates of survival and growth throughout larval development and five successful hatchery runs have now been completed in Tonga without using live micro-algae. This is a major break-through for hatchery culture of pearl oysters and has major implications for feasibility/simplification of hatchery culture throughout the region.
- Nursery and grow-out culture methods were developed for *Pteria penguin* and these methods were later optimised by research conducted as a 'mini project' (funded through FIS/2006/138) which was run by an ACIAR/USP MSc research student.
- Pearl farmers were directly involved with research to optimise oyster culture methods through project growth trials which were conducted on their farms. This approach broadened the scope of the research, provided more information about 'good' and 'bad' sites and facilitated capacity building within the pearl farming community through regular contact between Project/Fisheries staff and pearl farmers.
- Two Australian Youth Ambassadors were placed with the project in Tonga in 2009/2010 and 2010/2011 to assist with project activities and capacity building within Tonga Fisheries.
- Three postgraduate research students (two PhD and one MSc) completed their research theses within this project.
- Six publications in scientific journals resulted so far from the research activities of this project and a number of manuscripts are in review or being prepared (section 8.4.1). The project also generated information for more general media outlets (e.g. SPC Pearl Oyster Information Bulletin), as well as information that will be used for development of culture manuals and other extension materials.
- The major outputs of this project are: (1) routine hatchery production of *Pteria penguin*; (2) more effective culture techniques for this species; (3) expansion of the pearl industry and the number of pearl farmers in Tonga; and (4) considerably increased pearl oyster culture capacity within stakeholder organisations. They provide a basis for the follow-on ACIAR Pipeline Project FIS/2009/057 'Pearl Industry Development in the Western Pacific' which will start in 2012 and will support continued expansion of the pearl industry in Tonga.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Our knowledge of reproduction, development, growth, hatchery and nursery culture of *Pteria penguin*, and factors affecting their growth and survival has been considerably expanded during this project. This information will be broadly applied as a basis for industry expansion in Tonga but will also be applicable elsewhere to facilitate development of hatchery culture pearl oysters, with particular potential for *Pteria penguin.*

This project is the first to demonstrate that commercially available micro-algae concentrates can be used successfully to culture pearl oyster larvae through to settlement. This has important implications because a major constraint to hatchery development of pearl oysters (and other invertebrates) is a lack of the technical resources required for culture of live micro-algae in many developing countries. Demonstration of the successful culture in invertebrate larvae, without the use of live micro-algae is likely to stimulate further research to assess this potential for other species. Use of commercially available micro-algae concentrates as a larval food source has the potential to support expansion of hatchery development activities throughout the region.

This project has involved a Tongan MSc student and two Australian PhD students.

The scientific outputs of this project include three postgraduate theses (2 PhD and 1 MSc), six publications in peer reviewed scientific journals and a number of others in review or in preparation. This represents significant impact to the available scientific literature in this field.

Culture techniques developed during this project have already been taken-up by commercial pearl farmers in Vava'u, Tonga. The use of algae concentrates for commercial hatchery production of pearl oysters has been taken up in a regional pearl oyster hatchery and at least one hatchery in Australia and Indonesia.

It is likely that the scientific outputs of this project will have impacts in this field in five years and over a longer term. For example, development of hatchery and nursery culture techniques for *Pteria penguin* could facilitate development of pearl culture industries based on this species throughout its range (East Africa to central Pacific). Furthermore, the potential of commercially available micro-algae pastes to support hatchery production is likely to be investigated for a broad range of species; for example, it has already been used for both research and commercial-scale hatchery production of sea cucumbers in Australia (Jens Knauer, Darwin Aquaculture Centre, pers. comm., 2011). On this basis, it is likely that this research output will have ongoing impacts into the medium to longer term, through the simplification of hatchery culture of invertebrates. This is likely to be particular significance in the Pacific region, where there is growing interest in hatchery culture of pearl oysters and other invertebrates.

8.2 Capacity impacts – now and in 5 years

Capacity impacts have been made as follows:

- Establishment of a working hatchery facility suitable for production of pearl oysters and other invertebrates at a semi-commercial scale and for research.
- Establishment of ocean-based culture facilities for pearl oysters at Tongatapu and Vava'u for Fisheries and private sector.
- Training of Tonga Fisheries staff in aspects of pearl oyster culture and provision of new knowledge and skills in this field. Fisheries staff and pearl farmers have benefited directly from specialised inputs from a hatchery specialist (Andrew Beer),

Australian Youth Ambassadors (Scott Mactier and Richard Warner) and an Australian PhD student (Matt Wassnig).
- Training of local pearl farmers in aspects of pearl oyster culture and provision of new knowledge and skills in this field. A number of pearl farmers were directly involved in Project activities because their farms are used for grow-out culture of hatchery produced oysters. Maintenance of these oysters involves extension work from Tonga Fisheries staff.
- Extension activities facilitated and supported more frequent meetings of the Tongan Pearl Growers Association (PGA). As a result the PGA has built greater functional capacity as a representative body for all pearl farmers, developed a stronger relationship with Fisheries, has a much greater awareness of the value/need for research and greater capacity for uptake of new culture methods.

This increased capacity will provide a strong basis for pearl industry development into the future.

8.3 Community impacts – now and in 5 years

Provision of pearl oysters to pearl farmers, and training in more effective pearl culture methods, has generated clear benefits to the pearl industry with concomitant economic and social benefits.

8.3.1 Economic impacts

- Support of current levels of commercial pearl farming has prevented industry collapse and resulting job and income losses.
- The potential of regular supply of large numbers of pearl oyster juveniles to the pearl industry has stimulated renewed confidence in the industry. This has resulted in: (1) disengaged pearl farmers returning to the industry; (2) new farmers entering the industry; and (3) enquiries from potential new pearl farmers about pearl farming in new areas (e.g. Tongatapu).
- The above factors will allow greater numbers of the community to be involved directly with pearl farming and indirectly in the pearl handicraft sector.

Results showed that the *Pteria penguin* should ideally around three years old, before being used for half-pearl production. Linked ACIAR funded research in Fiji has shown that highest quality half-pearls are produced from *Pteria penguin* after a period of about nine months of culture. Therefore, all the hatchery produced spat resulting from this project have potential to produce half-pearls within a five year period.

Assuming the following:

- 30% of the spat produced by this project will reach pearl production (likely to be an underestimate).
- Oysters used for pearl production will produce a minimum of three saleable pearls.
- Average price of each saleable pearl will be AUD $30 (based on current prices for half pearls in Vauva'u Municipal Market).

Given that 50,000 juveniles produced by this project were provided to pearl farmers, it is reasonable to assume an economic impact within five years of this project, to be approximately AUD $1.35 million.

This estimate does not include income generated from associated pearl handicrafts (i.e. polished shell and pearl shell jewellery), which is likely to be substantial. Research within the ACIAR/PARDI Pearl Project in Fiji, for example, has shown that the value of the pearl handicraft industry is approximately five-fold that of pearl production.

8.3.2 Social impacts

Project activities in Vava'u have lead to greater awareness of (and interest in) pearl culture and the potential benefits from it. Project support of current pearling activities in Tonga provides benefits to women and younger people who are predominant in pearl/pearl shell handicraft activities. This impact will obviously broaden should project activities result in expansion of the pearl industry, as anticipated.

8.3.3 Environmental impacts

This project is focused on the hatchery production and husbandry of pearl oysters, development of more effective culture methods for them and the potential expansion of pearl farming in Tonga.

Hatchery production reduces pressure wild stocks of *Pteria penguin* which would otherwise be collected for pearl production. This potentially allows some recovery of wild stocks of this species. Oyster recruitment will be greatly enhanced once cultivated hatchery produced oysters reach reproductive maturity.

Hatchery production can have negative impacts on the genetic make-up of culture stock, and of wild stock through interbreeding. This impact is minimised through the use of large numbers of contributing broodstock in hatchery production, and through selection of broodstock from sites to which resulting spat will be returned.

Should project activities result in expansion of the pearl industry, environmental impacts will result from additional farming infrastructure which may provide navigational hazards and impact water flow. Pearl farming infrastructure, however, provides habitat and has been shown to positively influence local fish stocks. Furthermore, pearl oysters are filter feeders and pearl farming is generally considered to be a relatively benign form or aquaculture with minimal environmental impact.

8.4 Communication and dissemination activities

8.4.1 Publications

Student theses:

1. Finau, M. (2012). Factors effecting nursery and grow-out culture of the winged pearl oyster *Pteria penguin* in Tonga. MSc thesis, University of the South Pacific, Fiji.
2. Milione, M. (2011). Reproduction and growth of the winged pearl oyster, Pteria penguin (Roding, 1798), in the Great Barrier Reef lagoon. PhD thesis, James Cook University, Australia.
3. Wassnig, M. (2011). Developing hatchery culture techniques for the winged pearl oyster *Pteria penguin* (Roding, 1798). PhD thesis, James Cook University, Australia.

Journal publications:

1. Milione, M. & Southgate, P.C. 2011. Histological analysis of the reproductive cycle of the winged pearl oyster, *Pteria penguin* (Roding, 1793) (Pteriidae) in north-eastern Queensland. *Invertebrate Reproduction and Development* 55(3),
2. Milione, M. & Southgate, P.C. 2011. Seasonal changes in recruitment of *Pteria penguin* in north Queensland, Australia. *Journal of Shellfish Research* 30(1), 89-94.

3. Wassnig, M., & Southgate, P.C. 2011. The effects of egg density and antibiotic treatment on survival and development of winged pearl oyster (*Pteria penguin*, Röding) embryos. *Journal of Shellfish Research* 30(1), 103-107.
4. Milione, M., Saucedo, P. & Southgate, P.C. 2011. Sexual development, sex ratio and morphometrics of *Pteria penguin* (Bivalvia: Pteriidae), in northeastern Australia. *Molluscan Research* 31(1): 30-36.
5. Milione, M. & Southgate, P.C. 2011.The influence of culture method and environment on growth and survival of winged pearl oyster (*Pteria penguin*) juveniles. *Journal of Shellfish Research* (in press)
6. Wassnig, M., & Southgate, P.C. 2012. Embryonic and larval development of *Pteria penguin* (Roding, 1798) (Bivalvia:Pteriidae). *Journal of Molluscan Studies* (in press)
7. Milione, M. and Southgate, P.C. Growth of the winged pearl oyster, *Pteria penguin*, at different sites in north-eastern Australia. *Aquaculture* (in review)
8. Wassnig, M., & Southgate, P.C. The effects of stocking density and feed ration on the survival and growth of winged pearl oyster (*Pteria penguin*, Röding 1798) larvae fed a diet of preserved algal paste. (in prep)
9. Wassnig, M., & Southgate, P.C. The effects of microalgae diet, food concentration and water temperature on clearance rate, absorption efficiency and energy absorption by the winged pearl oyster, *Pteria penguin.* (in prep)

Five other manuscripts are being prepared. They will be submitted for publication in international scientific journals in 2012.

Regional Newsletters:

1. Teitelbaum A. and Fale P.N. 2008. Support for the Tongan pearl industry. SPC *Pearl Oyster Information Bulletin*, December 2008. pp 11-14.

8.4.2 Other

- Regular meetings have been held with pearl farmers and those involved with the pearl industry (and its products) in Vava'u Tonga to disseminate project objectives and research findings.
- Oysters produced by this project have been provided to pearl farmers and regular maintenance of them by Tonga Fisheries staff provides on-going extension and dissemination activity.
- In an activity related to this project, a pearl shell carving training workshop was organized by SPC in Vava'u, Tonga in 2008. It involved local craftsman and woman who wished to improve their pearl shell and mabè pearl handicrafts production. Tokerau Jim, a master carver from Rarotonga, Cook Islands, was contracted to deliver the hands-on, training (Teitelbaum & Fale, 2008).
- In April 2010 the Project Leader (Southgate) convened a meeting of the Tonga Pearl Growers Association (PGA) in Vava'u attended by Tonga Fisheries staff. The major objective was to provide background information about the local pearl industry for a supply chain analyst from the University of Adelaide (Theo Simos) as part of a scoping study for the new ACIAR Pacific Agribusiness Research & Development Initiative PC/2008/044 (PARDI).It provided an opportunity for the Project Leader to present an overview of Project activities and outcomes, and for the PGA to provide feedback regarding industry needs. The issues raised covered biological, technical and business aspects. These will form the basis for future ACIAR research through both the ACIAR-PARDI project and a larger follow-up project (FIS/2009/057) scheduled to begin in 2012.

9 Conclusions and recommendations

9.1 Conclusions

- Hatchery culture methods developed for other species of pearl oysters were applied successfully to *Pteria penguin* in this study. However like other species of pearl oysters, larval survival is relatively low and research-scale hatchery production of this species is unlikely to satisfy the demands of an expanding pearl culture industry in Tonga. Further expansion of this industry, which relies solely on hatchery produced oysters, must be accompanied by an appropriate increase in hatchery capacity in Tonga.
- Nursery and grow-out culture methods for other species of pearl oysters are also appropriate for *Pteria penguin;* however in this study, *Pteria penguin* shows similar behavioural characteristics (such as clumping) which, without regular husbandry, can negatively impact growth-rates and survival. *Pteria penguin* is similar to other pearl oysters in its susceptibility to high rates of bio-fouling and predation, particularly during nursery culture. Management of these problems, through development of appropriate husbandry regimes can minimise these impacts, which are indicated to be site-specific.
- The growth-rates of hatchery produced *Pteria penguin* were lower than expected and this prevented the pearl-quality component of this project from being conducted. Follow-up research is required to address this issue.
- Considerable capacity was built within the Aquaculture section of the MAFFF during this project, relating to hatchery, nursery and grow-out culture of *Pteria penguin.* Capacity was also built within the Tongan Pearl Growers' Association, relating to nursery and grow-out culture. This capacity was enhanced through the involvement of two AYAD positions during the life of the project and by full-time research assistant position, in the latter stages of the project. Such direct interaction is extremely important in maximising capacity building, particularly relating to hatchery and early nursery culture where repeated research activity is required to make relatively small improvements to outputs.
- The outputs of this project provide a sound basis for sustainable expansion and further development of the Tongan pearl industry. However, pearls are not an annual crop; results indicate that three years is required for hatchery produced oysters to reach pearl producing size, and a further 9-12 month is required for pearl production and processing. Because of this, some of the benefits of research in this field may not be apparent over the short term duration of a project such as this.

9.2 Recommendations

- The results of this project have demonstrated conclusively the feasibility of hatchery production of *Pteria penguin* as a basis for cultured pearl industry development. This project has increased availability of oysters (produced by the hatchery) to pearl farmers and, in doing so, facilitated expansion of the pearl industry in Tonga. However, Continued and sustainable expansion of the Tongan cultured pearl industry will require considerable increase in hatchery production capacity and this should be a major component of follow-up research.

- Early nursery culture of hatchery produced *Pteria penguin* is impacted by relatively high predation. Future research should optimise early nursery culture methods (which may be site specific) to maximise the output of hatchery production.
- Further expansion of the Tongan cultured pearl industry will require planning to ensure sustainability of the industry and to maximise potential benefits to the national economy and livelihoods. There is currently no development plan for the cultured pearl industry in Tonga; this aspect should be a priority for subsequent industry development initiatives.
- Lower than anticipated growth rates of pearl oysters produced by this project prevented assessment of pearl quality and determination of some of the factors affecting pearl quality. Clearly, industry value would be maximised by optimising pearl yield and pearl quality and, on this basis, future research should address these issues. Nevertheless, pearl production at a relatively small scale continued to be undertaken in Vava'u throughout this project. Some very high quality pearls are produced with clear export potential. Others have lower potential and are better suited to the local handicraft trade. However, there is limited understanding by pearl producers of the factors influencing pearl value and this prevents maximum income from pearl production. Future research should address this issue. It should also include assessment of the pearl value-chain in Tonga to provide a better understanding of the opportunities for the pearl industry and livelihood potential.

10 References

10.1 References cited in report

Acosta-Salmón, H. and Southgate, P.C. (2005). Mantle regeneration in the pearl oysters *Pinctada fucata* and *Pinctada margaritifera*. *Aquaculture*, 246 (1-4). pp. 447-453.

Acosta-Salmon, H. and Southgate, P.C. (2006). Wound healing after excision of mantle tissue from the Akoya pearl oyster*, Pinctada fucata. Comparative Biochemistry and Physiology- Part A: Molecular & Integrative Physiology*, 143 (2). pp. 264-268.

Beer, A.C. & Southgate, P.C. 2000. Collection of pearl oyster (Family Pteriidae) spat at Orpheus Island, Great Barrier Reef (Australia). *Journal of Shellfish Research*, 19(2): 821-826.

Doroudi, M.S., Southgate, P.C. and Mayer, R.J. (1999). The combined effects of temperature and salinity on embryos and larvae of the black-lip pearl oyster, *Pinctada margaritifera* (L.). *Aquaculture Research* 30, 271-277.

Fa'anunu and Manu, 1996. Aquaculture Development in Tonga. MoF, JOCV and JICA ed. Integrated Fisheries Survey Report. MoF, JOCV and JICA, Nuku'alofa, Tonga. pp 70- 75

Finau M. W, 2005. Tonga Country Report. SPC sub-regional technical meeting on pearl culture. Nadi, Fiji. 30 November – 2 December 2005.

Martínez-Fernández, E., Acosta-Salmon, H. and Southgate, P.C. (2006). The nutritional value of seven species of tropical microalgae for black-lip pearl oyster *(Pinctada margaritifera L.)* larvae*. Aquaculture*, 257 (1-4). pp. 491-503.

Matlins, A.L., 1996. *The Pearl Book: The Definitive Buying Guide*. Gemstone Press, Woodstock Vermont. pp 198.

Rose, R. A. and S. B. Baker. 1994. Larval and spat culture of Western Australian silver or gold-lip pearl oyster, *Pinctada maxima* Jameson (Mollusca: Pteriidae). *Aquaculture* 126:35–50.

Ruiz-Rubio, H., Acosta-Salmon, H., Olivera, A., Southgate, P.C., and Rangel-Davalos, C. (2006) The influence of culture method and culture period on quality of half-pearls ('mabe') from the winged pearl oyster *Pteria sterna,* Gould, 1851*. Aquaculture*, 254 (1-4). pp. 269-274.

Southgate, P.C. & Beer, A.C. 1997. Hatchery and early nursery culture of the blacklip pearl oyster *Pinctada margartifera* (L.). *Journal of Shellfish Research*, 16 (2): 561-568.

Southgate, P.C., and Beer, A.C. (2000) Growth of blacklip pearl oyster *(Pinctada margaritifera)* juveniles using different nursery culture techniques. *Aquaculture*, 187 (1-2). pp. 97-104.

10.2 List of publications produced by project

Student theses:

Finau, M. (2012). Factors effecting nursery and grow-out culture of the winged pearl oyster *Pteria penguin* in Tonga. MSc thesis, University of the South Pacific, Fiji.

Milione, M. (2011). Reproduction and growth of the winged pearl oyster, Pteria penguin (Roding, 1798), in the Great Barrier Reef lagoon. PhD thesis, James Cook University, Australia.

Wassnig, M. (2011). Developing hatchery culture techniques for the winged pearl oyster *Pteria penguin* (Roding, 1798). PhD thesis, James Cook University, Australia.

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Milione, M. & Southgate, P.C. 2011. Seasonal changes in recruitment of *Pteria penguin* in north Queensland, Australia. *Journal of Shellfish Research* 30(1), 89-94.

Wassnig, M., & Southgate, P.C. 2011. The effects of egg density and antibiotic treatment on survival and development of winged pearl oyster (*Pteria penguin*, Röding) embryos. *Journal of Shellfish Research* 30(1), 103-107.

Milione, M., Saucedo, P. & Southgate, P.C. 2011. Sexual development, sex ratio and morphometrics of *Pteria penguin* (Bivalvia: Pteriidae), in northeastern Australia. *Molluscan Research* 31(1): 30-36.

Milione, M. & Southgate, P.C. 2011.The influence of culture method and environment on growth and survival of winged pearl oyster (*Pteria penguin*) juveniles. *Journal of Shellfish Research* (in press)

Wassnig, M., & Southgate, P.C. 2012. Embryonic and larval development of *Pteria penguin* (Roding, 1798) (Bivalvia:Pteriidae). *Journal of Molluscan Studies* (in press)

Regional Newsletters:

Teitelbaum A. and Fale P.N. 2008. Support for the Tongan pearl industry. SPC *Pearl Oyster Information Bulletin*, December 2008. pp 11-14.