Report on an EU project grant to the WorldFish Center and the Solomon Islands Ministry of Fisheries and Marine Resources

Stimulating Investment in Pearl Farming in Solomon Islands

Report I. Past research and development on blacklip pearl oysters in Solomon Islands

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Summary

- Historically, the blacklip pearl oyster (*Pinctada margaritifera*) has been of commercial importance in Solomon Islands through the trade in mother of pearl. At its peak in 1991, 45 tonnes of shell were exported, valued at more than SBD600,000. This trade effectively finished in 1994 with the imposition of an export ban; the ban remains in place to the time of writing.

- Research into the possibility of farming the blacklipped pearl oyster began in the early 1990's, following the closure of the wild fishery for this species and *P. maxima* (the goldlip pearl oyster) as mother of pearl. The research first focussed on developing spat collection techniques, moved on to husbandry of young oysters and eventually to trial seedings and pearl production. Although all aspects of the research were successful, to date no commercial farming of *P. margaritifera* has been attempted in Solomon Islands.

- It was found that spat could be collected easily and cheaply using simple mesh collectors strung on lines. The best settlement of spat was found to occur where they were deployed in clear water, with moderate currents and at least 35 m from fringing reefs.

- Trial spat collections were made at 24 sites in seven regions around Solomon Islands. No difference in spatfall was found between regions, though significant differences between sites were found. Blacklip pearl oysters are spread throughout the archipelago. Two of the best sites for spatfall, Gizo and Noro, are located in Western Province, close to the WorldFish Center's research facility at Nusa Tupe; these sites were used for all further research.

- Long term records of spatfall at these sites show year-round recruitment, peaking during the summer months (November-February). There is some year-to-year variation in the exact timing of the recruitment peak and its strength. Long term averages of 4-5 spat per collector, of mean size 8 mm (geometric mean) were found at sites near Gizo and Noro.

- Of importance to Solomon Island spat collection is the high rate of predation on settled spat. Collectors accumulate not only spat, but also predatory gastropods (*Cymatium* spp.), crabs and flatworms. Research suggests that after three months in the water, the number of spat on collectors begins to fall as losses exceed recruitment.

- To counteract the problem of predation, an intermediate culture phase was introduced, which sees spat removed from collectors at a small size and deployed in baskets for 3-4 months. After this period they attain a size suitable for drilling and stringing onto ropes in helical culture. After another four months they are ready to be hung, in pairs, on dropper lines

- 12-18 months after capture, spat attain sufficient size for pearl implantation. This is substantially faster than in some other pearl-producing areas, such as the Cook Islands, where similar growth would take 22-24 months.

- Limited trials of pearl implantation showed that pearls of sufficient quality to be sold at auction could be produced with 12-18 months of implantation. Most pearls were silver grey in colour.

- Two different seeders had markedly different degrees of success in seeding Solomon Islands oysters. The most successful had an average mortality rate of <10%, nucleus rejection rates of 25% for virgin shell and <10% for reseedings. He was able to implant nuclei of 2-3 BU in April seedings, and slightly larger (up to 4 BU) in a single October seeding.

- Of a total of 1400 pearls evaluated by commercial buyers (from the first two crops), two-thirds were of low commercial value and the remainder of no value. Only 10% of pearls evaluated were round or near round, less than 10% had a high lustre and most (>70%) had a moderate or greater degree of surface spotting. One pearl was valued at AUD700.

- Hatchery production of spat has been successfully demonstrated in Solomon Islands, though on an experimental scale only. Hatchery-reared spat showed good survival in intermediate culture (70%) and, in a single experiment, grew at only slightly lower rates than wild-caught spat (35 compared to 40 mm in four months). Attempts to implant nuclei into hatchery-reared shell achieved similar rates of retention and survival to wild-caught.

- Updating a simple model developed in 1997 to predict the economic performance of pearl farming in Solomon Islands suggests a net positive income after eight years for a farm deploying 5000 spat collectors per year. The return is heavily dependent on the size of the farm, with profits increasing non-linearly with increasing numbers of spat. Unknowns at this stage include the costs to be incurred from use of customary owned land.

1. Introduction

Blacklip pearl oysters are of considerable importance to aquaculture in the tropical southwest Pacific. Their value comes mainly from the use of live, mature shell for the culture of pearls and in the last two decades this has provided substantial and sustainable incomes for communities in remote parts of French Polynesia, Cook Islands and, most recently, Fiji. Widely distributed in Solomon Islands, the harvest and sale of blacklip oyster shell as mother of pearl (MoP) was a significant rural industry (Richards et al., 1994). Dwindling stocks led to the closure of the MoP fishery in 1993, even though substantial catches were still being made (Richards et al., 1994). It was hoped that this closure would ensure that sufficient stock remained to eventually replenish the wild population and to ensure that sufficient spat could be harvested to support a pearl farming industry. The hope that pearl farming could offer long-term sustainable income opportunities for rural communities in Solomon Islands, one of the Pacific's two poorest countries, in a way that exploitation of wild stocks for MoP could not, was the driver for both the original research programmes, as well as the current project.

This report deals only with known information on blacklip pearl oysters. Subsequent reports from this project will describe other aspects that relate to the viability of pearl farming in Solomon Islands. These will, for example, deal with the white or goldlip pearl oyster (*Pinctada maxima*), environmental conditions, on the investment climate in Solomon Islands and the legislative and policy framework under which pearl farming will operate.

1.1. Information sources

Information currently available from Solomon Islands on blacklip pearl oysters (*Pinctada margaritifera*) and their potential culture comes from three main sources; records of past exploitation, occasional resource surveys that have included blacklip pearl oysters; and research on culture of blacklip oysters in Solomon Islands. Statistics on past exploitation are limited to export tonnage and value collected by the Statistics Unit of the Ministry for Fisheries and Marine Resources. Spatially resolved data from within the country, by island or by island group are not available. However, since export appears to have been through a single point, Honiara, these records are likely to reasonably accurately reflect the tonnage exported. Of the various resource assessments that have been undertaken the only recent, nationwide one that we are aware of is that coordinated and funded by The Nature Conservancy (TNC) in May-June 2004. All of the information on pearl farming in Solomon Islands is derived from a research project carried out in the period 1993-1997 by the WorldFish Center (previously the International Center for Living Aquatic Resource Management – ICLARM) in collaboration with MFMR and funded by the Australian Centre for International Agricultural Research (ACIAR). After 1997, through to the present, WorldFish continued research on blacklip pearl production, supported through its own funds, albeit at a reduced level.

2. History of blacklip trade in Solomon Islands

Some small scale trading and exchanges involving blacklip and other oyster shells, as well as copra, ivory, nuts, sandalwood and tortoise shell took place in the early history of Solomon Islands. However, there was no proper record kept, and thus no figures can be estimated on the amount and value of the shells traded during those early years.

The only up to date record of blacklip exports from the Solomon Islands was a list produced by the Statistics Division of the MFMR, on all marine species exported from the country. Reports on blacklip only show figures starting from 1983 to 1994 (Figure 1). For a decade from 1983 export volume fluctuated around a mean of 30,000 kg (equivalent to approximately 50,000 shell at 0.6 kg per shell[1]). No data are available on fishing effort between years, nor on the locations form which shell came. There was no legal export of blacklip exports after 1994 because of a Government ban on all pearl shell exports. It is important to note that these figures are only for exports and does not include records of blacklip shells that are used locally and perhaps traded as souvenir to tourists.

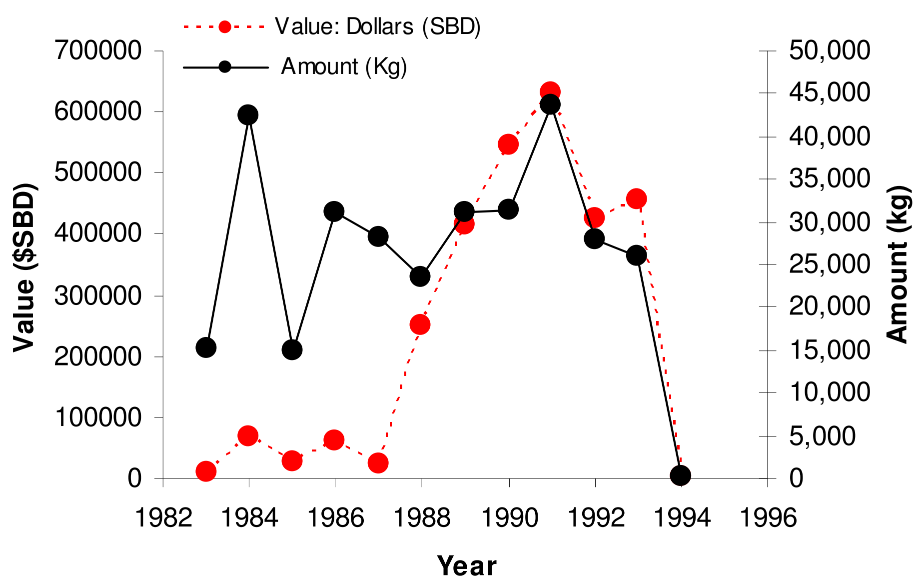


Figure 1. Export of blacklip shell from Solomon Islands for mother of pearl.

[1] 0.6 kg per individual based on weighing of 100 dry adult shells from the Nusa Tupe trial pearl farm.

3. Nationwide surveys

In May-June 2004, a nationwide survey of marine resources was undertaken by the Solomon Islands Ministry of Fisheries and Marine Resources, in collaboration with The Nature Conservancy. One section of this survey specifically looked at "Fisheries Resources: commercially important macroinvertebrates" (Ramohia, 2006). In this survey, 66 reef sites were visited, encompassing seven provinces within Solomon Islands. At each site six, 50 x 2 m swaths parallel to the reef crest and between 5 and 10 m depth were examined by SCUBA divers and the number and size of commercially important macroinvertebrates, including blacklip pearl oysters, was recorded. At 63 of these sites, a further survey was undertaken of deeper sites on the reef. In that survey, five, 50 x 5 m swaths were surveyed similarly.

Only 39 blacklip pearl oysters were found in this survey, 36 at shallow sites and three at deep sites. Of the 66 shallow sites, where 600 m^2 of reef was examined, 16 sites yielded a single oyster, five yielded 2 oysters, two four oysters and one five oysters. The low numbers found make any confident identification of preferred regions difficult. Of the six provinces surveyed, Western showed the highest number of sites with oysters, and was the main province in which more than 1 shell was found at a site (Table 1). At the deep sites, only 3 yielded oysters, in each case a single specimen. Overall, the surveyors suggested a tendency for more shell to be found in exposed than sheltered locations. Shell size was reported in 20-mm size bands, with the median and modal size of the 39 individuals being 140-160 mm (Figure 2).

Table 1. Number of shallow (5-10 m deep) sites examined during the TNC/MFMR resource survey, that yielded blacklip pearl oysters (BL). Figure in parentheses is percent of sites. Note total is not the sum of the provinces, as two sites were in disputed waters.

Province	Number of sites surveyed	Number of sites with BL (%)	Number of sites with >1 BL (%)
Central	9	3 (33)	1 (11)
Isabel	12	3 (25)	0
Choiseul	8	3 (37)	0
Western	13	8 (61))	4 (31)
Makira	10	3 (30)	0
Malaita	10	2 (20)	1 (10)
Guadalcanal	4	0	0
Total	**66**	**24(36)**	**8 (12)**

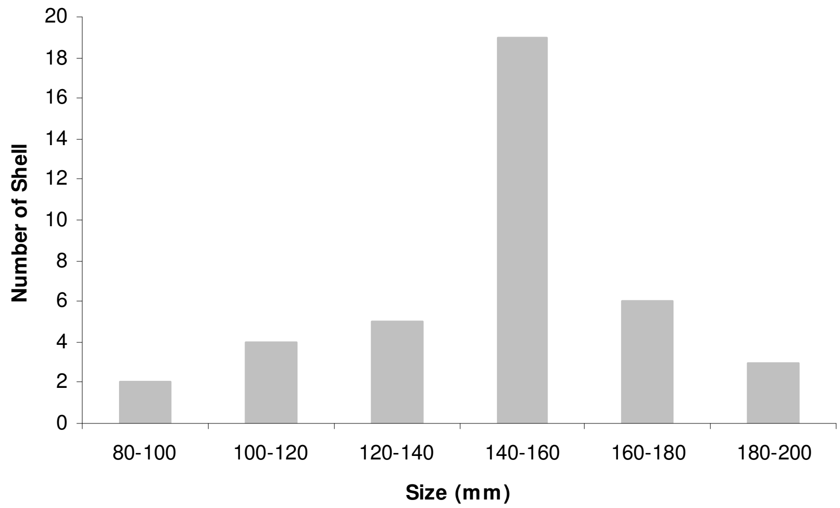


Figure 2. Size, as dorso-ventral measurement, of blacklip pearl oyster shell encountered during the TNC/MFMR national resource survey in 2004. Samples from all sites and depths have been pooled.

4. Farming of blacklip pearl oysters in Solomon Islands; spat collection

Much of the interest in establishing a pearl farming industry in Solomon Islands took as its starting point culture elsewhere in the southwest Pacific, particularly in French Polynesia. There, a mature industry had developed around capture of wild spat, transfer to suspension culture and implantation of pearl nuclei. However, it was immediately apparent that there are significant differences between Solomon Islands and French Polynesia that needed to be accommodated in transferring techniques. For example, reefs in French Polynesia there are many "closed" or "semi-closed" coral atolls. These atolls enclose large, relatively shallow lagoons which have limited exchange with the open ocean and many of the pelagic larvae released inside the lagoons tend to remain there. Pearl oyster farmers exploit this natural concentration mechanism by collecting and growing out spat inside the lagoons. Such lagoons are rare in Solomon Islands and there are few obvious places where spat would be naturally concentrated. Thus from the outset, identification of patterns of spat settlement (location, timing and strength) was identified as the highest research priority.

4.1 Spatial distribution of spat

The distribution of spat around Solomon Islands was investigated by Friedman et al (1998) through the deployment of spat collectors at 24 sites in seven regions, spanning 500 km of the Solomon Islands archipelago (Figure 3, Table 2). Collectors were deployed on seven occasions between January 1994 and July 1996. At each site, 10 spat collectors were attached at intervals along a 100 m longline made of 12 mm polypropylene rope. The most commonly used collector comprised a 0.8 m^2 panel of 55% shade mesh, folded concertina-fashion, threaded and tied in a bundle with monofilament line. Spat collectors were deployed every three months, and harvested six months later.

The longline to which collectors were attached was positioned perpendicular to the reef, with one end tied off to coral heads at approximately 5 m depth, and the other anchored in approximately 25 m water depth. Anchor lines and sub-surface buoys, at 20 m intervals, were used to hold the longline at a depth of 3 m (Figure 4).

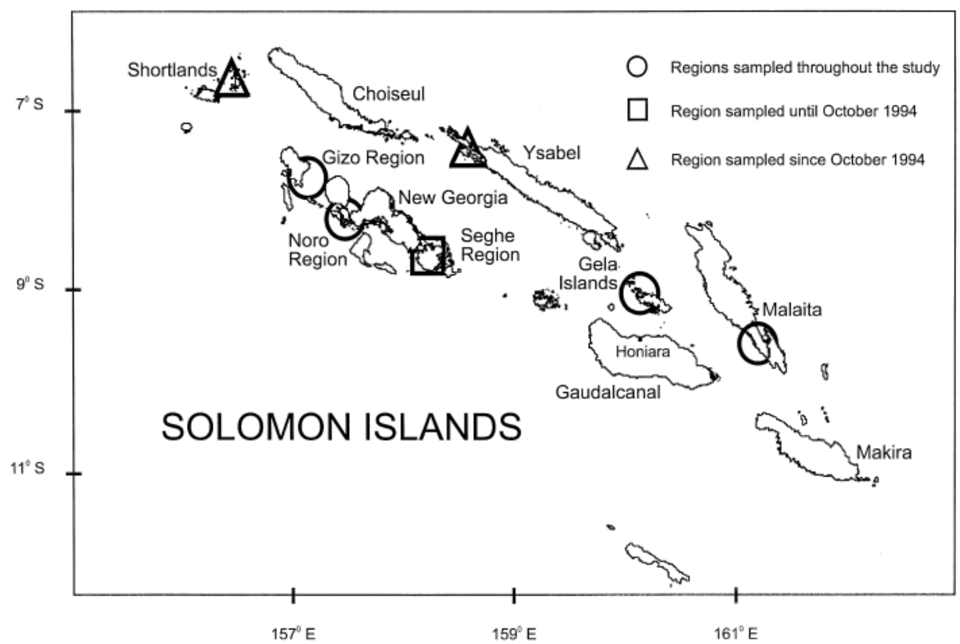


Figure 3. Sites used in the study of spat collection around Solomon Islands.

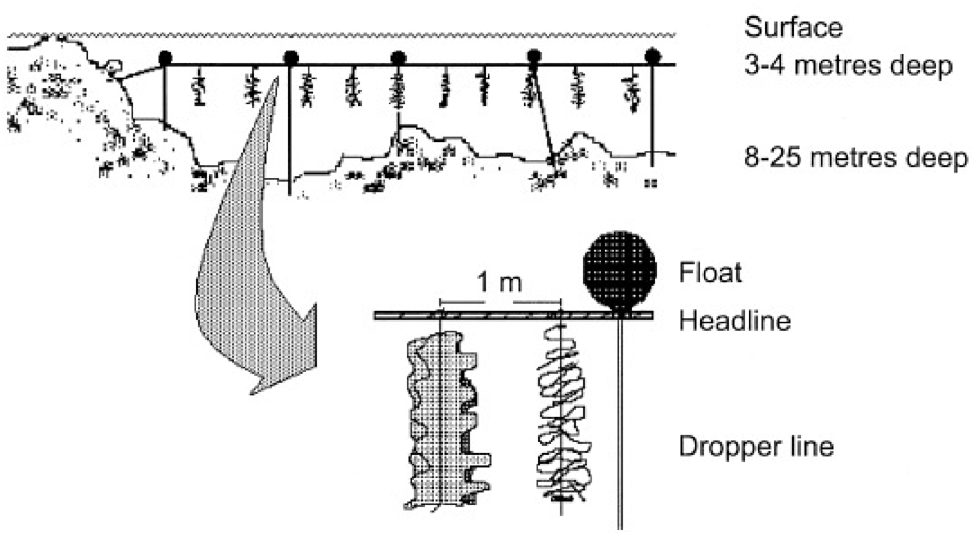


Figure 4. Arrangement of spat collectors and longlines at each of the collection sites.

The first series of deployments (Jan 1994 – Jul 1994) were made at 3-4 sites in each of 5 regions; Gela, Seghe, Noro, Gizo and Malaita. From October 1994 to the last deployment of the study in January 1996, Seghe was dropped and two extra regions, Santa Isabel Island and Shortland Islands (3 sites in each) were added, making the direct comparisons of spat yields complex. Table 2 provides an overall summary of spatfalls.

Table 2. Average spatfall per deployment (~10 collectors) at each of the sites.

Region	Site	Total	Live	Dead
Gela	Siriana	14.7	6.1	8.6
	Hararo	17.0	11.9	5.1
	Buena Vista	26.0	16.4	9.6
Seghe	Runway	0.0	0.0	0.0
	New Mitchi	0.0	0.0	0.0
	Uepi	2.0	1.0	1.0
Noro	Tambaka	0.0	0.0	0.0
	Noro	2.6	2.0	0.6
	Boeboe	1.3	0.6	0.7
	Outer	66.5	36.5	30.0
Gizo	Sageraghi	15.9	10.7	5.1
	Liapari	2.0	0.0	2.0
	Valapata	23.4	11.0	12.4
	Nusa Tupe	53.3	31.3	22.0
South Malaita	Ai'arai	12.3	6.4	5.9
	Pipisu	3.1	2.4	0.7
	Kau	0.5	0.5	0.0
	Warokai	9.0	0.5	8.5
Ysabel	Heta Heta	2.5	1.5	1.0
	Lelego	11.3	4.3	7.0
	Vohinari	53.0	40.0	13.0
Shortlands	Toumoa	37.7	25.3	12.3
	Tagarai	28.3	16.8	11.5
	Samanago	16.0	11.5	4.5

The wide and overlapping ranges of spatfalls at sites within regions (Table 2) meant that no statistically significant difference between regions could be detected from these data (ANOVA). However, statistically significant (at $p>0.05$) differences between sites within regions were found, indicating that site quality varies across Solomon Islands, but that "good" sites could be found throughout. Seghe was an exception, though low catches there appeared to be related to poor water quality in the Marovo Lagoon where sites were located.

The authors attempted to define characteristics of a good collection site. Unlike French Polynesia, all enclosed lagoons sampled in Solomon Islands were poor spat collection habitat and collectors there fouled rapidly with algae. Lagoons in Solomon Islands are often surrounded by high ground with substantial rainfall and run-off of sediments and nutrients (especially after logging has been carried out). This was thought to be the source of high turbidity and fouling algal growth that affected all lagoon collectors in Solomon Islands.

On a local scale, it was found that collectors deployed close inshore consistently recruited far fewer spat than those offshore. Offshore sites tended to have clearer water and greater water movement and probably suffered less predation by reef fish. Overall, factors which have been found to correlate with large spat hauls are;

- sites close to, but offshore of major reef systems
- clear water,
- moderate current flow,
- water depth > 15 m,
- at least 35 m from the nearest reef.

Sites with these properties can be found throughout Solomon Islands.

Several other observations made during this study triggered further research, particularly the observations of variable catches between types of spat collector, high spat mortality (Table 2 shows 47% of recovered spat were dead) and an apparent seasonality in spatfall with a summer maximum. Table 2 indicates how two of the best spat collection sties were at Gizo and Noro. These are conveniently located within 1 h of the WorldFish laboratory at Nusa Tupe and were selected for further research to address these observations.

4.2 Different types of spat collector

Several types of spat collector have been tried at the Gizo and Noro sites. The most comprehensive investigation into this compared two collector designs and two kinds of material (Figure 5); bundles of shade mesh or plastic sheet, either inside protective mesh bags made of 2 x 5 mm netting or with no protective bag (Friedman and Bell, 1996). The two material types were deployed as 1.6 m^2 lengths, either folded up concertina-fashion (shade mesh) or cut into strips (plastic sheeting). Twenty of each type of collector were deployed, 10 of each inside protective mesh bags and ten of each with no bag. Thus 10 replicates of each of four treatments were arrayed randomly along a longline and immersed for a six-month period.

On harvesting, the number and size of spat collected were recorded, together with the number of spat predators associated with each collector. Over twice as many spat were collected onto collectors made from mesh as onto plastic sheet, but bagging the collectors made no difference to catch rate. The type of material had no consequence for the recruitment of predators to the spat collectors and bags offered no protection from predators – rather predators tended to be retained inside the "protective" bags.

Other types of spat collector were also tried, including "rope" collectors similar to those in use in some French Polynesian farms and multiple mesh collectors. Rope collectors comprised a bundle of five, 500-mm lengths of spat rope, folded in half and secured at the top. Shade piece collectors comprised four, 0.2 m^2 sheets of shade mesh secured onto a 1.15 m length of line. Neither of these alternative collectors performed better than the standard concertina shade mesh sheet.

Some attention has been given to the orientation of longlines. It has been found that longlines should be deployed perpendicular to the current. This increases yield and minimises tangling of the lines.

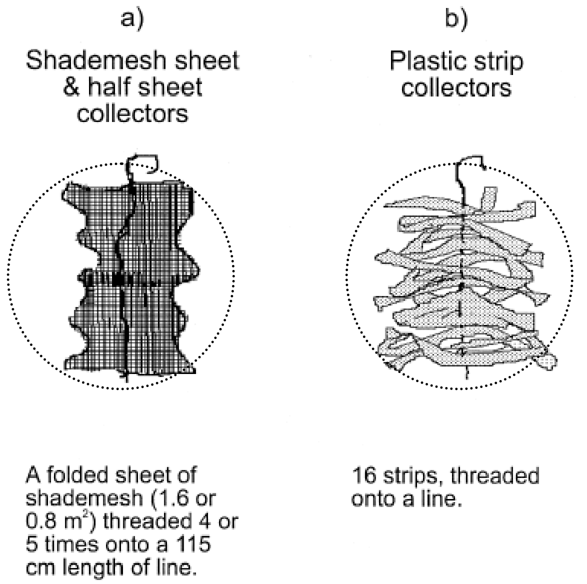


Figure 5. The two basic types of collector compared in the Friedman and Bell (1996) study. Twenty of each type were deployed, half in protective mesh bags and half open. The plastic sheeting was more effective than the shade mesh and the bags proved to have no protective effect.

4.3 Seasonal pattern of spatfall

From June 1997 to October 2003, ten spat collectors were deployed at three sites close to Gizo and four sites in Noro for two month immersion times, every two months. On harvesting the collectors the spat were counted and measured. The same collector type was used throughout, and the same staff were responsible for all practical aspects of the collection; this makes this an excellent dataset from which to extract seasonal patterns of settlement.

To examine the seasonal pattern of spat settlement we first normalised for the consistent differences between sites by dividing the catch for each period at each site by the overall median catch for that site. The normalised catch from all of the seven sites were combined and plotted against month as a single plot (Figure 6). A time-catch relationship was then determined by least-squares regression analysis. The best fit to the data was obtained with a sine function;

$$\text{Catch} = 1.8 + 1.34\cdot\sin(2\cdot\pi\cdot (\text{Month})/12+7.9) \quad \text{(equation 1)}$$

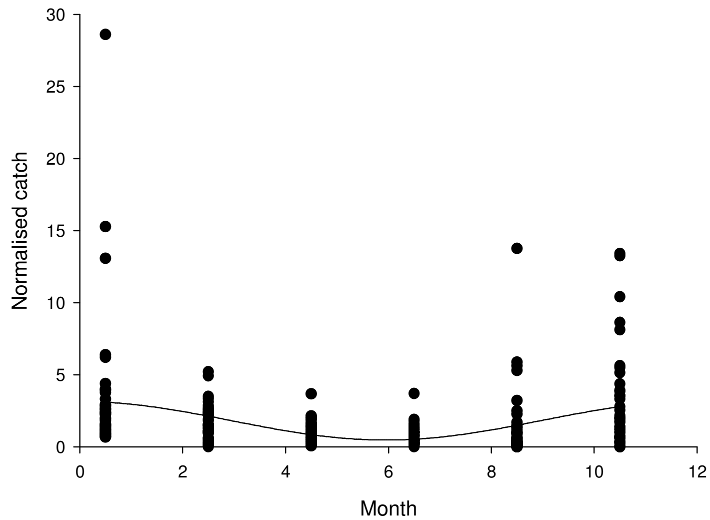


Figure 6. Seasonal pattern of spat collection during the 1997-2003 period. Each dot represents a single site, with the dot plotted in the middle of the two month deployment period. The curve is fitted by least-squared linear regression.

Figure 6 and equation 1 point to a cyclical pattern of recruitment to spat collectors, with a minimum in winter and a maximum in collectors deployed from October through to February. There was no period of the year in which no spat recruited, suggesting a prolonged breeding season. In the limited experience of Solomon Island hatcheries, operating at ambient temperature, the life of blacklip pearl oyster larvae prior to metamorphosis is around 25-30 days, suggesting a wild spawning peak in September-December.

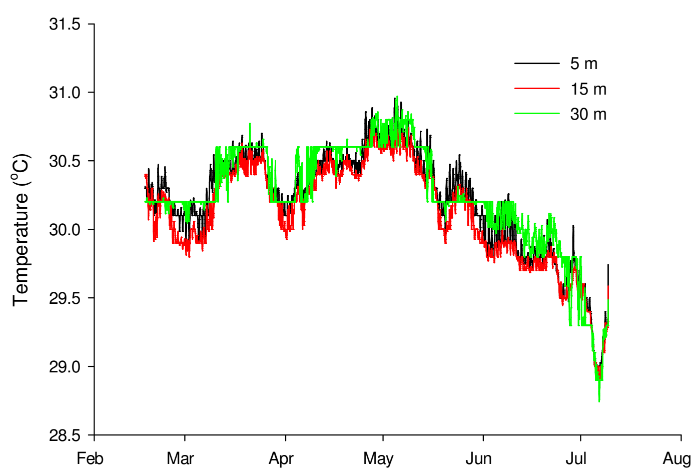


Figure 7. Water temperature at three depths in the Nusa Tupe lagoon for the first half of 2007. Boxcar smoothing has been applied, using the running 3.5 h mean (individual records are at 30 minute intervals.

Seasonal temperature variation is slight in Solomon Islands. An incomplete annual record for 2007 shows a maximum of close to 31^{o}C in May, falling with the onset of winter winds, lower insolation and air temperatures to 29^{o}C in July (Figure 7). The onset of the spawning peak in September is likely to coincide with the annual temperature minimum. Very little vertical temperature structure is evident in figure 7, with occasional period of weak temperature stratification that last for a few days to one week.

4.4 Inter-annual differences

Oengpepa et al., (2006) examined inter-annual differences in spat collection at sites in Noro and Gizo using an eight year dataset from 1997 to 2005. These data were a temporal extension of the dataset described in section 2.2, based on 10, 0.4 m^2 shade cloth bundles attached to a longline as in figure 4.These data are plotted as figure 8 and show the annual summer peak described above – though it is clear that in any one year the peak can be more pronounced than in the long term average of figure 6. Figure 8 indicates how the exact size and timing of the peak varies from year to year but show no obvious trend or periodicity. The range of peak spatfalls varied over more than an order of magnitude, with median values of 3.8-4.8 spat per collector. The latest a peak occurred was in collectors harvested in March, the earliest in December.

Table 3. Mean, maximum and minimum sizes of annual spat peaks (as spat per collector) on collectors deployed at Gizo and Noro from 1997-2005.

Measure	***Noro***	***Gizo***
Mean	5.8	5.5
Median	3.8	4.8
Maximum	19.6	11.1
Minimum	0.4	1.4

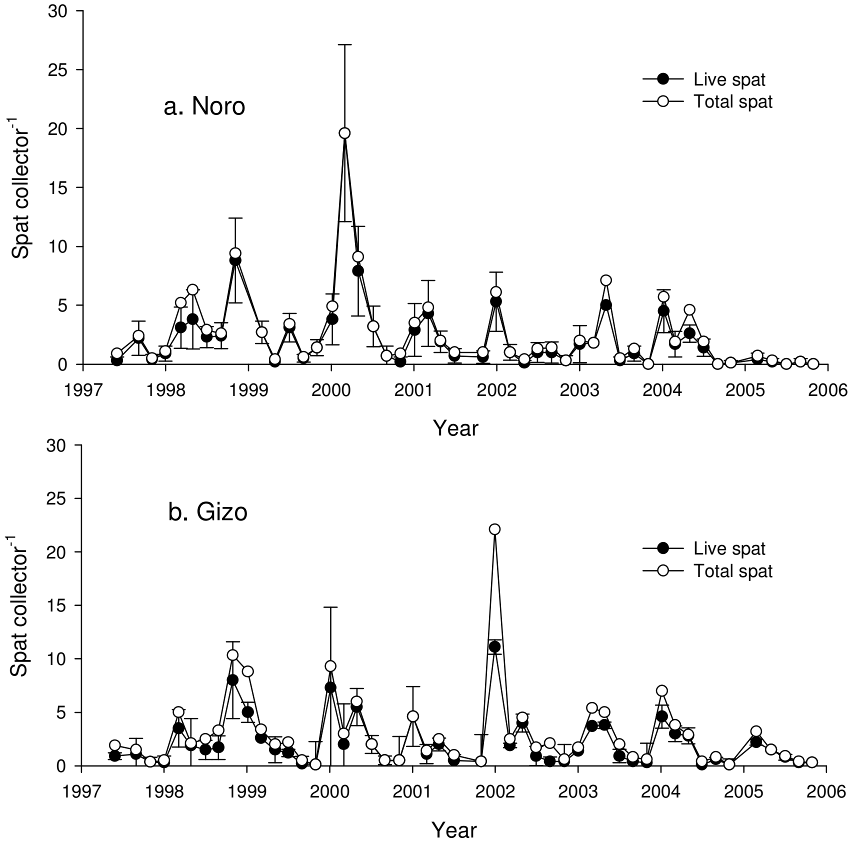


Figure 8. Mean abundance of spat (total and live) on collectors at a) Noro and b) Gizo in the Western Province of Solomon Islands. Error bars are 95% confidence limits around live spat.

4.5 The effects of immersion time on spat collections

While it might appear logical to expect that the number of spat collected and the size of those spat will increase with duration of immersion – as more spat recruit and recruits grow – this has proven not to be the case (Figure 9). Data in figure 9 were obtained by sequential harvesting of spat collectors deployed in December 1995 after 3, 4, 5 and 6 months (Friedman and Bell, 2000). The decline of numbers from three months onwards indicates a net loss of spat from the collectors i.e. losses exceeded recruitment. In a repeat of this experiment one year later, the authors found a similar response, though the number of spat peaked at four rather than three months, suggesting a longer or delayed recruitment relative to the first experiment.

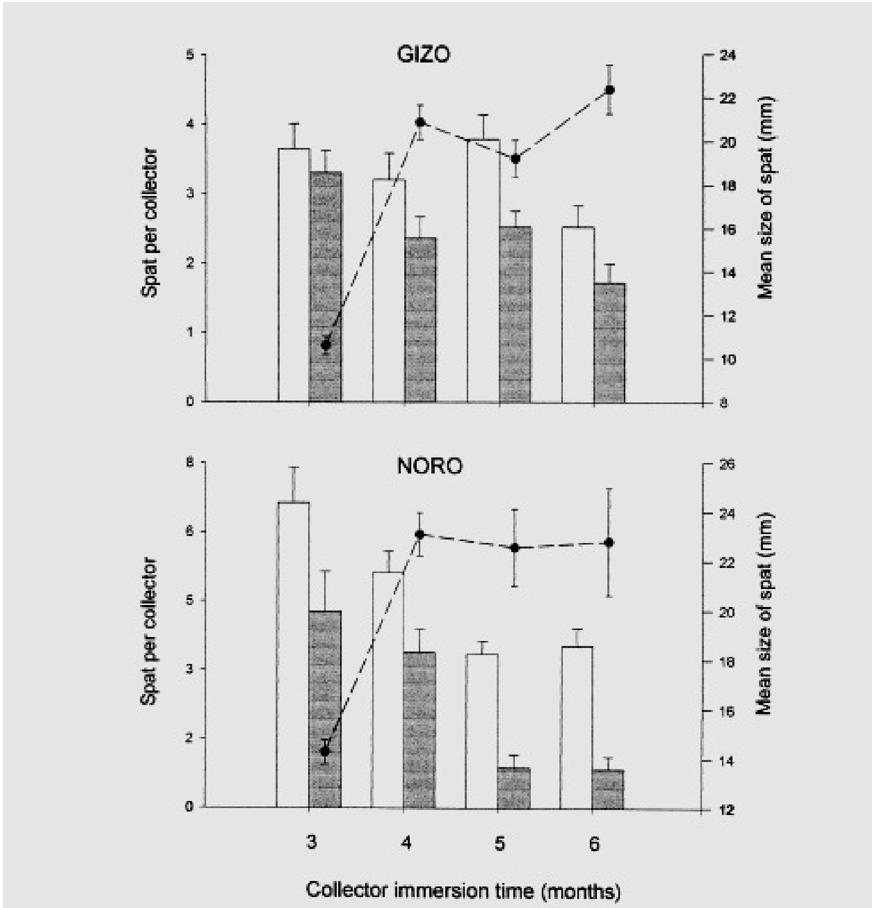


Figure 9. Total (blank columns).and live (solid columns) abundance, ± standard error, of blacklip spat harvested from collectors after 3, 4, 5 and 6 months at Gizo and Noro. The mean size, as dorso-ventral measurement ± standard error of live spat harvested each month is also shown.

As well as indicating a net loss of spat from the third month onwards, figure 9 also shows that this loss appears to prevent the mean size from increasing. Size-frequency plots from this study (Friedman and Bell, 2000) indicate that after three months most spat were <15 mm, after four months these spat had grown out to ~20-25 mm, but that after four months numbers in all size classes declined, with no evidence of further growth.

Spat predators as well as spat recruit to collectors on Solomon Islands. The dominant predators are gastropod snail of the genus *Cymatium*, though others, including various species of crab and flatworm are also found. There were significantly more, and larger, predators on the collectors recovered after six months than those after four months (Figure 10), providing circumstantial evidence that it is the accumulation of spat predators that reduces spat yields with increasing immersion time.

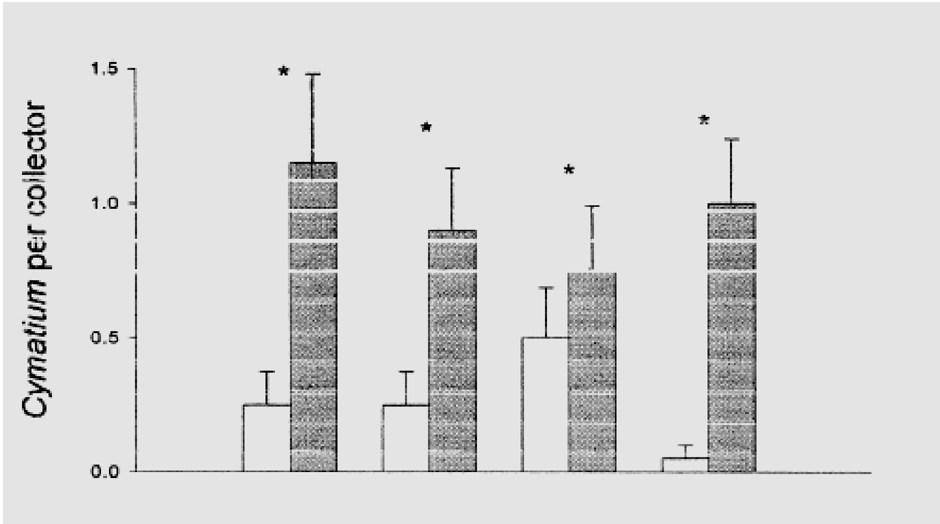


Figure 10. The number of *Cymatium*, a significant predator on spat, on collectors after four months (blank columns) and 6 month (solid columns) at four collection sites. Asterisks indicate significant differences between blank and solid columns (ANOVA p<0.05).

4.6. Hatchery production of spat

Experimental production of spat was undertaken prior to 2000 at the WorldFish Center's Aruligo hatchery close to Honiara in Solomon Islands. Three hatchery runs were made and, as this was *de novo* development, success increased with each run. The process that was developed was as follows;

- 20+ fecund wild oysters were selected.
- Spawning was induced by thermal shock.
- Male and female oysters were separated into containers when gametes are released
- Eggs were fertilised with sperm at 1-5 sperm per egg.
- Fertilised eggs were stocked into aerated indoor culture tanks at 30-50 per ml
- Tank water was changed every second day
- Antibiotics were used during incubation to prevent bacterial infections
- On days 2-18, larvae were feed twice a day with a mixture of 3 or 4 species of cultured micro-algae. Feeding rate was increased when it was observed that the larvae were digesting the food well and food consumption increases.
- On day 3 stocking density was reduced to 5 veligers per ml
- Around day 5, change to 2,5000-3,000L culture tanks and stock larvae at 3 per ml.
- On day 8-10 larvae had metamorphosed to the early umbo stage, by day 12 fully developed umbo larvae predominated
- On day 16-18 larval eye spots had become distinct. Spat collectors (shade mesh type) were then hung in the culture tanks.
- Stocking density was reduced to 1 per ml on day 20
- Day 21-23 pentigrade stage visible on spat collectors
- Day 25-28 spat collectors transferred to sea grow out site.

The third attempt at spawning yielded approximately 2000 spat, which were transferred to the Nusa Tupe research centre for experimental grow-out. Further experiments in hatchery culture were terminated when the Aruligo site was damaged during the ethnic tensions of 2000.

5. Spat grow-out

5.1 Development of intermediate culture

The high mortality of spat on collectors in Solomon Island waters means that the longer the spat collectors are deployed (after 3-4 months) the fewer spat are returned. Not only this, but there is little to be gained in terms of increase in average spat size from prolonged immersion of spat collectors. Thus the strategy used in many pearl farming locations of leaving spat on collectors until they are ready to be hung on lines may be inappropriate. Friedman and Bell (2000) found that mortality was 42% for spat left on collectors between month four and month six. This is higher than the 30% rate reported by Coeroli et al. (1984) for 6-12 month old juveniles in French Polynesian lagoons. An experimental intermediate grow-out system has been developed for Solomon Islands that takes spat from collectors at a small size and grows them out in trays until they reach a size large enough to be strung.

The benefit of intermediate growth is the increase in spat survival. Compared with the 58% survival of spat left on collectors, spat larger than 15 mm survived at 82-93% when they were removed and transferred to protective cages (panel nets; Friedman and Bell, 2000). For very small spat (<10 mm), panel nets offered no increase in survival, and a 44% mortality still evident. Panel nets foul with algae and predators and had to be cleaned every 2 weeks – a significant extra labour cost which needs to be weighed against the benefits of increased spat survival.

Further research has refined the intermediate culture technique. It has been found that gluing spat inside plastic trays (Figure 11) with a small drop of cyano-acrylate glue ("Superglue") provided for an overall survival of 87%, compared to 75% without gluing, with growth from 10 to 50 mm within 5 months, compared to 10 to 40 mm for unglued spat. Deploying grow-out units at greater depths reduces fouling and should enable a reduced cleaning schedule.

Figure 11. Intermediate culture trays with spat glued onto the base with "Super-glue". After lids are fitted the trays are suspended from long lines.

Intermediate culture can also be a stepping stone to helical culture. In helical culture, small shell are drilled close to the byssal opening, threaded onto low breaking strain fishing line (15 lb is used at the WorldFish Research Centre) and then wound into the groove of a 1 m length of laid rope, which is then placed inside a protective mesh sleeve. We have found that spat can be drilled for helical culture at around 25-30 mm, suggesting that most spat will require only three-four months of intermediate culture (e.g. Figure 12, 13). Helical culture provides enhanced growth conditions through improved water movement and still provides protection from fish predation.

5.2 Hatchery-reared spat in intermediate grow-out

A single experiment was undertaken in 1999 to compare the growth and survival of hatchery-reared and wild-caught spat. In each case, spat were glued inside plastic trays and incubated at random distances along a longline. Interpretation of survival data is complicated because the wild-caught spat suffered an unusually high rate of mortality in the early stages of growth (Figure 14). On average, hatchery-reared spat grew at a slightly but significantly slower rate than wild-caught spat (Figure 11). These data suggest that, should implantation of hatchery-reared spat prove successful, this could be a realistic alternative to reliance on wild capture.

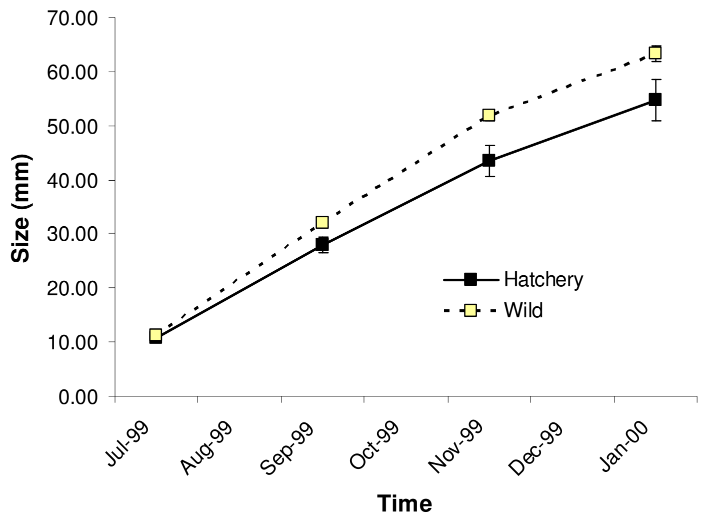


Figure 12. Comparison of growth of hatchery-reared and wild caught spat in intermediate culture trays. Points are means of four replicates ± standard error.

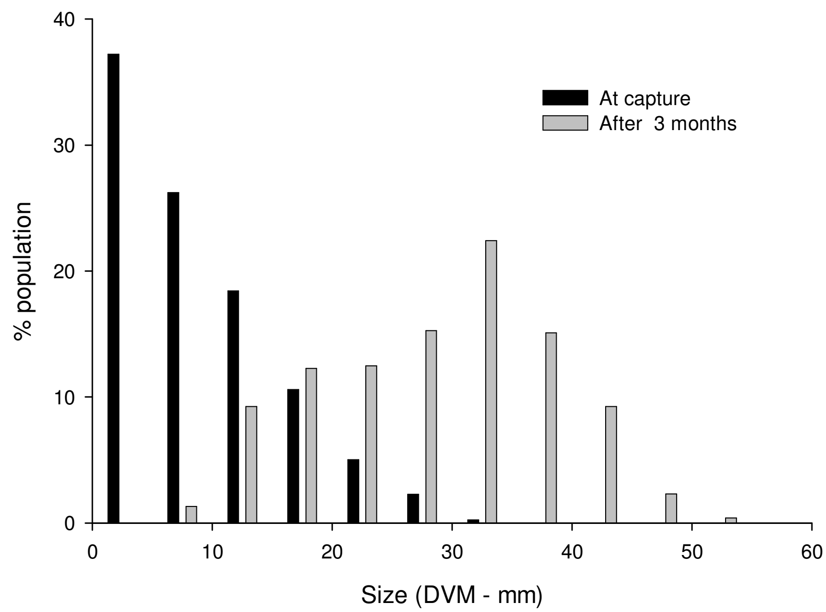


Figure 13. Typical performance of intermediate culture. This batch of 2000 spat were first measured after removal from spat collectors after four months immersion (November 2005-February 2006) and grown in intermediate culture for three months before re-measuring. During that time the trays were cleaned only once. Most (those above 25 mm) were then transferred to helical culture.

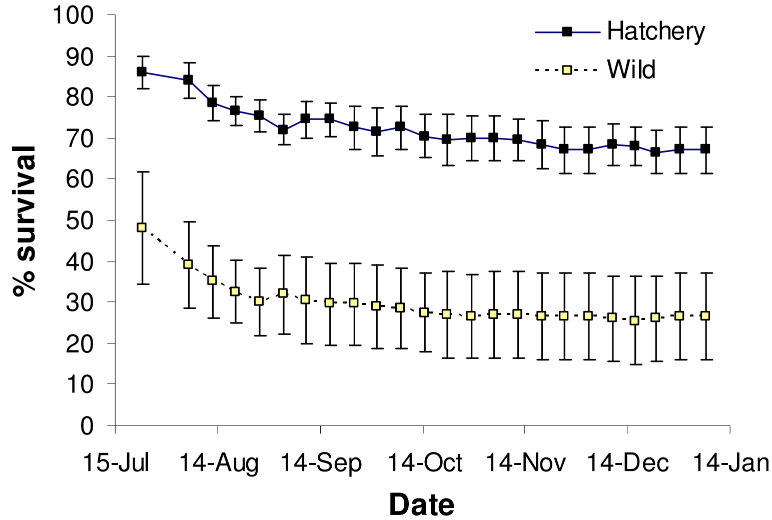


Figure 14. Survival of wild-caught and hatchery-reared spat in intermediate culture trays. Points are means of eight replicates ± standard error.

6 Juvenile growth

The next major stage in farming pearl oysters is the transfer of juveniles to dropper lines or "chaplets". The minimum size of shell for drilling and transfer to chaplets has been found to be 65 mm. The minimum size for seeding oysters with pearls has been 100 mm. Growth to chaplet size was discussed in section 3 and shown to require up to 8 months, depending on spat size at collection (Figure 15). The next growth phase of relevance is that to seeding size from first hanging on chaplets.

6.1 Growth to seeding size

There has been little research on this stage of culture in Solomon Islands. Figure 15 reproduces data from an ACIAR report (Friedman et al 1997; Friedman an Southgate, 1999) showing the growth of spat from a range of starting sizes over five months in intermediate culture (helical culture was not used) and growth of 80 individuals in four size classes transferred from intermediate culture to chaplets.

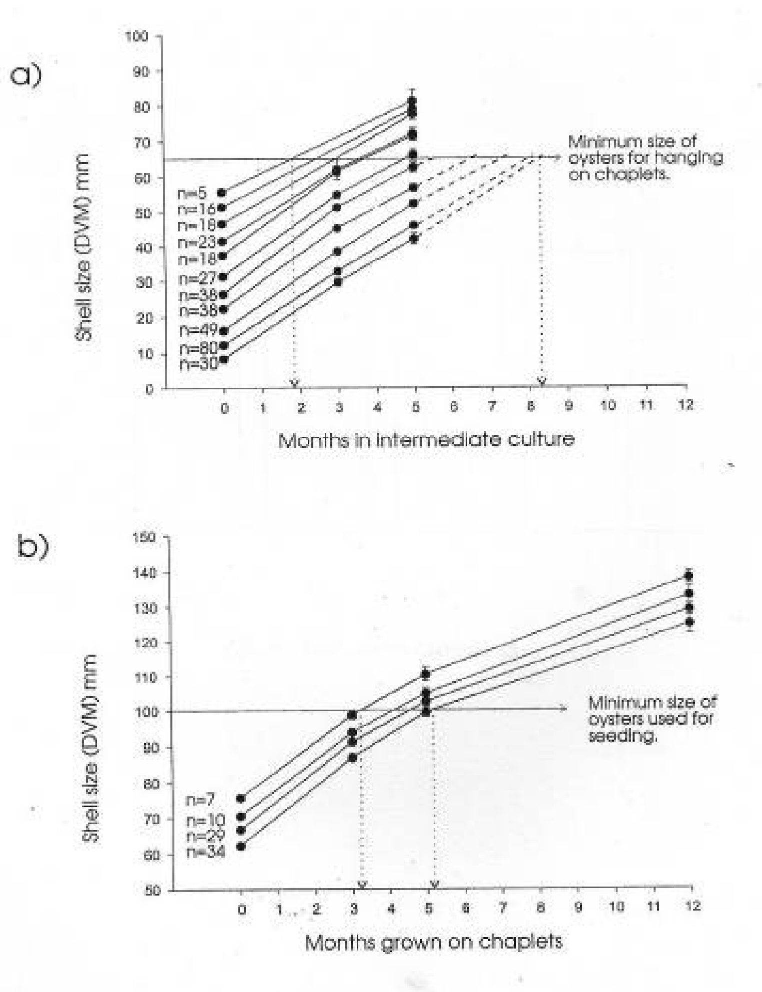


Figure 15. Growth trajectories for oysters of different sizes a) entering intermediate culture and b) placed on droppers for grow-out.

Extrapolation suggests that spat will take five to eight months to reach 65 mm from realistic spat starting sizes of 10-30 mm, followed by a further five months to reach 100 mm.

Growth rates of young oysters in Solomon Islands compares favourably with other locations. For example in Takapoto Lagoon in French Polynesia, 40-50 mm juveniles grew 30 mm in six months (Coeroli et al., 1984; Lintihac, 1987) and in the Cook Islands, 10 mm spat grew 16.4 mm in three months (Braley, 1997).

Survival of spat through intermediate culture was shown in section 3 to be approximately 70-90%, though some batches experienced lower survival. Survival of juveniles is much higher. Of a batch of 2000 young oysters hung on dropper lines as chaplets at the WorldFish research centre in 2000, 5.8% were lost after ~seven months. Most losses were associated with shells breaking off the chaplets; less than 1% were found dead on the chaplets.

Thus, under the regime developed in Solomon Islands, 70% of the spat taken from collectors can be expected to reach seeding size and this is likely to take 14-17 months from deploying spat collectors.

In Solomon Islands it has been found beneficial to hang oyster in pairs. This mainly relates to the strength of attachment and ease of cleaning. 95% of paired oysters attach to the rope or the other member of the pair by byssal threads, compared to 5% attaching to the rope in single shell, and cleaning of paired oysters was faster. The optimum frequency for cleaning of oysters on chaplets for attaining maximum growth rate was every three weeks. At this frequency, growth averaged 38 mm over a seven month period. This fell to 35 mm if cleaned fortnightly or at six week intervals, and to 36 mm if cleaning was every four weeks. At this frequency of cleaning, it was found that one full-time local staff member could look after ten longlines.

6.2 Morphometics of Solomon Island blacklip pearl oysters

Condition and quality of oysters can in part be related to morphometric relationships. We examined data recorded in July 1997 on the relationships between shell length, width, thickness and overall wet weight for a sample of oysters growing on chaplets at the WorldFish research station at Nusa Tupe. We used a log-log analysis to determine how shape changed as shells became bigger. We found that shells retained nearly the same length to width ratio across the available size range, but became slightly flatter as they grew. On average, a 120 mm long Solomon Island cultured oyster would be 124 mm wide and 30 mm thick and weigh 234 g. As it increased in size the ratio of weight to length would decrease from that expected from isometric growth[2]. Whether this represents a gradual thinning of shell or a reduction in tissue to shell volume ratio cannot be determined. We have no information on gonad or tissue mass in relation to shell size for Solomon Island pearl oysters.

7. Pearl production

There has been less research on pearl production than on collection and grow-out of spat. This is largely because of the assumption that results are more dependent on the skill of the seeder than on inherent properties of the Solomon Island oysters or growing conditions. This assumption is partly true, but there can be no doubt that growing conditions and the characteristics of the oysters will affect the size, colour and quality of pearl that can be produced; these aspects of pearl culture in Solomon Islands are under-researched. The history of seeding pearls into Solomon Island blacklip pearl oysters is shown in table 4. Batches 1-3 were operated on by the same experienced seeder from French Polynesia. Batch 4 was operated on by a less experienced Australian technician. In this section we summarise information on the seedings and the pearl yield. We note that, as was expected, the two technicians achieved quite different results using the same oysters on the same farm..

[2] Isometric growth occurs where all dimensions remain at more or less constant ratios as the shell grows. For weight, isometric growth should result in the weight increasing with the cube of length – in the data analysed here it increases with the power of 2.45, indicating allometric growth and a loss of "bulk" with increasing size.

Table 4. Summary of implantation and harvesting activities at the WorldFish Center experimental pearl farm.

Year	*Month*	*Batch 1*	*Batch 2*	*Batch 3*	*Batch 4*
1997	September	Implanted			
1998					
1999	April	Harvested	Implanted		
2000	October		Harvested	Implanted	
2001					
2002	April			Harvested	Implanted

7.2 Bead sizes

In the first seeding, 1644 spat-reared shell were implanted with nuclei of 2.0 to 2.4 BU (6.06-7.27 mm). In subsequent years a greater range of bead sizes were selected by the seeding technicians (Figure 16). Similar sizes could be implanted at the two April seedings, while it was possible to implant slightly larger nuclei in the single October seeding. This may relate to observations discussed in section 2.3 above, suggesting that the spawning peak is in September, allowing for empty gonads for the October seeding.

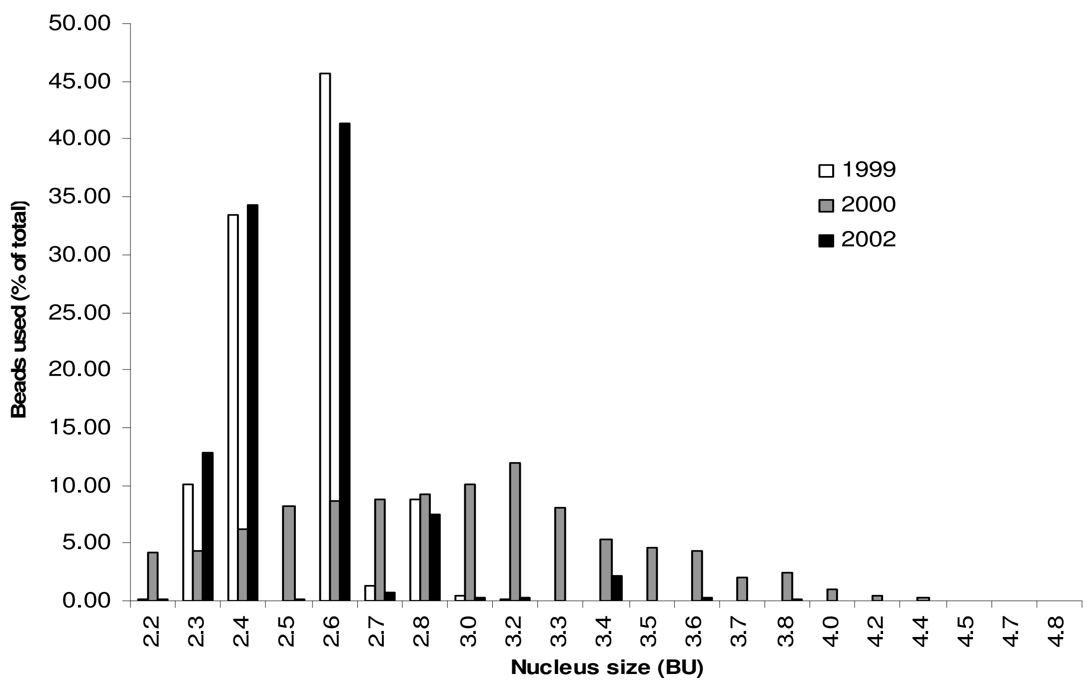


Figure 16. Nucleus sizes used during operations in 1999 (1203 total shell seeded), 2000 (2113 total shell seeded) and 2002 (2289 total shell seeded).

7.3 Retention and mortality after seeding

Post-operative mortality and rejection (vomit) of the implanted nuclei were much higher for the 2002 seeding than for any prior (Table 5). This corresponds to a change of seeder, and we suggest that the outcomes of the first three seedings provide the best picture of the seeding properties of Solomon Island shell.

Table 5. Post-operative mortality, nucleus rejection rate and overall survival of oysters derived from wild caught spat. Number = total number of each type of shell operated on. % dead indicates mortality within 4 weeks of operation, % vomit = shells ejecting nuclei with 4 weeks, % survival = shell surviving through to harvest.

Seeding	*Shell Type*	*Number*	*% dead*	*%vomit*	*%survival*
1997	Virgin	1644	9	26	86
1999	Virgin	1494	7	21	88
	1st re-seed	695	5	7	72
2000	Virgin	1292	14	27	59
	1st re-seed	506	11	3	84
	2nd re-seed	157	24	6	69
	Keishi re-seed	77	17	3	81
2002	Virgin	1793	21	57	No harvest[1]
	1st re-seed	1	0	0	No harvest[1]
	2nd re-seed	62	45	24	No harvest[1]
	3rd re-seed	20	45	20	No harvest[1]
	Keishi re-seed	4	25	25	No harvest[1]

1. No harvest was attempted from this seeding as for most categories fewer than 10% survived and retained nuclei.

For the first three seedings, the overall average post-operative mortality of virgin shell was 10%, with that of re-seeded shell similar (9%). Overall 25% of virgin shell vomited their nuclei, but this fell to 5-6% for reseedings. An average of 78% of shell operated on survived to harvesting.

7.4 Pearl yield and quality

As it was considered that the quantity and quality of pearls would reflect more the ability of the seeder than the quality of the oysters, relatively little attention has been paid to pearl yield and evaluation. The more successful of the two seeders achieved an overall return of 55% pearls per operation, though the return was highest for oysters receiving a repeat implantation (Table 6).

Evaluation reports were obtained for the pearls produced from the 1997 and 1999 seedings. These two reports evaluated different aspects of the pearls and only the first one provided estimates of commercial value. This 1997-crop report, the more comprehensive of the two, is reproduced as Appendix 1. By combining the two evaluations, quantification of; % pearls of no commercial value, and % of various colours, lustres, surface condition and shape can be obtained (Table 7).

In general, while one pearl was valued at AUD700, most were of low or no commercial value, yielding an overall average expected price for 1997 of less than $20 per harvested pearl. The evaluation (Appendix 1) does, however, suggest that the value and size of the pearls could be expected to increase as production proceeds.

The low value is reflected in the large proportion of pearls with low lustre, moderate to heavy pitting and poor (non-round) shape.

Table 6. Yield of pearls for various seedings and categories of oyster.

Seeding	*Shell Type*	*Number operations*	*Number pearls*	*% Pearl*	*Average weight (g)*
1997	Virgin	1644	886	54	?
1999	Virgin	1494	912	61	1.48
	1st re-seed	695	490	70	1.76
2000	Virgin	1292	338	26	1.68
	1st re-seed	506	463	81	1.60
	2nd re-seed	157	88	56	2.89
	Keishi re-seed	77	44	57	1.84

Table 7. Properties of pearls grown at the Nusa Tupe research station extracted from two commercial evaluations. All are given as percentage of total crop evaluated. The 1997 seeding yielded 886 pearls for assessment and from the 1999 seeding 514.

Property	*Category*	*1997*	*1999*
Value	None	17	61
	Low	82	39
	Moderate	<1	0
Shape	Round	13	6
	Other	87	94
Lustre[1]	A	8	
	B	27	
	C	65	
Surface[2]	0	2	
	1	0	
	2	4	
	3	68	
	4	22	
	5	4	
Colour	Greenish		25
	Silver-grey		47
	Dark-grey		20
	Black		7
	Magenta		2
	Gold		<1

1. Lustre was scored from A to C, with A the highest.
2. Surface condition was scored from clean (0) to 5 (severe spotting)

7.5 Seeding of hatchery-produced spat

A single trial seeding of 400 hatchery reared oysters was attempted. Unfortunately this was in 2002, when overall seeding results were very poor. Overall, the hatchery-derived shell suffered a 68% nucleus rejection (compared to 57% for wild-caught spat) and a 23% post-operative mortality (compared to 21% in wild spat).

7.6 Improving yield from Solomon Island pearl farms

The rate of growth of blacklip pearl oysters in Solomon Islands appears to be faster than at some other pearling locations. This may relate to the more fertile water (more run-off and upwelling close to the large landmasses) and the near-constant warm temperatures. This growth advantage may allow two strategies to be considered for Solomon Islands. Firstly, the size at first seeding could be increased, potentially allowing a larger bead to be inserted. By delaying from first reaching 100 mm to the second October after spat was collected, the shell is likely to have grown to >130 mm. Secondly the high rate of growth is also likely to apply to the pearl itself, and it may be possible to harvest the pearl earlier than at other sites, perhaps after less than one year, which is likely to improve the chance of a round, low-blemish pearl with good lustre.

8. Bio-economic model of pearl farming in Solomon Islands

In 1997, Friedman *et al.* prepared a draft budget for pearl farming in Solomon Islands as part of a report to ACIAR (Friedman *et al.*, 1997). This was based on the best biological and economical information available at the time, and suggested that, for a farm deploying 5000 spat collectors every year, and employing up to six staff (manager, foreman and four labourers). The model considered start-up and operating costs, together with pearl yield and value, and predicted that a profit would be returned after six years of operation, that would rise to over AUD1m after 10 years. It assumes that the pearl company would undertake all operations, from spat collector deployment to pearl harvesting, using a contracted seeding technician. No cost were included for rental of onshore land for construction of facilities, nor costs of agreements with owners of foreshore and seabed for use of the customary land. These issues will be covered in subsequent reports from this project, dealing with conditions of operating businesses in Solomon Islands, policy and legislation.

In hindsight, and with the benefit of more data, several of the parameters, both biological and economic, that were used in the budget can be improved on, changes that affect the net outcome of the budgeting exercise in both directions. As a conclusion to this review, we have revisited the Friedman budget and attempted to use updated values for key parameters. Table 8 shows how most of the biological parameters, that is the parameters that relate to the performance of oysters, have been adjusted downwards.

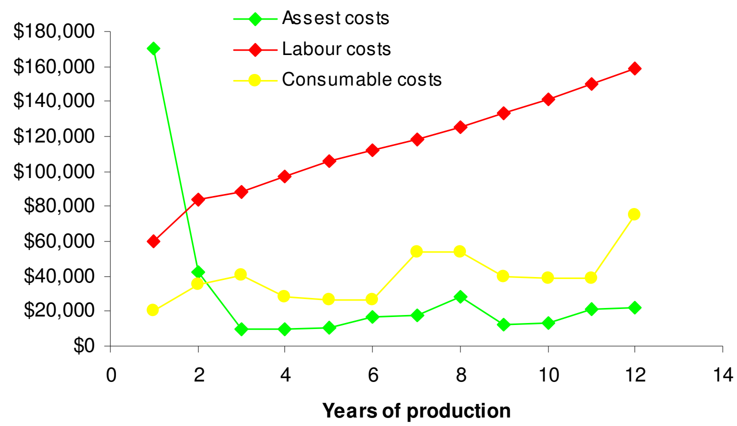
Table 8. Modifications to the biological parameters of the Friedman model on the basis of improved data.

Parameter	Original	Revision
Spat per collector	6	4
Spat survival through intermediate grow-out	0.8	0.7
Juvenile survival in grow-out to seeding size	0.95	0.9
Rejection rate of virgin shell at first seeding	0.12	0.1
Pearl retention by virgin	0.7	0.6
Rejection rate of shell at subsequent seedings	0.4	0.4
Pearl retention at subsequent seedings	0.85	0.8

Table 9. Costs incorporated into the budget for pearl farming in Solomon Islands. Unit cost refers to the cost at start-up, and Inflation rate indicates the annual rate of increase of these prices. Annual cost indicates the repair/servicing charge, or whether the item is an ongoing annual cost. Replacement time is the expected lifespan of the item.

Item		Unit cost, year 1 (AUD)	Inflation rate	Annual cost	Replacement time
Longlines (spat)		240 ea	6%	5%	5 yrs
Spat collectors		1.5 ea	6%	5%	5yrs
Longlines (shell)		270 ea	6%	5%	5 yrs
Chaplets		2.7 ea	6%	5%	Annual
Intermediate culture		18 ea	6%	5%	10 yr
Fuel		8000	10%	Yes	
Miscellaneous		8000	6%	Yes	
Housing		150,000	6%	5%	N/A
Dive equipment		15,000	6%	10%	6 yrs
Boats and engines		20,000	6%	10%	4 yrs
Labour					
	Manager	60,000 ea	6%	Yes	
	Foreman	10,000 ea	6%	Yes	
	Labourer	2,500 ea	6%	Yes	1 per 10 longlines

Using these parameters, we used a simple spreadsheet programme to follow the costs of operating the farm over 12 years, as stock numbers and pearl production stabilised. Costs are summarised in Table 9, and the opening position is that taken by Friedman of 5000 spat collectors deployed. By setting the annual intake of spat, this allows all other calculations to be undertaken, since the number of each item in table 9 required is determined by the number of spat and oysters in culture. Choice of a pearl value is critical to the profitability or otherwise of the enterprise. Friedman used values of $60 average price for the first pearl, $100 for the second and $150 for the third and fourth (all AUD). Given the valuation of the first batches of pearls from Nusa Tupe, and particularly the proportion of worthless pearls, these now seem overly optimistic. We have used average values of $25, $30 and $40 for the seeding categories. These are more conservative values, but based on data. We increased pearl values at a rate of 2% per annum from year three onwards. Using these modified parameters, the farm ends with a total number of shell in culture on chaplets of approximately 40,000, on a total of 40 longlines, reaching this quasi-stable state after seven years. With one local staff required for 10 longlines, after five years the staff stabilises at six. Note that in this model the costs of the seeding technician are not visible, but a cost of $4 per shell and 30% of pearl value cost is deducted straight from the income.



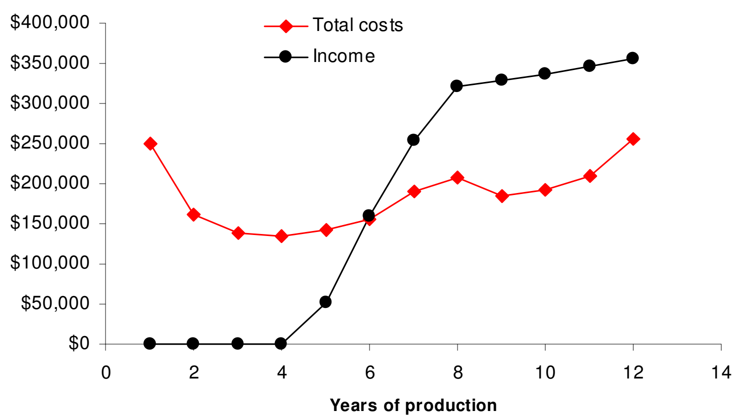


Figure 17. Predictions of possible costs and income from a pearl farm operating at similar efficiency to the Nusa Tupe trial farm, and based on 5000 spat collector deployed each year.

This very simple model suggests that if these are the only costs and the only income, then an operating profit (annual income minus annual costs) could be enjoyed after seven years which would tend to stabilise at around $150,000 (AUD) after eight years (Figure 17),. It would, however, take 12 years before any net profit (cumulative income minus cumulative costs) was returned, by which time almost $2 million would needed to have been invested. Returns would obviously vary if *any* of the parameters were to change. Permutations of the parameters are innumerable, but we considered the most likely option for increasing profitability to be an increase in farm size. This is accomplished in the model by increasing the number of spat collectors deployed and this increases the profitability in a way that is not linear with the number of collectors. A realistic scenario might be to increase the number of spat collectors by 5000 a year until a total of 20,000 are deployed in year four. Under these conditions, oyster numbers stabilise at close to 150,000 and the staffing needs increase to 16. However, labour is cheap in this model and despite increased costs, an operating profit is returned after six years. The potential profits increase to ~$1 million per annum and the return on investment to ~35%. An operation on this scale would still require commitment of ~$2 million before a net return was evident – in this case in year nine.

The bio-economic model described in this section is simplistic, but the intention is to show that, using realistic parameters, a sufficiently large investment in black pearl farming in Solomon Islands, over a sufficiently long period, should be profitable. Costs for which we have no information have not been included, notably provincial and national government licensing fees, costs of renting onshore and seabed facilities for both farming and spat collection and set-up costs relating to legislative requirements. These areas will be covered in other reports from this project, specifically from consultants dealing with the business climate in Solomon Islands, legislative requirements and government policy.

The Friedman/Bell model is for a pearl farm in which all of the functions are carried out by the enterprise, from spat collector deployment to pearl harvesting. The advantage of this approach is control of all aspects of production. An alternative model, in which specific activities such as spat collection and grow-out are more or less devolved to local communities, may be preferred by Solomon Island authorities. The range of options for pearl farming in Solomon Islands will be explored in subsequent reports from this project

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Appendix 1. Evaluation of the pearls from the 1997 (first) seeding.

Grading and valuation of the first crop of black South Sea Cultured Pearls from Solomon Islands by Rudi Zingg of Devino PTY Ltd.

I certify that I have examined 886 pearls delivered to me on the 6th August by Dr Johann Bell from the International Center for Living Aquatic Resources Management (ICLARM). Dr Bell informs me that the pearls were the first crop harvested from the demonstration pearl farm operated by ICLARM at Gizo in the Western Province of Solomon Islands.

Overall, the size and colour of the pearls are typical of those harvested from a first seeding of black-lip pearl oysters, although there are perhaps a greater percentage of pearls with a light olive colouration than is typical with other areas. The average size would be expected to increase once pearls from oysters that have been seeded for a second and third time are included in the crop.

My grading (see attached page) was done after all pearls had been polished and was based on size, shape, colour, surface condition (extent of “spotting”) and lustre:

Size: to the nearest 1mm
Shape: round, near round, semi baroque, and circle (including buttons and baroque)
Colour: this was variable within the range production by the black-lip pearl oyster and only described for the most valuable pearls.
Surface condition: ranging from a score of clean (0) to 5 (severe spotting)
Lustre: A, B, C.

The round and near round pearls were assessed individually, whereas the circle pearls were graded into three broad categories: A,B,C.

I have valued the pearls by attributing prices that I would expect them to fetch if they were being sold directly by the producer at a large pearl auction. The prices are in AUD and would be expected to increase 3 – 4 times if the pearls were sold through retail outlets.

Although the total value of the pearls is not remarkable, there is every reason to believe that pearls of high quality can be produced in Solomon Islands. The colours are attractive and acceptable and, over time, the average size of the pearls will increase as more shells are re-seeded for a second and third time. This factor alone should make a great difference to the value of the crop because the size of pearls contributes significantly to its value. Also, once experienced investors in the pearl industry are attracted to the Solomon Islands, it is reasonable to assume that they will improve the average quality of the pearls grown there by increasing the percentage of round and near round pearls beyond the 10% of such pearls in this crop. An experienced pearling company should be able to double or treble this percentage after 5 to 10 years, and also improve the surface condition and lustre of the pearls. This will depend mainly on the quality of the technicians (seeders) employed by the commercial enterprise. As is evident from the attached valuation, the total value of a crop of pearls can be increased substantially by even minor improvements in the percentages of high quality pearls. This trend has occurred elsewhere. For example, the black pearl industry in Tahiti has progressively increased the percentage of round pearls with good lustre and clean surfaces since the development of the industry.

In my view, the first crop of black pearls from Solomon Islands is encouraging. Assuming that experienced pearl farmers can be attracted to Solomon Islands, the question becomes not so much "are the waters around the islands suitable for growing pearls?" but "are the cost of producing pearls in Solomon Islands significantly lower than in other areas of the Pacific? It would be most helpful to prospective investors if ICLARM could prepare accurate costs for establishing and operating a pearl farm of, say, 50,000 oysters in Solomon Islands. Such information, combined with valuations of further crops from the demonstration farm, should be of major assistance in alerting pearl farmers to the opportunities in Solomon Islands.

Rudolf Martin Zingg
President
Devino PTY Ltd

10 November 1999

Grading and Valuation of 886 pearls from Solomon Islands

<u>Round and near round pearls</u>:	**AUD**
<u>Size 12 - 13 mm</u>:	
1 pce near round, 12.9mm, light peacock, clean surface, lustre B	700
1 pce near round, 12.5mm, grey, clean, hammered surface, lustre B	200
<u>Size 11 - 12 mm</u>:	
4 pces round, mixed colours, average spotting 2, lustre B	400
8 pces near round, mixed colours, average spotting 3, lustre B	800
<u>Size 10 - 11 mm</u>:	
22 pces round/near round, mices colours, av.spotting 3, lustre A and B	2,200
4 pces round, mixed colours, average spotting 5, lustre C	160
<u>Size 9 - 10 mm</u>:	
27 pces round/near round, mixed colours, average spotting 3, lustre B	2,160
<u>Size 8 - 9 mm</u>:	
20 pces round, mixed colours, average spotting 4, lustre B and C	500
6 pces near round, mixed colours, average spotting 3, lustre B	180
<u>Circle Pearls</u>:	
<u>Size >10 mm</u>:	
26 pces Grade A	1,560
87 pces Grade B	2,610
105 pces Grade C	525
<u>Size <10 mm</u>:	
20 pces Grade A	1,200
63 pces Grade B	1,890
338 pces Grade C	676
154 pces of pearls are of total reject and of no use or value	-------
Total estimated value of the crop **AUD**	**15,761**