Stimulating investment in pearl farming in Solomon Islands

FINAL REPORT

August 2008

Prepared by:

The WorldFish Center, Solomon Islands,
and
The Ministry of Fisheries and Marine Resources, Solomon Islands

Supported by funds from the European Union

Ministry of Fisheries and Marine Resources

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1 The Project

The overall objective of the project is the reduction of poverty in rural areas of Solomon Islands through creation of livelihoods based on sustainable aquaculture. This fits within the over-arching goals of the WorldFish Center in the Pacific to reduce poverty and hunger in rural communities, and with the Ministry of Fisheries and Marine Resources (MFMR) to stimulate rural development and to develop aquaculture. It has been recognised that the nature of the pearl farming industry means that a high chance of success requires a long term investment from an established pearl farming organisation. This project has been specifically designed to compile the elements of a pre-feasibility study to provide offshore pearl companies with sufficient information to investigate the potential for long-term investment in pearl farming in Solomon Islands.

The overall output of the Project was intended to be decisions by pearl farming companies in the region to invest, or not to invest as the case may be, in Solomon Islands, though these decisions are beyond the ability of project staff to influence. Throughout, staff have been admonished to provide unbiased, factual information free of weighting either for or against investment. The direct outputs leading to the decisions concerning investment are:

1. Documentation of past research and development on black-lip pearl oysters in Solomon Islands likely to be of interest to investors.
2. A national survey of the location, abundance and quality of white-lip pearl oysters in Solomon Islands.
3. Analysis of climatic and habitat comparative advantages of Solomon Islands for pearl farming.
4. A summary of the investment climate in Solomon Islands.
5. Policy guidelines for sustainable investment in aquaculture and pearl farming supporting small-holder community involvement.
6. High-level contacts within the offshore pearl companies most likely to consider investing in pearl farming in Solomon Islands.
7. Presentations to potential investors on the pearl oyster resources of Solomon Islands, results of research on culture methods and the advantages and risks of investment, and policies for development of aquaculture and pearl farming in Solomon Islands.
8. Recommendations to government concerning the licensing conditions for pearl farming to provide opportunities for small-holders to supply large farms, and to ensure that the industry operates in an environmentally sustainable way.
9. A synthetic report covering all project activities.

Each of these elements has been completed and this report represents the ninth of them. Rather than repeating the information contained in the individual consultants' reports, it will provide a broad narrative report synthesising the information obtained from the various project elements to describe current conditions in Solomon Islands with respect to investing in pearl farming. For ease of reference, the individual reports accompany this draft report as appendices. It is encouraging to note that interest from pearl farmers was positive, with half of those contacted requesting more information. Ultimate success lies in landing one interested investor however, and it has emerged that there are other activities that might assist this process. At the end of this report we highlight the areas of ongoing research that the investors consider will overcome the remaining barriers to investment in Solomon Island pearls.

2 Introduction

Solomon Islands is a tropical, maritime country. Comprising more than 900 islands and covering an area more than 900 x 250 km, the two parallel archipelagos that make up the geographical spine of the country run from 6.5^{o} to 11^{o}S. Outlying islands increase the area of the country still more. There are a myriad of undeveloped and unspoiled bays and semi-enclosed lagoons ranging from very small to the world's largest double-reef lagoon system at Marovo Lagoon. One of the planet's largest atolls, Ontong Java, is also found in Solomon Islands. For generations, Solomon Islanders have based their lives around the sea; today seafood still provides the bulk of dietary protein, fishing is part of a way of life for most rural Solomon Islanders and living away from the coast is a rarity.

As islanders' lifestyles have undergone steady monetisation, the sea has continued to provide, with trochus shell, beche-de-mer, shark fin and fish constituting important cash commodities. Mother of pearl (MOP), from black-, white- and brown-lipped pearl oysters has historically been an important cash commodity, although severe stock depletion led to the imposition of an export ban since 1994. With the hope that the ban has allowed stocks of pearl oysters to replenish and anecdotal evidence that this has been the case the Solomon Islands Government (SIG) has raised the question as to whether pearl farming, which contributes to the economies of some other Pacific countries, could be effective in Solomon Islands. This is a poor time to be entering the pearl farming community, especially black pearls. Pearls have become increasingly competitive in recent years and scope for a new player in the market may be limited. However, competition has caused some operators to move offshore to cut labour and overhead costs, to work with new stocks that may have marketable differences to traditional areas and escape the strict regulatory environment in some jurisdictions. Solomon Islands certainly has the right conditions for growth of pearl oysters and plenty of space for farm establishment, but crucially it may offer advantages in these economically important areas.

2.1 Pearl farming in the Pacific

Several species of pearl oyster (family Pteriidae) occur in the Pacific Islands region, including Solomon Islands. Two, the black-lip pearl oyster, *P. margaritifera*, and the white-lip pearl oyster[1], *Pinctada maxima*, are widely used in commercial production of farmed pearls, and both of these occur naturally in Solmon Islands. *P margaritifera* is the smaller of the two species, and is found throughout the Pacific Islands region, as well as in the Atlantic and Indian Oceans. *P maxima* has a more limited distribution, and is only found naturally in the western Pacific in high-island countries west of Fiji, although attempts have been made to introduce it to Palau, Kiribati, Tonga and other countries.

Commercial farming of white-lip pearl shell originally developed on the northern and western coasts of Australia. In recent years some Australian operators have moved offshore, as a result of which new farming operations have spread to Indonesia Vietnam, Cambodia, Philippines and Myanmar. Indonesia has now overtaken Australia as the world's largest producer of *P. maxima* pearls in terms of volume, although not yet in terms of value. A single white-lip pearl farm has been operating in Papua New Guinea since about 1995, but there are no others in the Pacific Islands region. Pearls from white-lip pearl oysters are generally more valuable than those from black-lip because of their gold-to-white coloration and larger sizes.

Pearl farming using the black-lip pearl shell has been the domain of the Pacific Islands region in the central Pacific. It has developed primarily in French Polynesia and Cook Islands, of which French Polynesia is by far the most prominent. In recent years black-lip pearl farming has spread to Melanesia and Micronesia, particularly to Fiji, where spectacular and unusually coloured pearls are being produced. Pearl farming went through a 25-year development phase in French Polynesia, and continues to be the biggest employer and export earner for the country. However the industry has declined significantly in recent years, mainly due to problems of overproduction and poor pearl quality (discussed more later). In 1998 French Polynesia produced around 5 tonnes of pearls worth over US$ 150 million; in 2002, it exported over 11 tonnes, worth about the same amount. Average pearl prices have fallen from around US$ 35/ gramme to about US$ 14/ gramme in the past ten years.

Pearl farming has contributed enormously to the French Polynesian economy, both due to the revenues it generates, and because it can be carried out in remote areas and thus contribute to rural earnings and livelihoods. In its heyday the development of the pearl industry was accompanied by a reversal of the trend towards urban drift, with many residents of the capital, Tahiti, returning to their original homes in the outer islands to take up pearl farming. As a result of falling pearl values, however, the social benefits being derived from the industry are also in decline. Between 1990 and 2008 the number of pearl farming concessions fell from 2,700 to around 700, with larger producers buying out many of the smaller family farms during that period. Around 7,000 people are now thought to be employed in the industry, down from more than three times that figure 15 years ago. There are new signs of population drift from outer islands to the capital and other urban centres, and concerns over the social problems this may engender.

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1 *P. maxima* is commonly referred to as white-lip, gold-lip and silver-lip. It is not known for certain whether only one or both these varieties occurs in Solomon Islands. The term white-lip is used here to include both varieties.

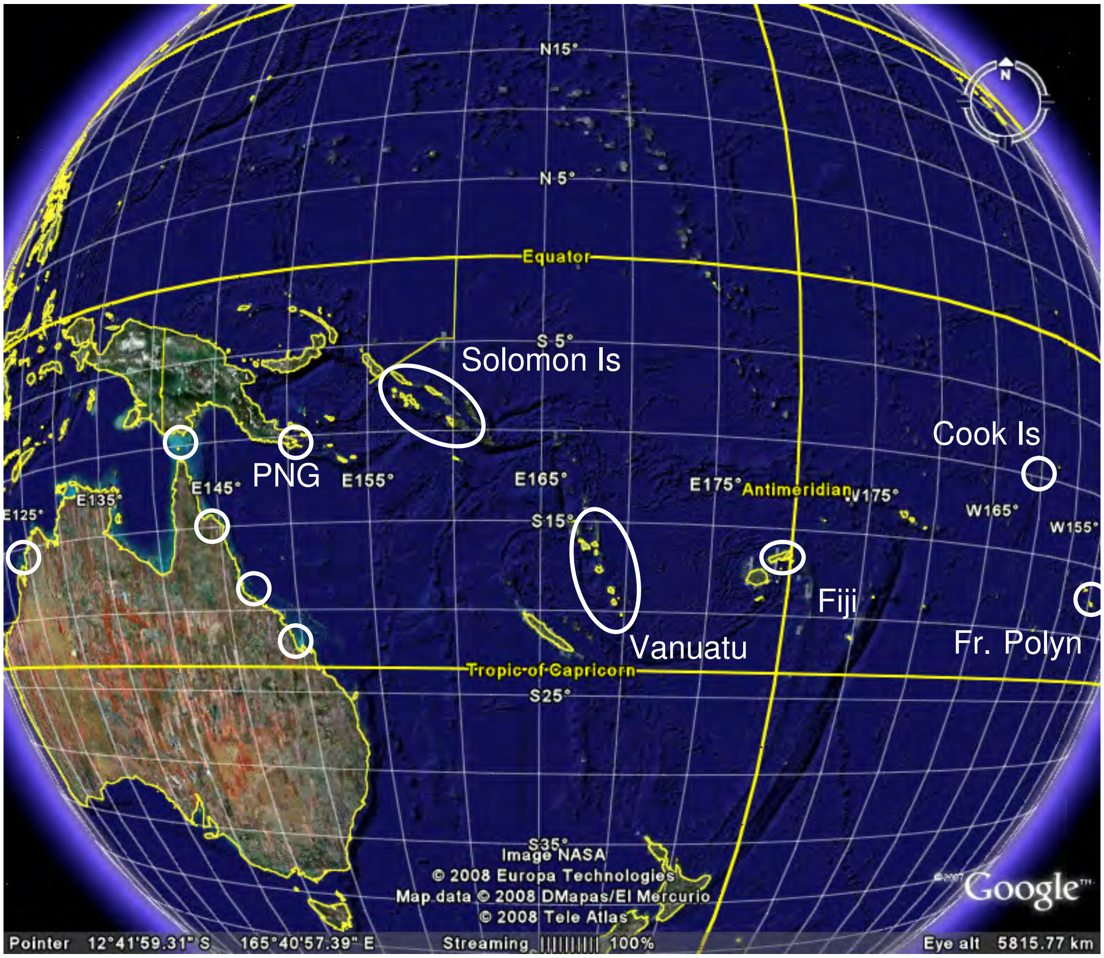

Figure 1. Google Earth image of the South Pacific showing pearl farming regions referred to in this document. Australian sites from the NW coast, through Torres Straight to southern Queensland are approximated.

2.2 Previous pearl oyster exploitation in Solomon Islands

Pearl farming in Solomon Islands is not a new idea (see Appendix I). Coincident with the first modern pulse of MOP harvesting in 1968-1972, attempts were made to establish a pearl culture industry, but this was not successful and closed with the commercial MOP fishery when stocks were so depleted that fishing became uneconomic. A second pulse of MOP harvesting occurred between 1987 and 1994, when an export ban came on in response to stock depletion. Shortly after the ban, an experimental black-lip pearl farm was set up near Gizo in Western Province. By 2000 pearls were produced and sold, but the experimental farm did not attract commercial investment and ceased to produce pearls in 2003 when research funds ran out.




Pearling is not new to Solomon Is. In 2000-2003 black pearls were successfully produced at an experimental farm in Western Province.

The period 2000-2003 was a poor time to be seeking investments in Solomon Islands. The country was wracked by civil strife from 1999 to 2003, when an Australian-led international intervention force, the Regional Assistance Mission to Solomon Islands (RAMSI) arrived. With order restored and the economy growing, the government is attempting to promote overseas investment, particularly in the rural areas. As part of this process, it has been assisted by the European Union's STABEX fund to produce a comprehensive portfolio of information to disseminate to companies and investors potentially interested in pearl farming in Solomon Islands.

3 The pearl oysters

3.1 Suitability of coastal habitat in Solomon Islands

Both species of pearl oyster that are currently used in the Pacific for cultivation of pearls, *Pinctada margaritifera* (the black-lip pearl oyster) and *P. maxima* (the white or gold-lip pearl oyster) are native to Solomon Islands (see appendices II and IV). Both have nation-wide distributions, although the preferred habitat for adult white-lip pearl oysters is more patchy than that of black-lip. Reef structure in Solomon Islands is akin to that in other Melanesian countries (Papua New Guinea, Fiji, Vanuatu) with reefs fringing islands, where they can form complex lagoon structures, but with atolls rare (e.g. Figure 2). Black-lip pearl oysters are usually associated with hard substrata in the shallower parts of such reefs, while adult white-lips tend to occur more in fast flowing channels amongst islands and reefs than on the reefs themselves.

Figure 2. Typical coastal habitat for much of Solomon Islands. Fringing reefs, a mix of high and low-lying islands and freely exchanging lagoon structures prevail. Closed or semi-closed atolls are rare.

The prevalence of fringing reefs rather than atolls contrasts with the situation in the Cook Islands and French Polynesia, where black pearl farms are typically based in atolls where black-lip pearl oyster reach their maximum abundance. Growth rates of oysters within these nutrient-poor lagoons are, however, less rapid than outside of the lagoons. Good results of grow-out of black-lip pearl oyster in Fiji and Solomon Islands confirm that, provided the requirement for high-quality water is met, fringing reef lagoons and embayments can be suitable sites for cultivating black pearls. We note that Solomon Islands has one of the world's largest atolls, Ontong Java, at 5^{o}S latitude, but there is no information on the status of pearl oysters there; it may be too far north and too warm for black-lip pearl oyster culture.

3.2 Spat collection and growout

Previous research programmes targeting pearl farming have yielded a good deal of information on the black-lip pearl oyster in Solomon Islands. As this research was targeted at modifying techniques in use in French Polynesia for Solomon Islands, the differences between the countries were investigated in detail. A feature of the atoll lagoons where pearl cultivation has been developed in Polynesia is that they facilitate collection of spat by trapping eggs produced within the lagoon. Spat is a key element of black-lip pearl oyster cultivation and spat collection in Solomon Islands is more difficult than in these Polynesian farms due to the more open reef structures and greater movement of water. However, research by the WorldFish Center has shown that spat can be successfully harvested from close to Solomon Island reefs throughout the country. Experimental spat collections have been made from Guadalcanal to Shortland Islands and most regions had broadly similar spatfalls. Of the areas where high collections are most frequent, Western Province (see Figure 3 for locations) stands out, though even here the yield per spat collector can be low (an average of 1-12 per collector deployment) and is variable between locations and years.

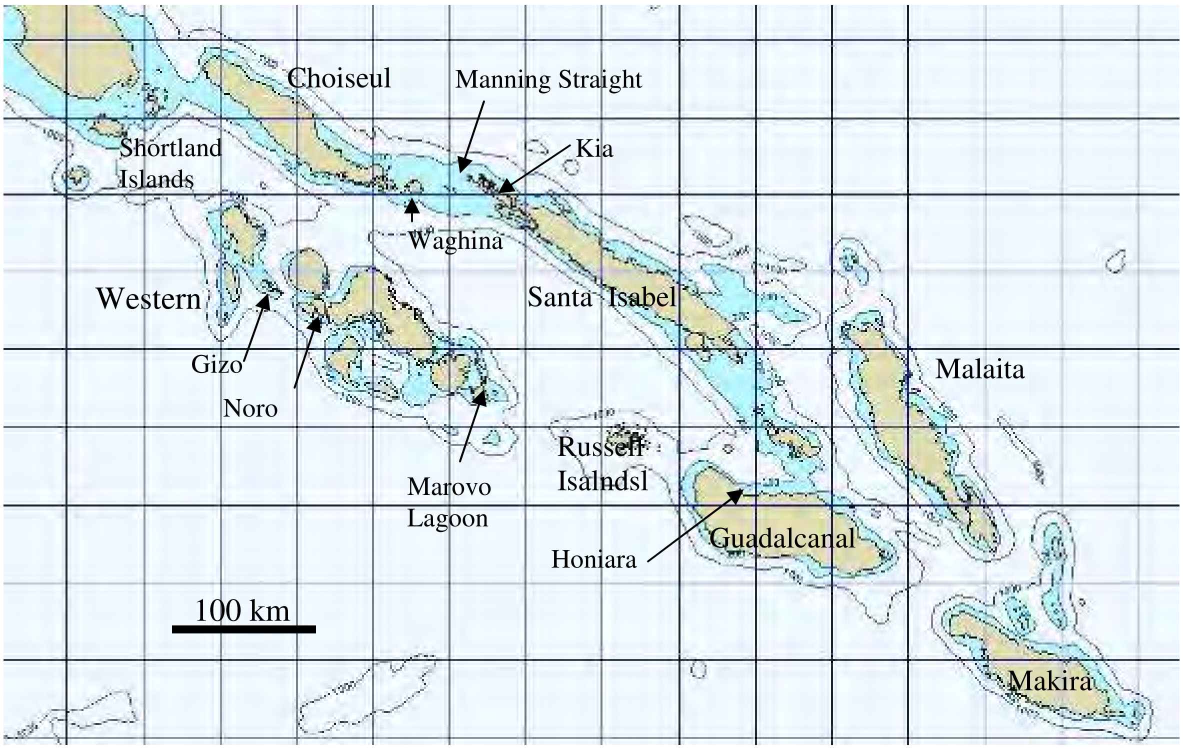

Figure 3. Map of Solomon Islands marked with provinces and main locations referred to in the text. The scale bar represents 100 km.

A significant issue in Solomon Islands has proved to be the high predation on young spat, which led the experimental pearl farm to amend the traditional protocols for spat collection and grow-out. Rather than leaving spat on collectors until they reach a size large enough for hanging from grow-out line, as dine in French Polynesia, spat were harvested from collectors at a small size (~10 mm) and an intermediate grow-out phase was introduced until they reached the size for transfer to hanging culture. The labour cost of this extra operation may be offset by the low labour costs in Solomon Islands (US$ 5-7 per day for semi-skilled workers compared to US$ 50 per day in Tahiti – see later sections). Once established, however, grow-out of oysters can be rapid at Solomon Islands, with spat able to reach 100-120 mm in one year. This is six months faster than is typical of atoll farms in Cook Islands. Preparing the report summarising the information on black-lip pearl oysters allowed Patrick Mesia from the Aquaculture section of MFMR to work alongside WorldFish science staff and gain experience and confidence with contributing to written reports.

3.3 Water Temperature

Solomon Islands' proximity to the equator and consistently high seawater temperatures (Appendix III) may in part be the cause of the rapid growth of black-lip pearl oyster. Figure 4 shows that Solomon Islands is the most northerly site in the region to grow black-lip pearls, and that temperatures tend to be slightly higher than other black pearl areas (Fiji, Cook Islands and French Polynesia). The white-lip pearl oyster, which tends to prefer warmer water than the black-lip, may also be an appropriate species choice for this location.

Temperature ranges for Solomon Islands and established pearling countries are shown in Table 1. The warm, stable temperatures of Solomon Islands are similar to white-lip farming regions at Northern Queensland/Torres Straight and PNG, and only slightly warmer than black-lip farms at Cook Islands. Environmentally, Solomon Islands should be suited to the culture of both black and white-lip pearl oysters.

Table 1. Approximate temperatures of Solomon Island waters and for pearl-producing regions. Where a range of values is given data are available across a latitudinal range.

Location	Minimum	Maximum	Range
Solomon Is	27-28	29-30	2
Northern Cook Is	27	29	2
Fiji	24-27	28-29	2-4
PNG	26-28	30	2-4
French Polynesia	24-27	27-29	2-3
NW Australia	24-25	28-30	4-5
Torres Straight	26	29	3
Vanuatu	24-27	28-30	3-4

3.4 White-lipped pearl oyster availability

Unlike black-lip pearl oyster, white-lip is not commercially taken as spat. Instead a mixture of harvested young adult shell and hatchery stock are used. Anecdotal reports of healthy populations of gold-lip pearl oysters at sites around Solomon Islands needed to be assessed and as part of this project a comprehensive survey was planned to assess stocks.

3.5 The national white-lip survey

The national white-lip survey was undertaken jointly by WorldFish Center and MFMR (see Appendix IV) and had four elements:

1. a preliminary survey of villages previously engaged in the MOP trade to obtain from local fishers information on the current distribution of gold-lip and to obtain permission to work in customary waters
2. a training phase for local staff in advanced diving techniques, including use of Hookah gear and in Survey techniques
3. the survey itself
4. analysis and reporting of the survey data, which included a training element for MFMR staff

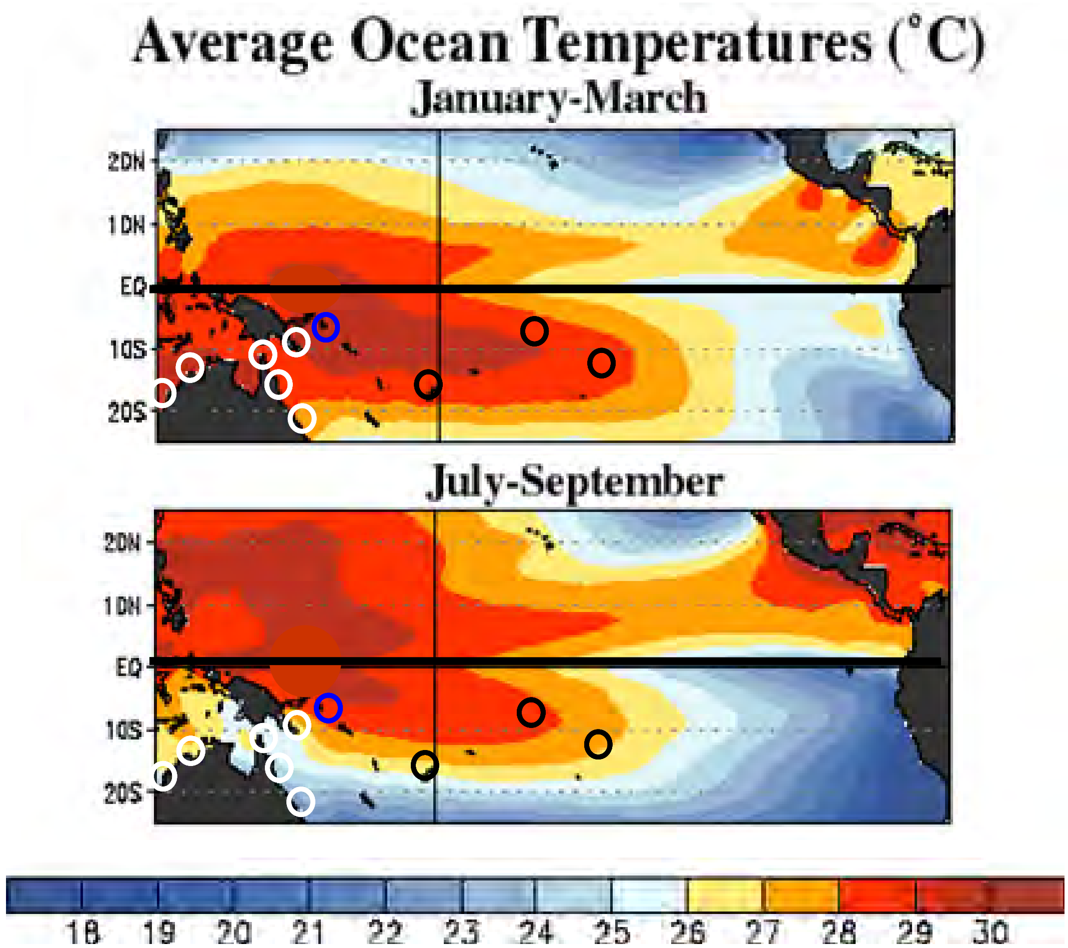

Figure 4. Locations of black- and white-lip pearl farms in the South Pacific superimposed on summer and winter temperatures derived from satellite imagery. Solomon Islands is indicated by the blue circle.

The preliminary survey was an essential part of the study. Locations (Figure 5) were selected on the basis of areas spread across the country but each with a record of substantial harvests of MOP in the data held by the MFMR. All locations were visited at least two weeks before the main survey took place. At each, village meetings were held to inform people of the study, to ask permission to work in customary waters and to conduct interviews regarding historical distribution of pearl oysters, likely current distribution (and, hence prospective sampling sites) and occurrence of any recent or ongoing exploitation. During each interview, the study team sought to have at least one person present who could speak/translate between Pidgin and the local dialect and one scientist from the survey team who was fluent in Pidgin and English. A questionnaire was used to structure the interviews and a minimum of five local people who expressed personal experience of pearl oyster fishing were interviewed. At each location, three sites were identified on the basis of fisher feedback that were most likely to yield high numbers of shell.

Figure 5. Sites selected for white-lip pearl oyster survey.

Communities at all eight locations were easily able to identify three or more sites where many oysters should be found. As will be seen later when we report results, not all communities were accurate in this regard. The replies to questionnaires, however, showed that even at the height of the mother-of-pearl industry, the pearl oyster was a substantial contribution to community income only at Kia and Waghina. These two locations consistently emerged as the centres for this species, a finding that confirms previous reports on the MOP industry.

The training element of the survey involved formal advanced SCUBA diving training, resulting in awards of recognised industry (PADI) qualifications, informal training in the use of Hookah (surface supplied) diving equipment and informal training in the survey techniques to be applied. Table 1 lists the national staff involved in underwater survey and indicates the training given, and copies of certificates are available from WorldFish Center, Solomon Islands.

The survey itself was in two phases. The first phase used the live-aboard charter vessel Marlin I, chartered from Papua New Guinea, and covered the eastern sites, from Maramsike on Malaita through to Telina in New Georgia. The western sites, Kia and Waghina, were undertaken by small boat from the WorldFish field station at Nusa Tupe, near Gizo. Initially it was intended to use the Marlin I for all sites, but this plan had to be modified as the survey was interrupted by the tsunami that hit Western Province on 2nd April. The tsunami hit just as the first training was being undertaken in Marovo Lagoon and, because many participants lived in Gizo, this had to be abandoned. Instead, after a period of assisting with the aid effort following the tsunami, the survey was resumed, but avoided the most affects areas. The charter period ran out before all sites could be completed, and finishing the survey by small open boat had to await the relatively calm weather of October.

Table 1. National staff receiving dive training through the project

Name	Organisation	Dive training	Survey training
Francis Kera	MFMR	Advanced Open Water	April 2007
Jon Leqata	MFMR	Advanced Open Water	April 2007
Alex Meloty	MFMR	Advanced Open Water	April 2007
Patrick Mesia	MFMR	Advanced Open Water	April 2007
Ronnie Posada	WFC	Advanced Open Water	April 2007
Peter Rex	MFMR	Advanced Open Water	April 2007
Stephen Sibiti	WFC	Rescue diver	October 2007
Mason Tauku	WFC	Rescue diver	April 2007
Ambo Tewaki	WFC	Rescue diver	October 2007
Regon Warren	WFC	Rescue diver	April 2007

The survey protocol that the national staff learned involved towed dives at each of the three sites at each of the eight locations. Apparatus was constructed locally to tow two divers behind weights lowered from the ends of a boom rigged across a 6 m aluminium boat, ensuring that they were able to remain in close contact with the sea bed (essential for spotting the cryptic oysters). At each site, the divers collected all the pearl oysters they observed along four randomly-positioned 4 m wide transects. All were measured, and up to ten at each site were sacrificed to determine the nacre colour. Also recorded were the latitude and longitude at the beginning and end of each transect, time and duration of the dive, maximum bottom depth and the type of substrata found along each transect. Position and depth were taken from a Hummingbird 737 combination GPS/Echo sounder and transect lengths were derived from straight line interpolations between start and finish points. All national staff were trained in all aspects of the survey technique and all had an opportunity to experience each role in the team. For many, this was their first opportunity to work with GPS and echo sounding equipment as well as the diving methods involved.

Divers were not able to access safely depths beyond 35 m. For observations down to 60 m a towed underwater camera was used, which recorded onto a Sony DVD recorder. Video surveys were made at four of the sites, where substrate and conditions permitted. Image quality of the camera was less than ideal, but while exact counts of organisms were difficult it was possible to ascertain whether or not dense populations of pearl oyster were present beyond diving depth.

Once the surveys were completed, reporting began. Two training elements were included. Jon Leqata was involved with external consultants in preparation of the report on the stock assessment and a draft manuscript for submission to the international journal Biological Conservation. Copies of that manuscript are available from WorldFish Center, Solomon Islands. In addition Dr Hawes from WorldFish Center led a 2-day workshop for all staff from the Research and Aquaculture sections of MFMR on data analysis, using the survey data as an example.

The results of the survey were disappointing. A total of 117 *P. maxima* were found, but only 33 of the 96 transects yielded any oysters. The mean (± standard error.) density of oysters per $400m^2$ transect ranged from 1.23 ± 0.38 at Waghina, 1.03 ± 0.27 at Kia and 0.66 ± 0.27 at Mboli Passage to <0.1 at Malaita, Marau Sound and Sandfly Passage (Figure 5). No *P. maxima* were found during the survey dives at either site in Marovo Lagoon, (Mbili Passage and Telina), though a single large specimen was taken during a preliminary dive at Telina. Overall, the oysters varied in size from 164 to 278 mm and had a mean (± S.E.) DVM of 219 ± 2.2 mm.

The best locations in Solomon Islands for white-lip pearl oyster were in the area around Manning Strait, where stocks were found on both Choiseul and Santa Isabel Islands (Figure 5). Between Kia and Waghina a total stock of around 500,000 shell was estimated, though a full spread of size structure was not seen. Only 4% of shells were <175 mm in size and the median shell sizes were 210-220 mm. Most of this shell tended towards a gold margin colouration (58%) and truly white-lipped shell comprised only 6% of total shell sampled (Figure 6). The remainder were pale gold. The size structure of the population, heavily biased towards older, large shells, suggests that recruitment is poor at all locations in Solomon Islands. The low adult density probably exacerbates naturally low and variable recruitment success, though it appears that illegal harvesting may be a contributor to the failure of the population to recover. For example over 3000 illegal white-lip shell were seized by enforcement officers in 2006.

The conclusion of the stock assessment was that the population was insufficient to allow any quota to be allocated for pearl farming at the present time, and that any industry establishing here would need to be based around hatchery reared stock. We note that any follow-up work to this project might address the question of whether such a hatchery could reasonably be established in Solomon Islands, and look in more detail at the areas around Kia and Waghina to obtain a more robust estimate of stock status; we believe that this would greatly enhance the possibility of the current research yielding success for the rural peoples of Solomon Islands. This finding does not prevent establishment of a pearl industry. Hatchery reared shell are in use in several other areas where wild stocks are small, and two of the investors to visit Solomon Islands make extensive use of hatchery shell in their other operations.

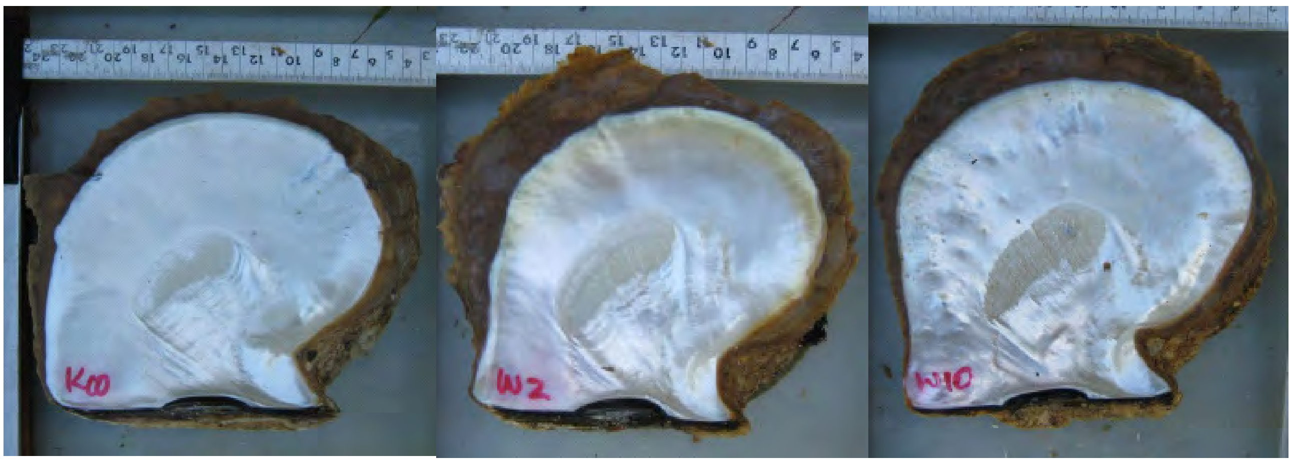

Figure 6. Examples of white (left), gold (centre) and off-white (right) shell taken from Kia and Waghina in the Manning Straight region.

3.6 Water quality

Water quality requirements differ between black- and white-lip pearl oyster. Black-lip pearl oyster are usually grown in clear, oceanic water with no effect from land run-off. White-lip pearl oyster appear more tolerant of moderate turbidity and salinity fluctuations than black-lip pearl oyster. In Western Australia some farms are in bays with substantial freshwater runoff, others in bays with little and experimental comparisons between turbid and clear embayments. Experimental comparisons have shown no significant difference in growth rate. The steep topography of some Solomon Island islands and the frequent heavy rainfall that these attract means that some coastal lagoons (especially those impacted by poorly managed forestry developments) are affected by turbidity and freshwater runoff. Such systems may be better suited to culture of white-lip pearl oyster than black. However, many other island-lagoon systems are smaller and low-lying and do not suffer from run-off.

3.7 Natural disasters

Environmental risks come in many forms, from earthquake, tsumani, cyclone, through to disease and long-term sea level rise. Most of these are poorly predictable or equally likely (or unlikely) over wide geographic scales. Of the few "extreme event"-related environmental risks that are frequent enough to be quantifiable, cyclones and their related phenomena can be devastating to pearl farms (see Appendix III). Analysis of the prevalence of cyclones at Solomon Islands (Figure 7) suggests that its risk profile is similar to Tahiti and places it between PNG, where cyclones are extremely unlikely and Northern Cook Islands, where one cyclone has passed within 50 km in the period 1969/70 to 2004/05. One cyclone has passed a similar distance from Honiara over that period, though none has passed though or affected the Western Province. Cyclones are much more likely to pass close to Fiji, Vanuatu and Australia. Cyclones can be seen as a minor risk for pearl farms in Solomon Islands, particularly if placed in they are located in the northern part of the country.

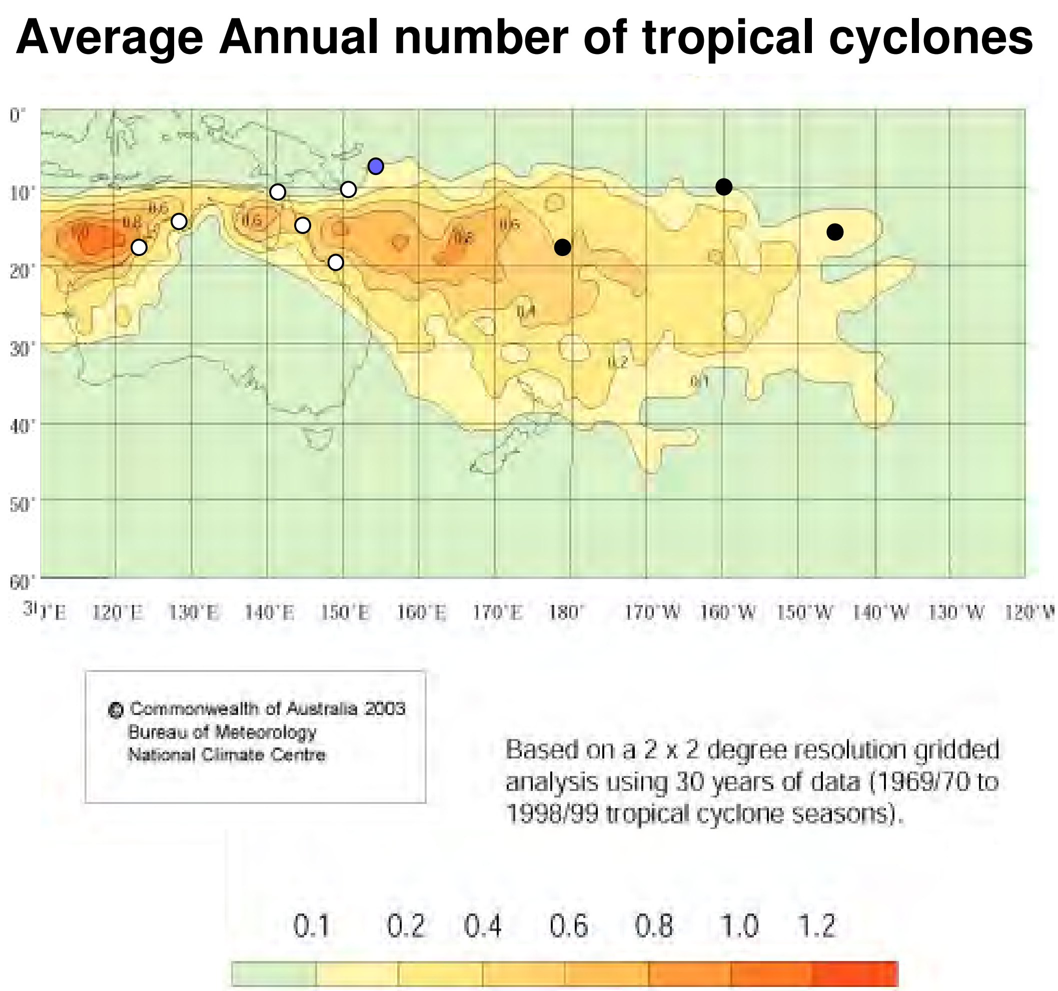

Figure 7. Approximate positions of existing black and white pearl farms and Solomon Islands (blue circle) superimposed on the average tropical cyclone frequency for the southwest Pacific.

4 Doing business in Solomon Islands

Environmental and ecological factors are a small part of the decision making that needs to accompany investment in Solomon Islands. Perceived problems over security, stability, corruption and government intervention may sometimes deter foreign investment but, if due caution is exercised, investment in Solomon Islands is as secure as in any Pacific islands country (see Appendix V). This is a particularly acute area for pearl farming, as in most cases little return is made for at least six years and net profit may take ten years or more to achieve. Long term stability is essential. An important preliminary to assessing what information needs to be given to potential investors was to attempt to determine which issues would be in their minds when considering investing in Solomon Islands. A workshop was held for MFMR staff and technical assistants which addressed this question circuitously by considering the advantages and disadvantages of Solomon Islands – and how disadvantages can be mitigated. Outcomes of this workshop were grouped under two questions, many of which have been covered already in this report, but others of which have not. The author's selection of key issues to address in the remainder of this report, which deals with economic, cultural and structural issues are italicised.

Why grow pearls in Solomon Islands?

- Both black-lip and white-lip pearl oysters are native to Solomon Islands
- A national ban on harvesting both species exists with no intention to rescind the ban
- There is a 10 year history of collection of spat of black-lip pearl oyster and production of pearls has been demonstrated
- Pearl oysters grow fast in the warm, well-flushed coastal lagoons of Solomon Islands
- The environment includes very many more-or-less sheltered coastal lagoons where suitable growth conditions may be found for either or both species
- Cyclones are very rare
- Labour is cheap, income opportunities in rural areas are rare and many rural communities are eager to negotiate use of land and waters
- Alternatively there is government land where leaseholds are secure
- The government is willing to negotiate incentives to committed investors
- There are no other pearl operations in the country and a unique branding is possible
- Solomon Islands are less than three hours by air from Brisbane, has an increasing expatriate community and tourism is expected to increase
- The Ministry of Fisheries and Marine Resources is eager to facilitate such an investment and has committed to assisting investors through the early phases of any such project
- Options exist for a phased entry, with joint public-private research towards commercialisation of Solomon Island pearls possible using existing hatchery and field facilities

- Legislative review is underway to provide a sound basis for commercial aquaculture.

Why not grow pearls in Solomon Islands?

- Pearls are a competitive product and the pay-back time on investment is likely to be many years
- Black-lip spat settlement is variable between years and sites and not always strong. Extensive spat collection sites and/or hatchery backup may be required
- Populations of white-lip pearl oysters are currently insufficient to allow commercially viable quotas of wild stock. A hatchery may be required
- Land tenure in some parts of the Solomon Islands is confused and unreliable. Careful site selection and negotiation, with the support of the Ministry will be required
- Investors will need to set up and maintain harmonious relationships with local communities
- In-country markets are currently weak but growing
- The country has a record of political instability, although since the arrival of RAMSI in July 2003 this has not been evident
- National and (especially) provincial authorities have limited capacity to develop and enforce regulations and agreements. Careful negotiation and support of the Ministry will be required
- There is no strong history of aquaculture within the country; the only current aquaculture being small scale culture of seaweed, giant clams and corals.

These issues have been grouped and addressed under three subheadings:

- ➢ Security of investment (government stability, security of tenure, physical security)
- ➢ Taxation and incentives
- ➢ Labour

4.1 Security of investment

4.1.1 Governance and law

Both National and Provincial Governments in Solomon Islands prioritise decentralised investment, creation of rural jobs and income opportunities and increased export earnings; pearl farming scores well all round and government interference in the investment process is unlikely. Solomon Islands government is not based around political parties, but around loose and dynamic groupings of independent politicians. While there is much news of “political instability” in Solomon Islands, this largely concerns who should be Prime Minister and thus in charge of patronage, while external relations with China/Taiwan and Australia are also a matter of debate. There are few discernible differences in policy among the various groupings and major shifts relating to foreign investment seem unlikely with changing governments.

Establishing investments in Solomon Islands has become simpler in recent years. Under current regulations, a company to be set up to farm pearls would need first to apply under the Foreign Investment Act. As pearl farming is not listed as a restricted or prohibited activity, a certificate of registration should be issued within five days. More detailed issues may then be addressed. This process is under judicial review of matters of law and the constitutional independence of the judiciary generally renders it free of political interference. The legal system is considered slow but fair and recently a change of government was precipitated by a Prime Minister's filling of the Attorney General's position with a close personal friend.

Unlike the judiciary, the Public Service has suffered from direct political interference and has been weakened by corruption in many departments. The departments with which an investor would mainly be dealing (investment registration, taxation, employment, immigration, lands, fisheries, provincial government) are all ostensibly aiming to promote and assist legitimate investment, but they vary in experience, effectiveness and speed of doing business. Investors should ensure that documents are carefully prepared and presented, and sufficient time allowed for processing and discussion of any difficulties with relevant officials. Any suggestion that additional unofficial payments would facilitate processing should be rejected.

4.1.2 Land and land lease issues

A key issue for investors will be securing long-term leasehold of suitable premises. Like much of Melanesia, land (and associated reefs and coastal waters) in Solomon Islands is held either under customary tenure (90%) or under a system of registration of land (10%). Registered land has gone through a process of title and rights investigation before being registered, and the interests in registered land recorded on the Land Register are the subject of indemnity by the government. Leases on such lands are secure. Customary land is more problematic. Definitions of customary land rights and boundaries are complex and often disputed, more so as customary authority and leadership have broken down in many areas under pressure from monetisation, education and the physical and financial stresses of commercial logging. The barriers that customary tenure erect against investment are appreciated and machinery does exist to convert customary tenure to registered land, though this requires extensive investigations of traditional use rights and community history. If attempting to acquire a registered interest in customary land, an investor would need to be assured of local acceptance of the proposed investment through extensive interactions with local leaders and communities before initiating the registration process.

In short, commercial investment on unregistered land by a foreign company would be risky and is not recommended. Conversion of customary land to registered status is complex and slow. Lease or purchase of an interest in land that is already registered, and has been or is now in use in some form of economic activity, is advised as the best solution to acquiring premises. Such lands exist in the following locations, with those perhaps most suitable to pearl farming (based on habitat quality) in italics:

- Shortlands (Ballalae airstrip), Gilbertese resettlement, close to Bougainville
- *Waghina, Gilbertese resettlement, Kagau (airstrip)*

- *Manning Strait islands*
- *Suavanao (airstrip)*
- *NW Isabel coastline, Allardyce Harbour*
- *Reef islands southeast of Gizo, including Nusa Ttupe (Gizo airport, WorldFish hatchery), tourist resorts and Gilbertese resettlement*
- South Vona Vona lagoon (Munda airport)
- NW Marovo lagoon reef islands (Ramata) (airstrip)
- SW Marovo lagoon (Uepi, Seghe) (Seghe airstrip)
- Russell Islands (Yandina airstrip)
- *Sandfly Island and passage (Maravari)*
- *Marau Sound, East Guadalcanal (airstrip) (shell jewellery, coral culture) (Tavanipupu resort)*
- East Makira

Registered leasehold interests in land, including land below the highwater mark, that is adjacent areas of lagoon, shore and coral reef, will be legally secure provided the appropriate procedures under the Land and Titles Act have been followed. However, it is always the case that good relations with local communities are crucial to successful operations in rural areas. It would be impracticable to make and operate any agricultural or maricultural investment in a rural setting in a hostile social environment. It will be necessary to make sure that local communities know and understand what is proposed, that the operation is designed to provide as much participation for local people as is reasonable and practicable, business transactions with them are transparent, on fair terms as to prices and quality and are properly recorded.

4.1.3 Physical Security

In rural locations in Solomon Islands physical security depends on a combination of factors. Regular patrolling by the police is simply not available. An investor with portable assets and stock to protect needs to take clear and non-provocative precautions against theft that are understood and accepted by neighbouring communities. As stressed earlier, a successful rural business must enjoy the support of the local community and efforts to include these people in the enterprise must be made.

There is no history in Solomon Islands (or the Pacific islands generally) of expropriation of commercial investment. Governments have shown a clear understanding of the damage such action would do the country's chances of attracting further investment. Solomon Islands subscribes to the APEC principles on non-expropriation and is a member of the Multilateral Investment Guarantee Agency, part of the World Bank Group of institutions, which provides financial guarantees against expropriation of foreign commercial investments by host governments. There is no significant expropriation risk to an investment that is conducted in a commercially and legally conventional manner.

4.1.4 Security of profits

The Central Bank operates exchange control regulations under which authority to approve and process routine trade transactions is delegated to commercial banks.

Authorised exporters are allowed to retain funds offshore to pay for imports to minimise inward and outward transaction costs.

Capital movements require Central Bank approval, which is readily given on proof of legal status and availability of funds, e.g. repatriation of declared dividends or of capital on sale of an investment. Anti-money-laundering legislation requires banks to report suspicious transactions, and customers may be required to provide proof of their identity and nature of transactions.

4.2 Taxation and incentives

4.2.1 Tax structure

The profits of resident corporations are taxed at 30%, non-residents at 35%. In calculating profit, deductions from income are allowed only for costs incurred in producing that income and capital expenditure is not normally a deductible expense, but depreciation is deductible at prescribed rates. 100% deduction of capital expenditure is allowed for certain agricultural, livestock and scientific purposes, and it should be possible to make a good case for the same treatment to apply to development of pearl farming. Tax losses can be carried forward for up to five years provided there is no change of shareholder control.

Employers are required to deduct personal income tax (PAYE) from their employees' wages and remit the proceeds to Inland Revenue. Individuals are taxed on an incremental scale. (In this section $ means SBD) Above a personal allowance of $7800 per year, income is taxed at 11% for the next $1-$15,000, 23% for the next $15,001-$30,000, 35% for the next $30,001-$60,000, and income above this is taxed at 40%. An additional required deduction is for the national superannuation fund to which employers contribute 7.5% and employees 5%.

Goods tax is charged though there are a number of categories of imported goods exempt from goods tax, including scientific and research equipment. Exemption from goods tax for any such equipment and other specialised imports required for pearl oyster development may be possible.

Import duties have been greatly reduced over the last ten years as part of trade liberalisation policy. When a schedule of technical and scientific equipment and other specialised imports is available, an investor should request exemption from import duty on the initial importation as a valuable form of assistance to undertake the investment.

4.2.2 Incentives

An Exemptions Committee of the Inland Revenue Division considers requests for tax breaks and makes recommendations to the Commissioner of Inland Revenue. Pearl farming's investment cost and benefit profile is unusual and will require careful explanation to the tax authorities, but it should be possible to make a good case for tax incentive treatment that fits the likely profile. The most likely and useful business tax incentive available to a pearl farm investment appears to be a tax holiday (exemption from business profits tax) for a period of up to 10 years, the actual period to be decided on basis of the projected performance of the business. A well argued case should obtain the maximum exemption. Many other countries offer such concessions for pioneer and rural industries, and for Solomon Island not to do so would reduce the relative attractiveness of the country to foreign investors.

As noted earlier, any pearl farming industry that develops in Solomon Islands will depend on the services of foreign seeding technicians, the majority of whom are Japanese. In other countries regulations requiring localisation of this work has led to a variety of problems for the industry. A clear statement by the Solomon Islands Government that licensed pearl farming operators will be entitled to receive work permits for foreign seeding technicians will be an encouragement to investors with long-term investment horizons.

One drawcard for a pearl farmer considering an investment in Solomon Islands is the existing WorldFish aquaculture facility at Nusa Tupe, in Western Province. Any investor who could gain access to this facility would immediately short-circuit the process of identifying a suitable culture site and negotiating a lease agreement, and constructing basic operating facilities, including a hatchery. If the stock of 2-3,000 adult black-lip shell currently being maintained at the facility were made available it could be implanted with nuclei immediately, so that the farm would commence generating revenue in two years rather than the usual 4-5. Spat collection and/ or hatchery production arrangements would still need to be developed so that the size of the farm could be progressively increased, but the existing stock would accelerate the process of achieving positive cash flow and profitability.

A cooperative venture with the WorldFish Center should thus be a significant attraction to any investor interested in exploring pearl farming in Solomon Islands. This should make it possible to leverage a cooperative venture which allows WorldFish and the Solomon Islands Government to continue research on aspects of pearl oyster biology and life history (growth rates, spat collection success, etc) or to access research information obtained by the commercial partner. Ultimately, if initial success was achieved at the WorldFish site, the company would need to negotiate its own site and facilities.

4.3 Labour

Work permits under the Employment Act and residence permits under the Immigration Act are required for foreign employees, including the investor himself/herself. The expectation will be that Solomon Islanders are used where they can already undertake the required work or when they can easily be trained to do so. For pearl farms, policy will advocate that local staff fill general labouring, maintenance, boat driving and SCUBA diving roles, though seeding technicians need not be local and provision have been proposed to ensure that they are freely able to obtain necessary work permits.

Wages in formal jobs in rural areas range from SB$30-50 per day for semi-skilled to SB$100-$150 per day for skilled workers. The legal minimum wage in agriculture, which includes mariculture, is SB$3.80 per hour or about SB$30 per day.

An oyster farm could expect to recruit all its unskilled and semi-skilled workers locally – this would greatly assist with maintaining harmonious relationships with local communities - and not be involved in transporting them to and from annual leave. Workers housed on site would receive free basic housing, water, sanitation and lighting. Supervisory and junior management pay in rural-based formal employment is in the range SB$30,000-$100,000 a year, plus free housing, water and electricity.

4.4 Environmental impact assessment.

Farming of pearl oysters will require an application for development consent under the Environment Act, 1998. The Director of Environment may require the preparation of a public environmental report or an environmental impact assessment, which would be published. After periods for public reaction to such report or assessment have elapsed the Director may issue the development consent with or without conditions, or may refuse consent. Given the need for environmental care in the rearing of oysters and the relatively small scale of the shoreside installations required, it is unlikely that environmental objections would arise in this case.

Pearl farmers operating in Solomon Islands will also be encouraged to submit an environmental management plan (EMP) or code of practice (COP) as part of their licence application. The purpose of the EMP or COP is to reassure the Fisheries Ministry that the operator is cognisant of the environmental risks of pearl farming, will minimise the environmental impacts of the operation, and has considered measures that may need to be taken in response to factors such as mass mortalities or disease outbreaks. It is expected that the presentation of an EMP or COP as part of the licence application will largely obviate the need for a separate EIA by the Ministry of Environment.

5 Policy, Regulation and Management guidelines

Development of sound policy and regulation is essential to the successful and long term establishment of pearl farming in Solomon Islands (see Appendix VI). In other countries, poor control of the industry has eventually led to problems and low-quality pearls entering the market chain have lowered the overall reputation of the industry. The French Polynesian authorities have attempted to put in place an industry code of practice, an active pearl marketing campaign that serves the industry as a whole, and a comprehensive system of quality control and certification, in which each pearl is sold along with an X-ray demonstrating the nacre thickness, as well as a government certificate of authenticity. These measures may have helped slow down the falling image and value of French Polynesian pearls, but have not completely arrested it, and the industry continues to decline. There is still a great deal of leakage, with large volumes of poor quality pearls continuing to enter the market. This undermines attempts by both government and large-scale producers to maintain the rarity value and exclusive image of their product.

The second most important producer in the Pacific Islands region is Cook Islands, where the industry was catalysed largely by developers from neighbouring French Polynesia who brought technical skills and investment funds to the country. The Cook Islands industry produced about US$18 million worth of pearls at its peak in 2000, but has declined since that time, with production of only about US$2 million in 2005. A major disease outbreak at the end of 2000, attributed mainly to overstocking and poor farming practices, decimated the industry, and it has still not fully recovered. Cook Islands has suffered more development problems than French Polynesia, including, in addition to disease, conflicts among farmers and persistent marketing of low-grade pearls, which has undermined prices in general and given Cook Islands a widespread reputation as a producer of a low-grade product. These examples highlight the importance of setting strict controls at the outset of any new pearl venture.

5.1 Policy

The current government's stated policy goal for the fisheries sector is 'the development and sustainable utilisation of sea and marine resources to benefit and contribute to the well being of Solomon Islanders'. The policy is accompanied by eight expected outcomes and a series of associated strategies, most of which relate to managing and increasing economic benefits from capture fisheries, especially tunas. None of the outcomes or strategies make any reference to aquaculture.

MFMR's Aquaculture Development Plan (hereinafter referred to as the Plan) contains a number of statements of policy in regard to aquaculture in general and pearl farming in particular. The Plan recognises that the Ministry lacks knowledge and experience of aquaculture, and that institutional strengthening and human resource development are required. It also acknowledges the absence of appropriate policies and regulations for aquaculture, and urges the development of these. Noting that the WorldFish Center operates the only aquaculture hatchery in Solomon Islands, the Plan recommends against the development of further hatcheries by government, although it encourages government support to the private sector in regard to hatchery development. Section 9 of the Plan states that MFMR will provide information to prospective aquaculture investors in regard to land and sea tenure, licensing, infrastructure and transportation, among other things. In regard to pearl farming, proposed actions by MFMR are:

- Collaborate with WorldFish and EU to attract private investors in Solomon Islands;
- Maintain the ban on the wild shell trade;
- Implement the policies and licensing conditions developed by the EU-funded project;
- Provide extension services for the participation of local communities through Provincial Fisheries Officer, after the establishment of private farms;
- Promote value added pearl oyster products particularly for rural communities in opportunities such as shell carvings or pearl mabe handicrafts.

At present there is no policy or management framework specifically intended for the pearl farming sector. The development of such a framework for an as-yet non-existent industry may be regarded by some as somewhat premature and liable to discourage investors. However in other Pacific Island countries where the pearl industry has developed the absence of any regulatory framework has led to major problems which have had to be addressed once the industry was already in a crisis. As with fisheries management, it is far better to learn from experience, anticipate problem areas and set the 'rules of the game' beforehand, rather than wait until the problems occur.

Properly formulated management guidelines should also be a source of reassurance to legitimate investors with a long time horizon. Bona fide investors will prefer to operate within a framework in which 'the rules of the game' are already in place and clearly spelled out, rather than in an uncertain environment where policy and regulations are ignored until there is a crisis, or are developed according to the whims of government ministers or public servants.

5.2 Legislation

Several government documents pertain to the management of fisheries aquaculture in Solomon Islands. Chief amongst these are the Fisheries Act (1998), Fisheries Regulations (2002) and the Ministry of Fisheries and Marine Resources' Aquaculture Development Plan.

Responsibility for the management and development of Solomon Islands' marine resources lies with the Ministry of Fisheries and Marine Resources (MFMR). The Fisheries Act (1998) (hereinafter referred to as *the Act*), is the major piece of legislation governing fisheries and fisheries-related activities. The Act is currently (August 2008) under review, but until new legislation is fully adopted will continue to apply to any prospective pearl farming activities. The Act provides the basic legal framework from which other subsidiary controls can be derived but in itself has minimal direct application to the overall control of aquaculture. The Act does not distinguish aquaculture from other fishing methods or fisheries, and the applicability of some provisions to aquaculture control is unclear. The Act does however have certain relevant provisions, as follows:

Section 31, *Aquaculture Operations*, requires the written permission of the Director of Fisheries, with or without conditions, for the setting up and operation of an aquaculture activity. Conditions that may be specified with a written approval deal with issues such as 'the location of the aquaculture facilities and its operation, the prevention of the spread of communicable fish diseases, the inspection of aquaculture sites and the provision of statistical information'. Contravention of the provisions of this section invokes a penalty of up to SI$ 100,000 on conviction.

Section 32, *Import and Export of Live Fish*, prevents the import or export of live fish without the Director's permission. The section imposes an assessment on the possible impacts of imported live fish being released into the wild. Contravention of the provisions of this section invokes a penalty of up to SI$ 500,000 on conviction.

Provisions for further aquaculture control come in the form of ‘regulation making powers’ under Section 59, *Minister’s Powers to Make Regulations*, under which the Minister may regulate, in general, any fishery activity in need of or requiring control for management and development purposes. Section 59(1)(xiv) specifically empowers the Minister to regulate the cultivation of seaweed and other aquatic organisms, and Section 59(1)(xv) empowers the licensing of fish farms and regulation of the importation of live fish.

Draft Aquaculture Regulations were developed by the MFMR Aquaculture Division and subsequently included as Part 2 of the Fisheries Regulations (2002). The Regulations apply to the farming of a range of species, including *Pinctada margaritifera*, *P. maxima* and *Pteria penguin*. The Regulations describe aquaculture licensing procedure and impose penalties upon violation of the licensing requirement. No licence is required for ‘any traditional practice of breeding, farming, culturing, taking or holding of live fish or aquatic organism the purpose of which is for subsistence, personal or traditional use only’ and ‘farming which is done by a local or a local community on a small scale and for subsistence purposes only’.

Under the provisions of the Regulations, any application for a licence should contain the following information:

details of the species, stage of the life cycle and quantity of the aquatic organism to be bred, farmed, cultured or held;
plans relating to the construction, development or modification of an aquaculture facility to which the application relates;
details of the location of the aquaculture facility and of all places, if applicable, at which the applicant intends to breed, hold, rear, process or sell fish or aquatic life;
details of the gear, tools or equipment that the applicant intends to use to take fish or aquatic life;
approvals required under any other law, and;
such other information as may be required by the Director.

The Regulations also specify the conditions of the licence that may relate, but are not limited, to:

the species of fish or aquatic life to be bred, farmed, cultured or held;
the stages of the lifecycle of fish or aquatic organism at which the same may be kept;
limitation of the quantity of fish or aquatic life that may be kept or sold;
the method of water discharge or waste disposal;
the location of the aquaculture facilities;
limitation of the use of chemicals or drugs, if any;
a requirement for the lodgement of a guarantee or security to cover the cost of damage that may be caused by the operation of the aquaculture facility.

The licence is not transferable. The Director may review, vary or alter the conditions of the licence, or temporarily suspend a particular condition. Under specific circumstances, the Director may cancel, revoke or suspend the licence. Any person aggrieved by such a decision of the Director, or the decision not to issue or renew the licence, may appeal to the Minister within 30 days following receipt of the notification of such decision.

In addition to the licensing requirement, all aquaculture facilities and equipment must be built, installed or constructed to standards approved by the Director of Fisheries. For example, all facilities need to have an effluent reservoir in which wastewater is to be treated before discharge. The Regulations also require biological means of effluent treatment to be used (as opposed to chemical means) unless circumstances render it costly or impractical. The Director may impose conditions to the aquaculture licence relating to the method of water discharge or waste disposal. After inspection of the facility, the Director may issue a certificate certifying the facility as fit and proper for aquaculture activities. Without this certificate it is prohibited to culture aquatic organisms in the facility.

Only one aquaculture operation has been licensed in the last few years, a land-based prawn farm on Guadalcanal, which is no longer operating. Because of the absence of appropriate licensing mechanisms, this was licensed as a fish processing establishment. The only other aquaculture licence thought to have been issued in Solomon Islands was to ICLARM (now the WorldFish Center) in the early 1990s for community aquaculture projects supported by that organisation based on the grow-out and export of giant clams produced in the WorldFish hatchery.

A revised version of the Fisheries Regulations was prepared in 2003, but for various reasons has never been gazetted. The existing Regulations are likely to be superseded as part of the ongoing review of the Fisheries Act. Like the 1998 Fisheries Act, the new draft Act as it currently stands pays only limited attention to aquaculture. There is a need to strengthen the aquaculture provisions of the new Act prior to its finalisation, and to ensure that aquaculture in general, and pearl farming in particular, are adequately covered in regulations or other subsidiary legislation. Representations and recommendations are being provided to the review team to this effect. A set of draft regulations has been prepared in consultation with the Attorney General's Chamber representatives and MFMR and these can be found as an appendix to the report on "farming policy and guidelines" (Appendix VI) produced by this project.

5.3 Licencing

Under present legislation, aquaculture facilities need to be licensed under the Fisheries Act 1998. It is recognised that the Act is extremely weak in its provisions for aquaculture, and there are no specific references or regulations relating to pearl farming. Detailed regulations for aquaculture were drawn up in 2002 and revised in 2003 but have never been gazetted, and are therefore not in force. The rare aquaculture operations that have been licensed in the past have been classified as fish processing establishments. A fee of SB$ 10,000 was payable for each species farmed, and the licence renewable annually.

The country's fisheries legislation is currently under review and is expected to be replaced in 2009 with a new Fisheries Act and Regulations. This is expected to include a specific regulation for pearl farming. Although the regulation is still subject to amendment, the most significant provisions are as follows:

- licences will be for an initial period of ten years. Annual renewal will extend the licence for a further, such that a pearl farmer is always guaranteed tenure of licence for ten years;

- licences will relate to a particular area. Relocation by more than one kilometre from the original site may require a new licence application (at the discretion of the Director of Fisheries);
- licencing will be structured so that pearl producing farms are distinct from shell feeder farms;
- farms must be situated at least 5 kilometres apart (measured by the shortest distance over water);
- farm size at any given location will be restricted to one million shell;
- pearl oyster stocking densities will be restricted to 100,000 per hectare or one shell per cubic metre of water occupied by the farm lines;
- movement of shell (spat or adult) over a distance of greater than 25 km will require a permit;
- importation of pearl shell from other countries will be prohibited;
- hatcheries will be required to have an effluent disposal reservoir;
- permits will be required for the importation of algal cultures and other biological material.

The main purpose of the proposed regulation is to protect bona fide pearl farmers from disease and environmental problems resulting from bad husbandry practices (such as overstocking and indiscriminate long-range movement of shell) by other operators.

Provincial business licences are also required. The weak financial condition of provincial governments has from time to time led them to impose unrealistically heavy licence fees and there is now a move within the national government to relieve provincial governments of this function.

Drafts of regulations, a policy statement and licence forms that we have prepared and recommended to the Solomon Islands' government are included in Appendix VI.

6 Investor visits

A list of pearl companies operating in the Western Pacific was prepared and submitted to an industry consultant for selection of companies most worth contacting. From these contacts, five companies showed interest and three were able to confirm and complete their visits. These were:

- Manihiki Pearls, Cook Islands
- Justin Hunter Pearls, Fiji (also representing Taylor Shellfish of the US)
- Arafura Pearls (Australia)

The three individuals who visited Solomon Islands were:

- Mr. Temu Okatai – Cook Islands
- Mr. Justin Hunter – Fiji

- Mr. Andrew Hewitt – Australia

All three individuals operate commercial pearl farms in their own countries. In the first two cases, these involve the black-lip pearl-oyster, *Pinctada margaritifera*; in the third case, the white-lip pearl oyster, *P. maxima*. During the visits, the investors met with each other and with the following agencies and individuals in Honiara and Gizo:

- Hon. Nollen Leni, Minister, and Dr. Chris Ramofafia, Permanent Secretary, Ministry of Fisheries and Marine Resources
- Anne-Maree Schwarz, Cletus Oengpepa and others, WorldFish Center, Nusa Tupe
- Tony Hughes, investment consultant
- Daniel Tuhanuku, Solomon Islands Chamber of Commerce
- Mark Corcoran, Bank South Pacific, Honiara
- Simon Tiller, Solomon Islands Marine Resources Institutional Strengthening Project
- Oliver Zapo, Deputy Premier, and Arnold Moveni, Permanent Secretary, Western Provincial Government
- Antonio Lee, LKK Ltd. (seaweed exporter/ seafood industry/ building and light industry)
- Willie Veitch, Aquarium Arts Ltd
- Bob Pollard, Pasifiki Services Ltd. (manager of Enterprise Challenge Fund)
- Gordon Anderson, AusAID Fisheries Advisor
- Mike Batty and Peter Philipson, Fisheries Development Advisors, Forum Fisheries Agency

As the visits occurred during two separate periods, some duplication of meetings was necessary, and not all investors met with every agency/ individual. Several meetings had to be re-scheduled because of delayed or cancelled domestic flights (of four flights taken, three were delayed, two by more than a day).

6.1 Investor Feedback

The following information is summarised from meetings and conversations between the investors, people met during the course of official meetings, and informal conversations.

All the visitors were satisfied that the research undertaken by the WorldFish Center had adequately demonstrated the technical feasibility of farming for black-lip pearl oysters in Solomon Islands. The investors noted that there are two varieties of black-lip pearl oyster, one of which is uncommon in Cook Islands and French Polynesia, leading to a more limited range of pearl colours from those countries. The other variety, which occurs commonly in Fiji, leads to a wider range of pearl colours, which are more valuable. This variety was observed in Solomon Islands during the visit, and is seen as a favourable sign.

In regard to white-lip pearl oysters, the investors noted that growth rates and husbandry characteristics under farm conditions in Solomon Islands have yet to be determined. Trials on white-lip pearl oyster were advised as a necessary pre-condition to the establishment of commercial operations using this species. White pearls produced by this species in Australia are 5 – 10 times more valuable than those from black-lip pearl oysters. However, gold and cream pearls, produced by the same species in Indonesia and Philippines, are worth much less. It will therefore be important to establish the likely proportion of high value pearls in the crop before any commercial investment is likely to take place.

As to where to invest, there are likely to be numerous potentially suitable farm sites around Solomon Islands. Marine environmental conditions are generally good, although concern was expressed over the numerous logging operations observed, and the considerable runoff and sedimentation problems they are clearly causing. Solomon Islands has seen few, sporadic assessments of water quality or the abundance of plankton on which pearl oysters feed. A routine monitoring programme of simple water quality variables would help identify the most suitable farming locations. There are pockets of relative abundance of natural pearl oyster stocks in the Manning Straits, Nggela and Marau Sound, so presumably these locations would be suitable areas for farming. However other areas may exist where conditions for growth are better, but where stocks have been fished out.

A source of concern for investment in Solomon Islands remains the ease with which pearl farmers might obtain secure exclusive rights over areas of water. All the investors have successfully negotiated aquatic leases in their own areas of operation, and established mutually acceptable working arrangements with customary landowners. However all recognised that, while clearly not impossible, this would be a first in Solomon Islands, and that assistance would be needed from national and provincial governments to ensure that the requirements are understood and arrangements will be respected. At full commercial scale farming may require one or more areas of coastal water of 150-250 ha each.

There was general agreement that, irrespective any regulatory requirements, it would be desirable for any overseas pearl farming investor to have a local business partner who understood the Solomon Islands operating environment and could act as the project interface when dealing with customary landowners, government agencies and local logistics and procurement. The local partner would preferably be someone with extensive business experience in Solomon Islands, as well as a significant financial stake in the operation.

6.2 Commercialisation and Financing

Specific issues that were highlighted during discussions between investors and local officials and businessmen included issues of commercialisation and financing.

Investors noted that in other pearl farming countries, significant industry consolidation has occurred in the past few years as a result of excess production, including of low-quality goods, and falling prices. As a result, large numbers of small farms have merged or been bought up by other operators, resulting in a smaller number of larger operations. In French Polynesia, 1500 'family farms' have been absorbed into about 250 larger farms: in Cook islands, the 70 or so farms previously operating are now down to about 20, with numbers still declining; in Australia, the current 15 or so operators will likely be reduced to 3 or 4 in the next few years. In general, small farming operations in which just a few thousand shell are nucleated each year are no longer commercially viable. To be successful, farms need to achieve economies of scale by nucleating between 100,000 and 300,000 shell each year. This of course requires significantly larger amounts of start-up capital than would be needed for a smaller farm, and increases the risk in the event of project failure, especially given the long lead-time (5 – 10 years) before a pearl farming operation could be expected to turn a profit.

The banking sector in Solomon Islands is unlikely to be a source of financing for a pearl farming venture. The relatively high risk profile, long lead-time before profitability, and lack of hard assets that can be used as loan security all make this type of project unattractive. This reflects the experience in other countries, where the agri-business sector is generally financed through other means.

One financing mechanism used in Australia is a Managed Investment Scheme, a tax-deferred share-farming arrangement marketed to relatively high net worth individuals who are paying the highest marginal rate of tax. Under such an arrangement, an investor would obtain tax exemption of up to 50% by investing in the scheme, under which revenues are deferred for 5-7 years. At the end of this period the investors funds plus earnings are returned to him tax-free, with an effective internal rate of return of 15% per annum during the investment period (equivalent to 30% p.a. if the tax savings are taken into account). This system has been successfully marketed to retail investors, and has now begun to attract the interest of institutional investors with much larger sums to invest. Because of likely changes in tax laws, the Managed Investment Scheme approach may no longer be available after 2008, but institutional investors are still interested in the pearl industry, even without the tax exemptions, because of its good investment return. It seems likely that, following appropriate due diligence (meaning field pearl farming trials), this mechanism could be used to raise financing for a significant commercial project in Solomon Islands.

Of particular interest was the Enterprise Challenge Fund, and AusAID business promotion scheme available in the Pacific and South-East Asia. The Fund is able to provide grants to businesses wanting to establish operations or expand into eligible countries, including Solomon Islands. Grants range from A$ 0.1 to 1.5 million, and must be matched by an equivalent investment from the project sponsor. Proposals are assessed according to a set of criteria which are shown at www.enterprisechallengefund.org, and include providing communities with jobs, livelihood opportunities and services. A pearl farming investment in Solomon Islands by an established overseas from would appear a priori to be eligible for ECF support, which would. The concept note submission deadline for the next round of ECF bidding is 30 January 2009.

Other possible sources of investment capital might include the Kula-2 Fund, a $17 million fund supported by the International Finance Corporation, the Asian Development Bank, and the Commonwealth Development Corporation. The Fund is managed by Aureos Capital, a private equity fund manager (www.aureos.com), and invests in selected business projects, including in fisheries, in the Pacific Islands region.

6.3 Investor's recommendations for next steps

As noted above, the investors considered that under current conditions a large scale investment would be required to produce a viable and profitable industry. At present the information that would allow someone to commit to this is extensive, but there are several key gaps that constitute barriers. This is particularly true in regard to the white-lipped pearl oyster, which are potentially most profitable but whose aquaculture-related characteristics in Solomon Islands have been less investigated than for black-lipped pearl oysters.

To meet the mixed and sometime contradictory goals of being (a) commercially attractive and (b) providing benefits to communities, a project should be formulated to provide realistic, commercially relevant data on the establishment of a pilot-scale farm for white-lipped oyster. The pilot farm should be established in an area where wild stocks of white-lip pearl shell are known to occur, as a means of ensuring suitable growing conditions. The pilot farm should commence growing significant numbers of pearl oysters under commercial or semi-commercial conditions, with appropriate study and monitoring of shell growth rates. Shell should initially be obtained from the wild, through purchasing from local fishers, and then be supplemented as soon as possible by hatchery-produced shell. Trial seeding should be undertaken to allow assessment of nacre deposition rates and pearl colour and quality.

The white-lip farming trial should be carried out in conjunction with a commercial partner, who would provide technical direction, management advice and, importantly, on-the-job training of pearl farming staff at the commercial partner's home base. Other activities that could be carried out during the pilot phase include a broad programme of plankton sampling and water quality testing to identify other potentially suitable farming sites. Again the commercial partner would provide advice and support in this field and, given the lack of information for the country at large, would be of wider general significance.

In parallel with the white-lip farming trial, an extension programme should be established to support community spat collection of black-lip pearl oysters. These should be grown in parallel with the white-lip shell, and farming of both black and white pearls should ultimately become part of the commercial operation. As well as focussing on the provision of community benefits, inclusion of black-lip pearl farming (which has already been shown to be feasible) provides a backup or 'Plan B' in the event that conditions prove unsuitable for white-lip farming.

The pilot project should be suitable for financing by an aid donor or development partner in Solomon Islands. The primary aims are assessment and demonstration of technical feasibility prior to commercialisation, establishment of necessary support/ infrastructure facilities, and human resource development, through on-the-job training and through the spat collection extension programme. Grant rather than loan financing should be sought for this phase, which is expected to last for 2-3 years. Unlike previous research projects, there is now demonstrated private-sector interest in taking the pilot results to a commercial phase.

Provided that growth rates and other farming characteristics of white-lip pearl shell are suitable, the trial project should scale up to full commercial operation after 2-3 years, in partnership with the identified commercial partner, who would be primarily responsible for raising investment capital and taking over project management. It may be appropriate to also seek other partners in the venture, especially in regard to the black-lip farming component, and in order to have the involvement of local business interests. This mixed private-public approach would overcome the existing barriers to investment that have been identified by this programme.

7 Conclusion

Overall, after considerable research, information gathering and consultation within the industry and legislators, the conclusions of our project are that there are few natural barriers to successful pearl farming in Solomon Islands. It is clear that pearl farming needs to be introduced with great care to ensure that the best investors are attracted and that conditions are set up to ensure that they are free to produce high quality product. Two areas at present remain barriers to investment. These revolve around the paradox that a large investment is required under the current state of the pearl farming industry to create a profitable enterprise, yet that this is a new enterprise for Solomon Islands that would be best carried out slowly.

The best prospects for establishing pearl farming are if a small amount of new commercially targeted research is undertaken to address uncertainties as to the ability to produce high quality white pearls in good numbers, as well as a variety of colours of black pearl, and for sufficiently strong financial incentives to be put in place by Solomon Islands Government and their international aid partners to attract long term investment.

A pilot project suitable for financing by an aid donor or development partner in Solomon Islands, and in conjunction with a commercial partner, is recommended to address these uncertainties.

Provided that findings are positive, the trial project should scale up to full commercial operation after 2-3 years. The identified commercial partner, would be primarily responsible for raising investment capital and taking over project management. This mixed private-public approach would overcome the existing barriers to investment that have been identified by this programme.

How the industry is developed and the arrangements made for use of custom waters and involvement of local communities in the various stages of the pearl production process will then determine the extent to which it will truly contribute to rural development and income generation.

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

Prepared by:

Ian Hawes
WorldFish Center
Gizo

Patrick Mesia
MFMR
Honiara

WorldFish CENTER

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

Contents

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 mad 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.

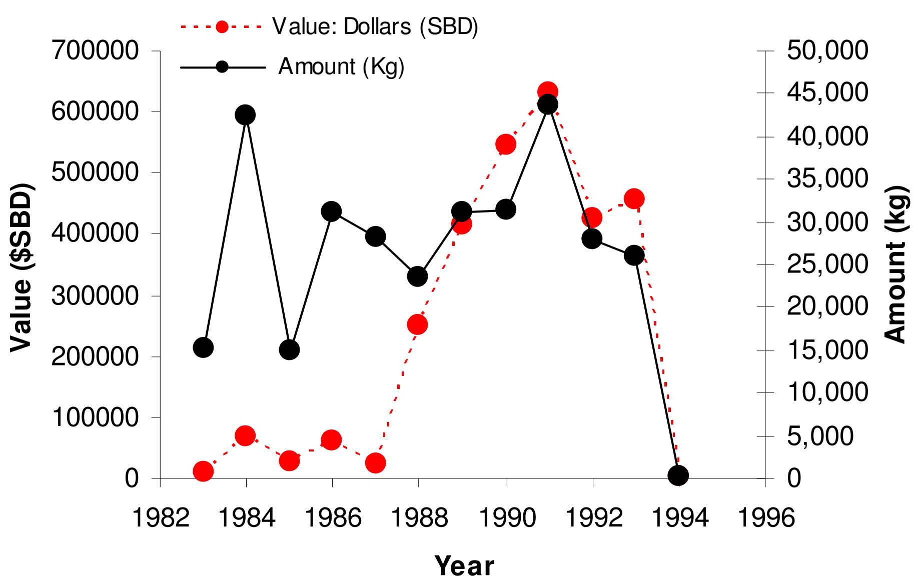

Figure 1. Export of blacklip shell from Solomon Islands for mother of pearl.

[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)**

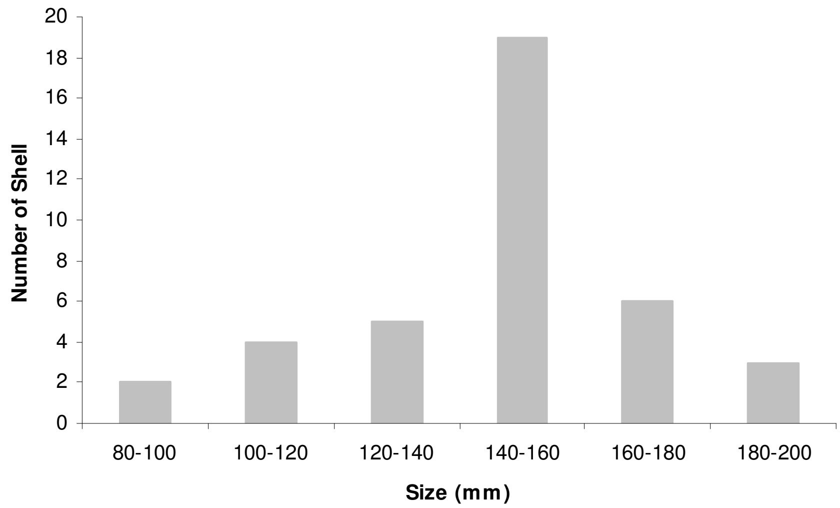

Figure 2. Size, as dorso-ventral measurement, of blacklip pearl oyster shell encountered during the TNC/MFMR national resource survey in 2004. Samples from all sites and depths have been pooled.

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).

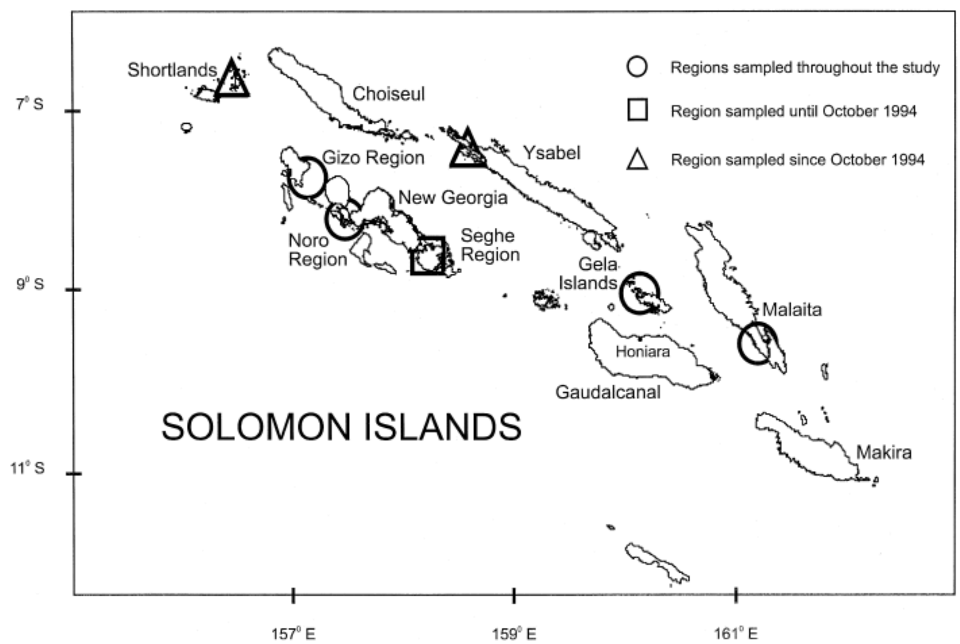

Figure 3. Sites used in the study of spat collection around Solomon Islands.

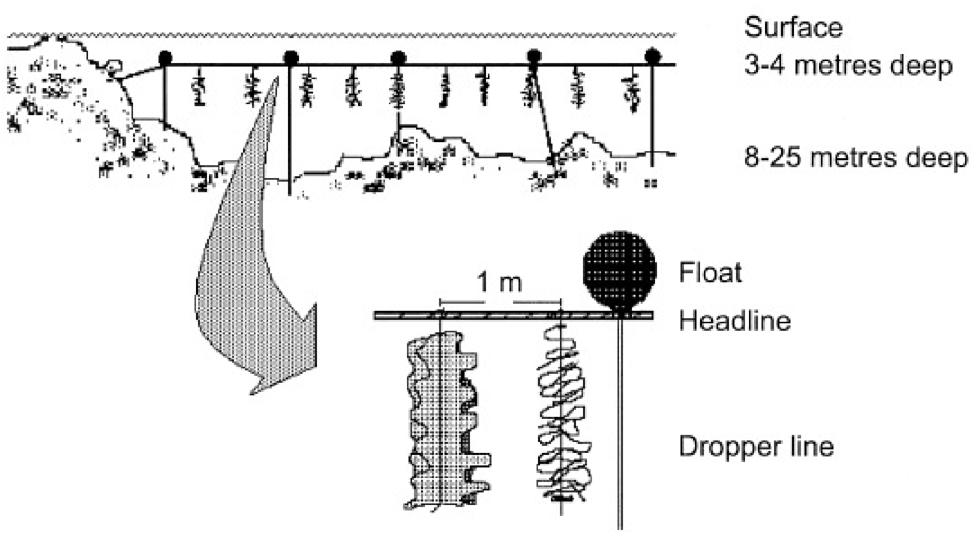

Figure 4. Arrangement of spat collectors and longlines at each of the collection sites.

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.

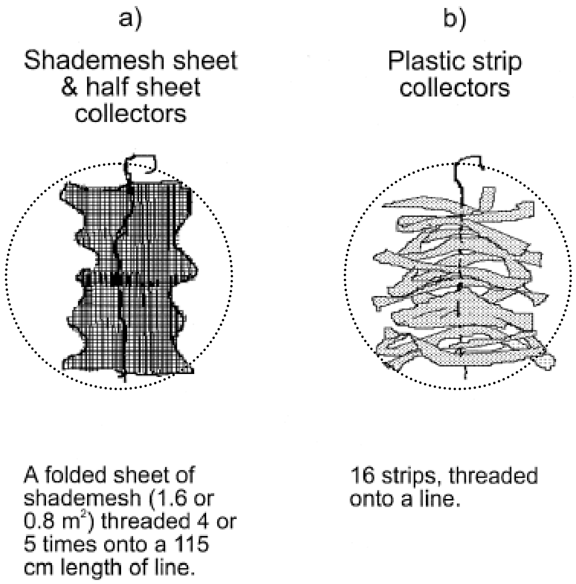

Figure 5. The two basic types of collector compared in the Friedman and Bell (1996) study. Twenty of each type were deployed, half in protective mesh bags and half open. The plastic sheeting was more effective than the shade mesh and the bags proved to have no protective effect.

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;

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

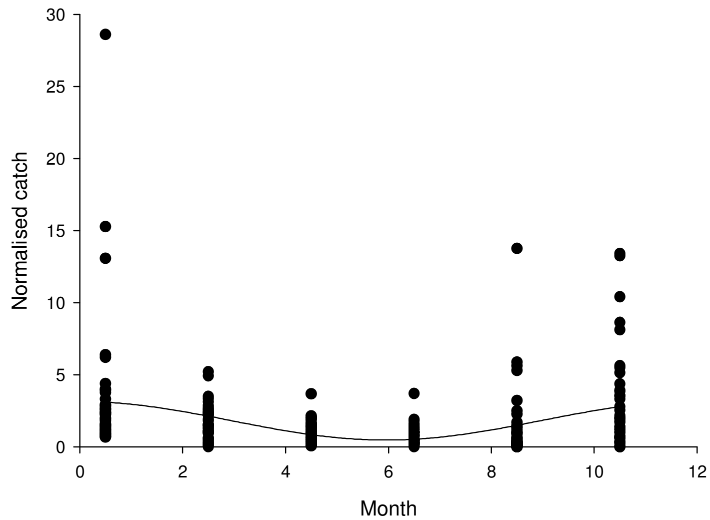

Figure 6. Seasonal pattern of spat collection during the 1997-2003 period. Each dot represents a single site, with the dot plotted in the middle of the two month deployment period. The curve is fitted by least-squared linear regression.

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.

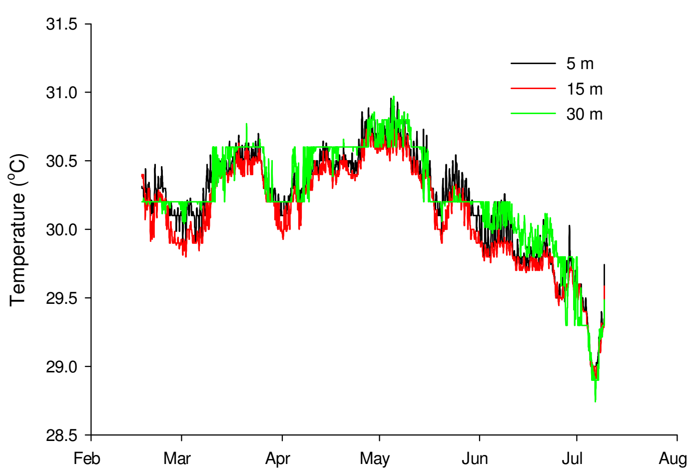

Figure 7. Water temperature at three depths in the Nusa Tupe lagoon for the first half of 2007. Boxcar smoothing has been applied, using the running 3.5 h mean (individual records are at 30 minute intervals.

Seasonal temperature variation is slight in Solomon Islands. An incomplete annual record for 2007 shows a maximum of close to 31°C in May, falling with the onset of winter winds, lower insolation and air temperatures to 29°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

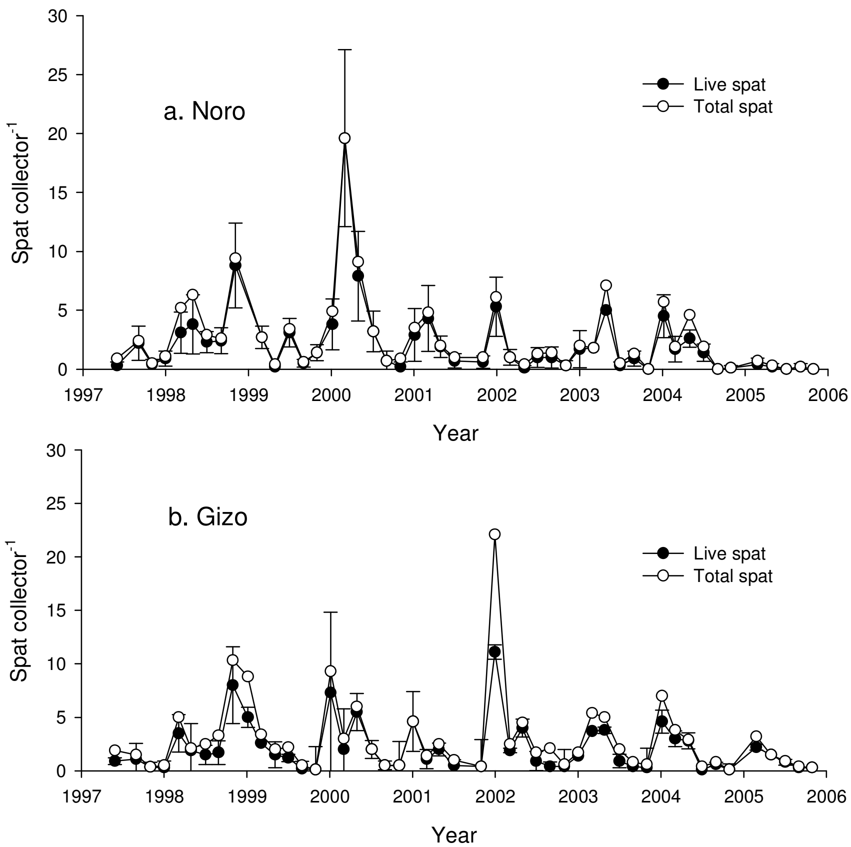

Figure 8. Mean abundance of spat (total and live) on collectors at a) Noro and b) Gizo in the Western Province of Solomon Islands. Error bars are 95% confidence limits around live spat.

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.

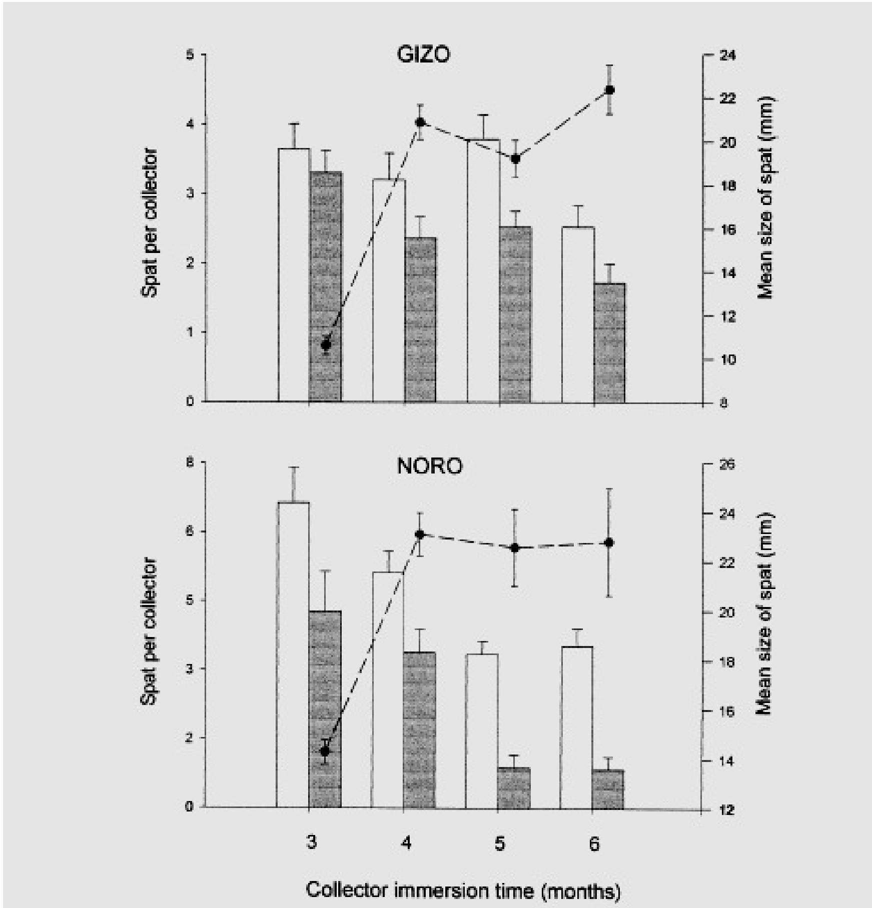

Figure 9. Total (blank columns).and live (solid columns) abundance, ± standard error, of blacklip spat harvested from collectors after 3, 4, 5 and 6 months at Gizo and Noro. The mean size, as dorso-ventral measurement ± standard error of live spat harvested each month is also shown.

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.

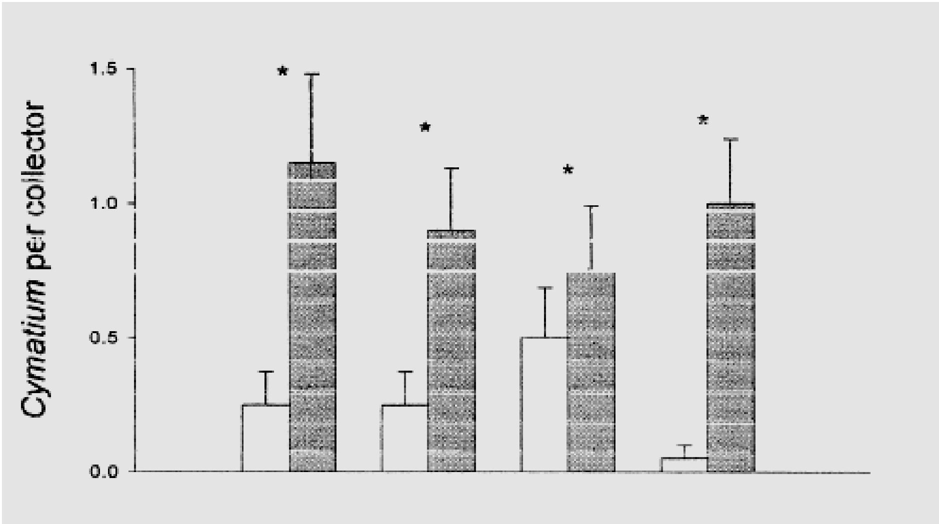

Figure 10. The number of *Cymatium*, a significant predator on spat, on collectors after four months (blank columns) and 6 month (solid columns) at four collection sites. Asterisks signifiyt significant differences between blank and solid columns (ANOVA $p<0.05$).

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.

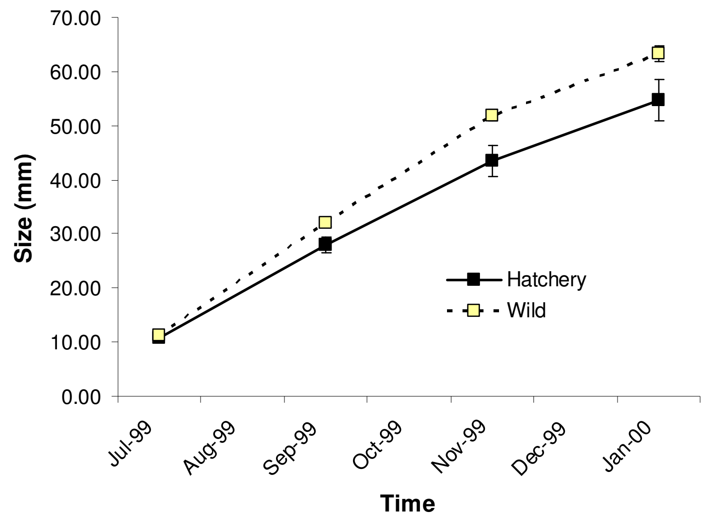

Figure 12. Comparison of growth of hatchery-reared and wild caught spat in intermediate culture trays. Points are means of four replicates ± standard error.

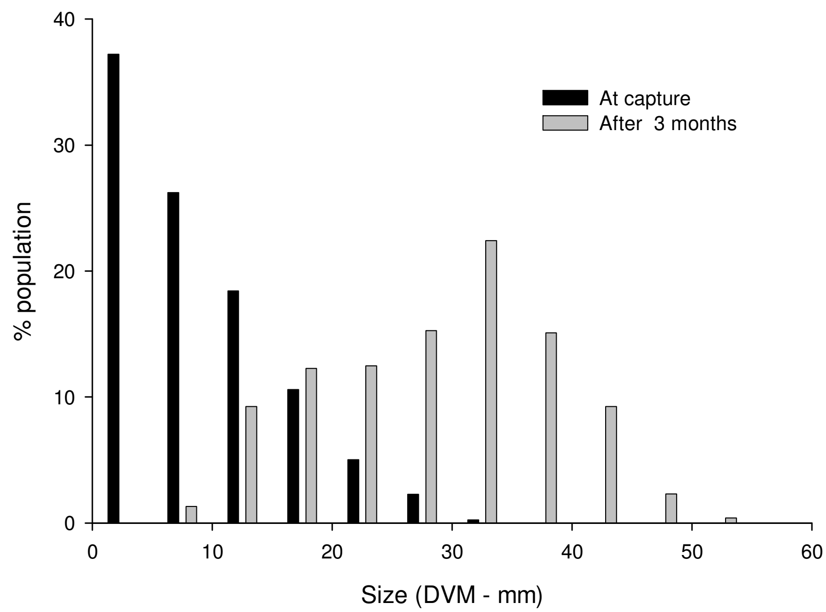

Figure 13. Typical performance of intermediate culture. This batch of 2000 spat were first measured after removal from spat collectors after four months immersion (November 2005-February 2006) and grown in intermediate culture for three months before re-measuring. During that time the trays were cleaned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

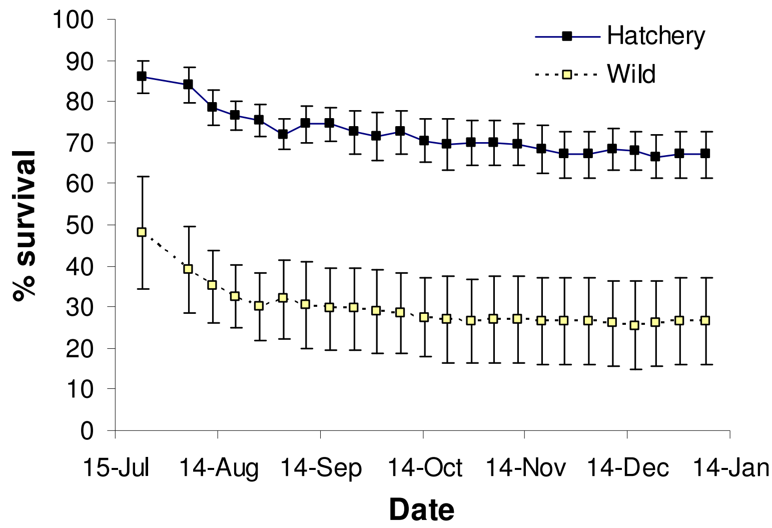

Figure 14. Survival of wild-caught and hatchery-reared spat in intermediate culture trays. Points are means of eight replicates ± standard error.

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.

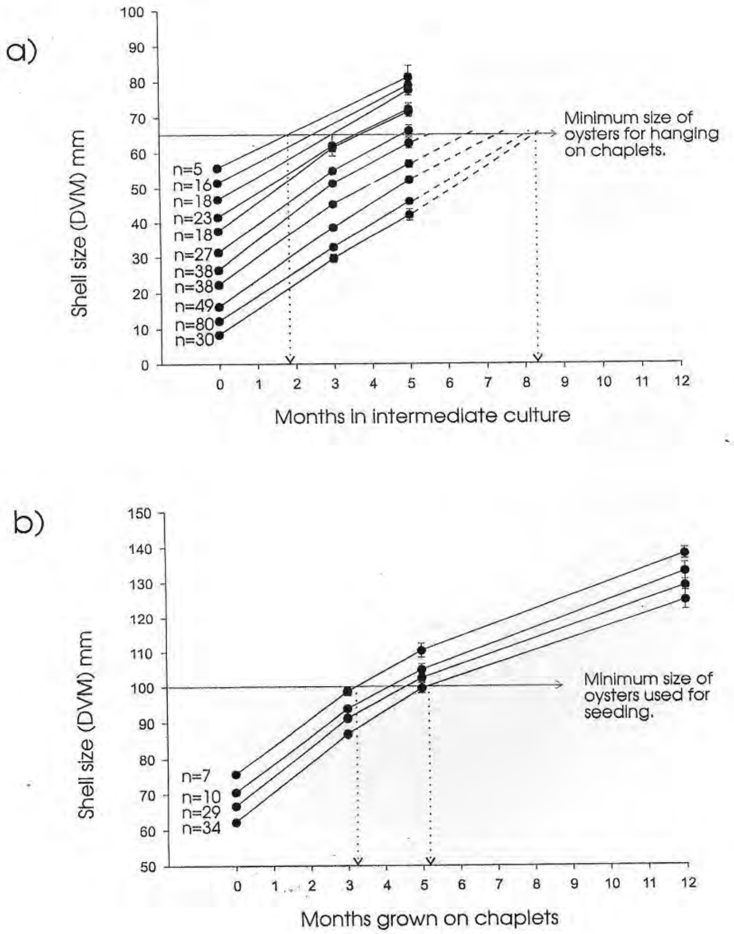

Figure 15. Growth trajectories for oysters of different sizes a) entering intermediate culture and b) placed on droppers for grow-out.

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.

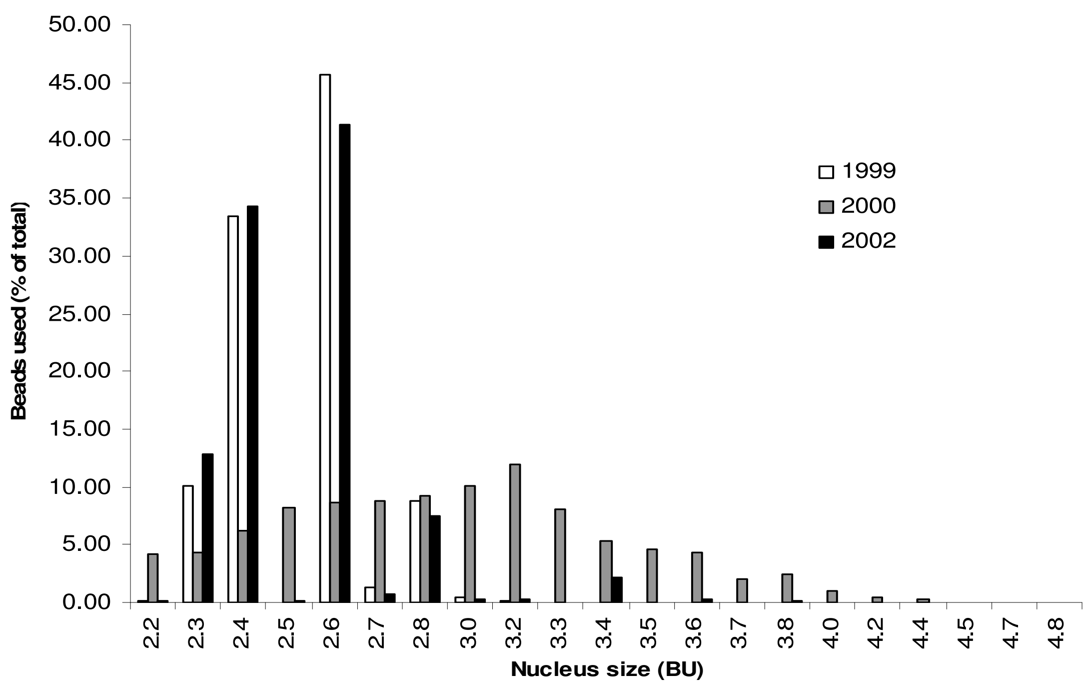

Figure 16. Nucleus sizes used during operations in 1999 (1203 total shell seeded), 2000 (2113 total shell seeded) and 2002 (2289 total shell seeded).

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 was 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 costs 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.

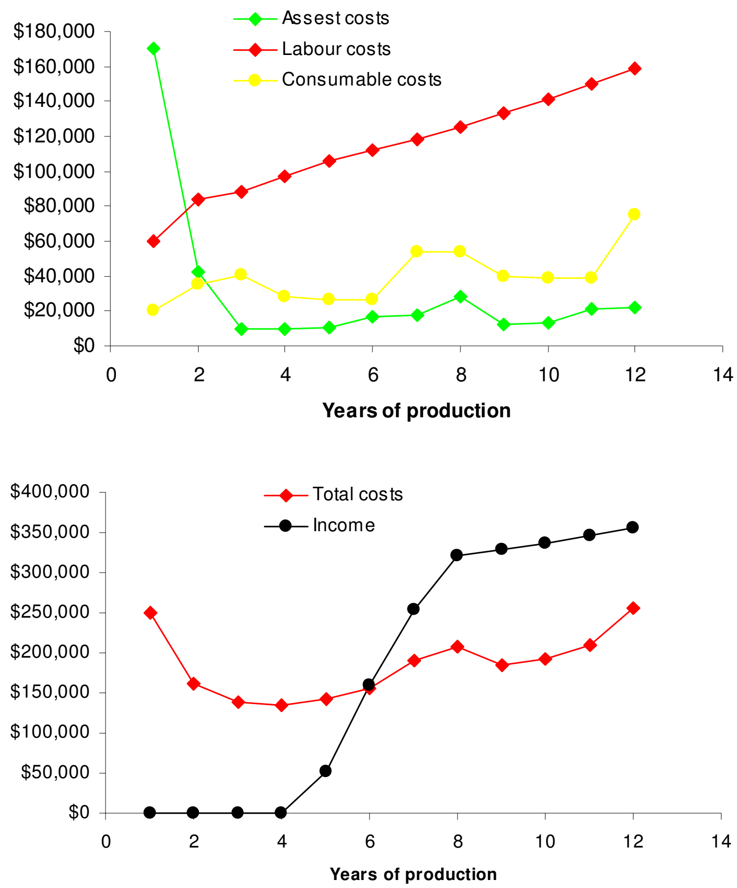

Figure 17. Predictions of possible costs and income from a pearl farm operating at similar efficiency to the Nusa Tupe trial farm, and based on 5000 spat collector deployed each year.

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

Round and near round pearls:	**AUD**
Size 12 - 13 mm:	
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
Size 11 - 12 mm:	
4 pces round, mixed colours, average spotting 2, lustre B	400
8 pces near round, mixed colours, average spotting 3, lustre B	800
Size 10 - 11 mm:	
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
Size 9 - 10 mm:	
27 pces round/near round, mixed colours, average spotting 3, lustre B	2,160
Size 8 - 9 mm:	
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
Circle Pearls:	
Size >10 mm:	
26 pces Grade A	1,560
87 pces Grade B	2,610
105 pces Grade C	525
Size <10 mm:	
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**

Report to:

World Fish Center

Suitability of Habitats in the Solomon Islands and Other Regions of the Pacific for Growth of Black-Lip and Silver-Lip Pearl Oysters

FINAL

June 2008

The Ecology Lab Pty Ltd

Marine and Freshwater Studies

Suitability of Habitats in the Solomon Islands and Other Regions of the Pacific for Growth of Black-Lip and Silver-Lip Pearl Oysters

June 2008

Report Prepared for:

World Fish Center
Jalan Batu Maung
Batu Maung,
11960 Bayan Lepas,
Penang,
Malaysia

Report Prepared by:

The Ecology Lab Pty Ltd
4 Green Street
Brookvale, NSW, 2100
Phone: (02) 9907 4440

Report Number – 55/0607B
Report Status – Final 5 June 2008

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SUMMARY

Background

The European Union has funded a project entitled 'Stimulating investment in pearl farming in the Solomon Islands'. The objective of this project is to provide offshore pearl companies with sufficient information to determine the potential for long-term investment in pearl farming in the Solomon Islands. The World Fish Centre sub-contracted The Ecology Lab Pty to prepare a report comparing coral reef lagoons and habitats suitable for growing black-lip (*Pinctada margaritifera*) and white-lip pearl oysters (*Pinctada maxima*) in the Solomon Islands with several other locations in the Pacific, for this project. The conclusions drawn about the suitability of coral reef habitats in these regions are based on existing information about the environmental needs of each species, the environmental conditions prevailing at farm locations, the different types of coral reef and lagoon habitats in the specified regions and their prevailing environmental conditions and the influence of the natural environment on the various culture phases.

Environmental needs of pearl oysters

The physiology, survival and productivity of bivalves is known to vary with temperature, salinity, type of substratum, depth of the water column, silt load, water currents, primary productivity and pollution. The response of black-lip and silver-lip pearl oysters to fluctuations in these environmental factors, however, is poorly documented. Experimental studies in Australian waters indicate that adult silver-lip pearl oysters are less tolerant of lower temperatures but more tolerant of high temperatures and are capable of coping with a wider range of food concentrations and more turbid conditions than their black-lip counterparts. This implies that they may be cultured under a greater variety of environmental conditions. It should, however, be noted that spat, juveniles and adults may exhibit different responses to these environmental factors and that the physiological responses of these species may vary across their latitudinal range. The review also suggests that little is known about the environmental conditions under which natural populations of black-lip and silver-lip pearl oysters grow in the South Pacific region. Most of the information obtained about the environmental needs of pearl oysters came from Australia or French Polynesia.

Environmental conditions at existing pearl farms

The most productive black pearl farms are located in atoll lagoons in French Polynesia and the Cook Islands. Considerable information is available about the environmental conditions in their vicinity of some of these farms. These lagoons differ markedly in total surface area, depth and degree of exchange with the ocean. The feasibility of establishing farms in other coral reef habitats has been investigated in Fiji, the Solomon Islands and Vanuatu, and commercial farms have since been established in Fiji and Australia. The farms in Australia utilize juvenile pearl oysters from hatcheries, whereas those elsewhere are based on wild spat or stock. Little information is available about the environmental conditions at these farms. The paucity of information on environmental conditions prevailing in Solomon Islands relative to Cook Islands and French Polynesia precludes an assessment of whether conditions for pearl farming would be comparable.

Silver-lip pearl oysters are currently being farmed in the northern part of Western Australia, Northern Territory, Queensland, Torres Strait Islands and in a few areas of Papua New Guinea. The silver pearl industries in West Australia and Queensland are based primarily on the collection of wild oysters and hatchery-derived spat, respectively. The industry in

the Northern Territory is based on oysters sourced from hatcheries and wild oysters imported from Western Australia. It is difficult to assess the suitability of Solomon Islands waters for silver-lip pearl farming because of the general paucity of information on the coastal environment in this region and on environmental conditions prevailing in the vicinity of the Australian and Papuan farms. It is, however, worth noting that the coastal waters off the larger Solomon Islands and the northern part of Australia are subject to heavy rainfall accompanied by freshwater runoff laden with silt.

Regional differences in availability of coral reef and lagoon habitats

In Solomon Islands, Fiji and Vanuatu, most of the coral reefs either fringe the high islands or occur in shallow, sublittoral areas. In Papua New Guinea, approximately half of the coastline and surrounding islands appear to be fronted by coral reefs with all reef types represented, but with fringing and barrier reefs dominating. On the north-east Australian coast, the major coral structure is the Great Barrier Reef, which comprises about 3,000 fringing reefs, submerged reefs, platform and barrier reefs. There are also fringing reefs along the Northern Territory and North West Australian coasts, a few atoll-like structures on the north-west continental shelf and coral reefs in the Houtman Abrolhos Islands, 400 km north of Perth. The reefs off the Melanesian islands and off the Australian coast have a relatively 'open' structure and considerable exchange of water is able to take place through the numerous passages linking patch, fringing and barrier reefs with deeper water. In the Cook Islands and French Polynesia, atolls are the predominant coral reef habitat and it is in their 'enclosed' or 'semi-enclosed' lagoons that the majority of black pearl farms are located. This type of coral reef structure is scarce in the Central West Pacific region.

Effect of habitat on culture of pearl oysters

Pearl oyster farming may involve several field-based operations, including collection of wild spat or stock, grow-out of juveniles in intermediate grow-out systems and on-growing of adults, all of which are to some extent dependent on the prevailing environment.

In French Polynesia and the Cook Islands, black pearl production is based on wild spat that settle on artificial collectors deployed in "enclosed" or "semi-enclosed" atoll lagoons for periods ranging from six months to two years. Reasonable quantities of black-lip pearl oyster spat have also been collected from 'open' reef systems in the Solomon Islands, particularly from sites with clear water and moderate currents that are at least 35 m away from the nearest reef. Collectors deployed within barrier reef lagoons yielded surprisingly few spat, probably because the collectors became clogged with sediment or overgrown by algae during the rainy season.

The growth rate of juvenile black-lip pearl oysters cultured in these 'open' reef systems is comparable with that observed in some of the atolls in French Polynesia and the Cook Islands. However, experimental studies on growth, survival and condition of small black-lip pearl oysters over a 14 month period in two contrasting environments adjacent to the Great Barrier Reef (Australia) indicated that environmental conditions were more suitable for the growth of juveniles at the near oligotrophic offshore location than in a mainland bay characterised by high levels of turbidity and large concentrations of particulate organic matter.

In the Cook Islands, growth of black-lip pearl oysters has been compared experimentally at different sites within a lagoon, among lagoons, in different natural habitats and under different culture conditions, but results are difficult to interpret because of the experimental design. In French Polynesia, the growth of black-lip pearl oysters has been compared in completely or almost closed atoll lagoons, largely open atoll lagoons, lagoons off high islands and in the open ocean. The growth rate of oysters and mean annual shell growth increment were significantly greater in island lagoons and the ocean habitat than in atoll lagoons. Oysters also attained a size suitable for implantation of a nucleus faster in the water off high islands and in the open ocean than in the atoll lagoons. Differences in growth rate were attributed to the negative effects of high (≥ 30 °C) water temperatures, differences in the degree of water renewal and food supply around the oysters. In Australia, the growth rate and survival of medium and large size oysters and condition of medium-sized animals were significantly smaller in turbid waters adjacent to the mainland than in near oligotrophic waters further offshore. The poor performance of black-lip pearl oysters under turbid conditions suggests that commercial culture may be less viable in this type of environment.

Silver-lip pearl oysters are often cultured in near-shore areas subject to large fluctuations in salinity and high inputs of terrigenous sediment and nutrients during seasonal rainfall events. The industry is based on adult individuals of a particular size range or hatchery-derived spat rather than wild spat, hence there is no information on the collection of spat. Reductions in salinity can have an adverse effect on growth rate of spat but not their survival of spat and can also cause detachment of juveniles. There is also evidence from Australia that the survival and growth of juveniles is poorer in winter. The timing of the introduction of hatchery-reared spat consequently requires careful consideration. Information about the environmental conditions prevailing at silver-lip pearl farms is scarce. Experimental studies on the growth, survival and condition of silver-lip pearl oysters undertaken in two dissimilar environments adjacent to the Great Barrier Reef indicate that the growth rate and final condition of oysters cultured in the mainland bay was not significantly different from that at the offshore location. This implies that silver-lip pearl oysters are physiologically adapted to a wide range of food concentrations and that they could potentially be cultured in a variety of habitats.

Overall conclusions

Although black-lip and silver-lip pearl oyster farming are lucrative industries, there is a surprising lack of basic information on the influence of environmental factors on their biology and ecology and on environmental conditions at existing farms and their influence on culture practices. Information on coral reef habitats within some of the specified regions of the Pacific Ocean is also lacking. This lack of information hinders assessments about the suitability of available habitats for growing pearl oysters in the Solomon Islands relative to those in the other Pacific regions. Despite this, it is clear from the literature sourced that, from an environmental perspective, there is potential for farming of both black-lip and silver-lip pearl oysters to take place in the Solomon Islands. The turbid waters adjacent to the leeward side of the mountainous islands are likely to be more favourable for farming silver-lip than black-lip pearl oysters.

GLOSSARY

‰ – parts per thousand (salinity).

°C – degree centigrade.

Atoll – a ring-shaped coral reef that fully or partially encloses a lagoon and is surrounded by open sea.

Black-lip pearl oyster – *Pinctada margaritifera.*

Chaplet – dropper rope connected to a longline from which juvenile or adult oysters are attached.

GBR – Great Barrier Reef.

Hoa - shallow channels separating individual narrow islands on atoll reefs.

Motu - narrow islands on atoll reefs.

Picoplankters - Very small, single-celled planktonic plants or animals between 0.2 - 2.0 µm long.

POM – particulate organic matter.

Pseudoatoll - coral reef surrounding an inner lagoon with several islands.

Pseudofaeces - Organic waste produced by filter feeding molluscs which includes faeces and rejected food particles.

SFG - Scope for Growth - Energy available to sexually mature animals for growth and reproduction.

Silver-lip pearl oyster - *Pinctada maxima.*

Spat – recently-settled juvenile mollusc.

SPM – suspended particulate matter.

Turbidity - a measure of the degree to which the water looses its clarity due to the presence of suspended particulates.

1.0 INTRODUCTION

The European Union has recently funded a project entitled 'Stimulating investment in pearl farming in the Solomon Islands'. The primary objective of this project is to provide offshore pearl companies with sufficient information to determine the potential for long-term investment in pearl farming in the Solomon Islands. Information on the following aspects is currently being compiled for this project:

- Publications on the availability and culture of black-lip pear oysters in the Solomon Islands;
- Availability and quality of silver-lip pearl oyster resources in the Solomon Islands;
- Availability of suitable habitats and environmental conditions for the growth of black-lip and silver-lip pearl oysters in the Solomon Islands and pearl-producing regions of the South Pacific;
- The investment climate in the Solomon Islands;
- Policy guidelines for the development of environmentally and financially sustainable pearl farming in the Solomon Islands; and
- Offshore pearl companies most likely to consider investing in pearl farming in the Solomon Islands.

In February 2007, The World Fish Centre commissioned The Ecology Lab Pty Ltd to provide a number of consultancy services for the EU project, including the preparation of the following report comparing coral reef lagoons and habitats suitable for growing black-lip and white-lip pearl oysters in the Solomon Islands with other locations in the Pacific, specifically French Polynesia, Cook Islands, Australia, Fiji, Vanuatu and Papua New Guinea. A comparison of this type requires an understanding of the environmental needs of each species and a sound knowledge of the environmental conditions prevailing at existing farm locations, the different types of coral reef and lagoon habitats in the specified regions and their prevailing environmental conditions and the influence of the natural environment on the various stages of culture. This report addresses each of these aspects in turn and draws conclusions about the suitability of the habitats available for growing pearl oysters in the Solomon Islands relative to those in the other Pacific regions.

2.0 ENVIRONMENTAL NEEDS OF PEARL OYSTERS

2.1 Introduction

The environmental factors that are likely to have the greatest influence on the biology and ecology of pearl oysters are temperature, salinity, type of substratum, depth of the water, silt load, water currents, primary productivity and pollution (Gervis and Sims 1992). Although such factors are known to have significant effects on the physiology, survival and productivity of bivalves (Jorgensen 1990; Gosling 2003) there have been relatively few studies on the responses of black-lip and silver-lip pearl oysters to fluctuations in environmental factors. The combined effects of temperature and salinity on embryos and larvae of black-lip oysters from the Great Barrier Reef and effects of salinity on growth and survival of silver-lip spat have been documented by Dourodi *et al.* (1999) and Taylor *et al.* (2004), respectively. The influence of salinity on detachment of silver-lip spat has also been described (Taylor *et al.* 1997). The effects of temperature and suspended particulate matter (SPM) on feeding of black-lip and silver-lip oysters from the Great Barrier Reef (GBR), Australia has been investigated by Yukihira *et al.* (1999, 2000). The influence of food availability on black-lip oysters in French Polynesia has also been investigated (Pouvreau *et al.* 1999a and b, 2000a and b; Loret *et al.* 2000a and b). When reading this overview, it is important to bear in mind that black-lip and silver-lip pearl oysters growing in other regions may exhibit different responses to those reported here and that responses of larvae, juveniles and adults to environmental factors are likely to differ.

The information that is currently available on the influence of each environmental factor is summarised below.

2.2 Geographic Distribution

Black-lip pearl oysters are found in the Persian Gulf, Red Sea, Sudan, Papua New Guinea, Australia, French Polynesia, Indonesia, Andaman and Nicobar Islands, southwestern part of the Indian Ocean, Japan and the Pacific Ocean. This species reaches its greatest abundance in the atoll lagoons of French Polynesia and the Cook Islands (Gervis and Sims 1992).

Silver-lip pearl oysters are distributed along the north coast of Australia, Burma, Thailand, Indonesia, Philippines and Papua New Guinea at depths ranging from low tide level to 80 m (Bueno *et al.* 1991; Gervis and Sims 1992).

2.3 Temperature

Temperature determines the rate of deposition of nacre on shells and nuclei and therefore limits pearl culture sites to areas within the optimum temperature range (Gervis and Sims 1992). Relatively little information, however, is available about the optimal temperature ranges of black-lip and silver-lip pearl oysters. It should also be noted that most of the studies on the effects of temperature on black-lip and silver-lip pearl oysters were done in waters off the Great Barrier Reef (GBR) on the north-east coast of Australia. It is therefore not known whether the ranges reported below are applicable throughout the species' geographic ranges.

Doroudi *et al.* (1999) reported that normal development of black-lip oyster embryos occurred only between 25 °C and 30 °C, that growth of larvae was optimal between 26 °C and 29 °C and that temperatures greater than 35 °C were lethal for larvae. Survival of larvae was greatest, but growth was slow, close to 20 °C, the lowest temperature examined.

Yukihira *et al.* (2000) examined the effects of temperature on suspension feeding and energy budgets of black-lip and silver-lip pearl oysters. They found that the clearance rate, absorption efficiency, amount of energy absorbed, respiration rate, excretion and hence Scope for Growth (i.e. energy available to sexually mature animals for growth and reproduction) of both species were much lower at 19 °C than between 23 °C and 32 °C. The clearance rate of and amount of energy absorbed by black-lip oysters declined between 28 °C and 32 °C, but that of silver-lip oysters remained fairly constant. The increase in absorption efficiency of black-lip pearl oysters was less marked that of silver-lip pearl oysters between 19 °C and 32 °C. The respiration rate of black-lip pearl oysters increased markedly between 28 °C and 32 °C, whereas that of silver-lip pearl oysters only increased slightly over this range. Black-lip oysters excreted less energy than silver-lip oysters over this temperature range. High temperatures had a marked effect on the rate of ammonia excretion in both species. The Scope for Growth of black-lip pearl oysters was adversely affected by both low (19 °C) and high (32 °C) temperatures, whereas that of silver-lip oysters was affected mostly by low temperatures. On the basis of these results, Yukihira *et al.* (2000) concluded that the optimum temperature ranges for black-lip and silver-lip oysters were 23 - 28 °C and 23 -32 °C, respectively.

In contrast, to the results from the GBR, temperature appears to have no effect on the physiology of black-lip oysters in Takapoto Atoll, probably because the temperature range is only 26 ºC to 30 ºC (Pouvreau *et al.* 1999a). The feeding responses of black-lip oysters, however, may differ in Polynesian atolls with wider annual temperature ranges (e.g. 22 – 32 °C) or larger quantities of POM Pouvreau *et al.* (2000a).

2.4 Salinity

Pearl oysters prefer full salinity seawater, but can tolerate a wide range of salinities (Gervis and Sims 1992). Taylor *et al.* (1997) found that exposure of juvenile silver-lip oysters to reduced (25-30 parts per thousand, ‰) or elevated (40-45 ‰) salinities resulted in greater detachment from the substratum than in ambient (34 ‰) seawater. Subsequent studies on the effects of prolonged (20 day) exposure to salinities ranging from 25-45 ‰ have shown that the survival of spat did not vary across this range, but growth was significantly reduced at 25‰, 40 ‰ and 45 ‰ (Taylor *et al.* 2004). Growth was also found to be significantly greater at 30 ‰ than at ambient salinity, suggesting that the optimal salinity range for rearing of spat may be between 30 ‰and 34 ‰. Dourodi *et al.* (1999) found that normal development of black-lip oyster embryos and optimal survival and growth of larvae took place between 25 ‰ and 35 ‰. These studies suggest that the reductions in salinity to levels as low as 25 ‰ that occur during the rainy season in northern Australia may have an adverse effect on the growth rate of silver-lip spats.

2.5 Habitat

Black-lip pearl oysters are most abundant around the low tide mark, but extend to depths of 40 m in the Torres Strait and Polynesia (Gervis and Sims 1992). This species is typically found in oligotrophic coral reef and atoll water, where primary productivity and turbidity levels are often low. In the Solomon Islands, black-lip pearl oysters are typically found in shallow water (1-2 m) (G Tiroba pers. comm. in Richards *et al.* 1994).

Silver-lip oysters are found in a variety of environments, ranging from shallow seagrass beds to deepwater reefs and on sedimentary substrata adjacent to continents and large islands, where the water is often turbid due to large inputs of terrigenous sediments and nutrients and higher productivity levels (Gervis and Sims 1992). They have been found at depths varying from 0 - 80 m (Gervis and Sims (1992) and occur at depths of 10 - 60 m in the Solomon Islands (G Tiroba pers. comm. in Richards *et al.* 1994).

2.6 Type of Substratum

The distribution of pearl oysters is thought to be limited by the availability of suitable substrata (Gervis and Sims 1992). Black-lip oysters are scarce or absent in some French Polynesian lagoons, because of limited substratum availability (Service de Pêche 1970 in Gervis and Sims 1992). Some workers indicate that this species is absent from soft bottoms, however, there is a report of them occurring only on sand in one of the Kiribati atolls. Spat of silver-lip oysters only settle on hard substrata and an aggregate or seabed with a hard crust covering a soft substratum is considered an ideal substratum in Western Australia. They also mentioned that adult silver-lip oysters occur on mud or sand in association with seagrass beds and that they may be shifted to these areas when their byssus detaches.

In Western Australia, silver-lip pearl oysters are found on areas of seabed consisting of flat basement rock with crevices which are generally covered by a few millimetres of fine sediment and a variety of organisms which extend up to 1 m off the bottom (Wells and Jernakoff 2006). Several distinct habitats are recognised within the pearl fishing grounds and these have been assigned the names "potato" bottom, "garden" bottom, "collar" and "asparagus", reflecting the form of the dominant inhabitants. Commercial quantities of silver-lip oyster are found only on potato bottom and garden bottom habitats. "Potato" bottom is dominated by a low, round densely-packed ascidian species, followed by a variety of sponges ranging in size from a few centimeters to 0.5 m high. "Garden" bottom is characterised by large hydroids (up to 1 m high) covered by a variety of other, colourful organisms, hence the name. Sponges, soft corals, sea pens, crinoids and a large species of ascidian are also found on "garden" bottoms. The composition of the habitat varies with depth, with "potato/asparagus" habitat predominating at 9-12 m, "potato/garden" bottoms occurring at 13-16 m and depths of 16-34 m being characterised by "garden bottom" (Hart and Friedman 2004).

In Solomon Islands, silver-lip pearl oysters have been found in a variety of habitats, including mud, sand, gravel, coral rubble and various mixtures thereof (The Ecology Lab 2008)

2.7 Currents

Gervis and Sims (1992) pointed out that silver-lip oyster beds often occur in areas with very strong currents and that growth of both species is greater in areas with strong currents.

2.8 Food Availability

Pearl oysters are filter-feeders and obtain their food resources by actively clearing organic particles, such as phytoplankton, from the water column. The quantity and quality of natural SPM has been shown to affect feeding and food utilization in black-lip and silver-lip pearl oysters from the Great Barrier Reef (GBR) (Yukihara *et al.* 1999). Both species reduced their clearance rates and absorption efficiency, but increased their production of pseudofaeces when exposed to large concentrations of SPM (i.e. high turbidity). Under turbid conditions, silver-lip pearl oysters had significantly greater clearance and ingestion rates and absorbed food more efficiently, but produced pseudofaeces at a slower rate than black-lip oysters. Silver-lip oysters also had a greater SFG under turbid conditions. Under these conditions, silver-lip pearl oysters are clearly more efficient suspension feeders than black-lip oysters. Black-lip oysters, in contrast, had a higher clearance rate, retained smaller particles and ingested a wider size range of particles at low SMP concentrations than silver-lip oysters. This study indicated that the optimum SPM concentrations for black-lip and silver-lip oysters were < 5 mg l^{-1} and 3-15 mg l^{-1}, respectively and their optimum particle size ranges were > 3 µm and > 4µm, respectively. This information may be useful for selecting optimum pearl culture sites.

The feeding responses of black-lip oysters has also been assessed in Takapoto atoll lagoon, French Polynesia, an oligotrophic system, dominated by small (< 2 µm) primary producers and characterised by very small quantities (<1.5 mg l^{-1}) of particulate organic matter (POM) > 1 µm. The retention efficiency of the oysters was found to be 98% for particles > 5 µm, but to decline to 35% and 15% for 1.7 µm and 1 µm particles, respectively (Pouvreau *et al.* (1999b). In this system, high clearance rates (200 to > 1500 l d^{-1} for animals aged 1-4 years) appear to compensate for the poor food quality. The feeding responses of black-lip oysters, however, may differ in Polynesian atolls with larger quantities of POM Pouvreau *et al.* (2000a). It is also worth noting that black-lip oysters from the GBR retain about 70% of 1.7 µm particles (Yukihira *et al.* 1999) and exhibit a lower clearance rate than those in Takapotoa atoll (Yukihira *et al*. 1998).

Loret *et al.* (2000a) have shown that the black-lip oysters in this lagoon are selective feeders, consuming large amounts of nanoflagellates, one of the most abundant groups of primary producers, but only small quantities of picocyanobacteria, the other dominant group, probably because they are too small to be retained. They also showed that cryptophytes, one of the less abundant phytoplankton groups, were consumed preferentially and that the digestion efficiency for chlorophytes and dinoflagellates was poor. These oysters are also capable of consuming and retaining ciliates (Loret *et al* 2000b). These results conflict with Gervis and Sims (1992) suggestion that pearl oysters are non-specific feeders.

2.9 Conclusions

Black-lip pearl oysters have a wider geographic distribution and are presumably adapted to a greater range of temperatures than silver-lip pearl oysters. The latter species, however, apparently occupies a greater variety of habitats and has a more extensive vertical distribution than its black-lip counterpart. The response of these two species to fluctuations in environmental factors is poorly documented and studies comparing the responses of the two species and different developmental stages of each species are rare. Comparisons are also hindered by the lack of information on latitudinal differences in physiological functions within each species. In Australia, adult silver-lip pearl oysters appear to be less tolerant of lower temperatures, but more tolerant of higher temperatures than black-lip pearl oysters. They are also capable of coping with a wider range of food concentrations and more turbid conditions than black-lip pearl oysters. This suggests that silver-lip pearl oysters have the potential to be cultured under a greater variety of environmental conditions.

The above review also suggests that little is known about the environmental conditions under which natural populations of black-lip and silver-lip pearl oysters grow in the South Pacific region. Most of the information obtained about the environmental needs of pearl oysters came from Australia or French Polynesia.

3.0 ENVIRONMENTAL CONDITIONS AT EXISTING PEARL FARMS

3.1 Black Pearl Farms

3.1.1 Australia

There is an emerging black pearl industry in the Abrolhos Islands and in Shark Bay, Western Australia based primarily on the supply of juvenile pearl oysters from hatcheries (Australian Aquatic Portal 2007). In Queensland, suitable-sized wild black-lip pearl oysters collected by the East Coast Pearl Fishery are translocated to aquaculture farms in Queensland and the Torres Strait for use in pearl production, but these comprise only a small amount of the live shells used for pearl production (Department of Primary Industry and Fisheries, Queensland 2007).

3.1.2 Cook Islands

Black-lip oysters are currently farmed in Manihiki, Penrhyn (Tongareva) and Rakahanga atolls in the northern Cook Islands (Cook Islands Government, 2007). This species occurs naturally in the larger lagoons of Manihiki and Penrhyn, but was introduced into Rakahanga (Sims 1994). The physical features of Manihiki Atoll and its lagoon have been well documented, but relatively little is known about Penrhyn and Rakahanga atolls. The characteristics of various atolls in the Cook Islands are summarised in Table 1 and discussed below.

Manihiki is a small pear-shaped atoll with two large islets to the north-east and west and many small islets in the south (Wells and Jenkins 1988). The lagoon is about 5 km in diameter and has a maximum depth of 72 m. The lagoon has a raised outer rim, which permits only minor water exchanges between the lagoon and the surrounding oceans, except during significant wave events. The reef flats between the small islets surrounding the lagoon are generally less than 1 m deep (Sharma *et al.* 2001). The outer reef has a typical morphology with buttresses, surge channels and deep water close in (Bullivant 1974 in Wells and Jenkins 1988). The greatest development of coral is found at the south-east perimeter of the lagoon, where the waves wash over the reef. The pinnacles within the lagoon are composed of living and dead coral. The islets within the lagoon are surrounded by small fringing reefs. Ponia *et al.* (2000) estimated that the lagoon, land, coral and reef components of the atoll had surface areas of 48.0, 9.8, 5.0 and 1.1 km^2, respectively. They also estimated that 25.3 km^2 of the lagoon lay at depths of 10-30 m and could be used for pearl farming, but noted that only 7.7 km^2 of the lagoon was being used for this purpose in 1999.

Penrhyn, the second most important area for pearl production has the largest lagoon in the Cook Islands surrounded by reef and many islets and has three large passages at its northern end. The lagoon, land, coral and reef components of this atoll have surface areas of 208.0, 9.8, 15.0 and 1.1 km^2, respectively (Ponia 2000). Rakahanga Atoll is small, with a total surface area of 4.0 km^2. The lagoon is surrounded by coral reefs and has two main islets to the north and south and seven smaller islets between these (Wells and Jenkins 1988).

3.1.3 Fiji

The largest black pearl oyster farm is located in Savusavu Bay (Islands Business International 2007). There are other smaller farms on Savusavu, Taveuni, Nakobo, Mali

Island in Macuata and Galoa Island in Bua. The fisheries department has also received a proposal for a pearl farm to be loctaed in Vuna, Taveuni and is looking at expanding pearl farming to Lomaiviti, Kadavu and Vanuabalavu in Lau.

3.1.4 French Polynesia

The pearl farming industry in French Polynesia is now based on collection of wild spat, but was based originally on collection of wild stock from the lagoons of certain atolls. Black-lip pearl oysters are currently being farmed in 30 atolls and islands of the Tuamotu and Gambier archipelagos and some volcanic islands of the Société archipelago, French Polynesia (Langy 2006). These farms are located either in lagoons associated with atolls/pseudo-atolls (e.g. Takapoto, Takroa, Manihi, Rangiroa, Fakareva and Mangareva) or in areas adjacent to high islands (e.g. Vairoa and Tahaa-Raiatea).

The lagoons where black pearls are currently being produced differ markedly in total surface area, depth and degree of exchange with the ocean, with some having only a few active channels between the lagoon and the ocean, whereas others are largely open systems with large active channels (e.g. Rangiroa and Mangareva) (Pouvreau and Prasil 2001). Considerable information is available about the environment of Takapoto and Rangiroa lagoons, but relatively little is known about Fakareva, Mangareva and Takroa.

The best-known atoll, Takapoto (14°30′ S, 145°20′ W), is located in the northwest of the Tuamotu Archipelago. The lagoon is 18.7 km long and 4.4 km wide, has a mean depth of 23 m, a maximum depth of 55 m and a total area of 81.7 km^2 (Buestel *et al*. 1995). It is surrounded by an almost closed reef rim approximately 600 m wide which isolates it from the ocean, except for a few shallow (< 50 cm deep) channels, where there are weak currents (Sournia and Ricard, 1976 in Niquil *et al.* 2001). The annual temperature range in the lagoon normally varies from 26 °C in August to 30 °C in March, except during El Niño events when it may rise to 31.5 °C (Pouvreau *et al.* 2000a). Salinity varies from 38 to 42 ‰. The water is transparent and the compensation depth exceeds the maximum depth of the lagoon (Charpy et al., 1992 in Niquil *et al.* 2001). The lagoon is oligotrophic, primary production is primarily due to picoplankters and both the particulate inorganic and organic content of the water are low (Pouvreau *et al.* 2000a). The movement of water within the lagoon is driven mainly by the east–northeastern trade winds; there is no tidal current. The tidal amplitude is 40 cm (Wells and Jenkins 1988). The residence time of water in the lagoon is ca. 4 years.

In the lagoon, there are numerous subsurface pinnacles with a good cover of molluscs and corals (Pirazzoli and Montaggioni, 1984 in Niquil *et al.* 2001). The total volume of these pinnacles is estimated to be between 1.3 and 1.5 km^3 (Buestel *et al*. 1995). Three distinct bottom types have been identified in the lagoon: sandy, hard and mixed substrata, which consists of small coral structures (< 1 m in diameter) on a sandy bottom (Zanini and Salvat 2000). The 0-10 m depth stratum is characterised by sandy slopes and the tops of large coral formations. The percentage of sandy bottom, however, decreases with depth while the percentage of mixed sub-stratum increases. Small, mainly dead, coral structures comprise about 58% of the total surface area of the lagoon and provide an ideal habitat for the attachment of wild pearl oysters. These coral structures and pearl oysters are more abundant at depths of 30-40 m, suggesting that a good substratum for colonisation is probably a major factor determining the distribution of this mollusc.

Rangiroa is the second largest atoll in the world and has a perimeter of 225 km and a total surface area of 1640 km^2 (Wells and Jenkins 1988). The atoll has around 240 motu (narrow islands on atoll reefs), mostly in the northwest. The rest of the rim is sandy and more or less submerged. The lagoon varies in width from 4-30 km and has an average depth of 20 m and a maximum depth of 35 m. The lagoon contains coral pinnacles, sand banks, islets and shallows, but has a silty bottom and a narrow silty beach in the north. There are two relatively wide (450-550 m), deep (14 and 35 m) passes on the northern side, each of which has a patch reef at their entrance to the lagoon. There are also about 150 hoa (shallow channels separating individual narrow islands on atoll reefs), some of which are open to the lagoon but blocked from the ocean, others are closed to the lagoon but open to the ocean while others are totally isolated. The water within the lagoon is similar to the ocean due to the exchange that takes place through the passes and its large size. The reef flat has an algal ridge approximately 10- 20 m wide. The submerged reef flat consists of a calcareous platform studded with small colonies of coral. The abundance and diversity of corals is small within the lagoon, but increases where the slope drops off. Patches of coral are relatively abundant in the shallow areas in the southern part of the lagoon, where the water is less silty, but abundance declines with depth. The pinnacles have a wide coral rock platform on their sheltered sides, which is covered with sand, and scattered patches of coral and a sandy shelf with *Acropora* and encrusting algae on their exposed sides. The area around the base of the pinnacles is also sandy. A variety of scattered corals are found on the slope.

Fakareva is a rectangular atoll. The lagoon is 56 km x 24 km, has islets at its eastern end and two passes. Takaroa atoll is 28 km x 8 km and has one pass into the lagoon.

The volcanic islands Raiatea and Tahaa are surrounded by the same barrier reef. The lagoon is continuous except for two sections on the west coast. Mangareva is a high volcanic island with a 150 m wide fringing reef on the south coast, a 100-500 m wide, well-developed reef on the east coast and reefs in shallow water on gentle slopes on the north and west sides, mainly around headlands.

3.1.5 Solomon Islands

The establishment of black pearl farms using wild spat and/or hatchery production has been investigated (Friedman et al. 1996; Lane *et al*. 2003). A demonstration farm based on the collection and rearing of wild spat has been established at Nusatupe, near Ghizo. This site is situated in the mid-lagoon and is subject to moderate near channel flows (Friedman *et al.* 1998). No information was found about water depth, temperature, salinity or food sources at this location.

3.1.6 Vanuatu

A black pearl culture feasibility study has been conducted at Peskarus in the Maskelyn Islands, but trials were abandoned because there were insufficient stocks to support a commercial farm (SPC 2002). The potential for establishing black pearl farms has been investigated (Lane *et al*. 2003).

3.1.7 Conclusions

The most productive black pearl farms are located in sheltered lagoons associated with atolls in French Polynesia and the Cook Islands, where this species reaches its greatest natural abundance and wild spat for rearing are readily available. The feasibility of establishing farms based on collection and rearing of wild stock/spat has also been investigated in other coral reef habitats in Fiji, the Solomon Islands and Vanuatu. Several farms have subsequently been established in Fiji. Commercial farm operations based on the supply of juvenile pearl oysters from hatcheries have also recently been established in Western Australia. Information is available about the environmental conditions in the vicinity of some of the farms in French Polynesia and the Cook Islands, but not those in Fiji and

Australia. The paucity of information on environmental conditions prevailing in Solomon Islands relative to Cook Islands and French Polynesia precludes an assessment of whether conditions for pearl farming would be comparable.

3.2 Silver-White South Sea Pearl Farms

3.2.1 Australia

Silver-lip pearl oysters are currently being farmed in the northern part of Western Australia, Northern Territory, Queensland/Torres Strait Islands (Australian Aquatic Portal 2007).

The West Australian silver pearl industry is based primarily on the collection of wild oysters that are seeded with a nucleus under laboratory conditions on board ship, then placed in seabed panels which are turned regularly for two to three months before being transferred to pearl farms where they are grown on panels suspended from long lines for two years (Wells and Jernakoff 2006). Farms have been established along the Kimberley Coast, Canning Coast, Eighty Mile Beach, Pilbara Coast, Shark Bay Coast and Central West Coast (Department of Fisheries, Western Australia 1997). The geographic location of each of these regions their coastal characteristics, typical marine habitats, and location pearl farms within them is summarised in Table 2. The pearling industry is based in Broome (Department of Fisheries, Western Australia 2002).

In the Northern Territory, the production of silver pearls is based on oysters sourced from hatcheries or on wild harvested oysters from Western Australia (Department of Primary Industry, Fisheries and Mines, Northern Territory 2006). Active pearl farms are located in two main areas: Coburg Peninsula/Croker Island and the English Company Islands/Truant Islands. There are several other lease sites owned by licensees, but these are not currently being used for cultivation of pearls. The farm sites experience heavy rainfall during the rainy season which may reduce the salinity of the water to < 30 ‰ for two or more weeks. Such salinities may have an adverse effect on the growth rates of spat (Taylor *et al.* 2004). The associated runoff from shore, silt and other effluent may also influence coastal pearl culture sites (Taylor *et al.* 2004).

In Queensland, most of the silver-lip oyster shells used for pearl cultivation are obtained from hatchery-derived spat (Department of Primary Industry and Fisheries, Queensland 2007). Spat hatcheries have been established at Albany Island, Turtle Head, and Fitzroy Islands (Gemmological Association of Australia, 2005). Suitable-sized wild silver-lip pearl oysters collected by the East Coast Pearl Fishery are also translocated to aquaculture farms in Queensland and the Torres Strait for use in pearl production, but account for only a small amount of the live shells used for pearl production. There are pearl farms in several regions of the Torres Strait (i.e. near Albany, Friday, Roko, Prince of Wales and Saibai Islands), at three locations off the Great Barrier Reef (Arlington Reef, Double Island and Fitzroy Island) and in Hervey Bay, Southern Queensland.

3.2.2 Papua New Guinea

A commercial silver-lip pearl farm has been in operation on Samurai Island in Milne Bay since 1998 (SPC 2002). The pearl hatchery established at this location in 2002 has conducted two successful spawnings of black-lip and silver-lip oysters (National Fisheries Authority, Papua New Guinea 2005). A pearl farm has also been established on Ungan Island in New Ireland.

3.2.3 Cook Islands

In 1905, silver-lip oysters were introduced into the Cook Islands for culture, but this venture was discontinued after the area was hit by a cyclone (SPC 2002).

3.2.4 Conclusions

The geographic distribution range of silver-lip pearl oysters is more restricted than that of black-lip pearl oysters, hence commercial silver-lip pearl farms have been established only on the north coast of Australia and in Papua New Guinea. The silver pearl industries in Western Australia and Queensland are based primarily on the collection of wild oysters and hatchery-derived spat, respectively, whereas that in the Northern Territory is based on oysters sourced from hatcheries and wild oysters imported from Western Australia.

It is difficult to assess the suitability of Solomon Islands waters for silver-lip pearl farming, because of the general paucity of information on the coastal environment in this region and on environmental conditions prevailing in the vicinity of the Australian and Papuan farms. It is, however, worth noting that the coastal waters off the larger Solomon Islands and the northern part of Australia are subject to heavy rainfall accompanied by freshwater runoff laden with silt.

4.0 OVERVIEW OF CORAL REEF AND LAGOON HABITATS IN KEY PACIFIC REGIONS

4.1 Australia

The following overview of tropical Australian reef systems is based on Veron (2000). Sub-tropical coral reef systems have not been described, because they are not comparable to those in the South Pacific region. In the tropical region of Australia, the best-developed coral reefs are found along the northeast coast, there is less development of coral reefs along the northwest coast and only limited development along the north coast. On the north-east coast, the major reef structure is the Great Barrier Reef (GBR), which comprises about 3,000 fringing reefs, submerged reefs, platform and barrier reefs spanning the continental shelf of the Pacific coast of Queensland and merging in the north with the reefs of the Torres Strait and Papua New Guinea (Figure 1a). There are also scattered and remote reefs in the Coral Sea. The GBR extends from the tropics into the subtropics and has various regions which differ in terms of climate (wind patterns and rainfall), tidal regimes, water quality, bathymetry, island types, substrata and even geological histories.

Capricorn and Bunker reefs, in the southern section of the GBR, are characterised by well-defined, distinctly elevated platform reefs with entire, steeply sloping sides, moderately deep water between reefs and vegetated cays. The Pompey Complex and Swain Reefs, two of the most offshore extensions of this section of the GBR, have a greater range of habitats and more diverse corals than the Capricorn/Bunker Reefs. The Pompey Complex, consists of interlocking reefs, channels, sandbars and lagoons and has 'deltaic' reefs composed of solid limestone on its outer edge which are separated by U-shaped channels characterised by very strong, reversing, tidal currents. This complex experiences the greatest tidal range of the GBR and is a major barrier to tidal water movement. The Swain complex forms a southward pointing wedge. The reefs on both sides of the wedge have exposed outer faces and protected inner margins, but are ecologically dissimilar.

The central section of the GBR is characterised by lower reefs than the southern and northern sections, a lack of cays and well-defined outer barrier reefs. The coastal waters are relatively shallow, turbid, protected from strong wave action and subject to seasonal terrigenous inputs of silt, freshwater and organic nutrients when rivers are in flood. The fauna and flora of the inshore reefs and inter-reefal areas are conseqently very different from those occurring offshore.

In the northern section of the GBR, ribbon reefs are found where the GBR shelf meets the Queensland Trough. These ribbon reefs occur all the way along the shelf-edge break to Torres Strait (720 km). Those on the eastern side are exposed to ocean swells and drop steeply into the abyssal depths of the Queensland Trough. The band of water inside the ribbon reefs is largely devoid of reefs. The mid-shelf, however, supports extensive areas of reefs with roughly parallel east-west margins, that were cut in the past by rivers at low sea levels. The inner shelf contains a variety of reef types, high islands and coral cays, many of which are vegetated. In the far north, where the continental shelf widens, there are extensive shelf edge reefs and numerous nearshore reefs. In the Torres Strait, the outer barrier reefs are broken up into a series of delta-like formations similar to the reefs of the Pompey Complex, and an almost impenetrable line of 'dissected' reefs. Inside this barrier, there is a variety of reef complexes, high islands and cays. The sea gradually becomes more shallow and turbid towards the west, finally forming the Warrior Reefs, a series of enormous mud flats fringed in the east by coral.

Fringing reefs occur along the coastline of the Northern Territory. The shallow, turbid waters of the eastern Arafura Sea, however, are not conducive to growth of corals, hence most of these reefs are shallow. The development of reef increases to the west and reaches modest diversity in the vicinity of Essington Peninsula.

On the coast of Western Australia, there are substantial areas of coastal fringing reefs at Ningaloo Reef, in the Dampier and Monte Bello archipelagos and in the Kimberley region (Figure 1b). Ningaloo Reef is the largest fringing reef in Australia (230 km long). The reefs of the Dampier Archipelago, situated off the Pilbara coast are the best known reefs on the west coast. The marine environment in this archipelago ranged from muddy inshore to clear offshore waters, all mixed by strong tidal currents. The reefs of the Kimberley coast are poorly documented, probably because they are exposed to turbid waters and large tidal fluctuations. In the north-west, there are 'shelf-edge atolls', Scott Reef, Seringapatam Reef and Rowley Shoals, and an atoll-like structure consisting of a large sedimentary accumulation with reef patches, Ashmore Reef. The only true atoll in Australian waters is the Cocos (Keeling) Atoll in the eastern Indian Ocean. There are also coral reefs and areas of coral growing on rocky reefs in the Houtman Abrolhos Islands, 400 km north of Perth. The Houtman-Abrolhos Islands is a small archipelago of 122 low-lying islands situated near the edge of the continental shelf at latitudes of 28°15' to 29°00'S. Three of the islands are of continental origin and have extensive sand dunes, whereas the others are composed of limestone. The Abrolhos has the southernmost development of coral reefs in the Indian Ocean and is one of the highest latitude coral reef systems in the world.

4.2 Cook Islands

The Cook Islands are located between 8 ° and 23° S and 156° and 167°W and are divided into two disjunct groups: the Southern and Northern Cook Islands (Figure 2). The Islands of the Southern Group differ in form, structure and relief and include one high mountainous, volcanic island (Rarotonga), four low volcanic, raised islands surrounded by fossil reefs (Mangaia, Mauke, Mitiaro, and Atiu), a low lying elongated sand cay surrounded by coral reef (Takutea), two atolls (Manuae and Palmerston) and a near atoll with a volcanic core (Aitutaki). The volcanic islands are surrounded by fringing reefs. The Northern Group consists of five atolls (Suwarrow, Penrhyn, Manihiki, Rakahanga and Pukapuka) and one oval flat sand cay on a coral foundation (Nassau). A brief description of these islands based on the information in Wells and Jenkins (1988) is presented in Table 2.

4.3 Fiji

Fiji is one of the largest and most scattered groups of archipelagos in the South Pacific region, consisting of about 844 high islands, cays and islets, located between 15-23° S and 177-178° W (Vuki *et al.* 2000). The islands are divided into seven main groups: Rotuma, Vanua Levu and associated islands, the Lau Group, the Lomaiviti Group, the Yassawas, Viti Levu and associated islands and Kadavu and associated islands (Wells and Jenkins 1988) (Figure 3). The main archipelago accounts for 87% of the total land mass and includes the two largest islands, Viti Levu and Vanua Levu, and three other large islands, Taveuni, Kadavu and Gau. Most of the islands are volcanic and formed from molten rock that cooled and solidified below the surface of the earth.

Coral reefs are well developed and found around all the island groups. Many of the reef systems are complex, consisting of barrier, platform and patch reefs (Wells and Jenkins 1988). Coral reefs vary in size from patch reefs less than 50 m long, to the 100 km long Coral Coast fringing reef system on Viti Levu and the 370 km long broken barrier reef chain of the

Mamanucas/Yasawas/Great Sea Reef System (Vuki *et al.* 2000). Fringing reefs, the major type of coral reef, are found around most of the high islands and are distributed from the southern end of the Mamanuca Group almost to Beqa, south of Viti Levu (Wells and Jenkins 1988). Barrier reefs, the second major type of reef, are found at the edges of island shelves and are separated from the mainland by a fairly narrow, shallow lagoon channel in which the water is generally turbid and of low salinity at the surface. Oceanic ribbon reefs, another type of barrier reef, occur in association with lagoons or areas of sea with normal salinity. The Great Sea Reef, Beqa Barrier Reef, Great Astrolabe Reef and some of the barrier reefs in the Lau Group are oceanic ribbon reefs. Platform reefs are found only in shelf waters and are common inside the Great Sea Reef and within the Mabualau-Ovalau barrier reefs off eastern Viti Levu. There are only two shelf atolls: one in the Lau Group and the other to the east of Vanua Levu.

Coral reefs in Fiji have also been classified according to their position on the insular shelf (outer-, mid and inner shelf) and their exposure to the prevailing wind and seas (windward and leeward) (Zann and Vuki, 2000). Windward reefs are found on the eastern, south and southwestern sides of exposed islands. The outer margins of the fore reef wave terrace have spurs-and-grooves and there is often a large amount of coral debris on the upper reef slope and low coral cover. Barrier reefs have moderate coral cover and diverse assemblages of hard and soft corals. Leeward inner-shelf reefs are well protected and their slopes are generally composed of coral rock with a low coral cover. The reef tops consist of coral rock and rubble and slope into areas dominated by macroalgae and seagrasses.

4.4 French Polynesia

French Polynesia stretches across 2,500,000 km^2 of ocean from 134° 28′ W to 154° 40′ W and 7° 50′ S to 27° 36″ S. There is 3,430 km^2 of emergent land, 12,800 km^2 of reef formation totalling more than 2,000 km in length (Gabrié, 1998 in Salvat *et al.* 2000) and about 7,000 km^2 of lagoon (Wells and Jenkins 1988). French Polynesia consists of 118 islands distributed across five archipelagos: Society, Tuamotu, Gambier, Marquesas and Austral Islands, each of which is situated along a south-east to north-west axis (Salvat *et al.* 2000) (Figure 4). Eighty-four of the islands are atolls and most of the others are mountainous, volcanic islands.

Tuamotu, the largest archipelago, consists of 76 islands, 75 of which are low atolls, capping the tops of cones which rise steeply from a huge ridge (Wells and Jenkins 1988). The other island, Makatea is a raised atoll. The atolls vary in size (from a few to more than 1,000 km^2), their lagoons, if present, cover a few to 92 % of the total area of the atoll and range in depth from 2 to 60 m (Dufour 2001). The characteristics of the apertures in the atoll rim, the area and depth of the lagoon and position of gaps, natural channels and immersed coral ring with respect to the predominant currents affect the rate of renewal of water. The degree of connection between the lagoons and the surrounding ocean, as expressed by the ratio of the perimeter of passes + gaps + immersed crown to the perimeter of the atoll varies from 0.01 to 0.59. Forty-five atolls lack natural passages to the surrounding ocean, whereas 10 have several passages.

The Society Archipelago comprises nine high, volcanic islands and five atolls. Tahiti, the largest high volcanic island, has discontinuous fringing reefs with a chain of interrupted barrier reefs partially enclosing a lagoon. Moorea, the second largest high volcanic island, has a barrier reef with twelve passes enclosing a shallow (0.5-3.0 m) lagoon that is 500-1500 m wide. Deeper channels in the lagoon are orientated parallel to the coast and open into the passes. The small twin volcanic islands, Huahine Nui and Huahine Iti are surrounded by a narrow barrier reef which has five passes and raised terrace at its northern end. There is also a fringing reef around the islands, but it is mostly dead. The reefs found in association with Raiatea and Tahaa islands are described briefly in Section 3.1.4. Bora-Bora, one of the smaller high volcanic islands has a large, deep lagoon with one pass and a barrier reef with well-developed islands. Mehetia, the smallest high volcanic island lacks fringing reefs, but has colonies of coral on its submarine slopes. The atolls vary in size from 2.6 km^2 (Maupihaa) to 1288 ha (Tetiaroa) and either have islets on a barrier reef or around the lagoon. Tupai has a narrow shallow closed lagoon with numerous patches of coral and Maupiti has a shallow, partially reticulated lagoon.

The Gambier Islands and associated reefs cover an area of 35 km from north to south and 30 km from east to west (Wells and Jenkins 1988). Mangareva, Taravai, Aukena and Akamaru, the four principal islands are volcanic in origin and surrounded by a single barrier reef, which is continuous for 90 km. A large section (42%) of the reef crest in the north-west, north, east and south-west corner is emergent or very shallow. Elsewhere the depth drops to 15 m, however, there are no deep passes. There are about 25 motus on the reef, the southern sides of which are very exposed whereas the western sides are the most sheltered. The water in the three large bays (Gatavake, Kirimiro and Taku) is turbid, hence there is little coral growth. The large islands have narrow insular shelves on which there are fringing reefs. The outer slope of the reef is gentle to 25-30 m, but then drops steeply. The barrier reef is between 200 m and 1100 m wide, corals are rare on the external slope and disappear below 30-40 m. The coral fauna of the fringing reef is rather poor, but that of the lagoon is rich due to the numerous pinnacles that are present. The Gambier Lagoon is unusual in that it contains numerous soft coral assemblages.

The Marquesas, the most northerly islands in French Polynesia are divided into two groups, with that in the north-west consisting of three principal islands, several islets and banks and that to the south-east comprising four main islands, and several islets, rocks and banks. Most of the reefs in the Marquesas are poorly developed, consisting of small, fringing or patch reefs and occurring in shallow water in bays or along protected shores.

French Polynesia is located at the eastern end of the Indo-Pacific Province and has a relatively poor coral fauna due to the prevailing currents and winds, relatively low water temperatures and remoteness of the islands from continental masses (Wells and Jenkins 1988). The fringing and barrier reefs around high volcanic islands generally have a more diverse fauna than that of the low atolls. The fauna of the outer slope and rim of the atolls is less variable than that within the lagoons. This reflects the variation in depth and degree of exchange of lagoons with the open ocean. In open atolls, the coral fauna in the vicinity of passes is generally the most diverse. Open atolls also have a more diverse fauna than closed atolls. The coral fauna in closed or semi-enclosed lagoons is generally impoverished. The Tuamotu and Society archipelagos have large reefs and a variety of reef types, and a moderately high coral diversity.

4.5 Papua New Guinea

Papua New Guinea (PNG) encompasses the eastern half of the island of New Guinea, the islands in Milne Bay Province, the Bismarck Archipelago (New Britain, New Ireland, Manus Provinces and other smaller islands) plus Bougainville and Buka in the northern part of the Solomons Islands archipelago (Wells and Jenkins 1988) (Figure 5). The coastline is over 10, 000 km long and is estimated to support at least 40,000 km^2 of reef and associated shallow water habitats at in the 0-30 m depth range. The largest concentration of reefs is found in Milne Province and covers a total area of approximately 12, 870 km^2 (Dalzell and Wright 1986). These figures are likely to be underestimates because information on the extent and location of corals reefs in PNG is limited (Huber 1994). Over one half of the coastline and surrounding islands appear to be fronted by coral reefs (Quinn and Kojis 2000). All reef types are represented, but fringing and barrier reefs are the most common. The following description of reef and lagoon habitats is based on the information presented in Wells and Jenkins (1988).

The Western Province of the mainland is characterised by numerous patch reefs with extensive seagrass beds. There are two major embayments, Port Moresby Harbour and Bootless Inlet. The headlands between these bays are bordered by narrow (less than 100 m wide) fringing reefs. There are also large barrier reefs in the Port Moresby area. The coral assemblages on the steep leeward back-slopes of the barrier reefs and on the near vertical flanks of island fringing reefs facing deep channels and passes with strong currents are diverse and profuse. Bootless Bay has a diverse range of habitats including mainland and island fringing reefs, mangroves, seagrass beds, soft bottom assemblages, patch reefs and a well developed barrier reef (Maniwavie 2000). The Papuan Barrier Reef is situated about 5 km off the south coast and stretches for 563 km from just west of Port Moresby to the Louisiade Barrier at about 151° E. This reef has four major and numerous small channels. Near Port Moresby, it encloses a lagoon which has an opening in the north-west and there are fringing reefs and barrier reefs in the south-east, where the lagoon narrows.

On the northern side of the mainland, fringing reefs with large coral cover and species diversity occur between Condor Point in Madang Province and East Cape. There is also a fairly continuous fringing and barrier reef between Condor Point and Cape Ward Hunt in southern Morobe. The reef crest is this area lacks rubble and large boulders. The development of offshore shoal reefs is limited by the steeply-shelving seabed. The eastern coast south of Lae is fringed by reefs and there are numerous offshore islands within 50 km of the coast that have reefs. The islands in the Fly and Longuerue Groups are surrounded by fringing reefs which have a similar structure to those on the mainland. The growth of reefs within Huon Gulf is limited by sediment inputs from the Markham River. The coast between Cape Arkona and Finschhafen is lined by fringing reefs, except around river mouths. There is a small atoll, Tami, with three elevated limestone islets situated in the ocean approximately 10 km off Finschhafen. The lagoon is about 18 m deep, has a sandy bottom, but there is little coral growth below a depth of 10 m. The fringing reefs between Finschhafen and Madang are generally less than 100 m wide and lack a well-defined lagoon, except at some sites. There is a double barrier reef around and 10 km to the north of Madang inside which there are hundreds of small reef islands and depths down to 50 m. Hansa Bay, to the north of Madang, the site of the last major reefs south of the two largest rivers in PNG (Ramu and Sepik), has a discontinuous fringing reef. During the rainy season, the water within Hansa Bay is often reduced in salinity, muddy and rich in organic material discharged from the Ramu and Sepik rivers. In the dry season, the current comes from the south-east and brings clear water, short swell and strong waves to the reef. Laing Island, the only emergent portion of the north-south aligned reef within the bay, has a small (400 x 200 m) lagoon along its western shore and is surrounded by a well-developed fringing reef.

Milne Bay Province covers an area of approximately 265,000 km^2 and encompasses the extreme southeastern tip of mainland Papua New Guinea and the extensive offshore area immediately to the east. The province includes three major mainland districts: the 130-km long stretch of the south coast between Samarai and Orangerie Bay, Milne Bay proper, and Goodenough Bay, lying immediately northward, and the adjacent southeastern part of Collingwood Bay. The province also encompasses the Papuan Island Group to the east which comprises the Trobriand Islands and associated Lusancay Reefs, d'Entrecasteaux Islands, Muyua and the reefs and islands in the Louisiade Archipelago (Wells and Jenkins

1988). The entire area is characterised by an extensive and complex system of submerged and emergent coral reefs. This area includes the Trobriand-Normandy, East Cape-Nuakata Barrier and Sideia-Basilaki Barrier Reefs and Gallows reef which separates the first two barrier reefs. Over the past decade, two rapid marine biodiversity assessments have been undertaken in Milne Bay province(Werner and Allen 1998; Allen *et al. 2003*). The first assessment focused on Milne Bay proper, East Cape area, D'Entrecasteaux Islands, Engineer Group, Conflict Group, Nuakata region, and the southern tier of islands including Samarai, Sideia, and Basilaki. The second assessment focused on Goodenough and Collingwood bays on the mainland, the Amphlett Islands, D'Entrecasteaux Islands, Rossel Island, Sudest Island and Calvados Chain in the Louisiade Archipelago. The sites surveyed included outer reefs and passages, isolated platform reefs, fringing reefs and lagoons and patch reefs.

The North Louisdiade Barrier Reefs situated to the east of the Papuan Island Group comprise the Shortland Reefs, Engineer Reef, Esmerald Reef, Conflict Group and Torlesse Island, the Deboyne Group and Redlick Atoll. There are fringing reefs around many of these islands and numerous patch reefs. This area also includes several shelf atolls, barrier rim atolls, oceanic atolls and raised atolls and two major insular barrier reefs. The Calvados Barrier Reef is separated from the rest of the New Guinea Barrier system by narrow channels. The reef, which is 180 km long, 48 km in diameter and 500 km in circumference, is one of the largest atoll structures in the world. It is separated from the Sudest and Calvados Chain by a 8-32 km wide lagoon, which is 50-60 m deep away from patches reef and high islands. The barrier is more like a "ribbon reef" on its south-eastern and southern side and is submerged for 40 km in the south-west. Most of the passes in the barrier are relatively shallow (10-20 m depth), however, there are some passes over 50 m deep. The second major insular barrier reef, the Rossel Barrier Reef, is located 11-16 km to the east of Sudest. There are secondary barrier reefs on the north-west side of the Calvados Barrier and around some of the small isolated islands to the south-east of East Cape and fringing-barrier transition reefs in the Deboyne Islands, Misima and Muyua.

There are extensive reefs around Central, Bougainville, New Ireland and Manus Provinces, but only discontinuous reefs around New Britain and East and West Sepik.

4.6 Solomon Islands

The Solomon Islands archipelago is orientated south-east to north-west and located between latitudes 5-12° S and longitudes 152-170°E (Ramohia 2006). The archipelago consists of six major islands, 30 medium size islands and 886 smaller islands (Hughes 2006). The six main islands (Choiseul, Isabel, Malaita, Makira, Guadalcanal and New Georgia) are arranged in a double chain with the two strands separated by the New Georgia Sound and Indispensable Strait (Sulu *et al.* 2000)(Figure 6).

The first broad-scale survey of the geomorphology, composition and ecology of coral reef habitats in the Solomon Islands was undertaken in 1965 by The Royal Society of London (Stoddart 1969a-c, Morton 1974). During these studies, 36 fringing reefs distributed across the Florida and Russell Islands, Guadalcanal and New Georgia, in the southern Solomon Islands were examined. Morton (1974) noted that these reefs were generally associated with uplifted shores and that they were either attached to volcanic coastlines or grew seaward from elevated coral limestone benches. He distinguished four types of fringing reef:

- Broad fringing reefs, up to 500-600 m across, located in sheltered embayments;

- Sheltered reefs situated within and near the mouths of land-enclosed estuaries where run-off of freshwater and particulate matter from the land does not inhibit coral growth;
- Narrow fringing reefs less than 50 m across located on protected leeward coasts which are exposed to relatively light wave action; and
- Reefs on south-facing coasts, which are regularly exposed to wave action and surge generated by the prevailing onshore winds.

Morton (1974) considered that the sheltered reefs within land-enclosed waters were the most comparable in terms of exposure regime and coral composition to the reefs associated with atoll systems. The sheltered reefs studied were located at Honiara and Paruru Bay in Guadalcanal, Banika Island in the Russell Group and Marovo Lagoon, New Georgia.

The following description of the lagoon complexes in New Georgia is based on the description given in Wells and Jenkins (1988), which in turn was derived from Stoddart (1969c). Marovo, Gerasi and Togavai lagoons on the north-east coast and Roviana Lagoon on the south-west coast are enclosed by raised barrier reefs. The north-eastern lagoons form a shelf with a total surface area of 700 km^2. Marovo Lagoon, the largest system, is 35-55 km long and 500 m to 8 km wide. The main body of this lagoon is 25 m deep, but the bottom drops to 50-60 m in some of the inshore passages between the eastern barrier islands. Njae passage, for example, is about 40 m deep and the area of the lagoon to the west of this is 50-60 m deep, but the depth drops to 80 m at the entrance to the ocean. The maximum depth in the eastern part of the lagoon is 25-30 m, but the water is shallower on the east coast. The lagoon contains numerous sand cays, mangrove islets, raised reef islands and some small volcanic islands. The lagoon has three major habitats: sand cay complexes consisting of sand islets on patch reefs with a thin fringe of mangroves; estuarine complexes with shallow water, muddy bottoms, variable salinity and freshwater inputs rich in organic detritus; and barrier islands with markedly different environments on their ocean-facing and lagoon side reefs (Baines 1985 in Wells and Jenkins 1988). Coral reefs are found throughout the lagoon, but their growth is poor at the surface.

The partly submerged barrier reef that extends from the south to the north coast fringing reef on Guadalcanal encloses a 1000 km^2 area known as Marau Sound. The depth of water within the channel of the sound varies from 20-60 m and increases from west to east and towards the barrier entrances. The reef flats in the sound cover an area of 25 km^2 and were raised 0.6 m in 1961 by an earthquake. The flats on the barrier reef are up to 2 km wide, but have little living coral, probably because they dry out at low tide.

A recent report on the status of coral reefs in the Solomon Islands (Sulu *et al.* 2000), indicates that some of the largest areas of coral reef are found in association with large lagoon complexes and lists the following as significant areas:

- around the Shortland Islands near Bougainville;
- inside the barrier reefs along the northeastern shore of Choiseul;
- on either side of the Manning Strait between Choiseul and Santa IsabeI and along the southwestern shore of Santa Isabel;
- in the Ghizo–Vonavona lagoonal area on New Georgia's southern shore;
- encircling Vangunu in southeastern New Georgia and along the northeastern coast area past Ramata almost to Lever Harbour (Marovo Lagoon);
- in the north at Lau Lagoon and west at Langalanga Lagoon in Malaita;

- and in eastern Guadalcanal (Marau Sound).

Sulu *et al.* (2000) also described the other types of reef habitat found in the Solomon Islands. There are relatively small, submerged barrier reefs along the northeast coast of Choiseul, near Ghizo and near Munda in New Georgia, off Star Harbour in eastern Makira, northeast of the Russell Islands, across the entrance of Kangava Bay on the south coast of Rennell and around Utupua Island in the easterly Santa Cruz Islands. Barrier reefs in excess of 20 km in length are found westwards of the Reef Islands in the Santa Cruz Islands and at The Great Reef which is situated slightly further north. Atolls are relatively scarce. The largest, Ontong Java, is 70 km long and 11-36 km wide and has a wide reef flat enclosing a lagoon with a surface area of about 1400 km^2. In the Stewart Islands, about 200 km northeast of Malaita, there is a small triangular atoll, Sikaiana, about 10 km wide surrounded by a narrow coral reef which drops steeply to great depths. There are three raised atolls (Oema, Rennell and Bellona) in Bougainville Strait. There are also several mid-ocean reefs covered with coral, including Roncador and Bradley reefs to the south of Ontong Java, the Indispensable Reefs south of Rennell, and several small shoals north of the Santa Cruz Islands.

In 2004, a comprehensive scientific survey of the marine environment in the Solomon Islands was undertaken by The Nature Conservancy in collaboration with community, government, and non-government partners (Green *et al.* 2006). Benthic assemblages occurring at depths of 8-10 m were surveyed at 66 sheltered and exposed sites distributed across six regions (Hughes 2006). This study showed that coral cover declined from 47% in the west to 29% in the east and that the cover of coral was much greater in the Western, Isabel and Choiseul Provinces than in the Guadalcanal, Makira and Malaita and greater in exposed than sheltered locations in all of the regions, except Guadalcanal. The macroalgal cover and non-living cover were both poorest in the Western Province. The greatest macroalgal and non-living covers were found in the Malaita and Makira regions, respectively. Both the macroalgal and non-living cover were similar at the other locations.

4.7 Vanuatu

Vanuatu is an archipelago consisting of over 80 islands stretching across 1,300 kilometres in the Western Pacific Ocean (Figure 7). The islands are composed either of igneous formations or from limestone derived from uplifted fringing coral reefs (Preston, 1996 cited by Naviti and Aston 2000). There are relatively few extensive shallow water reefs surrounding the islands in the Vanuatu archipelago. Inner reef areas are limited to narrow fringing reefs and reef platforms surrounding islands and a few lagoons and barrier reefs, totalling an area of approximately 408 km^2 (Bell and Amos, 1993 cited by Naviti and Aston 2000). In 1988, a comprehensive survey of the condition and character of coral reefs and associated ecosystems was undertaken by scientists from the Australian Institute of Marine Science (AIMS) and the Great Barrier Reef Marine Park Authority at 35 locations throughout Vanuatu (Done & Navin, 1990). Exposed coral reef slopes and crests were found to be dominated by coralline algae and robust plating and branching corals (*Acropora* and *Pocilloporidae*), whereas areas 3-5 metres below the level of the reef flat were dominated by massive and branching corals. Sheltered parts of the outer reef were characterised by various species of *Acropora* and *Montipora.* Massive *Porites* were common in open embayments while sheltered embayments were strongly dominated by soft corals. Subsequent surveys have been conducted on an ad hoc basis, as part of the feasibility assessment of foreshore development projects and as a result of the establishment of a Marine Protected Area in Hogg Harbour (Naviti and Aston 2000).

4.8 Conclusions

The coral reef habitats in the Solomon Islands are similar to those found in association with other high Melanesian islands (i.e. Fiji, Papua New Guinea and Vanuatu) and off mainland Australia, but different from those found in the Cook Islands and French Polynesia. In Melanesia, the coral reefs generally either fringe the high islands or occur in shallow, sublittoral areas (Wells and Jenkins 1988). These reefs have a relatively 'open' structure and considerable exchange of water occurs through the numerous passages linking patch, fringing and barrier reefs with deeper water. On the north-east Australian coast, the major reef structure is the Great Barrier Reef, which comprises about 3,000 fringing reefs, submerged reefs, platform and barrier reefs. There are also substantial fringing reefs along the Northern Territory and West Australian coasts and 'shelf-edge atolls' and an atoll-like structure in the north-west. There are also coral reefs and areas of coral growing on rocky reefs in the Houtman Abrolhos Islands, 400 km north of Perth. In the Cook Islands and French Polynesia, atolls are the predominant coral reef habitat and it is in their 'enclosed' or 'semi-enclosed' lagoons that the majority of black pearl farms are located. This type of coral reef structure is scarce in the Central West Pacific region and there is only one true atoll in Australian waters, the Cocos (Keeling) Atoll in the eastern Indian Ocean.

5.0 THE EFFECT OF HABITAT ON CULTURE OF PEARL OYSTERS

5.1 Introduction

Pearl oyster farming may involve the following stages: production of larvae and spat in a hatchery, collection of wild spat on artificial collectors, grow-out of juveniles in intermediate grow-out systems, collection of juveniles or adults from wild populations, seeding and grow-out of juveniles and adults on dropper ropes or "chaplets" connected to submerged longlines (Lane *et al.* 2003). Production of larvae and spat in a hatchery and seeding of oysters are not discussed here, because they are laboratory-based operations that take place under controlled conditions. Existing information on the suitability of various coral reef and lagoon habitats for collection of wild spat, grow-out of juveniles and adults are summarised in the following sections.

5.2 Collection of Wild Spat

5.2.1 General

Collection of wild spat is most effective in areas in which there are sufficient numbers of adults in the surrounding waters to produce large numbers of larvae and in areas where competent larvae aggregate prior to settlement (Lane *et al*. 2003). The effectiveness of spat collection also depends on the type of spat collector, location, season and depth at which the collector is deployed (Gervis and Sims 1992). Spat collection is likely to be less effective in open lagoons or nearshore areas with high rates of water exchange, because larvae may be flushed away before they are competent to settle on collectors (Haws and Ellis 2000). In relatively enclosed lagoon systems, densities of spat are likely to be greater in areas away from passages and on the down-current side of patch reefs, where currents tend to form eddies. In enclosed lagoons, where water movements are driven by wind in a reverse circulation pattern, densities should also be higher on the down-current side (Sims 1992). In areas in which spat collection is ineffective, it may be possible to ship in spat from elsewhere. In 1997, a pearl farmer on Raiatea in the Society Archipelago, French Polynesia received an air shipment consisting of a 4-ton supply of juvenile oysters from Takaroa, Tuamotu Archipelago, (Tisdell and Poirine 2000). At present, culture of silver-lip oysters is not based on wild caught spat.

5.2.2 Black-lip Pearl Oysters

In French Polynesia and the Cook Islands, black pearl production is based on spat that settle on artificial collectors deployed in the lagoons of "enclosed" or "semi-enclosed" atolls, many of which have limited exchange of water with the open ocean. The period of deployment varies from 6 months in some parts of French Polynesia to up to two years in Manihiki Atoll in the Cook Islands, by which time animals have reached 65-90 mm dorsoventral measurement (Friedman and Southgate 1999). In these areas, spat are very abundant and although some may be lost to predators, there are usually enough survivors to stock pearl farms (Haws and Ellis 2000).

Friedman *et al. (*1998) examined the availability of wild spat in seven habitats across seven regions (Gela, Seghe, Noro, Gizo, South Malaita, Ysabel and Shortlands) of the Solomon Islands:

- inner lagoons with low water movement and periodic run-off from land masses;
- mid lagoon in shallow areas or close to reefs, where there was either low, some or moderate water movement;
- mid lagoon near channel flows, where there was moderate water movement;
- the outer edge of lagoons, near channel flows with moderate water flow; and
- outside barrier/fringing reef, near channel flows with moderate waterflows).

They showed that reasonable quantities of spat could be collected from some habitats within "open" reef systems, particularly from sites with clear water and moderate currents that were at least 35 m from the nearest reef. The inner lagoon habitats at Seghe, Noro, Gizo and South Malaita yielded the smallest numbers of spat, which is in contrast to the situation in Polynesia. Friedman *et al.* (1998) noted that these lagoonal sites differed from the atoll systems in Polynesia in that they were smaller, shallower, had soft rather than firm substrata, and were more turbid due to runoff of sediment and nutrients from their adjacent land masses. They suggested that collectors were less effective at these sites, because they became clogged with particulate matter and overgrown with epiphytic algae, particularly during the rainy season. Sites that were located near extensive reef systems with clear water, had moderate current flow, depths > 15 m and were at least 35 m from the nearest reef generally yielded the most spat, with the greatest numbers being collected at mid lagoon sites at Nusa Tupe, Gizo and an outside barrier/fringing reef site at Noro. Their study also showed that the collectors attracted predatory gastropods and crabs and that a large proportion (42%) of the oyster spat collected was dead. Friedman *et al.* (1998) concluded that there is potential for black-lip pearl cultivation in these "open" reef systems based on collection of wild spat, provided that the high rate of mortality can be reduced.

Friedman and Bell (1999) subsequently examined seasonal differences in the availability of spat in offshore and inshore zones of "open" reef systems in two contrasting geographic regions bordered by major landmasses, an embayed lagoonal system at Gizo and an enclosed sound at Noro. They predicted that more spat would be collected from offshore than inshore zones and that spatfall in the offshore zone would be similar in "wet" and "dry" seasons, but greater during the "dry" than in the "wet" season in the inshore zone.

In both seasons, significantly more spat were collected in the offshore zone than in the inshore zone at both locations (Friedman and Bell 1999). The offshore-inshore pattern of abundance could be due to environmental conditions suitable for the settlement of spat being less suitable inshore than offshore because of the greater influence of runoff from the land masses, greater flows offshore may result in more water and larvae coming into contact with the collectors, differential predation after settlement or differential supply of larvae between zones. Although the influence of these factors was not determined, Friedman and Bell (1999) concluded that differential predation after settlement was unlikely to be a major factor because the variation in abundance of living spat was similar to that for total number of spat. In the offshore zone, similar numbers of spat were collected at Gizo during both seasons, but at Noro significantly more spat were collected during the "dry" than the "wet" season. The seasonal decline in abundance of spat in the offshore zone at Noro may have been due to greater than average runoff resulting from cyclone activity being channelled through the sound further offshore than usual. At Gizo, the runoff is more likely to have been retained within the inshore lagoon. This suggests that heavy rains during cyclones may have a significant effect on the availability of spat.

5.2.3 Silver-lip Pearl Oysters

No information was found about the collection of wild silver-lip pearl oyster spat, probably because the industry is based on wild adult individuals of a particular size range or hatchery-derived spat.

5.3 Intermediate Grow-out of Juveniles

5.3.1 General

Juvenile pearl oysters originating from hatcheries or spat collectors are often placed in intermediate grow-out systems until they become a large enough (e.g. 50-60 mm shell length) for transfer to the main grow-out system. These systems are usually deployed in sheltered environments which provide protection from rough seas and adverse weather conditions. Bays, inlets, channels and lagoons with gentle tides and an area of land nearby for establishing a land base are considered suitable grow-out locations (Passfield 1989).

5.3.2 Black-lip Pearl Oysters

In the Solomon Islands, the use of intermediate grow-out systems is essential to reduce mortality caused by invertebrate and fish predators. The growth and survival of juveniles has been assessed in lantern nets suspended from longlines at depths of 3-4 m at nine shallow water sites throughout the Solomon Islands and at depths of 9-12 m and 35-45 m within an area of the Gizo Lagoon, which had numerous passages and submerged reefs linking it to the ocean and an average depth of 40 m (Friedman and Southgate 1999). Juveniles with initial DVM of 8.3-51.5 mm increased in size by 20.4-24.8 mm in three months and 30.7 to 36.5 mm in five months. These growth rates are comparable with those reported in Takapoto atoll, French Polynesia, where juveniles of 40-50 mm DVM grew 30 mm in six months (Coeroli *et al.* 1984), and are much better than in the Cook Islands, where hatchery produced juveniles with a DVM of 10 mm grew 6.4 mm in three months (Braley 1997). The survival of juveniles in lantern nets deployed in shallow water was poor due to predation by fish and invertebrates. Mortality due to reef-associated fish was reduced by moving the culture systems into deeper water. Friedman and Southgate (1999) pointed out that whilst the high nutrient load in the Solomon Island lagoons may have a positive effect on rate of growth, it also has an economic cost because it promotes algal fouling which needs to be removed regularly from the culture units.

The growth rates, survival and condition index of small black-lip pearl oysters over a 14 month period has also been compared in two contrasting environments within the Great Barrier Reef lagoon, a mainland bay (Bowling Green) and an area located adjacent to a fringing reef on the leeward side of Orpheus Island approximately 20 km offshore (Yukihira *et al.* 2006). The bay is subject to seasonal input of sediment from rivers and periodic re-suspension of fine material during strong winds, so the water is typically turbid and contains large amounts of SPM and POM. The water at the offshore location, in contrast, is relatively clear and characterised by small concentrations of SPM and POM, similar to those found within an oligotrophic French Polynesian lagoon (Takapoto). The temperature range within the bay (19.8 - 30.7 °C) is also slightly greater than that at the offshore location (21.5 - 29.6 °C). Small black-lip pearl oysters grew faster, suffered significantly less mortality and maintained a better condition at Orpheus Island than in Bowling Green Bay. This implies that the environmental conditions were more suitable for the growth of juveniles offshore than in the mainland bay.

5.3.3 Silver-lip Pearl Oysters

Yukihira *et al.* (2006) also compared the growth, survival and condition of small silver-lip pearl oysters cultured in two dissimilar environments in the Great Barrier Reef lagoon (see Section 5.3.2 for a brief description of these sites). These animals, in contrast to black-lip oysters, grew at similar rates at both sites and exhibited distinct seasonal differences with no or minimal growth occurring in winter. At the end of the study, there were no significant differences between sites in the condition of the oysters. The lack of difference in growth rates and condition between sites is surprising given the substantial differences in their SPM and POM concentrations. It suggests that there may be also be a difference in quality as well as quantity of POM between sites and that the food at the offshore location may have been of better quality than that in the bay. Small oysters failed to survive at both sites, with most of the mortality occurring in winter. The rate of mortality was slightly smaller in the mainland bay (50%) than offshore (60%). The seasonal difference in survival suggests that pearl farmers should not transfer spat from hatcheries or warmer environments to sites where the temperature drops below 25°C in winter (Yukihira *et al.* 2006).

No other information was found about the influence of habitat on grow-out of juvenile silver-lip pearl oysters, presumably because most of the industry is based on wild caught oysters of a target size (120-160 mm).

5.4 Ongrowing of Adult Pearl Oysters

5.4.1 Black-lip Pearl Oysters

In the Cook Islands, the growth of black-lip pearl oysters has been investigated at different sites within Manihiki Lagoon (Tauhunu, Paerangi and the Fishing Reserve), among lagoons (Rakahanga, Manihiki and Suwarrow), in different natural habitats (rock vs sandy bottom at two depths 15-17 m and 33-35 m) and under different culture conditions (platform and longline) (Sims 1994). The results, however, are difficult to interpret because of the experimental design. At Paerangi, growth on long-lines was faster than that on the platform with estimates for time to reach 120 mm DVM (T_{120}) being 1.2 and 1.4 years, respectively. The linear growth of oysters deployed on longlines and platforms was almost three times greater than those placed on rock bottom. At Tauhunu, linear growth rates of oysters in the 100-119 mm size class were twice as great on the platform as on rock, but no such difference was evident in the 120-139 mm size class. Linear growth of oysters in the 80-99 mm size range was faster on platforms at Paerangi than at Tauhunu. In Manihiki Lagoon, the estimated time to reach T_{120} ranged from 1.2 years on long-lines to over 6 years for oysters placed on natural substrata in deep water. Linear increments at depths of 15-17 m were twice as great as those at depths of 33-35 m. Growth rates also differed between substrata in deep water, with maximal length being significantly higher on rock than on sand and linear growth being slightly faster on rock, particularly in larger size classes. In mid-depths, there was no difference in growth between sand and rock trials. Growth on platforms in Manihiki was slightly faster than in Rakahanga. Growth of oysters on longlines was more than twice as fast in Manihiki (T_{120}=1.2) as in Suwarrow (T_{120} = 2.9). Differences in growth between sites in Manihiki were attributed to either differences in densities of oysters on platforms or site-specific factors such as currents and circulation patterns, or food availability, all of which are important to commercial farming.

In French Polynesia, the growth of cultured black-lip pearl oysters has been compared in three completely or almost closed atoll lagoons (Takapoto, Takaroa and Manihi), three largely open atoll lagoons (Rangiroa, Fakareva and Mangareva), in lagoons off two high islands (Raiatea-Tahaa and Vairao on Tahiti) and in the open ocean near Takapoto atoll, French Polynesia (Pouvreau and Prasil 2001). The growth rate of oysters more than two years old was significantly greater in island lagoons and ocean habitat than in atoll lagoons. The time oysters took to reach a size suitable for implantation of a nucleus (i.e. 100 mm) ranged from 21 to 26 months and was greater in atolls (25 months) than in islands or open ocean (22 months). The mean annual shell growth increment after this year, which is an indirect but reliable index of nacreous deposition rate on the pearl nucleus, was also greater in the islands and open ocean (26.1 mm y^{-1}) than the atolls (21.3 mm y^{-1}). Potential pearl farming performances were high in the island lagoons and ocean, moderate in Mangareva, Takaroa, Rangiroa and Manihi lagoons and low in Takapoto and Fakareva lagoons. Pouvreau and Prasil (2001) attributed the differences in growth rate to the negative effects of water temperatures close to or in excess of 30 ° C at Takapopto and Fangareva, differences in the degree of water renewal and food supply around the oysters. They also suggested that the POM content and hence potential availability of food in atoll and island lagoons may be responsible for some of the differences in growth between these habitats. The observation that pearl oysters cultured in the open ocean, an environment known to have lower POM concentrations than lagoons, had the maximal growth rate, however, appears to be at odds with this hypothesis.

Yukihira *et al.* (2006) also compared the growth, survival and condition of medium and large size black-lip pearl oysters at the two dissimilar environments within the Great Barrier Reef lagoon (see section 5.3.2 for a brief description of these sites). The growth rate and survival of both groups and condition of medium-sized animals were significantly smaller in the bay than offshore. All of the medium or large-sized oysters cultured at the offshore location survived. These results indicate the environmental conditions at Orpheus Island were more suitable than those in the mainland bay for this species.

5.4.2 Silver-lip Pearl Oysters

Yukihira *et al.* (2006) compared the growth, survival and condition of medium and large size silver-lip pearl oysters at the two dissimilar sites in the Great Barrier Reef lagoon (see Section 5.3.2 for a brief description of the sites). The growth rate of both groups of oysters was similar in the two environments. By the end of the study, they had also attained a similar condition in both environments. Seasonal differences in growth rate were confined to medium-sized animals and followed a similar pattern to that described for juveniles (see Section 5.3.3). All of the oysters survived.

6.0 CONCLUSIONS

6.1 Black-lip pearl oysters

Most of the existing black-pearl farms in the Cook Islands and French Polynesia are located in fairly deep, 'closed' or 'semi-enclosed' atoll lagoons, some of which contain natural black-lip pearl oyster populations. The limited exchange of water between these systems and the open ocean results in the retention of pelagic larvae produced by the broodstock and facilitates the collection of wild spat. These lagoons are typically oligotrophic and have low turbidity levels (Pouvreau *et al.* 1999). Black-lip pearl oysters appear to compensate for the low food concentrations by having a high clearance rate, retaining a wide size range of food particles and, in some circumstances, feeding selectively on certain components of the phytoplankton (Pouvreau *et al.* 1999b; Loret *et al.* 2000a).

This species is also found throughout Melanesia and off the north Australian coast, where more 'open' coral reef habitats predominate. In these systems, there is much greater exchange of water with surrounding habitats than in atoll lagoons. Spat are consequently less likely to be retained within 'open' systems. Despite this, it is clearly feasible to collect wild spat from 'open' reef habitats in the Solomon Islands, particularly from sites with clear water, moderate currents that are at least 35 m away from the nearest reef (Friedman *et al.* 1998). Surprisingly, collectors deployed in lagoons within barrier reefs, the reef habitat most comparable to atoll lagoons in terms of enclosure, yielded the fewest spat. The low yield appeared to be due to collectors becoming clogged with sediment or overgrown by algae during the rainy season, when there is considerable runoff from the adjacent land mass. The lack of a suitable hard substratum within the barrier reef lagoon may also have contributed to the low spat yields.

Friedman and Southgate (1999) have shown that the growth rate of juvenile black-lip pearl oysters cultured in the 'open' reef systems of the Solomon Islands compares favourably with that observed in some of the atolls in French Polynesia and the Cook Islands. They suggest that the high nutrient load in the Solomon Island lagoons, resulting from runoff during the rainy season, may have contributed to the good growth rates.

In north-east Australia, black-lip oysters grown in a sheltered mainland bay took 14 months longer to reach a size appropriate for the first pearl nucleus implantation than those grown offshore of a fringing reef site located 20km offshore (Yukihira *et al.* 2006). The poorer performance of oysters in the mainland bay was attributed to the adverse effects of high concentrations of SPM and POM, derived from the seasonal input of sediment from rivers and periodic re-suspension of fine material deposited on the bottom by waves during strong winds, on the species energetic processes. The poor performance of black-lip pearl oysters under turbid conditions suggests that commercial culture may be less viable in this type of environment.

6.2 Silver-lip pearl oysters

Silver-lip pearl oysters are often cultured in near-shore areas subject to large fluctuations in salinity and high inputs of terrigenous sediment and nutrients during seasonal rainfall events. Reductions in salinity to levels as low as 25 ‰ during the rainy season has an adverse effect on growth rate and results in detachment of juveniles, but has no effect on survival of spat (Taylor *et al*. 1997 and 2004). This suggests that hatchery-reared spat should not be transferred to these environments during the rainy season. The poorer survival and minimal growth of juveniles in winter suggests also that pearl farmers should not transfer spat from hatcheries when temperatures at grow-out locations drop below 25°C (Yukihira *et al*. 2006) No information was found about the effects of reduced salinities on the larger oysters used by some sectors of the Australian silver pearl industry. The use of large oysters, however, probably avoids the potential problem of minimal growth in winter.

Information about the environmental conditions prevailing at silver-lip pearl oyster farms is scarce. The experimental studies on the growth, survival and condition of silver-lip pearl oysters undertaken in two environments in the Great Barrier Reef lagoon differing in terms of SPM and POM concentrations indicate that the growth rate and final condition of oysters cultured in the mainland bay was not significantly different from that at the offshore location (Yukihira *et al*. 2006). This implies that silver-lip pearl oysters are physiologically adapted to a wide range of food concentrations and that they could potentially be cultured in a variety of habitats, including areas of the Solomon Islands that are subject to high rainfall and inputs of terrigenous sediments.

6.3 Overall Conclusions

Although black-lip and silver-lip pearl oyster farming are lucrative industries, there is a surprising lack of basic information on the influence of environmental factors on their biology and ecology and on environmental conditions at existing farms and their influence on culture practices. Information on coral reef habitats within some of the specified regions of the Pacific Ocean is also lacking. This lack of information hinders assessments about the suitability of available habitats for growing pearl oysters in the Solomon Islands relative to those in the other Pacific regions. Despite this, it is clear from the literature sourced that, from an environmental perspective, there is potential for farming of both black-lip and silver-lip pearl oysters to take place in the Solomon Islands. The turbid waters adjacent to the leeward side of the mountainous islands are likely to be more favourable for farming silver-lip than black-lip pearl oysters.

8.0 ACKNOWLEDGEMENTS

This report was written by Dr Theresa Dye and reviewed by Dr Marcus Lincoln Smith.

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TABLES

Table 1. Type, total area and characteristics of the coral reef and lagoon habitats associated with each of the Cook Islands.

Table 2. Geographic location of each of the aquaculture regions in Western Australia, their coastal characteristics, typical marine habitats, and location of pearl farms.

Table 1. Type, total area and characteristics of the coral reef and lagoon habitats associated with each of the Cook Islands (Wells 1998).

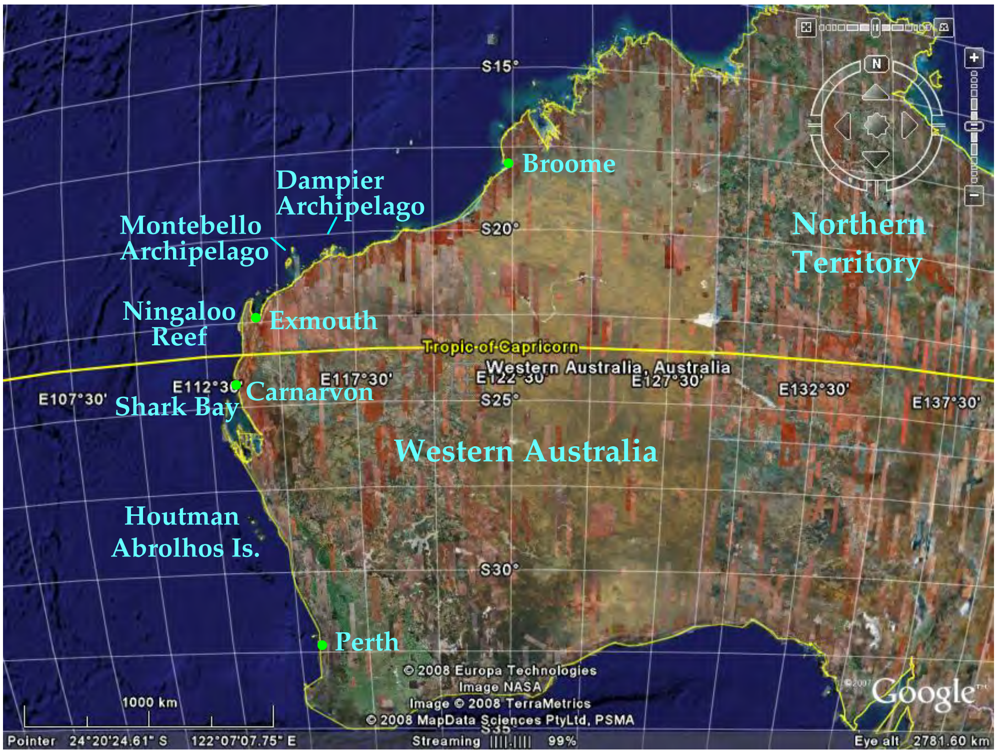
Island	Type	Area (km^2)	Characteristics of Reefs and Lagoons
Manihiki	Atoll	5.2	Outer reef has buttresses, surge channels and deep water nearby. Corals are best-developed at the south-east end of the lagoon, where waves wash over the reef. Lagoon is about 5 km in diameter and has a maximum depth of 72 m. Two large islets in north-east and west and many small islets at southern end of lagoon.
Penrhyn	Atoll	9.8	Many islets
Rakahanga	Atoll	4.0	Small lagoon surrounded by reef with two main islets to north and south and seven smaller islets in between them.
Rarotonga	High, volcanic	67.0	Fringing reefs are 400-800, 100-200m and 50-100m wide on the south, west and north and east coast, respectively. Reef edge is almost continuous. Reef flats are shallow and covered with sand. Algal ridge is present on the reef.
Mangaia	Low, volcanic uplifted	71.0	Fringing reef with narrow living reef flat, steep outer reef slope that levels off to a wide terrace at a depth of 30-40 m depth
Mauke	Low, volcanic, raised	18.4	Surrounded completely by a 50-100m wide reef flat dominated by hard reef rock pavement. Outer reef slopes gently to depths of 8-15 m, and then steeply to 80 m, with few shelves.
Mitiaro	Low, volcanic	22.3	Fringing reef with narrow living reef flat
Atiu	Moderate, volcanic, raised	28.2	Fringing reef with narrow living reef flat, except on the north side where there is no reef flat.
Takutea	Low, lying elongated sand cay	1.3	Surrounded by reef
Manuae	Atoll with two flat coral sand islets.	22.0	Shallow closed lagoon surrounded by continuous reef with a single narrow boat passage
Palmerston	Atoll	2.6	Elongated lagoon with eight islets surrounded by reef
Aitutaki	Triangular volcanic cone forming an almost atoll	106.0	Large (66 km^2), shallow (75% < 4.5 m deep) lagoon. Triangular barrier reef, 600-1700 m wide. Steep outer edge on south and east sides and intermediate slope on west side. Small patches of reef in south and south-west of lagoon.
Suwarrow	Atoll with a near continuous rim and 22 islets		Atoll is surrounded by a well developed algal ridge and 100-800 m wide reef flat. Patch reefs < 100 m diameter occur in the central lagoon and small patch reefs around its western edge. Lagoon has 10 km diameter, maximum depth of 80 m and covers 133 km^2. A wide, 10 m deep pass in the north-east allows good exchange of water.
Pukapuka	Triangular atoll with three islets at the apices and several sand banks.		Atoll is surrounded by a closed reef, except for an artificial passge at NW end. Lagoon is 8 km x 3-5 km and ranges in depth from 10-50 m.
Nassua	Oval, flat sand cay		Narrow reef flat

Table 2. Geographic location of each of the aquaculture regions in Western Australia, their coastal characteristics, typical marine habitats, and location of pearl farms

Aquaculture Region	Coastal Characteristics	Coastal/Marine Habitats	Location of Pearl Farms
Kimberley Coast - Northern Territory border to Cape Leveque on the Dampier Peninsula	Macro-tidal, low wave energy, subject to seasonal cyclones and large inputs of fluvial sediments during the wet season.	Nearshore areas are characterized by numerous mangrove forests, wide tidal flats and turbid waters. Coastal fringing reefs occur on hard substrata. Numerous mid-shelf and shelf edge islands, banks and reefs, many built on platform coral reefs.	Silver-lip oysters farmed in King Sound, Doubtful Bay and Kuri Bay
Canning Coast - Cape Leveque to Cape Missiessy	Very large tidal range, moderate to low wave energy and little fluvial inputs.	Long sandy beaches in deeply-indented bays flanked by rocky headlands, reefs and sand flats with large mud flats and mangroves at their heads. One group of offshore islands (Lacepedes)	Carnot Bay, Pender Bay, Roebuck Bay and Lacepede Islands
Eighty Mile Beach - Cape Missiessy to Cape Keraudrin	Very large tidal range and moderate wave energy.	Sandy beach sloping to wide, muddy tidal sand flats. Mangroves in small bays.	Oysters cultured onlonglines or in baskets at some sites off Eighty Mile Beach
Pilbara Coast - Cape Keraudrin to North-West Cape	Moderate tidal ranges, low wave energy, influenced by cyclones, periodic run-off and strong tidal flows.	Coastal deltas, barrier islands and lagoons with extensive mangroves backed by wide, supra-tidal flats. Shoreline has long beaches and muddy tidal flats. Numerous islands and coral reefs on Rowley Shelf.	Exmouth Gulf, Dampier Archipelago, off Port Hedland, Dampier and Montebello Islands.
Shark Bay Coast - Point Quobba to Kalbarri. Bernier, Dorre and Dirk Hartog Islands consititute the seaward boundary.	Eastern shore of the bay experiences low wave energy. Leeward and windward side of the islands are exposed to moderate and strong wave action, respectively.	Large marine embayment with world's largest seagrass meadow, small coral reefs, sheltered sandy beaches and low limestone cliffs. Eastern shore has mangroves and wide tidal flats. Southern part of the bay is hypersaline.	Silver-lip oyster hatchery at Oyster Creek, Carnarvon. Black-lip oysters are cultured within Shark Bay.
Central West Coast - Kalbarri to Perth including Abrolhos Islands	Coast experiences high wave energy, relatively small tides and limited freshwater run-off.	Long sandy beaches with limestone cliffs and headlands, sheltered by extensive offshore limestone reef systems with large algae and seagrass beds inshore. Abrolhos Islands have coral platforms and reefs.	Black-lip oysters are cultured in the Abrolhos Islands

FIGURES

(a) Western Australia



(b) Queensland

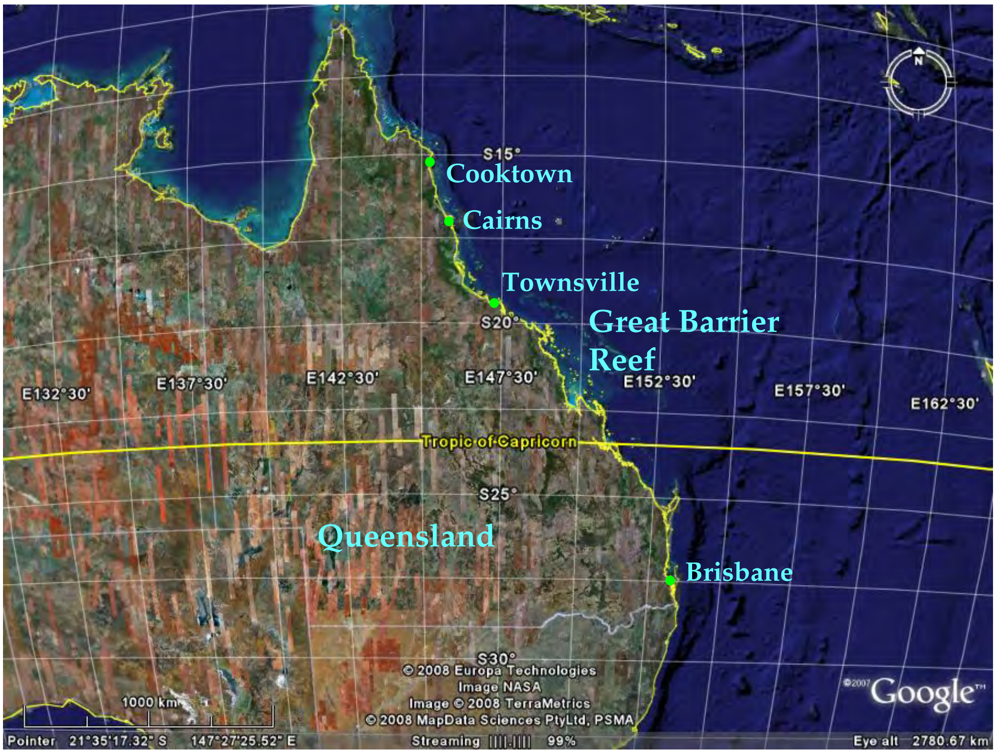
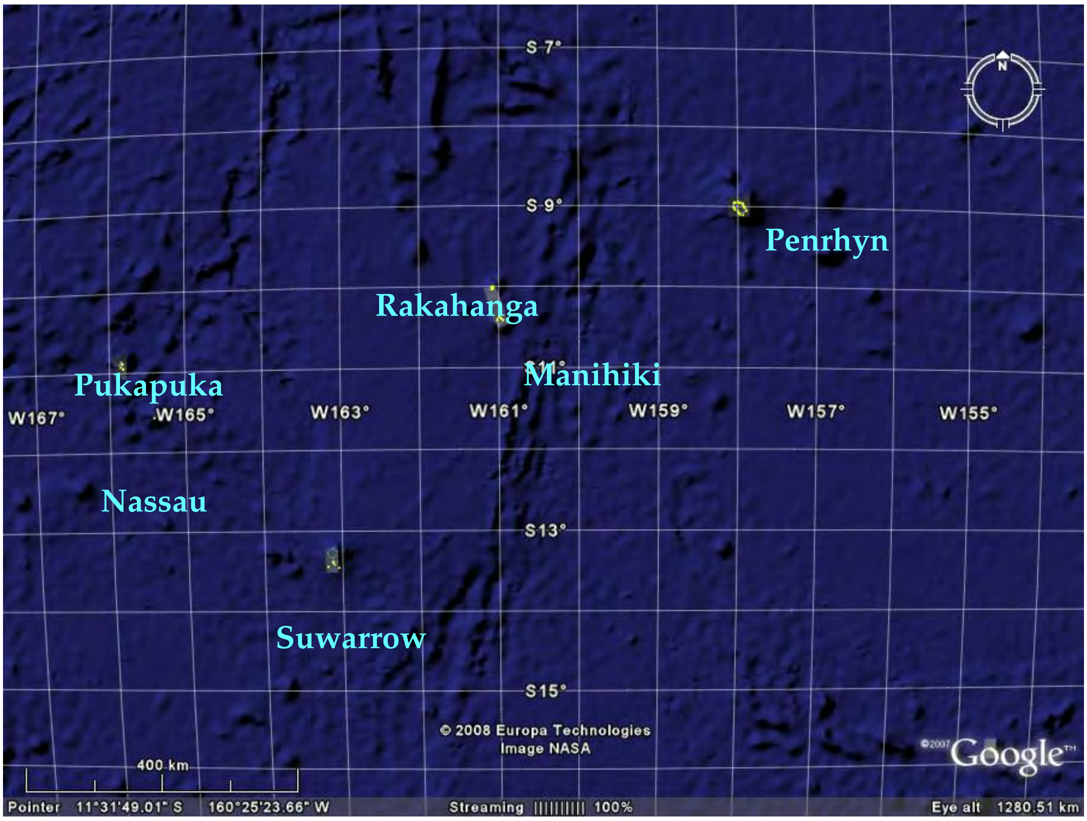


Figure 1: Google earth image showing the location of the major coral reef systems in (a) Queensland and (b) Western Australia.

(a) Northern Cook Islands



(b) Southern Cook Islands

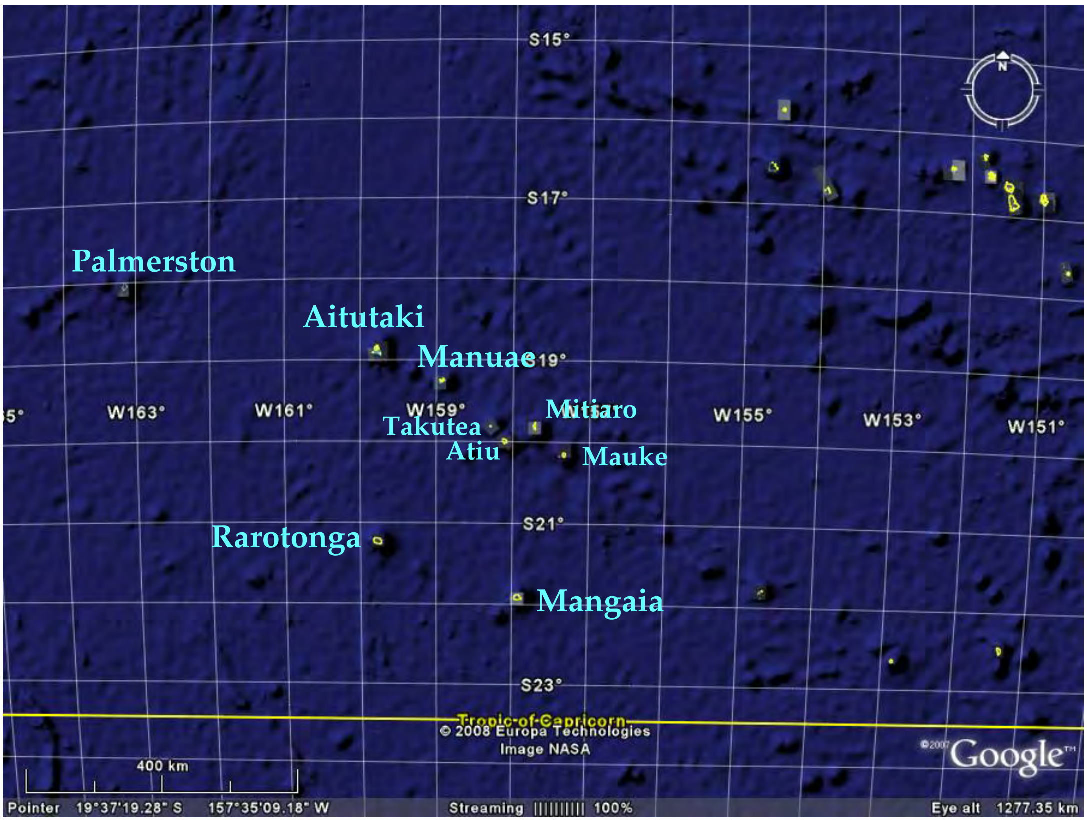


Figure 2: Google earth image showing the relative position of the islands in (a) the northern and (b) the southern Cook Islands.

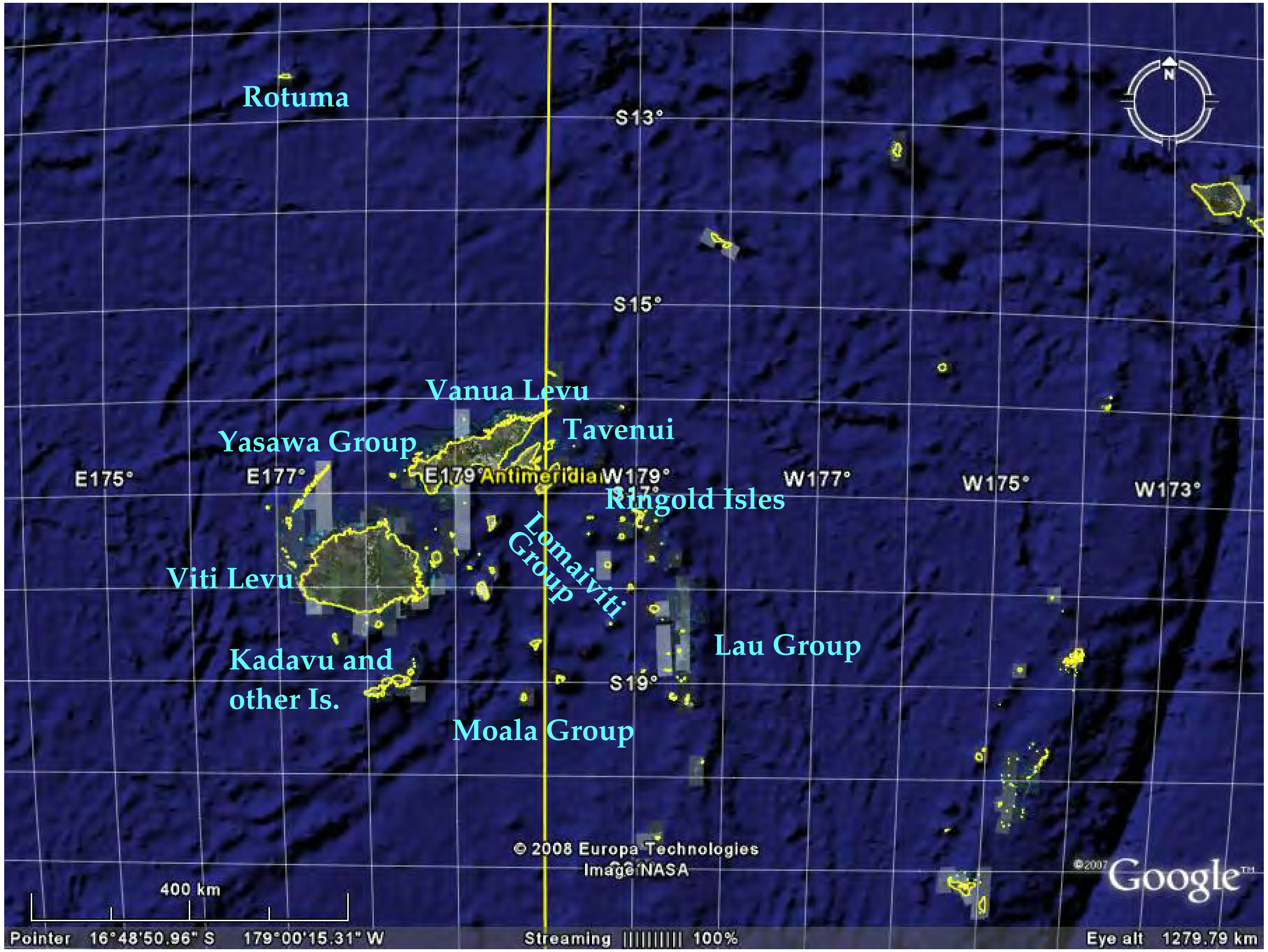
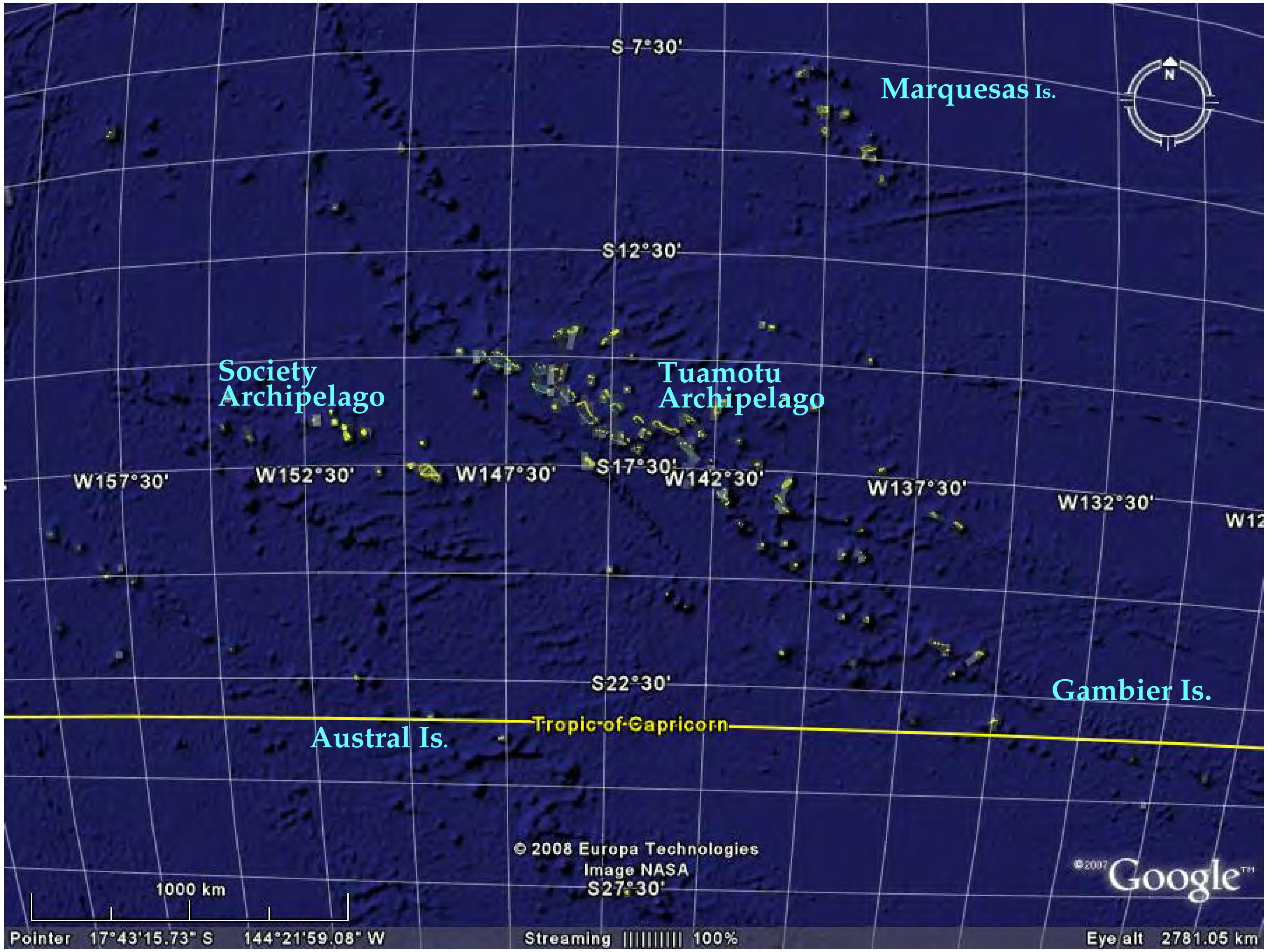


Figure 3: Google earth image showing the relative position of the major groups of Fijian islands. .



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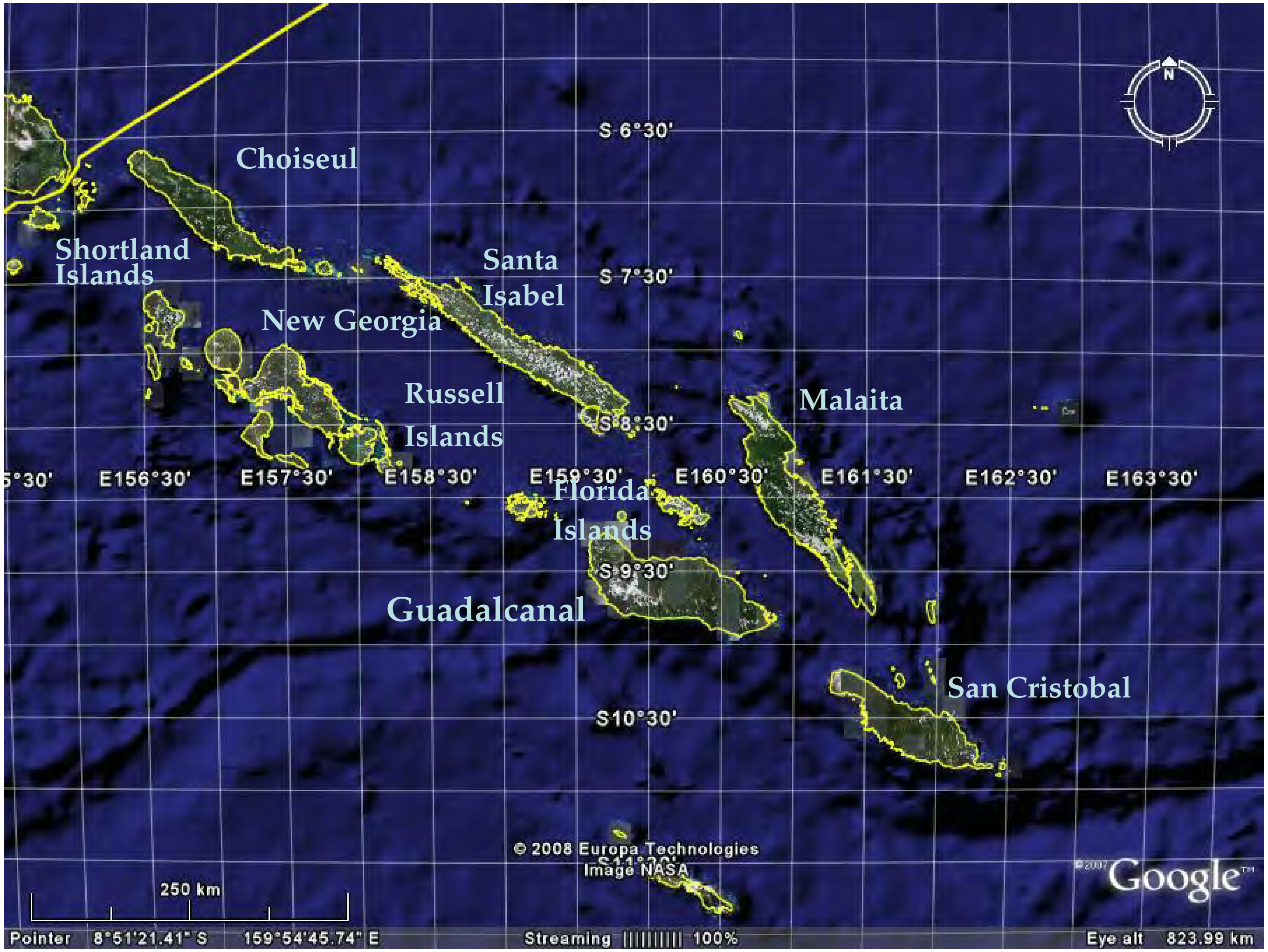

Figure 6: Google earth image showing the relative position of the major and some of the medium-sized islands in the Solomons Island Archipelago

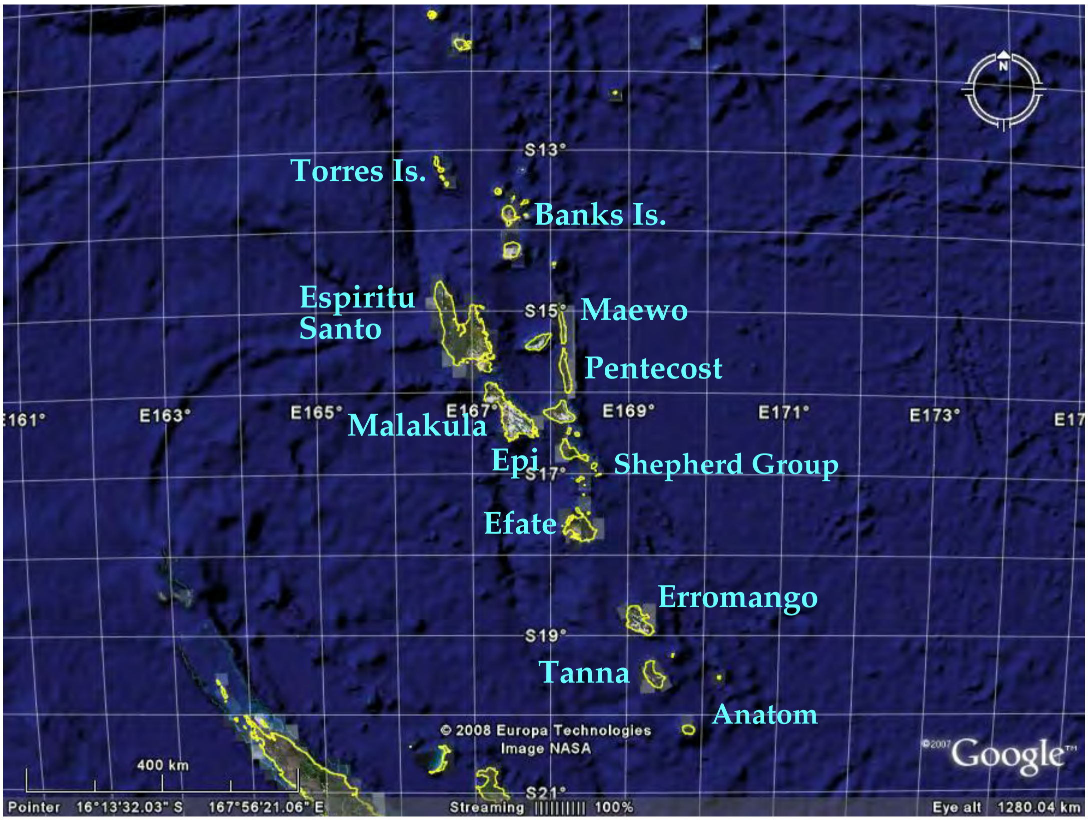

Figure 7: Google earth image showing the relative position of the major and medium-sized islands in the Vanuatu archipelago.

Report to:

World Fish Center

Water Temperature and Cyclone Frequency in the Solomon Islands and other Key Regions of the Pacific: Implications for Pearl Farming

FINAL

June 2008

The Ecology Lab Pty Ltd

Marine and Freshwater Studies

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June 2008

Report Prepared for:

World Fish Center

Jalan Batu Maung

Batu Maung,

11960 Bayan Lepas,

Penang,

Malaysia

Report Prepared by:

The Ecology Lab Pty Ltd

4 Green Street

Brookvale, NSW, 2100

Phone: (02) 9907 4440

Report Number – 55/0607C

Report Status – Final 5 June 2008

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SUMMARY

Introduction

The European Union has funded a project entitled 'Stimulating investment in pearl farming in the Solomon Islands'. The objective of this project is to provide offshore pearl companies with sufficient information to determine the potential for long-term investment in pearl farming in the Solomon Islands. The World Fish Center sub-contracted The Ecology Lab Pty Ltd to prepare a report on water temperatures and cyclone frequencies, in terms of advantages and disadvantages for pearl farming in the Solomon Islands relative to French Polynesia, Cook Islands, Australia, Fiji, Vanuatu and Papua New Guinea.

Knowledge of sea temperature ranges at various locations would be advantageous to offshore pearl companies, because temperature influences the rate of deposition of nacre on oyster shells and implanted nuclei as well as the reproductive development, spawning activity, survival, recruitment, growth, condition of cultured stocks and their susceptibility to disease. Knowledge of regional differences in cyclone activity would also be useful, because the accompanying heavy rainfall, high winds and storm surges can damage pearl farms and associated infrastructure.

Sea Temperature

Little is known about the temperature requirements of black-lip and silver-lip oysters. The only information that is available indicates that the optimum temperature ranges of black-lip (*Pinctada margaritifera*) and silver-lip (*Pinctada maxima*) pearl oysters on the north-east coast of Australia are 23 – 28 °C and 23 – 32 °C, respectively. This implies that silver-lip pearl oysters may be better suited to culture in tropical latitudes than black-lip pearl oysters. These ranges may not be applicable to other parts of the species geographic ranges, particularly if their responses to temperature vary with latitude.

Sea temperature is traditionally measured *in situ* by either dipping a thermometer into a bucket of water drawn from the sea surface, or using electrical temperature probes deployed in the intake port of large ships or on either fixed or drifting buoys. Sea surface temperature (SST) measurements are also derived from sensors on board polar-orbiting satellites that record the amount of visible and infrared radiation reflected and/or emitted from the Earth's surface. These instruments take thousands of measurements of broad swaths of the Earth each day and/or night, resulting in concurrent data sets of the entire planet. Several different SST data products have been derived from satellite-based sensors, depending on the type of sensor used and the type and version of the algorithms used to process the data. The products also vary in terms of the time span covered and their spatial resolution on the ground. Records from temperature probes, SEAFRAME gauges and satellite-borne sensors could all be used to identify potential farm locations with suitable prevailing temperature regimes. Products with fine–scale spatial resolution, however, are likely to be most relevant to prospective pearl farmers.

In situ sea temperature measurements taken by probes deployed for lengthy periods at an appropriate depth were obtained from locations in the Cook Islands and French Polynesia, where there are extensive black-lip pearl farms, and from locations in Western Australia adjacent to areas with silver-lip pearl farms. Temperatures measured in the Cook Island lagoons ranged from ca 28 – 31 °C, whereas those in the French Polynesian lagoons ranged from ca 26 – 31 °C and 21 – 29 °C, depending on latitude, and those off high islands varied from 25 – 30 °C. In other parts of the world, black-lip pearls oysters are cultured at temperatures ranging from 17 – 30 °C (Japan) and 21 – 34 °C (Sudan). The mean monthly

temperature records for silver-lip pearl oyster farms in Western Australia ranged from ca 19 – 30 °C, 21 – 31 °C and 25 – 32 °C. This implies that black pearl farms are either located in areas where the water temperature is outside the optimum temperature range or that the optimum ranges of this species in other countries differs markedly from that in north-east Australia. Some of the Western Australian silver-lip pearl farms are located in areas where the minimum water temperature is below the lower limit of the optimum temperature range or where the maximum water temperature is close to the upper limit of the optimum range. If global warming causes a 0.4-1.0^{o} C increase in the sea temperature off the north-west coast of Australia as is predicted, temperatures at some farm locations could exceed the optimal temperature range of silver-lip oysters.

Temperature probes have also been deployed at several other locations in northern Australia and Fiji and from one location in Papua New Guinea. The long-term data set obtained from a probe deployed at one particular location in Fiji indicates that there is considerable inter-annual variability in SST. This suggests that time series data would probably be more useful than average monthly SST estimates, for gauging prevailing temperature regimes.

The sea-level fine resolution acoustic measuring (SEAFRAME) gauges installed at single locations in the Cook Islands, Fiji, Papua New Guinea, Solomon Islands and Vanuatu in the early 1990s provide contemporaneous records of SST. These indicate that the temperature range off Papua New Guinea (4.8 °C) and the Solomon Islands (5.4 °C) is narrower than that off the Cook Islands, Fiji and Vanuatu (8.2-8.5 °C). The records also show that mean water temperatures off Papua New Guinea and the Solomon Islands were about 2° C cooler than normal during the 1997/1998 El Niño event.

SST measurements derived from sensors carried on board polar-orbiting satellites were also examined. Comparable SST data for locations in the regions of interest were obtained from the Modern Average Global SST Dataset produced by the US Geological Survey. These data were derived from weekly measurements taken by an Advanced Very High Resolution Radiometer sensor over the period October 1981 to December 1990. More recent monthly SST climatology data were obtained for locations around Australia by using the surface temperature search tool maintained by the Australian Department of Defence. Time series data for five locations on the north-east coast of Australia were obtained from the SST web atlas for the Great Barrier Reef region produced by the Australian Institute of Marine Science and CRC Reef Research Centre. Time series for five locations in Australia and two locations in the South Pacific were also obtained from the National Oceanic and Atmospheric Administration's Coral Reef Watch Program.

The limited information that is available on sea temperatures in Solomon Islands indicates that the prevailing regimes are similar to those in some areas of the Cook Islands and French Polynesia, where there are productive black-lip pearl farms. Similar temperature regimes also prevail in some areas of Vanuatu, Fiji and Papua New Guinea. The fact that the temperature of the water at locations in the Solomon Islands and Papua New Guinea regularly exceeds 29 °C in summer, however, implies that these regions may be more suitable for culturing silver-lip than black-lip pearl oysters. The temperature regimes at most of the locations in Fiji and Vanuatu, in contrast, appear to be suitable for culturing both species of pearl oysters, but silver-lip pearl oysters do not occur naturally in these waters. On the basis of our current knowledge, it is not possible to say whether the sea temperature regime in Solomon Islands would be more advantageous for pearl farming than that in the other South Pacific nations considered.

Cyclone Activity

Tropical cyclones are non-frontal low pressure systems characterised by sustained gale force winds in excess of 63 km/h and wind gusts greater than 90 km/h near their centre and that persist for at least six hours. They vary in intensity, life cycle, pattern of movement, size and impact. Their activity and intensity also varies within seasons, between years, decades and over multi-decadal timescales. In the Australian/Southwest Pacific basin, tropical cyclones generally occur between late October/early November and early May and peak in late February/early March. The total number of tropical cyclones per year varies markedly, with two events being recorded in this basin in 1981 and 16 in 1971. The annual variation in cyclone numbers has been linked with local sea surface temperature before and at the start of the cyclone season and the El Niño-Southern Oscillation (ENSO) phenomenon.

The frequency of tropical cyclones also varies spatially. Between 1970/1971 and 2003/2004, the South Pacific region experienced 8.6 cyclones on average per season, 4.1 of which were severe and 1.7 intense, whereas the Australian region experienced 12.8 cyclones per season, 6.3 of which were severe and 2.5 intense. The South Pacific region was also exposed to tropical cyclones and severe cyclones for fewer days on average than the Australian region. The frequency of cyclones also varies across the South Pacific, with the greatest number on average occurring around Vanuatu, followed in turn by Fiji, the Cook Islands, French Polynesia and the Solomon Islands. Cyclones rarely hit Papua New Guinea. In Australia, tropical cyclones are more frequent in the northwest, between Exmouth Gulf and Broome, and in northeast Queensland, between Port Douglas and Maryborough. In widespread nations, such as French Polynesia, the risk of cyclones varies across the archipelagos. During El Niño years, there is a marked shift in the regional pattern of cyclone risk, with activity being greater than on average in the vicinity of Vanuatu, Fiji, the Cook Islands and French Polynesia, of similar incidence in the Solomon Islands, but less frequent off the north Australian coast. During La Niña years, cyclones are more common than on average in the vicinity of Vanuatu, New Caledonia and the South Coral Sea, but not evident beyond longitude 150° W. Whilst cyclones are clearly less frequent in Solomon Islands than in most pearl farming areas, it is not possible, on the basis of our current knowledge, to determine whether pearl farming would be more advantageous in Solomon Islands than in other South Pacific nations.

The occurrence and intensity of tropical cyclones may change with global warming. In Australia, there is expected to be a decrease in total number of tropical cyclones per year, but an increase in the proportion of the more intense categories of cyclones. Cyclones that hit the east coast are expected to persist longer than at present. In the South Pacific, there is expected to be little change in cyclone frequency, but an increase in their intensity and lifespan. Tropical cyclones are also expected to spread further east and track further south than at present.

The gale force winds accompanying cyclones can cause extensive property damage, turn airborne debris into missiles and generate rough seas. The heavy rainfall that occurs as the cyclone passes over can cause extensive flooding, which, in turn, can result in extensive damage. The storm surge that accompanies some tropical cyclones is another potentially destructive phenomenon, particularly if it coincides with high tide.

The impact of tropical cyclones on the physical environment depends on their frequency, intensity, speed of movement, longevity, size and proximity to land. The physical features of the landscape also influence their response to the geomorphic and hydrological processes triggered by cyclones. Low-lying coral islands, such as the atolls of Cooks Islands and French Polynesia, are prone to overtopping by storm surge and wave action generated by cyclones. On the high islands of Fiji, Papua New Guinea, Solomon Islands and Vanuatu, the major impacts are landslides on hills and deposition of sediment in valley bottoms resulting from heavy cyclonic rainfall.

Tropical cyclones within the Australian region have caused the loss and stranding of pearling boats, demolishment of pearling camps and numerous deaths. The accompanying heavy rainfall, high winds and storm surges have also caused widespread movement of pearl oysters and equipment on experimental lines and commercial oyster farms, damaged benthic habitats, caused fluctuations in the availability of wild stock and reduced the landings of the pearl oyster fishery in Exmouth Gulf. In 2000, damage to pearling facilities and loss of eight boats in the vicinity of Broome resulting from a tropical cyclone was estimated to have cost the industry A$6 million. A tropical cyclone that hit the Cook Islands in 1997caused the loss of harvested pearls and equipment, damaged above-water infrastructure and villages, resulted in the loss of 19 lives, but caused only limited damage to underwater farming operations. The reduction in number and total area of pearl farms in Manihiki Atoll that occurred between 1996 and 1999 has been linked with the impact of this cyclone. In 1983, French Polynesia was hit by five cyclones; the attendant 4-5 m rise in sea level and 8-10 m high waves destroyed boats, fishing equipment and pearl aquaculture rafts and submerged many villages on the atolls.

General Conclusions

In the South Pacific region, the identification of potential culture sites for black-lip and silver-lip pearl oysters is hindered by the lack of information on latitudinal differences in their optimum temperature ranges and the lack of easily-accessible information on prevailing sea temperatures. Whilst sea temperature and cyclone frequency are important, they are only two of a range of environmental factors that could influence production of pearl oysters. The identification of potential culture sites should also be based on a sound knowledge of fluctuations in other environmental parameters, particularly food and silt levels, plus an appreciation of the vulnerability of different areas to earthquakes, tsunamis, sea-level rise, volcanic eruptions and large-scale pollution events. As a number of variables operating over spatial scales ranging from regional to site-specific determine the suitability of a location for pearl farming, it is impossible, given our current state of knowledge, to say whether any one variable confers a significant advantage or disadvantage for a particular location.

Due cconsideration should also be given to ways of avoiding or minimizing damage to pearl farms. The development of better advance cyclone warning systems could enable farmers to move longlines into deeper water and bring portable equipment ashore before weather and sea conditions deteriorate. It may also be possible to cyclone proof sub-surface farm infrastructure by using better attachments or "bunching up" longlines on the lagoon floor to reduce impacts from surges.

1.0 INTRODUCTION

The European Union has recently funded a project entitled 'Stimulating investment in pearl farming in Solomon Islands'. The primary objective of this project is to provide offshore pearl companies with sufficient information to determine the potential for long-term investment in pearl farming in the Solomon Islands. Information on the following aspects is currently being compiled for this project:

- Publications on the availability and culture of black-lip (*Pinctada margaritifera*) pearl oysters in the Solomon Islands;
- Availability and quality of silver-lip (*Pinctada maxima*) pearl oyster resources in the Solomon Islands;
- Availability of suitable habitats and environmental conditions for the growth of black-lip and silver-lip pearl oysters in the Solomon Islands and pearl-producing regions of the South Pacific;
- The investment climate in the Solomon Islands;
- Policy guidelines for the development of environmentally and financially sustainable pearl farming in the Solomon Islands; and
- Offshore pearl companies most likely to consider investing in pearl farming in the Solomon Islands.

In February 2007, The World Fish Center commissioned The Ecology Lab Pty Ltd to provide a number of consultancy services for the EU project, including preparation of the following report on water temperatures and cyclone frequencies, in terms of advantages and disadvantages for pearl farming in the Solomon Islands with other locations in the Pacific, specifically French Polynesia, Cook Islands, Australia, Fiji, Vanuata and Papua New Guinea. The search for information from Australian waters has been limited to areas in which black-lip and silver-lip pearl oysters occur. This area extends from Champion Bay (29° S) in Western Australia across the northern coast of Australia to Moreton Bay (28° S) in southern Queensland in the case of black-lip pearl oysters and from 25° S on the west coast across the northern coast to 20° S on the east coast for silver-lip oysters (Hynd 1955; Gervis and Sims 1992).

Knowledge of sea temperature ranges at various locations would be advantageous to offshore pearl companies, because temperature influences the rate of deposition of nacre on oyster shells and implanted nuclei (Cahn 1949; Watabe 1952; Alagarswami 1975 in Gervis and Sims 1992), as well as reproductive development, spawning activity, survival, recruitment, growth, condition and health of cultured stocks (Gervis and Sims 1992; Department of Fisheries, Western Australia 2002; Pass *et al.* 1987). Knowledge of regional differences in cyclone activity is also important, because the various phenomena associated with cyclones can damage pearl farms and associated infrastructure. They should also be aware of the potential impacts global warming may have on sea temperatures and tropical cyclone activity.

2.0 SEA TEMPERATURES

2.1 Introduction

Black-lip pearl oysters occur across a wide latitudinal and longitudinal range, having been recorded in the Indian and Pacific Oceans, eastern Mediterranean and Ryukyu Archipelago (Gervis and Sims 1992). Silver-lip pearl oysters are restricted in their geographic distribution to tropical waters in the central Indo-Pacific region. The different geographic distributions of these species suggest that their optimum temperature ranges are also likely to differ markedly. The only available information about the optimum temperature ranges of black-lip and silver-lip pearl oysters comes from studies done off the Great Barrier Reef on the north-east coast of Australia (Doroudi *et al* 1999; Yukihira *et. al*. 2000). The optimal temperature ranges reported in these studies may not be applicable throughout the species geographic ranges, particularly if the responses of black-lip and silver-lip pearl oysters to temperature vary with latitude.

Doroudi *et al.* (1999) noted that normal development of black-lip oyster embryos occurred only between 25 °C and 30 °C, that growth of larvae was optimal between 26 °C and 29 °C and that temperatures greater than 35 °C were lethal for larvae. Survival of larvae was greatest, but growth was slow, close to 20 °C, the lowest temperature examined.

Yukihira *et al.* (2000) found that the clearance rate, absorption efficiency, amount of energy absorbed, respiration rate, excretion and hence Scope for Growth (i.e. energy available to sexually mature animals for growth and reproduction) of black-lip and silver-lip pearl oysters were much lower at 19 °C than between 23 °C and 32 °C. The clearance rate and amount of energy absorbed by black-lip oysters declined between 28 °C and 32 °C, but that of silver-lip oysters remained fairly constant. The increase in absorption efficiency of black-lip pearl oysters was less marked that of silver-lip pearl oysters between 19 °C and 32 °C. The respiration rate of black-lip pearl oysters increased markedly between 28 °C and 32 °C, whereas that of silver-lip pearl oysters only increased slightly over this range. Black-lip oysters excreted less energy than silver-lip oysters over this temperature range. High temperatures had a marked effect on the rate of ammonia excretion in both species. The Scope for Growth of black-lip pearl oysters was adversely affected by both low (19 °C) and high (32 °C) temperatures, whereas that of silver-lip oysters was affected mostly by low temperatures. On the basis of these results, Yukihira *et al.* (2000) concluded that the optimal temperature ranges for black-lip and silver-lip oysters were 23-28 °C and 23-32 °C, respectively. This implies that silver-lip pearl oysters may be better suited to culture in tropical latitudes, such as Solomon Islands, than black-lip pearl oysters or in shallow areas where temperatures are more variable.

2.2 Measurement of Sea Surface Temperature

The temperature of the sea surface (SST) can be measured *in situ* by either dipping a thermometer into a bucket of water drawn manually from the sea surface, measuring the temperature of water in the intake port of large ships or using electrical temperature probes deployed at a specific depth on fixed or drifting buoys (Reddy 2001). The most exact and repeatable measurements come from fixed buoys equipped with robust electrical temperature probes located at a particular depth (e.g. 1 m) below the water surface (NOAA Coastal Services Centre undated). *In situ* temperature measurements have two major shortcomings: the spatial coverage of the data is limited and there may be considerable variation in measurement error from one observation to the next, depending on the methods employed (Metoffice UK, undated). Measurements taken from the intake of ships, for example, are not consistent, because the depth of the water intake and where the temperature is measured vary from vessel to vessel.

An alternative remote method of SST measurement based on data collected by infra-red radiometers on board satellites has been in operation since 1978. One of the principal instruments used to measure SST from space is the Advanced Very High Resolution Radiometer (AVHRR) carried on board the polar-orbiting satellites operated by the National Oceanic and Atmospheric Agency (NOAA) (NASA Oceanography 2005). The AVHRR has an array of five small sensors that record the amount of visible and infrared radiation reflected and/or emitted from the Earth's surface. This instrument takes thousands of measurements of broad swaths of Earth each day and night, resulting in concurrent data sets of the entire planet (National Atlas of the United States 2007). Two other satellite-borne sensors, the Moderate-Resolution Imaging Spectroradiometer (MODIS) and Advanced Microwave Scanning Radiometer for EOS (AMSR-E) are also commonly used to measure SST (NASA Oceanography 2005). MODIS, like AVHRR, uses a radiometer to measure the thermal infrared radiation given off by the surface of the ocean, but is sensitive to five different wavelengths of radiation and can therefore provide more detailed SST measurements than AVHHR (NASA Oceanography 2005). The MODIS sensor has a viewing swath width of 2,330 km and scans the entire surface of Earth every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385 µm and acquire data at three spatial resolutions: 250 m, 500 m, and 1,000 m (NASA Jet Propulsion Laboratory 2007). AMSR-E is a passive microwave radiometer that measures radiation from the ocean surface. The measurements derived from satellite-borne sensors are corrected for the effects of atmospheric water vapour which reduce the strength of the signal emitted and are calibrated and quality controlled against SST data collected from ships and drifting buoys, which are co-located in both space and time.

Satellite-borne sensors provide SST data over much large spatial scales than traditional methodologies, but there are a number of problems associated with their use. First, infra-red sensors take radiation measurements from the top "skin" of the ocean, a layer less than 0.1 mm thick, rather than bulk SSTs (Metoffice UK, undated). The temperature of the "skin" is usually lower than the bulk SST, because of the loss of radiant and latent heat through evaporation and mixing. The "skin" temperature also varies during the day, because of diurnal solar heating at the sea surface. This problem can be overcome by restricting data to night-time measurements. Long-term trends in SST derived from AVHRR and MODIS sensors also tend to have a "fair weather" bias, because these instruments cannot see through cloud cover (NASA Oceanography 2005). SST data may consequently be sparse in some seasons or in some regions of the world. The AMSR-E sensor, however, is able to measure radiation from the ocean surface through most types of cloud cover. Various algorithms have been developed to correct for signal attenuation by atmospheric effects.

Despite these limitations, a number of SST data products have been derived from satellite-based sensors, including near real-time images, contour charts, analysed fields, SST anomalies, maps of coral bleaching hot spots and charts showing degree heating weeks, an indicator of the accumulation of thermal stress that coral reefs have experienced over the past 12 weeks. The products that are available depend on the type of sensor used and the type and version of the algorithms used to process the data. They also vary in terms of the time span covered and their spatial resolution on the ground. SST data derived from the NASA MODIS sensors on board the Terra and Aqua satellites, for example, are available from February 2000 and from July 2002 to present, respectively. The data from both satellites are available at four temporal scales (daily, 8 - day, monthly and annual) and two spatial scales (4.63 and 9.26 km) (NASA Jet Propulsion Laboratory 2007). SST data derived from AVHRR Pathfinder version 4.0 are available from 1985 to July 2003 at three temporal scales (daily, 8 - day, monthly) and three spatial scales (9 km, 18 km and 54 km), while that from AVHRR pathfinder version 5.0 are available from 1985 to 2006 at six temporal (daily, 5-day, 7–day, 8-day, monthly and annually) and one spatial scale (4 km). The maximum resolution of the SST products derived from AVHRRs , for example, varies from 1.1 km (Composite) to 9 km (Pathfinder) and 18 km (MCSST). AMSR-E has a coarser resolution than the thermal infrared sensors. Fine resolution data products are more relevant to pearl farming ventures, because the SSTs of waters immediately overlying coral reefs are usually somewhat higher than the SSTs observed offshore by satellite-borne sensors (Strong *et al.* 1996).

2.3 *In-Situ* SST Measurements from Key Regions of the South Pacific and Australia

2.3.1 Black Pearl Farms

2.3.1.1 Cook Islands

In November 2003, The Ministry of Marine Resources assisted by the South Pacific Applied Geoscience Commission (SOPAC) installed oceanographic monitoring buoys which automatically record a variety of parameters, including SST, at hourly intervals within Manihiki and Penrhyn lagoons. The data recorded were retrieved daily with an uplink via satellite phone, automatically updated on the SOPAC web page, downloaded from the web page and disseminated to pearl farmers on a weekly basis through the Ministry of Marine Resources (McKenzie 2004). The objective of this monitoring was to provide farmers with an early warning system of environmental conditions that may cause disease outbreaks in pearl oysters, so that they could adjust their farming practices. The mean monthly sea temperature over the period the buoys were deployed (November 2003 to January 2005) varied from 28.3 °C (August 2004) to 30.6 °C (December 2004) at Manihiki and from 28.6 °C (July 2004) to 30.1 °C (December 2004) at Penrhyn (Figure 1).

2.3.1.2 French Polynesia

A probe deployed within Takapoto Lagoon (14°63′ S, 145° 21′ W) between July 1990 and September 1991 indicated that the mean water temperature varied from 26.5 - 30.5 °C (Buestel *et al.* 1995). The annual cycle was divided into four distinct periods: a relatively cold period between July and September characterized by temperatures between 26.5 °C and 27.5 °C, a warm period between December and April with temperatures between 29.5 °C and 30.5 °C and two periods of rapid change in October-November and May to June. Measurements taken on calm days during summer (January to March 1991) indicated that there was a 0.7 °C variation in mean water temperature between 06h00 and 14h00. A subsequent study in Takapoto Lagoon, involving the deployment of a multi-parameter probe over the period March 1997 to April 1998, indicated that the temperature varied from 26 °C (August) to 31 °C (March) (Pouvreau *et al.* 2000a).
Similar temperature ranges have been recorded in Takaroa, Manihi, Rangiroa and Fakareva lagoons, but the temperature of the water around the high islands of Tahiti and Tahaa-Raiatea situated further south is slightly cooler, varying from 25.3 - 29.5 °C and 25.5 - 29.7

°C, respectively (Pouvreau and Prasil 2001). The water temperature in Mangareva Lagoon, situated even further south and to the east (23° 10′S, 134° 95′W), varies from 21.3 - 28.8 °C (Pouvreau and Prasil 2001). During El Niño years, the water temperature in Takapoto Lagoon may reach 31.5 °C (Pouvreau *et al.* 2000b). In November 1985, vertical temperature profiles were measured over a 3 day period in Rangiroa Lagoon (Rougerie 1985). These indicated that the temperature of the water down to a depth of 30 m was similar to that at the surface.

In other parts of the world, black-lip pearl oysters are cultured in water with much more variable temperature regimes. For example, at culture sites at Dongonab Bay, Sudan and Kabira Bay, Japan temperatures range from 21 – 34 °C and 17 – 30 °C, respectively (Reed 1966; Sugiyama and Tomori 1988).

The temperature ranges reported above suggest that black pearl farms are either located in areas where the water temperature is outside the optimum temperature range or that the optimum ranges in other countries differs markedly from that in north-east Australia.

2.3.2 Silver Pearl Farms

CSIRO Marine Research (2003) has compiled coastal ocean temperature statistics for various locations off the West Australian coast, including two silver-lip pearl oyster farms located in Roebuck Bay near Broome (18° 2′ S) and Whalebone Island in Exmouth Gulf (22° 11′ S), respectively. The mean monthly sea temperature varied from 21.4 °C (July) to 30.9 °C (January) in Roebuck Bay and from 19.5 °C (August) to 29.7 °C (February) in Exmouth Gulf (Figure 2a). These data are based on measurements taken over different study periods and at different depths (1992 to 1998 near the seabed in 12 m of water in Roebuck Bay versus 1994 to 1998 and 1 m above the seabed in about 6 m of water at Whalebone Island) and are not therefore directly comparable. The water temperature at a silver-lip pearl farm in Kuri Bay, Western Australia ranged from 25-32 °C (Pass *et al.* 1987).

The temperature ranges reported above suggest that some Western Australian silver pearl farms are located in areas where the minimum water temperature is below the lower limit of the optimum temperature range and that some are situated in areas where the maximum water temperature is close to the upper limit of the optimum range.

2.3.3 Other Locations

2.3.3.1 Northern Australia

CSIRO Marine Research (2003) has also compiled coastal ocean temperature statistics for three other locations off the North West Australian coast. The mean sea temperature ranges for these locations are depicted in Figure 2b and are as follows:

- Barrow Island (20° 48′ S) - 21.6 °C in August to 29.0 °C in March, with temperatures at a depth of 15 m similar to those on the surface;
- Osprey Bay at Ningaloo Reef (22° 14′S) - 22.2 °C in August to 27.1 °C in March at a depth of about 5 m.;
- Entrance to Shark Bay (26° 8′S) - 20.9 °C in October to 23.8 °C in March/April).

It should be noted that the temperatures at the entrance to Shark Bay are unlikely to be representative of the Bay itself, because of the influence of strong tidal flows (CSIRO Marine Research 2003).

The annual sea temperature range has also been recorded in outer (37 m depth) and inner (11 m depth) waters of the Dampier Archipelago, North Western Australia. These records indicate that the annual range for these waters is approximately 22–30 ºC and 20–30 ºC, respectively, and that minimum and maximum readings occurred in July/August and February/March (Woodside Petroleum Development Pty. Ltd, 1979a, b in Jones 2004). It was also noted that temperatures within shallow embayments in the archipelago can range from 18 ºC in winter to 34 ºC in summer (Jones 2004).

In the late 1980s/early 1990s, the Australian Institute of Marine Science installed a series of remote weather stations on the Great Barrier Reef (GBR) in Queensland, four of which measure sea temperature at a depth of ~1 m at low tide. (AIMS 2003). The mean monthly temperature ranges, daily minimum and maximum records for these stations from their commencement of operation until July 2000 are as follows:

- Agincourt Reef (16° 2′S, 145° 49′E) - 24.0 ºC to 28.6 ºC, 22.6 ºC and 31.7 ºC;
- Myrmidon Reef (18° 16′S, 147° 22′E) - 24.2 ºC to 28.9 ºC, 22.1 ºC and 29.5 ºC;
- Davies Reef (18° 50′S, 147° 41′E) -23.4 ºC to 28.4 ºC; 22 ºC and 30.8 ºC;
- Hardy Reef (19° 44′S, 149° 10′E) – 22.3 ° C to 28.4 ° C, 20.8 ºC and 30.0 ºC.

The pattern of change in temperature through time was consistent across all four stations with peaks occurring in February and troughs in August (Figure 3).

In the mid-1990s, the Great Barrier Reef Marine Park Authority established a long-term sea temperature monitoring program based on *in situ* data loggers installed at representative sites on and adjacent to the Great Barrier Reef, on the north-east coast of Australia. Loggers have been deployed at three levels: on the reef flat at the astronomical low tide level, on the upper reef slope at depths ranging from 5-9 m and on the lower reef slope at depths of about 20m.

2.3.3.2 Cook Islands

Wells and Jenkins (1988) indicate that the mean sea surface temperature in the Cook Islands varies from 25.5 °C in June to 27.3 °C in January.

The SEAFRAME (Sea Level Fine Resolution Acoustic Measuring Equipment) gauge installed in Avaitu Harbour, Rarotonga in February 1993 indicates that sea temperatures since then have varied from a minimum of 22.0 °C in August 1998 to a maximum of 30.2 °C in February 2002 (Bureau of Meteorology, Australia 2006a).

2.3.3.3 Fiji

Wells and Jenkins (1988) indicate that the sea temperature in Fiji has an annual range of 6 °C, reaches a maximum of 30 °C in summer and is always greater than 20 °C.

Underwater temperature recorders were deployed at a depth of approximately 10 m at Suva Barrier Reef in September 1996 and at Vuna Point, Taveuni in July 1997 as part of the Sea-water Temperature Monitoring Project run by the University of the South Pacific, Fiji (Cumming *et al.* 2000). The records from Suva Barrier Reef show that temperatures exceeded the maximum monthly mean (MMM) of 28.5 °C for five months, remained above 29 °C for 3.5 months and peaked at 30-30.5 °C between early March and early April. Similar patterns and peak temperatures were noted at Vuna Point, Taveuni, except that the MMM was 0.3 °C lower.

This *in-situ* logger network has subsequently been expanded by the Fijian branch of the Global Coral Reef Monitoring Network (Sykes 2007). By December 2006, sea temperature was being monitored in nine regions (Coral Coast, Savusavu, Suva, Somosomo Straits, East Tavenui, Yasawa Island, Namena, Kadavu and Vatu-i-Ra). An additional logger was installed in Beqa Lagoon, near Storm Island in January 2007. Data from January 1997 to November 2007 were obtained from a logger facing the ocean at a depth of 5-7 m on Mount Mutiny, a pinnacle, in Vatu-i-Ra Passage (Figure 4). During this period the temperature varied from approximately 24.0 °C (September/October 1997) to just over 30 °C (February 2002). It is also evident that the minimum water temperature in 1997 was well below that experienced in any of the other years and that the minimum temperatures in 1998, 2002-2005 were below those in 1999-2001 and 2006-2007. An analysis carried out on data from January 1999 to May 2006 indicated that the number of days per year with temperatures in excess of 29 °C varied from < 20 in 1999 and 2003 to > 80 in 2000 and 2002 (Sykes 2007).

Temperature data from the loggers deployed at Yasawa Island, Vatu-i-Ra, Kadavu and Suva Harbour over the period September 2006 to October 2007 have also been compared (Figure 5) (Helen Sykes pers. comm.). The overall trend was similar across the four locations, however, peak temperatures were clearly maintained over a longer period (January to April) at Yasawa and Vatu-i-Ra than at Suva and Yasawa Island (February to April). The temperature at Yasawa Island was generally greater while that at Kadavu was smaller than at the other locations. From December to April, temperatures in excess of 29 °C were relatively common at Yasawa Island, but of rare occurrence at the other locations.

The SEAFRAME gauge installed at Lautoka on the western side of Viti Levu in October 1992 indicates that sea temperatures since then have varied from a minimum of 24.2 °C in August 1993 to a maximum of 32.5 °C in April 2006 (Bureau of Meteorology, Australia 2006b).

2.3.3.4 French Polynesia

In French Polynesia, the sea temperature varies from 20-22 °C in winter and from 26-30 °C in summer (Wells and Jenkins 1988). In this region, sea temperatures decrease southward and eastward to Rapa, where the minimum temperature suitable for growth of coral is found. In the Gambier Archipelago, the sea temperature varies from about 22 °C in August to 26 °C in March.

2.3.3.5 Papua New Guinea

A water temperature probe deployed on the eastern side of Lion Island in Bootless Bay, Papua New Guinea between August 1998 and February 2000 indicated that water temperature ranged from 25.55 °C (September 1999) to 30.85 °C (February 2000) (Quinn and Kojis 2000). Sea temperatures recorded during a rapid assessment of marine biodiversity in Milne Bay Province ranged from approximately 26 °C to 30 °C, with the northern section of Milne Bay experiencing warmer temperatures (28-30 °C) than the southern section (26-28 °C) (Allen *et al.* 2003). The highest temperatures were recorded at Fergusson Island, Amphletts Group, and Cape Vogel and the lowest temperatures in the western part of the Calvados Chain.

The SEAFRAME gauge installed at Lombrum on Manus Island in September 1994 indicates that sea temperatures since then have varied from a minimum of 27.8 °C in September 1997 and April 1998 to a maximum of 32.6 °C in November 2000 (Bureau of Meteorology, Australia 2006c). The SEAFRAME records also show that mean water temperatures off Manus Island were about 2 °C below normal during the 1997/1998 El Niño.

2.3.3.6 Solomon Islands

In the Solomon Islands, sea surface temperatures are consistently in the upper 20s (Sulu *et al.* 2000). The temperature is generally coolest between August and October and warmer between January and March. On some occasions, mean monthly sea temperatures in excess of 29.5 °C have been recorded for 4 or 5 consecutive months. Ramofafia *et al.*(2001) noted that the mean monthly seawater temperatures recorded daily at the ICLARM Coastal Aquaculture Centre at Aruligo to the west of Honiara, Guadalcanal over the period May 1995 to December 1998 varied between 27.3 °C (September/October 1997) and 30.2 °C (February/March 1996).

The SEAFRAME gauge installed at Honiara on the north-west coast of Guadalcanal in July 1994 indicates that sea temperatures since then have varied from a minimum of 26.5 °C in October 1998 to a maximum of 31.9 °C in March 2000 (Bureau of Meteorology, Australia 2006d). The SEAFRAME records also show that mean water temperatures off Honiara were about 2 °C below normal during the 1997/1998 El Niño.

2.3.3.7 Vanuatu

According to Wells and Jenkins (1988), the water temperature in Vanuatu ranges from 24.5 °C in September to 28.1 °C in February. The SEAFRAME gauge installed at Port Vila on Efate Island, however, indicates that sea temperatures since January 1993 have varied from a minimum of 23.3 °C in September 1994 to a maximum of 31.7 °C in February 2000 (Bureau of Meteorology, Australia 2006e).

2.4 SST Measurements Derived from Satellites

Numerous SST data products were considered, but only four contained composite data that could be easily accessed using a Personal Computer. These were the Modern Average Global SST dataset produced by the US Geological Survey, the SST web atlas for the Great Barrier Reef region produced by the Australian Institute of Marine Science and CRC Reef Research Centre, the National Oceanic and Atmospheric Administration's Coral Reef Watch Program and the surface temperature search tool maintained by the Australian Department of Defence.

2.4.1 Modern Average Global SST Dataset

Comparable SST data for various locations in the regions of interest were obtained from the modern average global sea-surface temperature dataset produced by the US Geological Survey (Schweitzer 1993). These data are derived from weekly measurements taken by an Advanced Very High Resolution Radiometer (AVHRR) from October 1981 to December 1990 in nine separate regions of the world's oceans. The dataset was obtained by downloading the SST display application in format EXE Stand-alone runtime for Microsoft Windows. This software package was used to view the monthly images for the South-east and South-west Pacific oceans and extract estimates of the monthly SST data averaged across the 10 year study period. It should be noted that averaging the images in this way tends to reduce the number of grid cells that lack valid data and suppresses inter-annual variability. Data for the locations of interest were obtained by overlaying a latitude/longitude grid over the image and selecting the nearest pixel which contained SST records. Data are presented for five locations distributed across the geographic extent of most of the South Pacific countries of interest (Figure 6). The dataset was less complete around the Solomons Islands and Vanuatu, so data for fewer locations are presented.

Figure 6 shows that the variation in average monthly SST values was generally greater off the Northern coast of Australia than in the South Pacific countries of interest. The maximum average monthly SST values in northern Australia, however, were similar to those recorded in Papua New Guinea and the Solomon Islands, but greater than those in the other Pacific countries. The average monthly SST values were more similar among locations in the Solomon Islands than among locations in the other countries, probably because the former have a less extensive geographic distribution. In most countries, the average monthly temperature declines with latitude. August was the coldest month of the year throughout the Cook Islands and Fiji, but only at some locations in French Polynesia, Papua New Guinea, the Solomon Islands and Vanuatu. At the other locations, the minimum monthly SST values occurred either in July, throughout July and August, in September or throughout August and September. The occurrence of the warmest month of the year was even more variable, occurring in January, February, March or April or from November-February, January to February, February to March, February to April or March to April.

2.4.2 Surface Temperature Search Tool

SST data for some of the locations in northern Australia where pearls farms have been established were obtained by using the web-based surface temperature search tool (Directorate of Oceanography and Meteorology, Department of Defence, Australia 2007). These data are predicted average monthly SSTs based on data within a 1° latitude and longitude radius of a coastal town and do not therefore take into account local environmental factors. They are provided by the US Naval Oceanographic Office who process AVHRR data from the polar operational environmental satellites NOAA-14 and NOAA-15 (Paul Sliogeris, pers. comm.). The data are calibrated against drifting buoy measurements and represents a 10 day composite analysis of sea surface temperature.

The mean monthly sea temperature ranges for these locations are:

- Houtman Abrolhos Islands – 20.4 °C to 23.9 °C;
- Carnarvon - 21.5 °C to 25.3 °C;
- Broome - 23.4 °C to 29.0 °C;
- Exmouth – 23.9 °C to 28.1 °C;
- Dampier - 24.1 °C to 28.4 °C;
- Coburg Peninsula - 26.5 °C to 30.0 °C;
- Prince of Wales Island, Torres Strait - 26.7 °C to 29.2 °C; and
- Hervey Bay – 21.3 °C to 26.3 °C.

Figure 7a indicates that the minimum monthly temperatures and monthly maxima were not coincident at the six locations on the north-west coast. The minimum temperatures occurred in August at Broome and the Coburg Peninsula, in September in the Houtman-Abrolhos Islands, but from August through to September at the other locations. The maximum temperatures were recorded in January at Broome and the Coburg Peninsula, but in March at the Abrolhos Islands, Exmouth and Dampier and in April at Carnarvon. The trends at the two widely spaced locations on the north-east, however, were similar, except that the maximum temperature was maintained over a three month period (January to March) at Prince of Wales Island, but for January only at Hervey Bay (Figure 7b).

2.4.3 SST web atlas for the Great Barrier Reef

The CRC Reef Research Centre in conjunction with the Australian Institute of Marine Science (AIMS) developed an SST web atlas for the Great Barrier Reef region based on the AVHRR satellite data archive with a spatial resolution of approximately 1 km (AIMS 2008). Sea temperature time series data for the period August 2003 to December 2007 were obtained for one offshore (Swain Reef) and four inshore locations (Agincourt, Davies and Hardy Reefs and Halftide) from the recently-developed sea surface temperature website (AIMS 2008). It should, however, be noted that this is an experimental facility and that there may be significant errors in the data, because they have not been corrected for the effects of undetected cloud and other aerosols. Figure 8 shows that the temperatures at these locations are generally in excess of 20 °C and that at all five locations they sometimes exceed 30 °C.

2.4.4 NOAA's Coral Reef Watch Program

Monthly night-time sea surface temperatures derived from AVHRR measurements taken between December 2000 and October 2007 were also obtained for 50 km^2 pixels surrounding or close to Coburg Park, Scott Reef and Ningaloo Reef on the north-west coast of Australia, Davies Reef and Heron Island on the north-east coast of Australia, Beqa in Fiji and Moorea in Tahiti (NOAA 2007). The mean monthly sea temperature ranges obtained for these locations were:

- Coburg Park - 25.4 °C to 30.7 °C;
- Scott Reef- 25.7 °C to 30.7 °C;
- Ningaloo Reef - 22.9 °C to 29.2 °C;
- Heron Island - 21.6 °C to 28.3 ºC;
- Davies Reef - 23.0 °C to 29.3 °C;
- Beqa - 24.4 °C to 29.7 °C; and
- Moorea - 26.2 °C to 29.3 °C.

Figure 9a shows that the minimum monthly temperatures occurred at more or less the same time at Scott Reef and Coburg Park, but sometimes occurred one or two months later at Ningaloo Reef. The monthly maxima also occurred later at Ningaloo Reef than at Scott Reef and Coburg Park. Trends in temperature were coincident at the two locations on the north-east coast of Australia (i.e. at Heron Island and Davies Reef) (Figure 8b). At Beqa, the peak temperatures occurred either in February, March or April, while troughs occurred either in August, August through to September, September or from September through to October (Figure 9). The peaks in temperature at Moorea were also not consistent across the survey period (Figure 9). In most years, the temperature peaked in March, however, in 2002 it did so in April and in 2004 it peaked in January. The minimum temperature was generally recorded in September, but in 2003 it occurred in October and from 2004-2005, it spanned August and September.

3.0 TROPICAL CYCLONES

3.1 Introduction

Tropical cyclones are non-frontal low pressure systems that form over warm tropical waters. They are characterised by organized convection, sustained gale force winds in excess of 63 km/h and wind gusts greater than 90 km/h near their centre that persist for more than six hours (Bureau of Meteorology, Australia 2007a). The gale force winds can extend more than half way around the cyclone near their centre and can extend hundreds of kilometres from the cyclone centre. Tropical cyclones derive their energy from the ocean and form only when the following conditions are met:

- the sea-surface temperature exceeds 26.5 °C and this temperature extends down to a depth of least 50 m;
- the atmosphere cools fast enough to encourage thunderstorm activity;
- there are relatively moist layers near the mid-troposphere (5 km);
- there is sufficient Coriolis force (earth's spin) to maintain the low pressure of the system;
- there is a pre-existing disturbance near the surface with sufficient spin and inflow; and
- low vertical wind shear (i.e. change in the wind with height that is less than 40 km/h from surface to tropopause).

They do not occur within 5° north or south of the equator, because the Coriolis Force is weaker at these latitudes.

Tropical cyclones vary in intensity, life cycle, pattern of movement, size and impact (wind, storm surge and flooding). They are assigned intensity categories ranging from 1 to 5 on the basis of the average maximum wind speed, strongest gust and central pressure. Severe tropical cyclones are characterized by sustained winds near the centre of 118 km/h and gusts in excess 165 km/h. Most tropical cyclones have a life-cycle of 3-7 days, but they can persist for several weeks if they remain in a favourable atmospheric environment. Weak cyclones, in contrast, only reach gale force for a brief period of time. These low pressure systems usually dissipate over land or colder oceans.

The activity and intensity of tropical cyclones varies within seasons, between years, decades and over multi-decadal timescales. In the Australian/Southwest Pacific basin (east of 142°E), tropical cyclone activity generally begins in late October/early November, reaches a single peak in late February/early March, and then fades out in early May (Atlantic Oceanography and Meteorological Laboratory 2007). Between 1968 and 1989/1990, the total number of tropical cyclones that occurred in this basin per year varied from 2 in 1981 to 16 in 1971 while the number of severe cyclones varied from 1 in 1979 to 11 in 1971 (Neumann 1993). The variation in number of cyclones from year to year is correlated strongly with local sea surface temperature before and at the start of the cyclone season, particularly with those in October (Nicholls 1984). The El Niño-Southern Oscillation (ENSO) phenomenon also affects the number of cyclones that occur per year. During El Niño events, there is a pronounced shift back and forth of cyclone activity with fewer tropical cyclones occurring between 145°E and 165°E and more across the South Pacific east of 165°E. There is also a tendency for tropical cyclones to originate a little closer to the equator. During La Niña events, the opposite pattern is observed.

3.2 Exposure of Key Pacific Regions to Tropical Cyclone Activity

The South Pacific region (east of 160°) generally experiences fewer tropical cyclones than the Australian region. Between the 1970/1971 and 2003/2004 seasons, the South Pacific experienced 8.6 cyclones on average per season, 4.1 of which were classified as severe and 1.7 as intense (McInerney *et al.* 2006). During this period, the South Pacific region was exposed to tropical cyclones for 31.7 days on average and to severe cyclones on 10.9 days. In the Australian region (90°E - 160°E), there were, on average, 12.8 cyclones per season, 6.3 of which were classified as severe (i.e. had maximum wind speeds > 33 m/sec) and 2.5 as intense (i.e. had maximum wind speeds in excess of 44 m/sec. The Australian region was exposed to tropical cyclones for 50 days on average and to severe cyclones on 15 days.

The spatial patterns of occurrence of tropical cyclones in the South-West Pacific Ocean across latitudes 10º and 22º S between 1969/1970 and 1988/1989 and their dependency on the Southern Oscillation phenomenon and sea surface temperatures was initially described by Basher and Zheng (1985). For this report, more up-to-date information on the average annual occurrence of tropical cyclones and average annual numbers during El Niño, La Niña and neutral years in the different regions has been obtained by accessing the southern hemisphere tropical cyclone archive (Bureau of Meteorology, Australia, 2007b). This archive is based on a 2 x 2 degree resolution gridded analysis of cyclone best track data for the period 1969/70 to 1998/99. The map showing the average distribution of tropical cyclones across the southern hemisphere over this period shows that cyclone activity is greatest between latitudes 10° and 20° S, extends over a greater latitudinal range in the South Pacific than in the Indian Ocean and that numbers decrease from west to east across the southwest Pacific (Figure 10). The latter trend reflects the progressive west-east decline in the ocean-surface temperature to the west of 170° E (Terry 2007). An area to the north of Port Hedland on the northwest coast of Australia is the most prone to tropical cyclones, experiencing one such event per year on average (Bureau of Meteorology, Australia, 2007b). Three other "hot-spots" of cyclone activity are evident in the South West Pacific region, two of which are located in the Coral Sea between longitudes 148° and 151°E, 156° and 158° E, respectively while the third is to the west to Vanuatu and New Caledonia (between about 163° and 166° E). The latter region experiences 0.8 cyclones per season on average. Figure 10 implies that the incidence of cyclones is, on average, greatest around Vanuatu, followed in turn by Fiji, the Cook Islands, French Polynesia and the Solomon Islands. In widespread nations, such as French Polynesia, the risk of cyclones varies across the archipelagos, averaging one per century to the north of the Marquesas, 1-3 per century from the Marquesas to the region to the north of the Tuamotu group, 4-8 per century from the Tuamoto group to the Gambiers and one every 2-3 years in the Austral areas (Gabriel and Salvat 1985 in Wells and Jenkins 1988).

During El Niño years, there is a marked shift in the regional pattern of risk with cyclone activity extending further east towards longitude 120° W, being greater than on average in the vicinity of Vanuatu, Fiji, the Cook Islands and French Polynesia, of similar incidence in the Solomon Islands but less frequent off the north Australian coast (Bureau of Meteorology, Australia, 2007b) (Figure 11). During La Niña events, the risk of cyclone activity does not extend beyond longitude 150° W, cyclones are more common than on average in the vicinity of Vanuatu, New Caledonia and South Coral Sea (Figure 12). The incidence of cyclones also shows a north-south shift, with activity extending further south during El Niño than La

Niña events. Basher and Zheng (1995) noted that cyclones were more common at latitudes greater than 19º S during La Niña events, but most common between latitudes 12º S and 23º S during strong El Niño events. They also estimated that the risk to the Southwest Pacific region as a whole was 28% greater than average during El Niño events.

NIWA (1997) estimated the annual chance of a cyclone occurring within 100 km^2 of the main island groups based on data averaged across the period 1969/1970 and 1988/1989. The risk was estimated to be 60%, 50%, 30%, 15% and 10% for Vanuatu, Fiji, Southern Cook Islands, French Polynesia and the Solomon islands, respectively. During strong El Niño events, they indicated that the risk of cyclones increased to 75% for the Southern Cook Islands and 50% for French Polynesia, but remained at 50% for Fiji, declined to 40% for Vanuatu and was considered negligible for the Solomon Islands. The average number of tropical cyclones per year passing within 550 km (5°) of the major island groups in the South Pacific has also been estimated (Salinger *et al.* 2007). The estimates are 3.0 for Vanuatu, 2.3 for Fiji, 1.5 for the southern Cook Islands, 1.3 for the Solomon Islands, 0.8 for the Northern Cook Islands, 0.8-0.1 for the major archipelagos in French Polynesia, and 0.6 for Papua New Guinea. They also point out that on average about four cyclones per season have wind speeds in excess of 118 km/h (category 4) and two of these usually reach category 5 status with mean wind speeds greater than 167 km/h.

The total number of tropical cyclones that passed within 50, 100 and 200 km of various locations within the specified regions between1969/1970 and 2004/2005 was estimated by examining the tracks in the southern hemisphere tropical cyclone archive compiled by the National Climate Centre, Bureau of Meteorology, Australia (Bureau of Meteorology 2007c) (Table 1). During this period, fewer tropical cyclones passed within 50 km and 100 km of Broome and Exmouth on the north-west Australian coast than most of the locations in Vanuatu and some of those in Fiji. More tropical cyclones passed within 200 km of the Vanuatu coast, than both the Fijian and north-west Australian coast. Table 1 also suggests that the risk of a tropical cyclone passing varies within individual countries. In Fiji, for example, seven tropical cyclones passed within 50 km of Viwa, but only one passed near Lakeba, Matuku and Suva. Likewise in Vanuatu, nine tropical cyclones passed within 50 km of Aneityum, Lamap, Port Vila and Sola, but only five did so near Pekoa Airport.

The north-west coast of Australia between Exmouth Gulf and Broome has the highest incidence of tropical cyclones in the southern hemisphere (Bureau of Meteorology, 2008). This region is also the most prone to severe tropical cyclones. About five tropical cyclones, on average, form each season over the warm ocean waters off the northwest coast between longitudes 105°E and 125°E. Only two of these usually cross the coast and only one of these is severe. Broome has experienced 22 tropical cyclones since 1910. This is equivalent to about one every four years, however, the frequency has declined in recent decades, with only two cyclones occurring between 1990 and 2004 (Bureau of Meteorology 2007d). In the Exmouth area, tropical cyclones with wind gusts greater than 90 km/h occur about once every two to three years on average, but only three gale-causing cyclones have occurred since 1982 (Bureau of Meteorology 2007e). In the Northern Territory, there are on average 7.7 days of cyclone activity per season (Bureau of Meteorology 2007f). The Gulf of Carpentaria usually averages two cyclones a year, while the Arafura and Timor Seas average one per year. On the east coast of Australia, there are on average 4.7 tropical cyclones per year.

3.3 The Influence of Climate Change on Tropical Cyclones

The effects of global warming on the characteristics and behaviour of tropical cyclones also need to be considered. On a global scale, there is considerable uncertainty about the influence of global warming on cyclone frequency, but a general acceptance that tropical cyclone intensities will increase. The latest report on climate change in Australia indicates that there is likely to be an increase in the proportion of the tropical cyclones in the more intense categories, but a possible decrease in the total number of cyclones (CSIRO 2007). The computer modelling studies undertaken by Walsh *et al*. (2004) and Leslie *et al*. (2007) suggest that there will be no significant change in the number of tropical cyclones off the east coast of Australia to the middle of the 21st Century. The simulations made by Abbs *et al*. (2006), however, indicate that there will be a significant decrease in numbers of cyclones, particularly off the west coast. All three studies agree that there will be a marked increase in the frequency of severe tropical cyclones. The projections made by Abbs *et al.* (2006) and Leslie *et al.* (2007) suggest that cyclones will be more long-lived on the east coast. Abbs *et al.* (2006) indicate that there will also be a decline in long-lived cyclones off the west coast.
In the South Pacific region, global warming is predicted to have some or all of the following effects on tropical cyclone activity:

- Change the origin of cyclones so that there is less clustering and more spreading to the east than at present;
- Little change in total cyclone numbers or frequencies, but more storminess east of longitude 180°;
- Increase in the intensity of tropical cyclones, with lower central pressure and greater maximum wind speeds;
- Greater precipitation;
- Longer cyclone lifespans;
- More southerly trend in cyclone tracks; and
- Longer cyclone tracks with greater southward movement prior to decay (Terry 2007).

3.4 Impact of Tropical Cyclones

3.4.1 General Impacts

The gale force winds accompanying cyclones can cause extensive property damage, turn airborne debris into potentially lethal missiles, and produce heavy seas which are dangerous to vessels at sea and in harbours and cause serious erosion of foreshores (Bureau of Meteorology, Australia 2007a). The heavy rainfall that occurs as the cyclone passes over can produce extensive flooding which can in turn cause damage. Heavy rain can persist as the cyclone moves into central and southern parts of Australia and cause flooding inland. The most potentially destructive phenomena associated with tropical cyclones are storm surges, raised domes of water about 60 to 80 km across and 2 to 5 m higher than the normal tide level. If the arrival of a storm surge coincides with a high tide it can cause extensive inundation of the coast, particularly in low-lying areas.

3.4.2 Impact on the Physical Environment of Key Pacific Island Groups

The impact of tropical cyclones on the physical environment of Pacific Island groups depends on their frequency, intensity, speed of movement, longevity, size and proximity to the island groups and how the physical features of the affected islands influence their response to the geomorphic and hydrological processes triggered by the cyclone (Terry 2007). Low-lying coral islands, such as those on atolls, are the most vulnerable to impacts. These islands consist of unconsolidated heaps of coralline sands and gravel on top of reef foundations and are prone to overtopping by storm surge and wave action generated by cyclones. On mountainous volcanic islands, characterized by rugged topography and weathered clay soils, heavy cyclonic rainfall can result in landslides on hills and deposition of sediment in valley bottoms. Tropical cyclones usually have less impact on limestone islands, because these have no significant relief on which slope failures can occur and no surface drainage channels that can be flooded.

3.4.3 Impacts on Pearl Fishing and Farming

In November 1910, a cyclone, with winds estimated at 175 km/h caused 34 pearling boats to be wrecked or sunk and a further 67 boats to be blown ashore in the Broome region, northwest Australia (Bureau of Meteorology, Australia 2007c). In March 1935, a cyclone devastated the pearling fleet at the Lacepede Islands, caused the deaths of 141 people and demolished pearling camps in Broome. In March 1989, the storm surge accompanying Cyclone Mahina destroyed the pearling fleet and killed 400 people at Bathurst Bay, near Cape Melville, Queensland (Emergency Management, Australia 2003). In Exmouth Gulf, Western Australia, cyclone-induced damage to benthic habitat has led to fluctuations in the availability of wild stock and reductions in landings by the fishery (Department of Fisheries, Western Australia 2002). The heavy rainfall (395 mm), high winds (with gusts up to 273 km/h) and storm surge that accompanied category 5 cyclone Vance in March 1999, caused widespread movement of pearl oysters and equipment on experimental lines and commercial oyster farms in Exmouth Gulf (Hart and Joll 2006). In April 2000, Cyclone Rosita caused wide-scale damage to pearling facilities and the loss of eight boats in the vicinity of Broome. Paspaley pearls estimated that the losses to the Broome pearling industry amounted to about A$6 million (Department of Primary Industries, Western Australia 2002). Cyclone-induced movements of sand and silt can impact on pearl oyster banks by smothering brood stock and recruits. In the early stages of this fishery, cyclones led to loss of human life and boats.

Aquaculture installations situated within the cyclone belt may also be subject to episodic damage by storm surges and strong winds. The reduction in number and total area of pearl farms in Manihiki Atoll, Cook Islands that occurred between 1997 and 1999 has been attributed to the impact of Cyclone Martin in 1997 (Ponia *et al.* 2000). Although damage to underwater farming operations was limited, this cyclone caused the loss of harvested pearls and equipment, damage to the above-water infrastructure and villages and loss of 19 lives (Macpherson 2000). Within a two month period in 1983, French Polynesia was hit by five cyclones; more than in the previous 150 years. The attendant 4-5 m rise in sea level and 8-10 m high waves resulted in the total submergence of many villages on the atolls, and destroyed boats, fishing equipment and pearl aquaculture rafts (UNESCAP 2000).

4.0 CONCLUSIONS

4.1 Sea Temperature

Although sea temperature is known to influence the physiology of cultured oysters and the rate of deposition of nacre on oyster shells and implanted nuclei, surprisingly little information is available about the optimum temperature ranges of black-lip and silver-lip oysters. The only information that is available comes from north-east Australia and indicates that the range for black-lip oysters (23 – 28 °C) is narrower than that for silver-lip oysters (23 – 32 °C) (Yukihira *et al*. 2000). It should be noted that optimum temperature ranges at other locations may differ, particularly if there are latitudinal differences in these species. Information about the sea temperatures prevailing at culture sites in Australia and the South West Pacific is also fairly limited. In French Polynesia, the temperatures reported at black pearl farms range from 21.3 - 28.8 °C, 25.5 - 29.5 °C and 26 – 31 °C, depending on latitude (Pouvreau and Prasil 2001). In north-west Australia, temperatures reported at silver pearl farms range from 19.5 - 29.7 °C, 21.4 - 30.9 °C and 25 – 32 °C (Pass *et al.* 1987; CSIRO 2003). This implies that black pearl farms are either located in areas where the water temperature is outside the optimum temperature range or that the optimum ranges of this species in other countries differs markedly from that in north-east Australia. Likewise, some of the Western Australian silver pearl farms are located in areas where the minimum water temperature is below the lower limit of the optimum temperature range or where the maximum water temperature is close to the upper limit of the optimum range. It should also be noted that if global warming causes a 0.4 - 1.0 ºC increase in the sea temperature off the north-west coast of Australia by 2030 as predicted by CSIRO (2007), this could result in prevailing temperatures at some farm locations exceeding the optimum temperature range of silver-lip oysters.

This review has shown that *in-situ* sea temperature measurements derived from underwater probes are available for numerous other locations in Australia, particularly those adjacent to the Great Barrier Reef on the north-east coast, but relatively little data of this type is available from the South Pacific nations of interest. Sea surface temperature measurements derived indirectly from data collected by infra-red radiometers carried on board satellites are available for locations throughout the world. If the spatial resolution of these data is too coarse, they will be of limited value to offshore pearl companies. SST products that provide measures of variability within months and years would also be more useful to prospective pearl farmers than average monthly climatologies, because they provide an indication of extreme SSTs that regions may experience and their likely duration. It should also be noted that SST measurements derived from satellite-borne sensors tend to be somewhat lower than the SSTs of waters immediately overlying coral reefs (Strong *et al.* 1996).

The limited information that is available on sea temperatures in Solomon Islands indicates that the prevailing regimes are similar to those in some areas of the Cook Islands and French Polynesia, where there are productive black-lip pearl farms. The temperature regime in the Solomon Islands is also similar to that in some areas of Vanuatu, Fiji and Papua New Guinea. The average monthly SST measurements indicate that the temperature of the water at locations in the Solomon Islands and Papua New Guinea regularly exceeds 29 °C in summer. This implies that these regions may be more suitable for culturing silver-lip than black-lip pearl oysters. The temperature regimes at most of the locations in Fiji and Vanuatu, however, appear to be suitable for culturing both species of pearl oysters. It should, however, be noted that there are no natural populations of silver-lip pearl oysters in these waters. On the basis of our current knowledge, it is not possible to say whether the sea temperature regime in Solomon Islands would be more advantageous for pearl farming than that in the other South Pacific nations considered.

4.2 Risk of Damage to Pearl Farms from Tropical Cyclones

As the South Pacific region (east of 160°) usually experiences fewer tropical cyclones than the Australian region, the risk of damage to pearl farms and associated infrastructure is also likely to be smaller. The risk of cyclone damage also differs across the South Pacific region, being 60%, 50%, 30%, 15% and 10% for Vanuatu, Fiji, southern Cook Islands, French Polynesia and the Solomon Islands, respectively (NIWA 1997). It is, however, important to note that in a widespread nation, such as French Polynesia, the risk of cyclones varies across the archipelagos and that the risk of cyclones within the Australian/South-West Pacific Basin also depends on the ENSO phenomenon. For example, during El Niño years, the risk of cyclones in the Southern Cook Islands and French Polynesia increases to 75% and 50%, respectively, remains at 50% in Fiji, but decreases to 40% in Vanuatu and 10% in the Solomon Islands. The risk of tropical cyclones also declines in the Australian region (Nicholls 1984).

If the strength or frequency of El Niño events increases, as is predicted with global warming, the easterly shift in tropical cyclone activity in the South Pacific region is likely to become the norm rather than an occasional event. Tropical cyclones are also expected to persist for longer and travel further south before they lose energy and decay. The low-lying nature of many of the islands in the Cook Islands and French Polynesia means that they are vulnerable not only to overtopping by storm surges and extreme wave action generated by cyclones, but also to sea-level rise associated with global warming. The pearl farm industries in the Cook Islands and French Polynesia are both known to have been adversely impacted by cyclones in recent decades (Ponia *et al.* 2000; UNESCAP 2000). In the future, they are likely to be impacted not only by cyclone activity, but also by sea-level rise.

Although impacts from cyclones are periodic, it may be wise to establish new pearl farms in nations, where the risk of damage from natural disasters and climate change is smaller. Whilst cyclones are less frequent in Solomon Islands than in most pearl farming areas, it is not possible, on the basis of our current knowledge, to determine whether pearl farming would be more advantageous there than in other South Pacific nations.

Due consideration should also be given to ways of avoiding or minimizing damage to pearl farms. The development of better advance cyclone warning systems, for example, could enable farmers to move longlines into deeper water and bring portable equipment ashore before weather and sea conditions deteriorate. It may also be possible to cyclone proof sub-surface farm infrastructure by using better attachments or "bunching up" longlines on the lagoon floor to reduce impacts from surges.

4.3 Overall Conclusions

In the South Pacific region, the identification of potential culture sites for black-lip and silver-pearl pearl oysters is currently hindered by the lack of information on latitudinal differences in their optimal temperature ranges and the general lack of easily-accessible information on prevailing sea temperatures. Whilst sea temperature and cyclone frequency are important, they are only two of a range of environmental factors that could influence production of pearl oysters. The identification of potential culture sites should also be based on a sound knowledge of fluctuations in a number of other environmental parameters, particularly food and silt levels, plus an appreciation of the vulnerability of different areas to other environmental hazards, particularly earthquakes, tsunamis, sea-level rise, volcanic eruptions and large-scale pollution events. As a number of variables operating over spatial scales ranging from regional to site-specific determine the suitability of a location for pearl farming, it is impossible, given our current state of knowledge, to say whether any one variable confers a significant advantage or disadvantage for a particular location.

5.0 ACKNOWLEDGEMENTS

This report was written by Dr Theresa Dye and reviewed by Drs Marcus Lincoln Smith. The following people assisted by providing information and we are most grateful for their help:

Dr Helen Sykes, Research Support, Suva, Fiji;

Dr Robert Smith, Pacific Islands Applied Geoscience Commission (SOPAC);

Paul Sliogeris, METOC Geospatial Services, Directorate of Oceanography & Meteorology, Royal Australian Navy.

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TABLES

Table 1. Average number of tropical cyclones passing within 50, 100 and 200 km of selected locations in Australia, Cook Islands, Fiji, French Polynesia, Papua New Guinea, Solomon Islands and Vanuatu between 1969/1970 and 2004/2005.

Table 1. Total number of tropical cyclones passing within 50, 100 and 200 km of selected locations in Australia, Cook Islands, Fiji, French Polynesia, Papua New Guinea, Solomon Islands and Vanuatu between1969/1970 and 2004/2005. Source: Bureau of Meteorology, Australia (2007b).

Country	Location	Latitude (°S)	Longitude (° E or W)	Number of cyclones within		
				50 km	100 km	200 km
Australia	Broome	17.94	122.23 E	6	12	28
Australia	Exmouth	19.24	146.76 E	6	11	30
Australia	Cairns	16.87	145.74 E	6	10	24
Cook Islands	Penrhyn	9.00	158.50 W	1	1	4
Cook Islands	Rarotonga	21.11	159.80 W	5	7	23
Fiji	Labasa Airfield	16.47	179.34 E	2	12	26
Fiji	Lakeba	18.24	178.81 E	1	9	26
Fiji	Matuku	19.13	179.74 E	1	10	27
Fiji	Nabouwalu	16.99	178.69 E	2	8	27
Fiji	Nadi	17.76	177.44 E	2	13	28
Fiji	Oni I Lau	20.66	178.72 E	5	18	23
Fiji	Rotuma	12.51	177.54 E	2	11	19
Fiji	Suva	18.15	178.45 E	1	9	29
Fiji	Vanua Balavu	17.25	178.95 E	3	5	25
Fiji	Viwa	17.15	176.91 E	7	13	28
Fiji	Vunisea	19.67	178.17 E	4	18	25
Fiji	Yasawa-i-Rawa	16.70	177.57 E	5	15	31
French Polynesia	Tahiti	19.00	210.00 E	0	4	11
Papua New Guinea	Kavieng	2.58	150.80 E	0	0	0
Papua New Guinea	Madang	5.22	145.78 E	0	0	0
Papua New Guinea	Port Moresby	9.45	147.20 E	0	1	3
Solomons Islands	Honiara	9.40	159.97 E	1	5	11
Solomons Islands	Lata	10.70	165.80 E	0	3	10
Solomons Islands	Munda	8.33	157.27 E	0	1	7
Solomons Islands	Taro Island	6.70	156.40 E	0	1	6
Vanuatu	Aneityum	20.23	169.78 E	9	15	34
Vanuatu	Lamap	16.42	167.81E	9	18	41
Vanuatu	Pekoa Airport	15.50	167.22 E	5	14	43
Vanuatu	Port Vila	17.75	168.31 E	9	21	39
Vanuatu	Sola	13.87	167.55 E	9	16	32

FIGURES

Figure 1. Mean monthly sea surface temperatures derived from the hourly data collected by oceanographic monitoring buoys deployed in Manihiki and Penrhyn Lagoons, Northern Cook Islands.

Figure 2. Mean monthly coastal ocean temperatures recorded by probes deployed at (a) silver-lip pearl oyster farms in Roebuck Bay and Exmouth Gulf and (b) at Barrow Island, Osprey Bay and Shark Bay, Western Australia.

Figure 3. Mean monthly sea surface temperature records from weather stations at Agincourt, Davies, Hardy and Myrmidon reefs on the Great Barrier Reef, north-east coast of Australia.

Figure 4. Variation in sea temperature records from an *in-situ* logger deployed at a depth of 5-7m on Mount Mutiny, Vatu-i-Ra, Fiji for the period January 1997 to November 2007.

Figure 5. Comparison of sea temperatures recorded by *in-situ* loggers deployed at Yasawa Island, Vatu-i-Ra, Kadavu and Suva Harbour over the period September 2006 to October 2007.

Figure 6. Average monthly sea surface temperatures derived from AVHRR sensor measurements taken between October 1981 and December 1990 for various locations in (a) Northern Australia, (b) Cook Islands, (c) Fiji, (d) French Polynesia, (e) Papua New Guinea, (f) Solomon Islands and (g) Vanuatu.

Figure 7. Mean monthly sea surface temperature records derived from AVHRR measurements for various locations on (a) the north-west coast and (b) the north-east of Australia where pearl farms have been established.

Figure 8. SST time series data derived from satellite-borne AVHRR sensor measurements taken over (a) Agincourt Reef, (b) Davies Reef, (c) Hardy Reef, (d) Halftide and (e) Swain Reef, North-east Queensland between August 2003 and December 2007.

Figure 9. Mean monthly sea surface temperature records from NOAA Coral Reef Watch for (a) Ningaloo Reef, Scott Reef and Coburg Park on the north-west coast, (b) for Heron Island and Davies Reef on the north-east coast of Australia and (c) Beqa, Fiji and Moorea, Tahiti in the South Pacific.

Figure 10. Distribution map showing the average annual number of tropical cyclones in the southern hemisphere per season between 1969/1970 and 1998/1999.

Figure 11. Distribution map showing the average annual number of tropical cyclones in the southern hemisphere during El Niño years between 1969/1970 and 1998/1999.

Figure 12. Distribution map showing the average annual number of tropical cyclones in the southern hemisphere during La Niña years between 1969/1970 and 1998/1999.

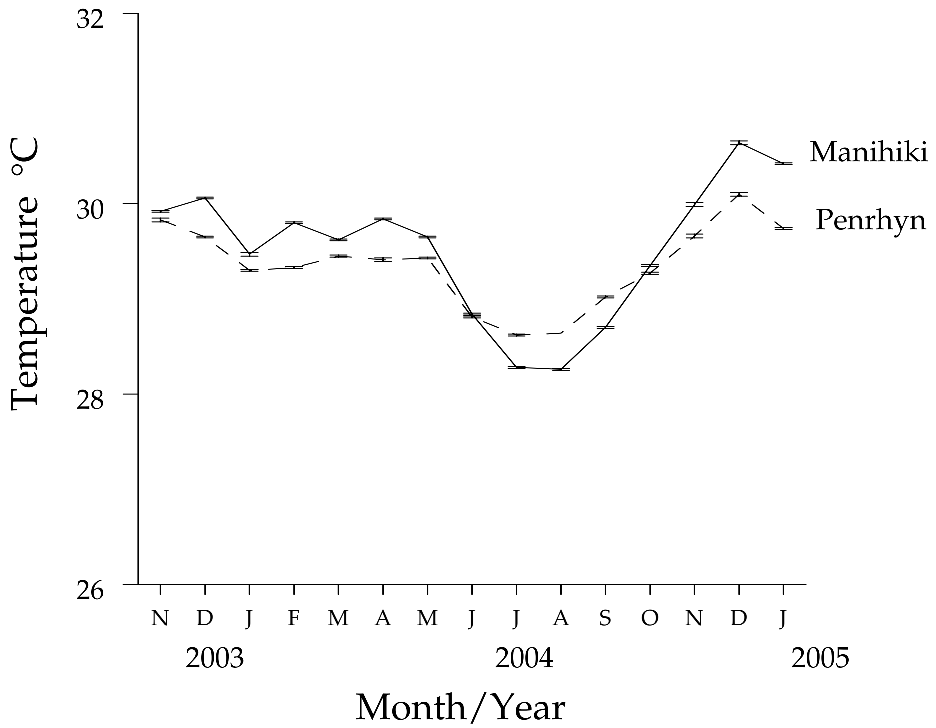


Figure 1. Mean monthly sea surface temperatures derived from the hourly data collected by oceanographic monitoring buoys deployed in Manihiki and Penrhyn Lagoons, Northern Cook Islands. Source: SOPAC.

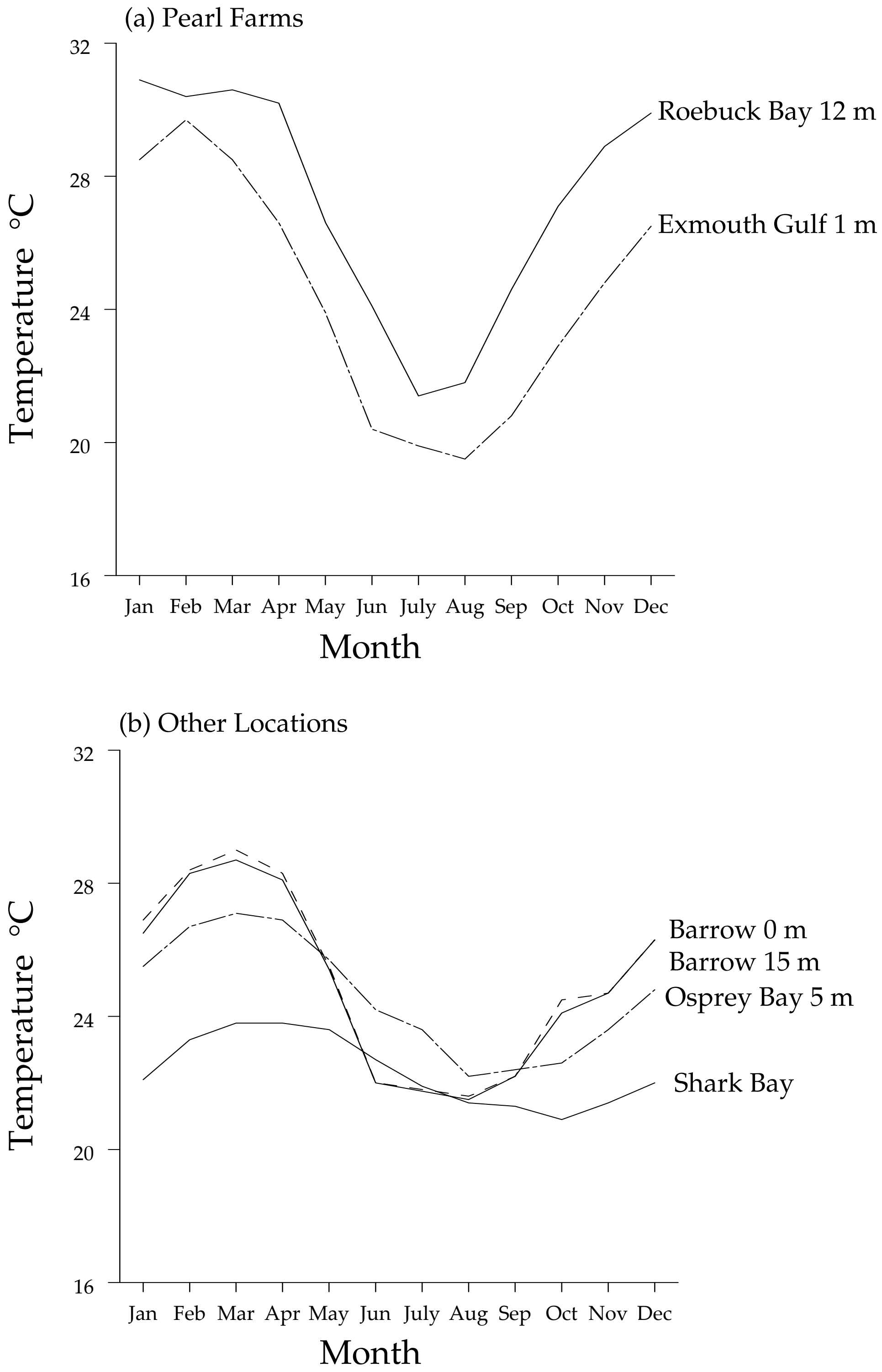


Figure 2. Mean monthly coastal ocean temperatures recorded by probes deployed at (a) silver-lip pearl oyster farms in Roebuck Bay and Exmouth Gulf and (b) at Barrow Island, Osprey Bay and Shark Bay, Western Australia. Source: CSIRO Marine Research (2003).

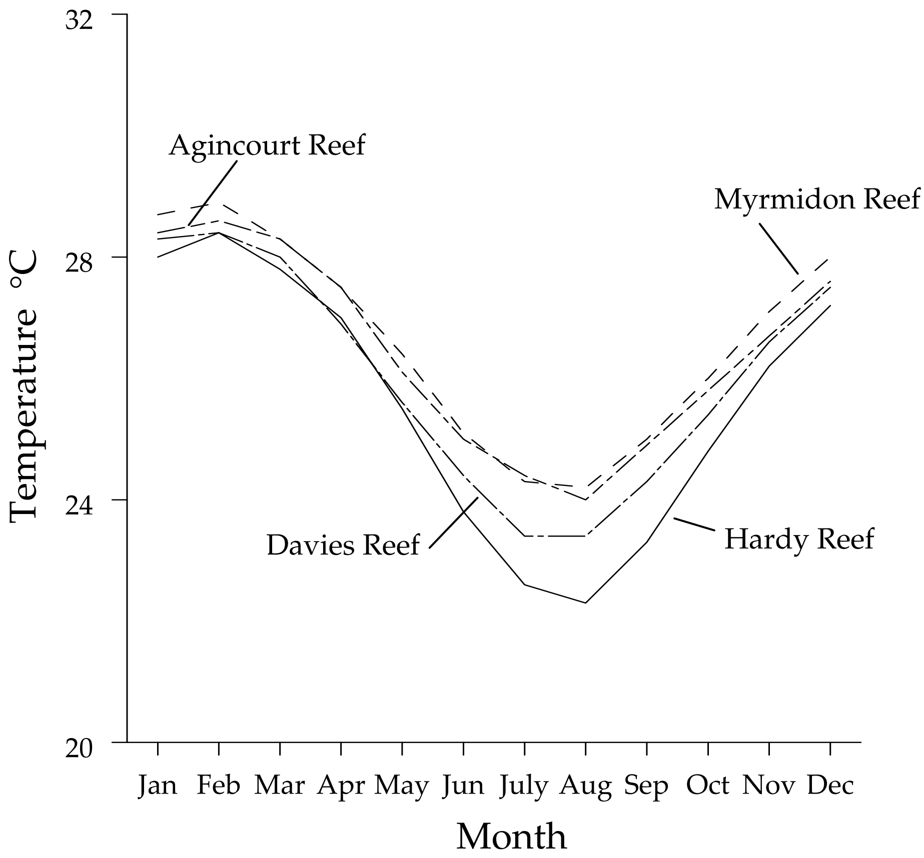


Figure 3. Mean monthly sea surface temperature records from weather stations at Agincourt, Davies, Hardy and Myrmidon reefs on the Great Barrier Reef, north-east coast of Australia. Source: AIMS (2003)

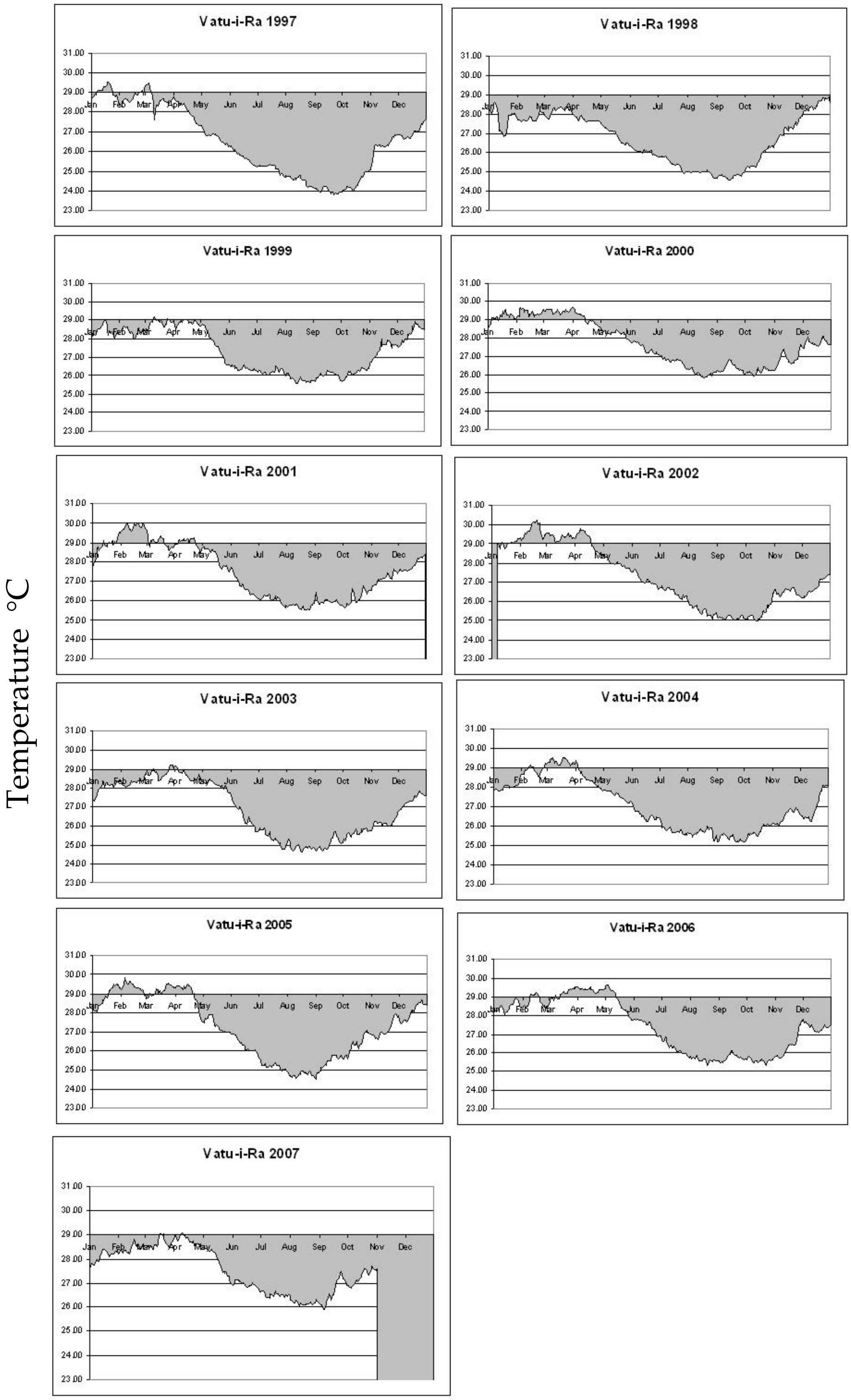


Figure 4. Variation in sea temperature records from an *in-situ* logger deployed at a depth of 5-7m on Mount Mutiny, Vatu-i-Ra, Fiji for the period January 1997 to November 2007. Source: Sykes (2007)

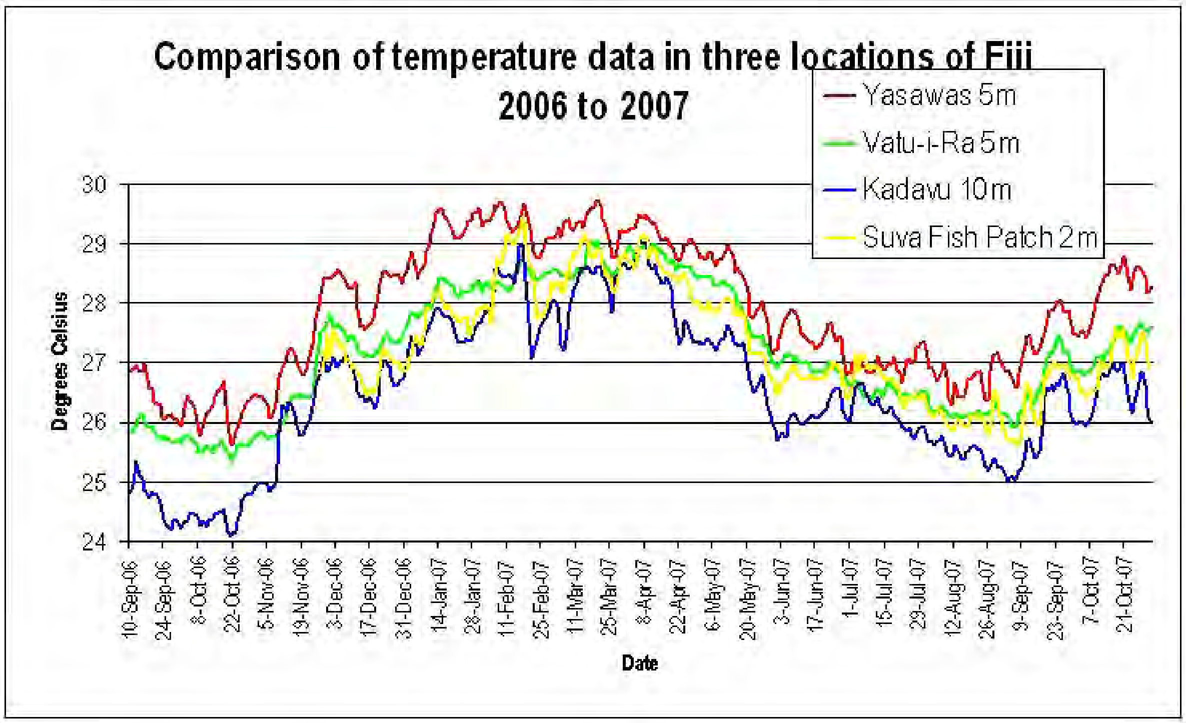


Figure 5. Comparison of sea temperatures recorded by *in-situ* loggers deployed at Yasawa Island, Vatu-i-Ra, Kadavu and Suva Harbour over the period September 2006 to October 2007. Source: Sykes (pers. comm.)

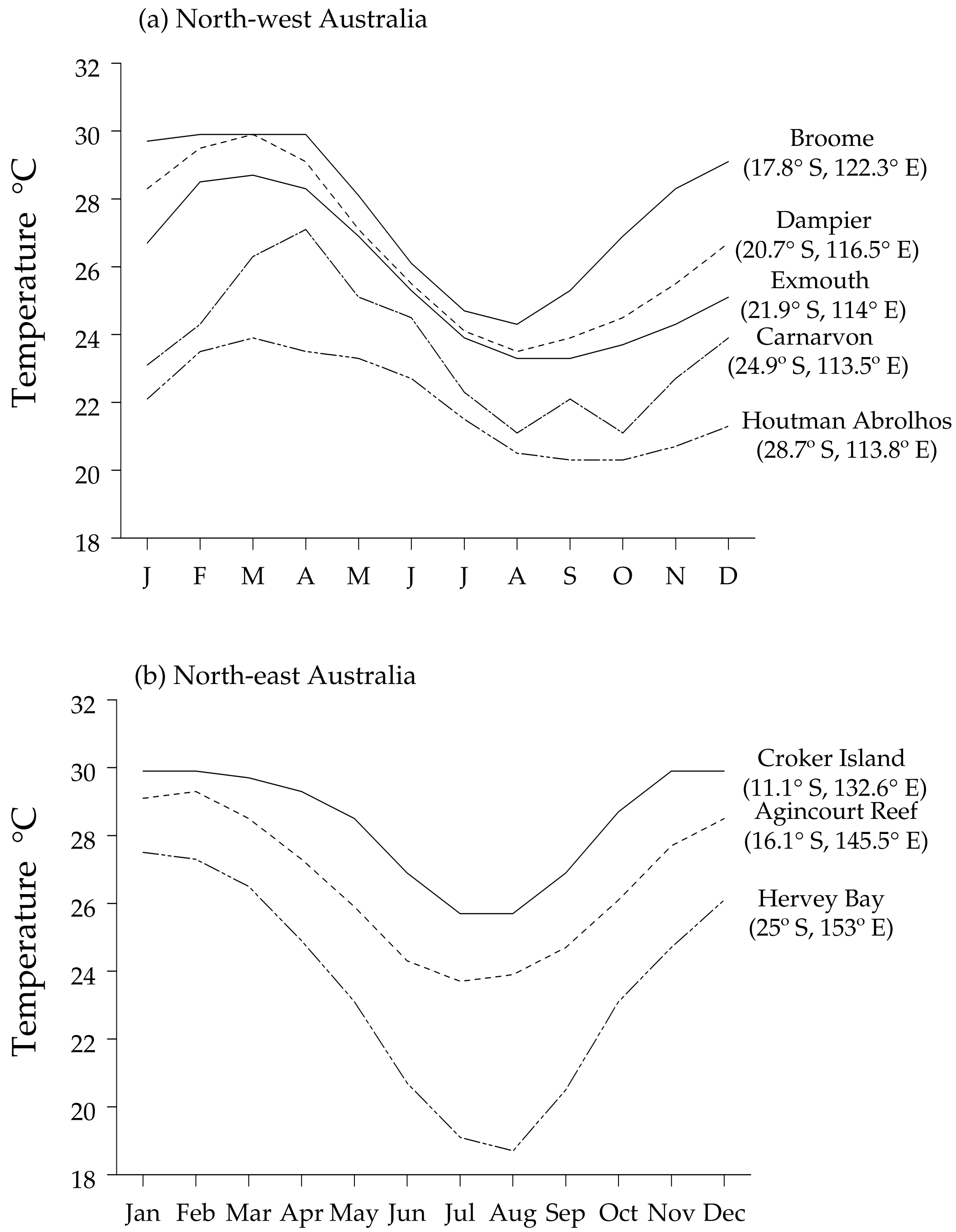
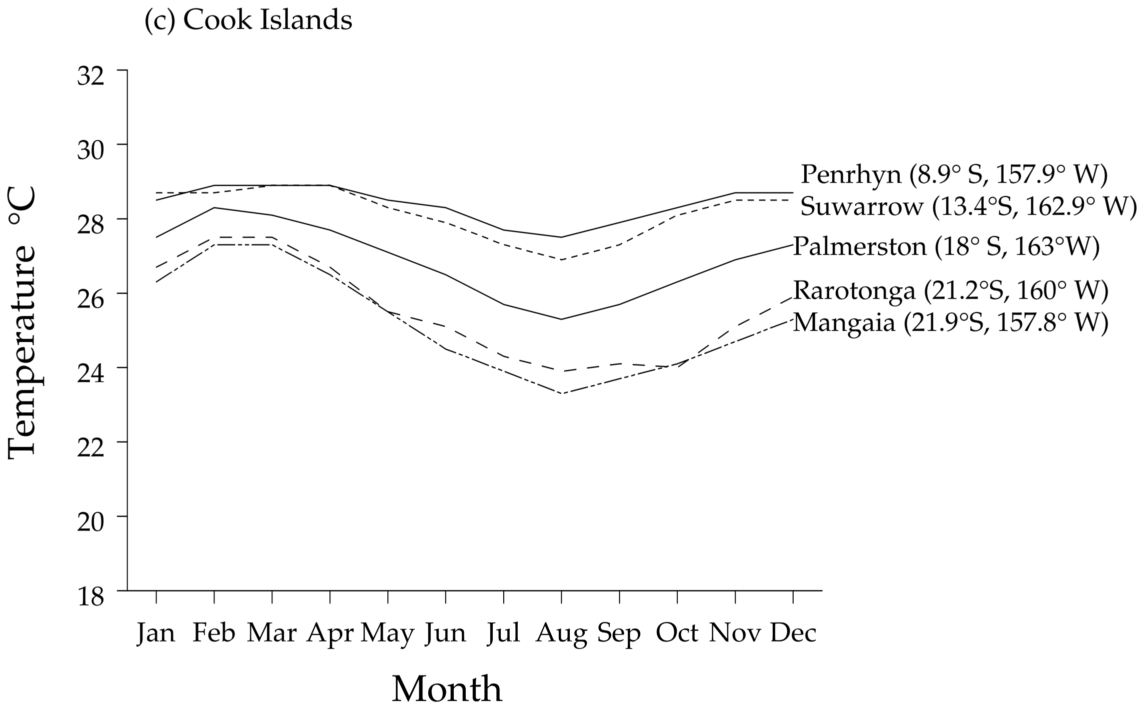
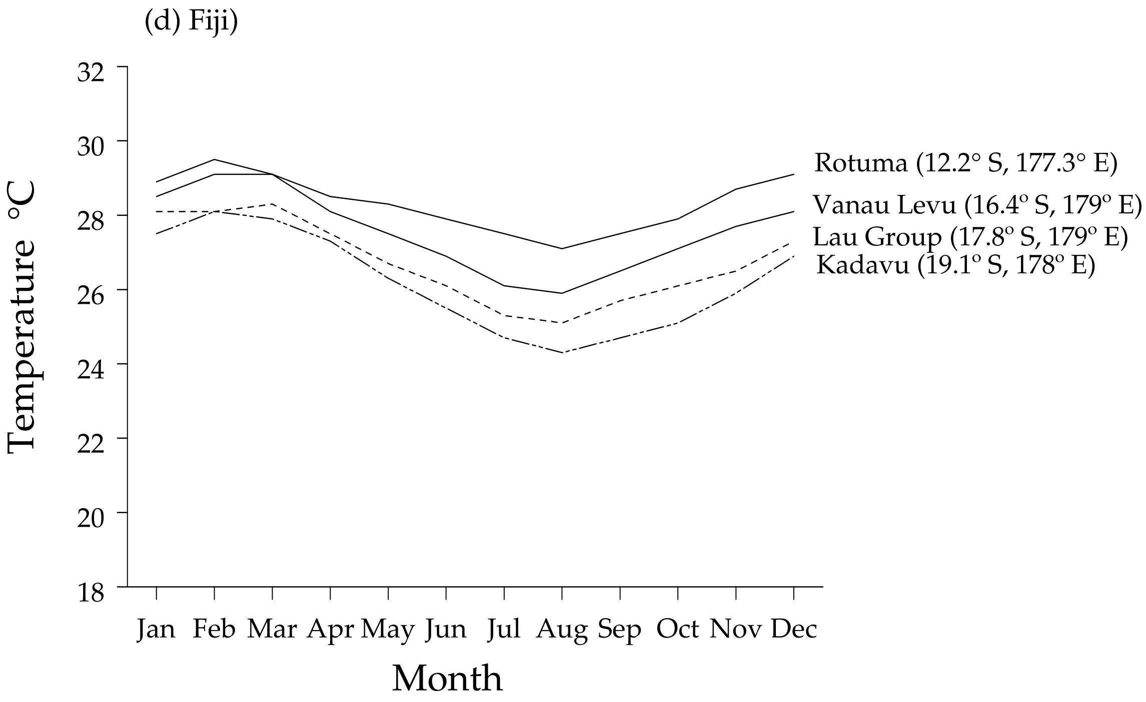


Figure 6. Average monthly sea surface temperatures derived from AVHRR sensor measurements taken between October 1981 and December 1990 for various locations in (a) North-west Australia, (b) North-east Australia, (c) Cook Islands, (d) Fiji, (e) French Polynesia, (f) Papua New Guinea, (g) Solomon Islands and (h) Vanuatu. Source: Schweitzer (1993).





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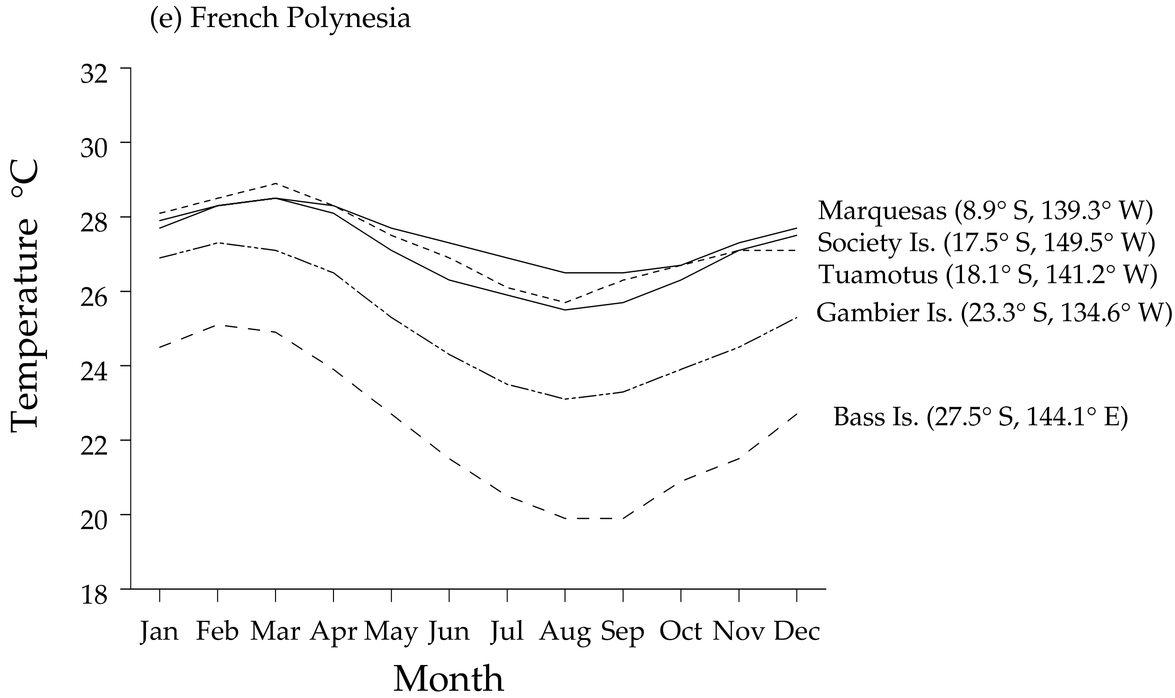

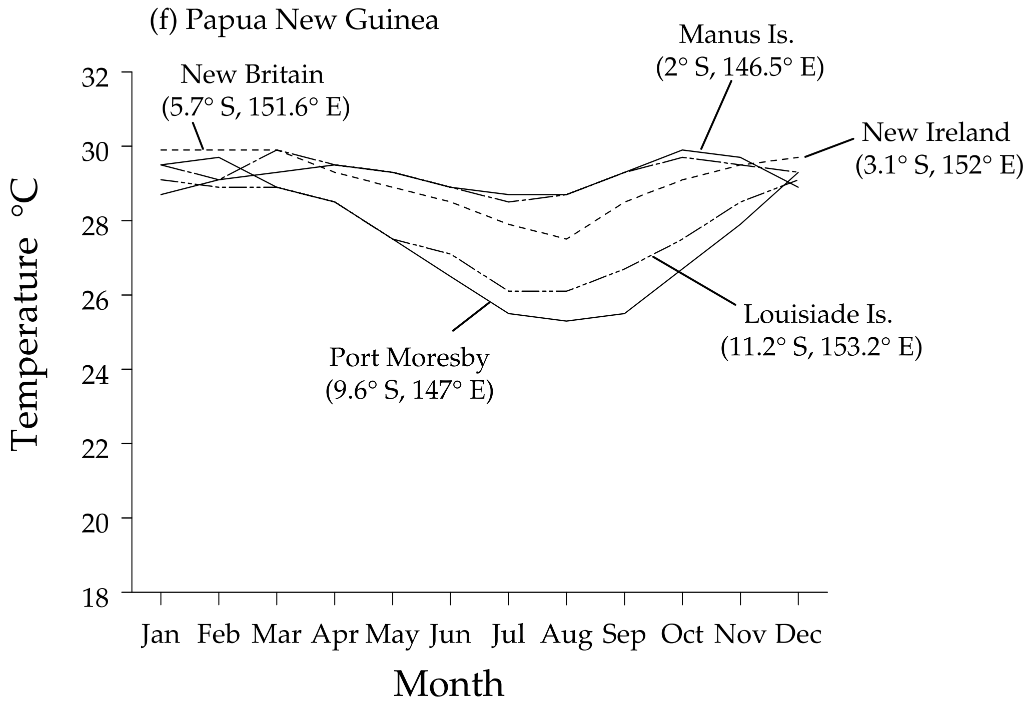

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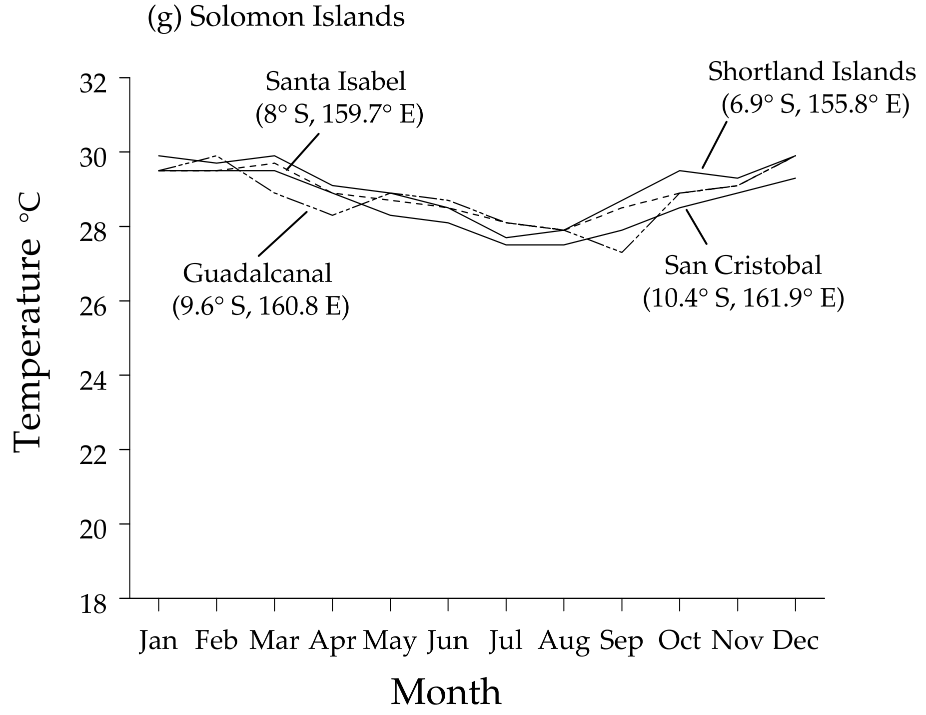

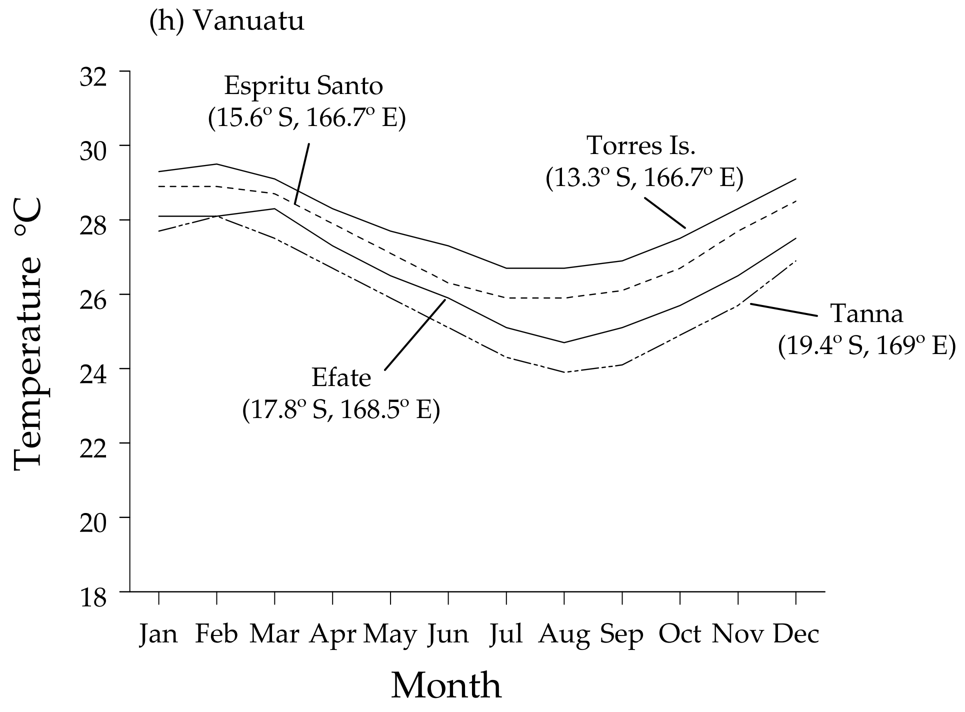

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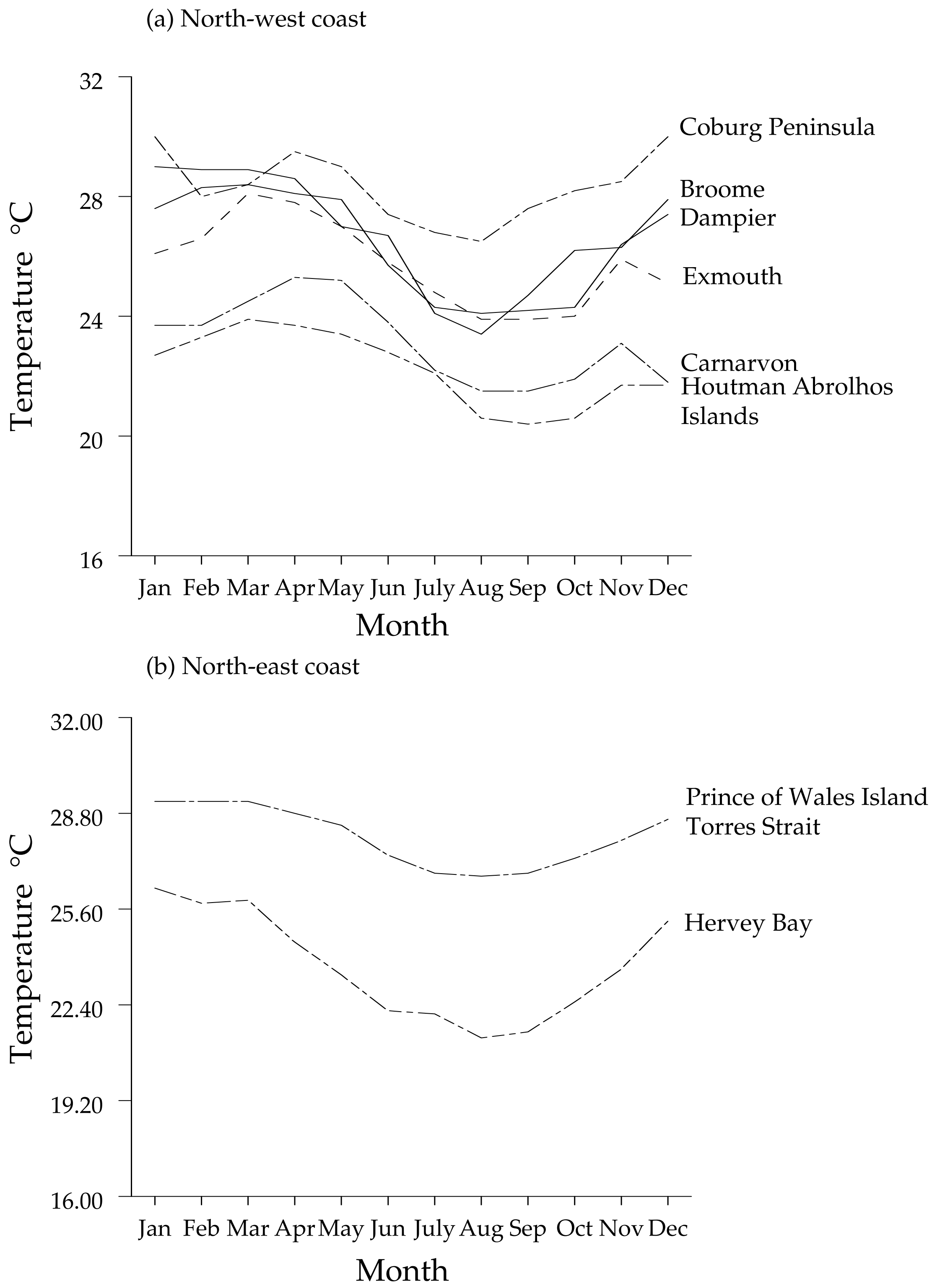

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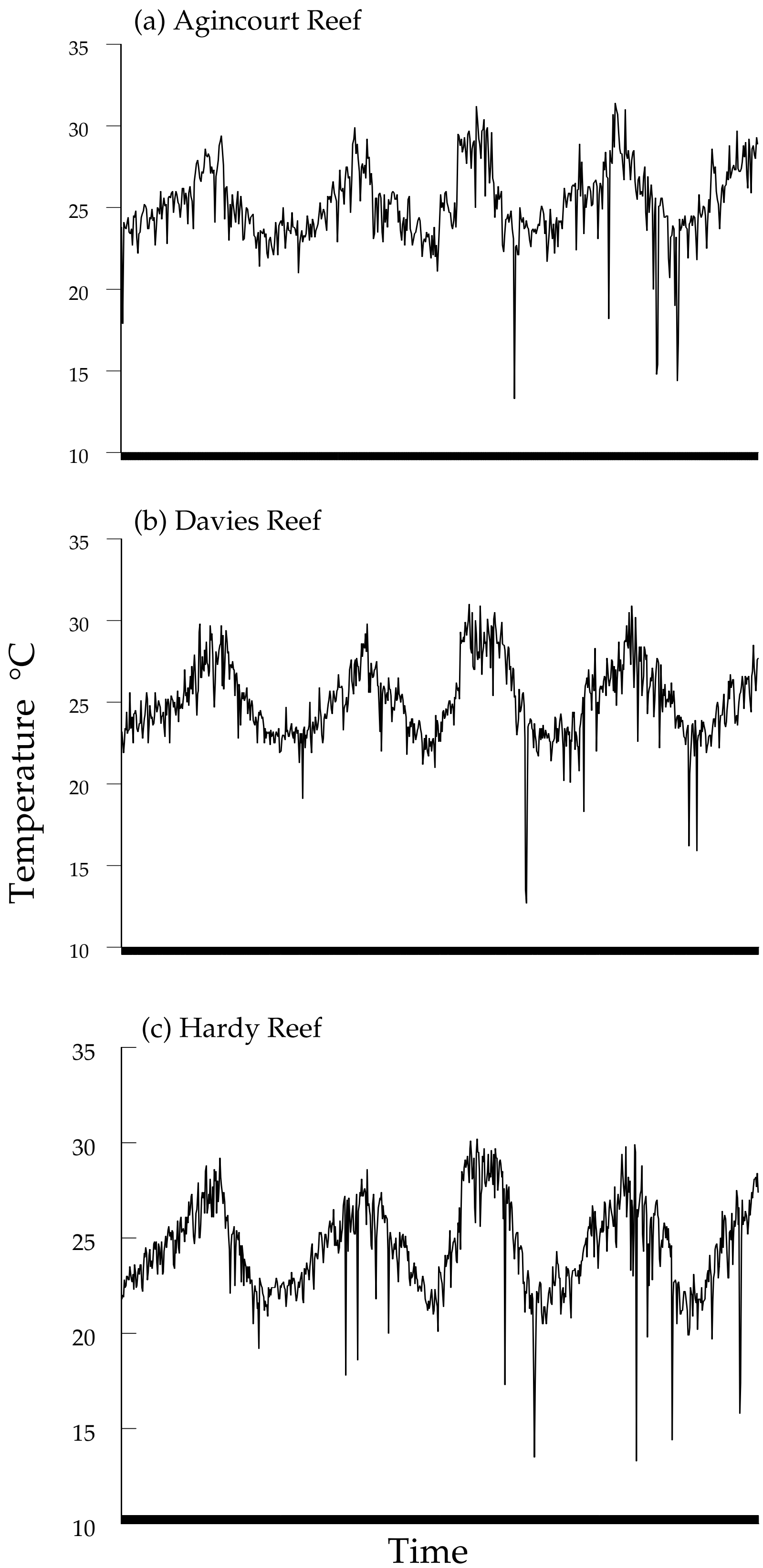

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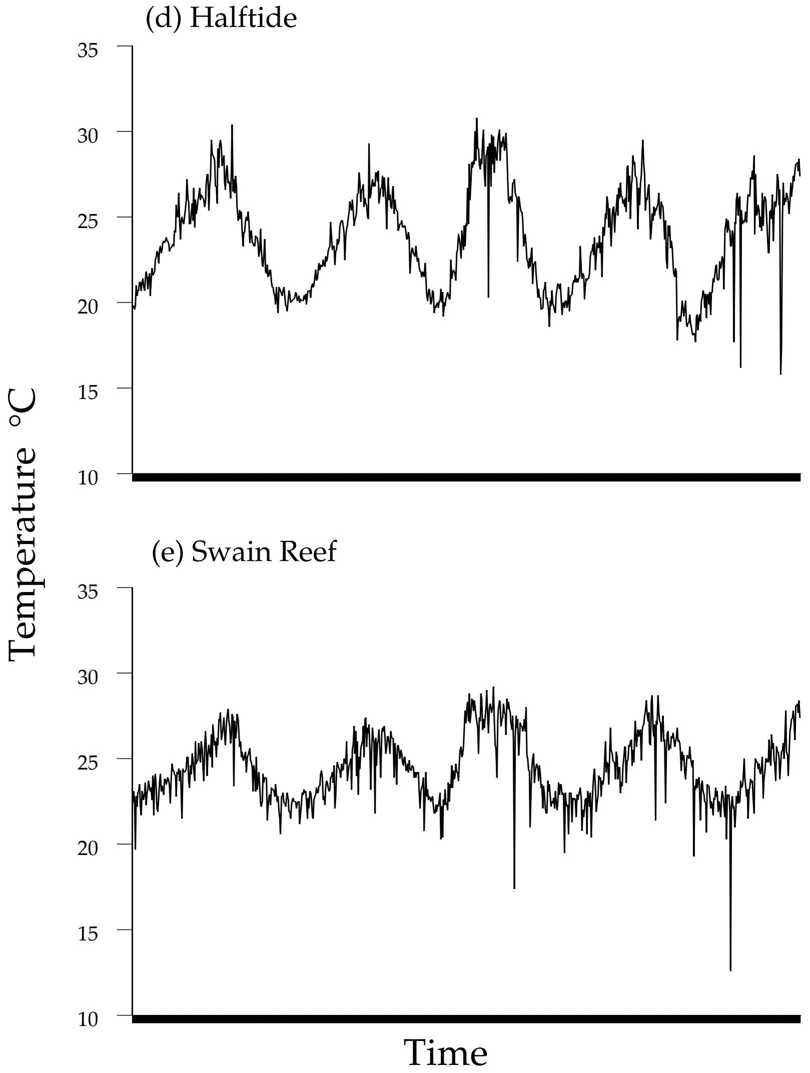

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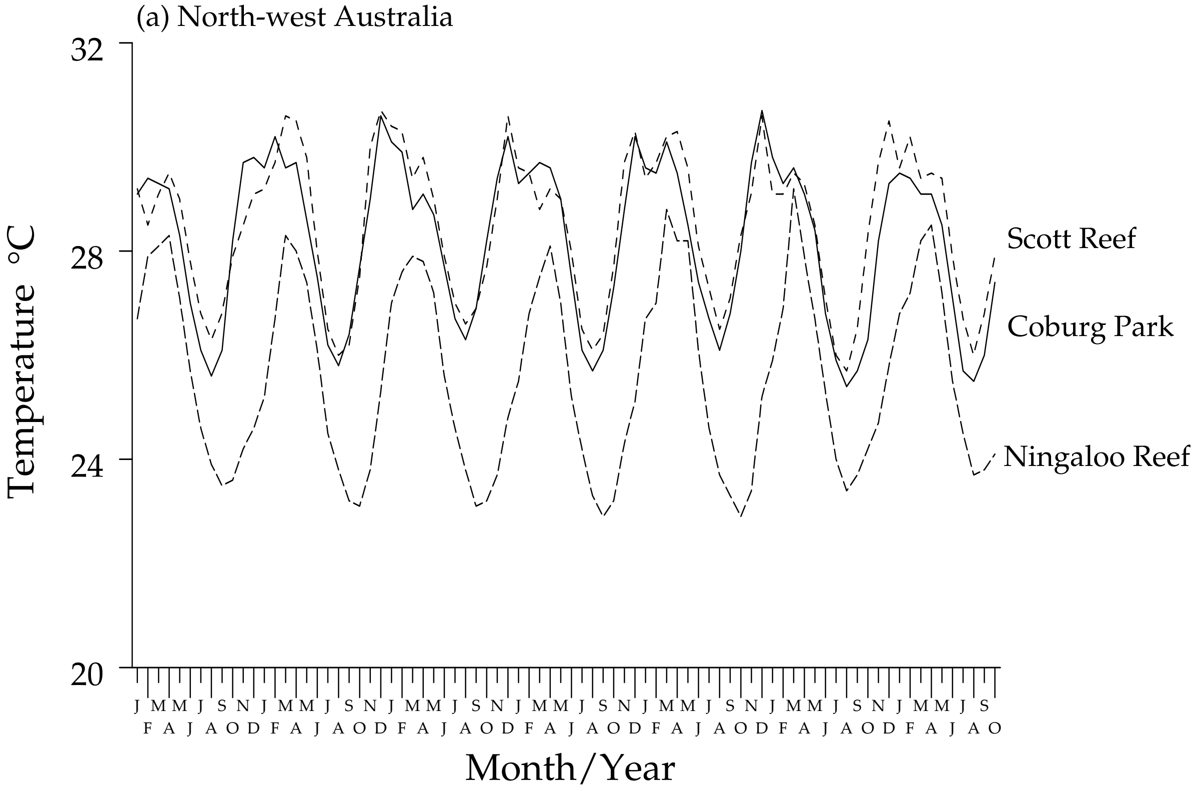

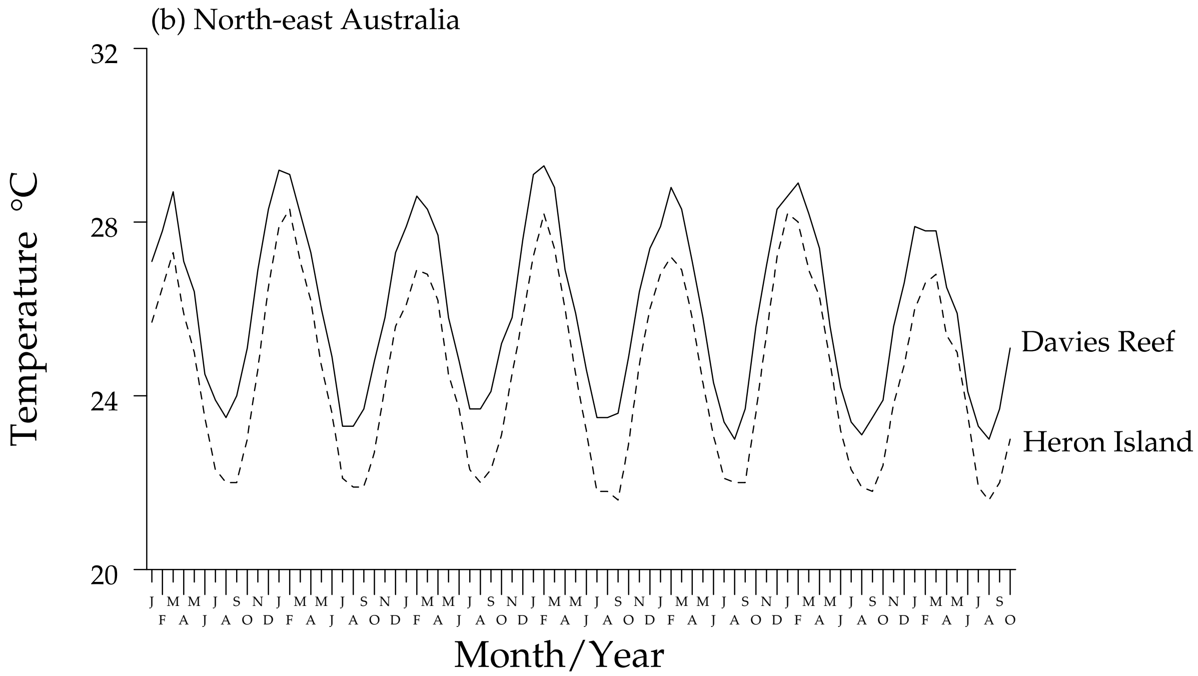

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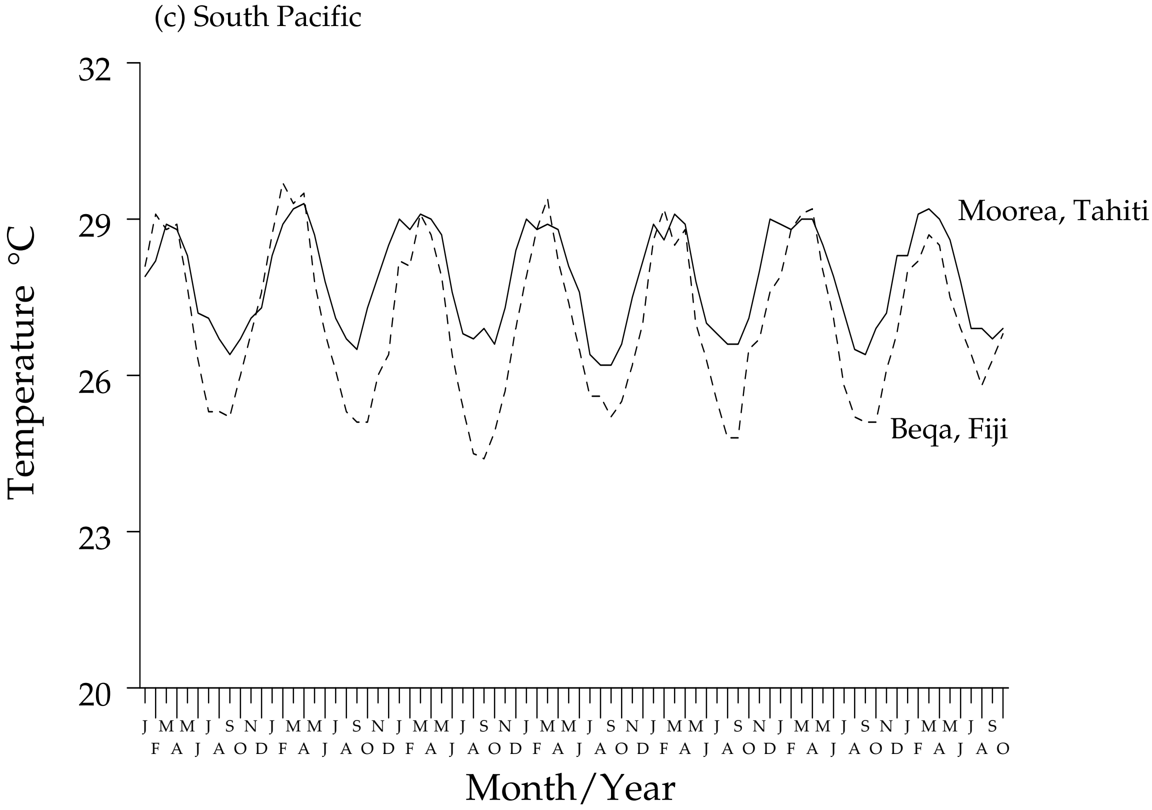

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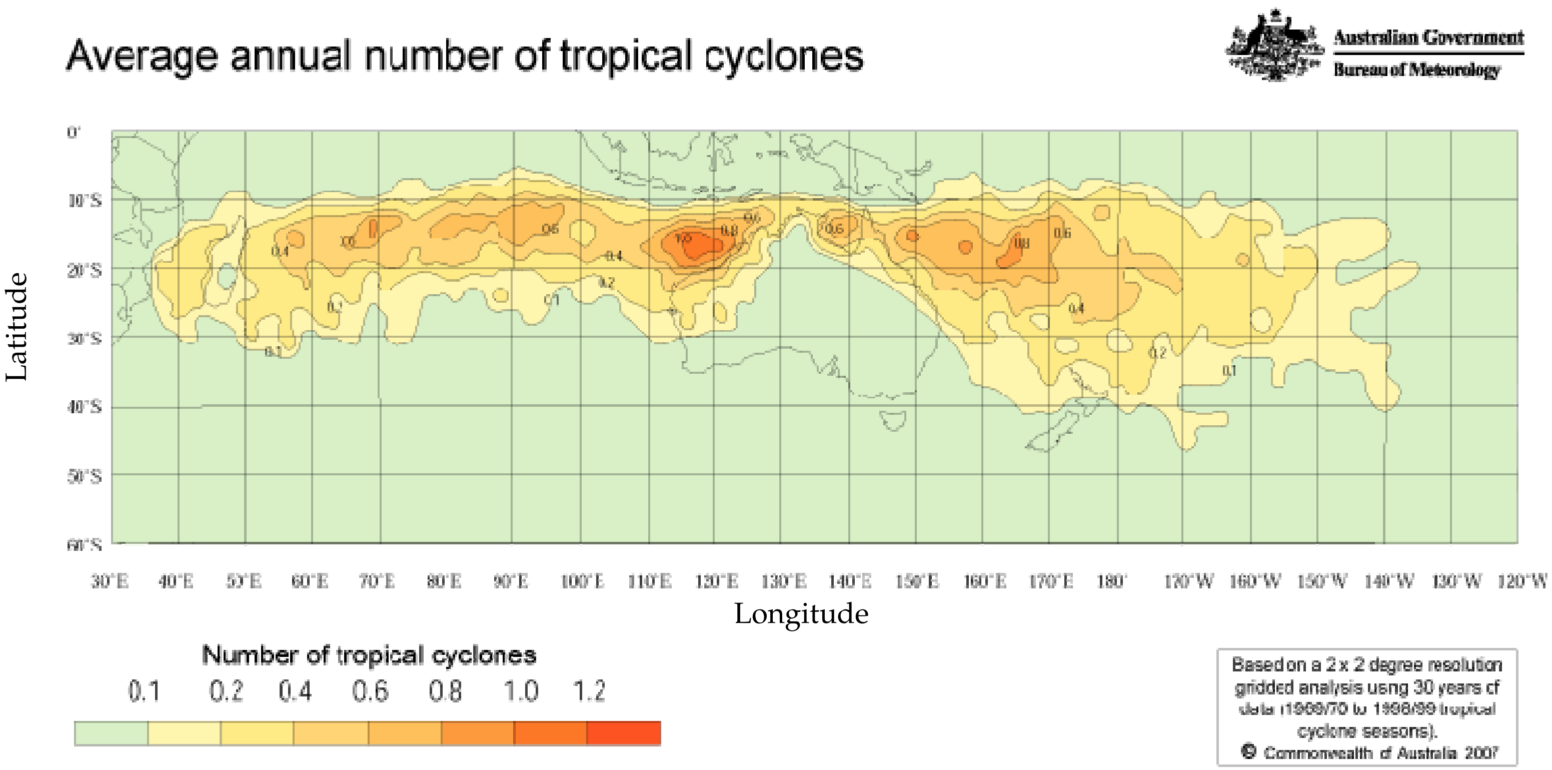

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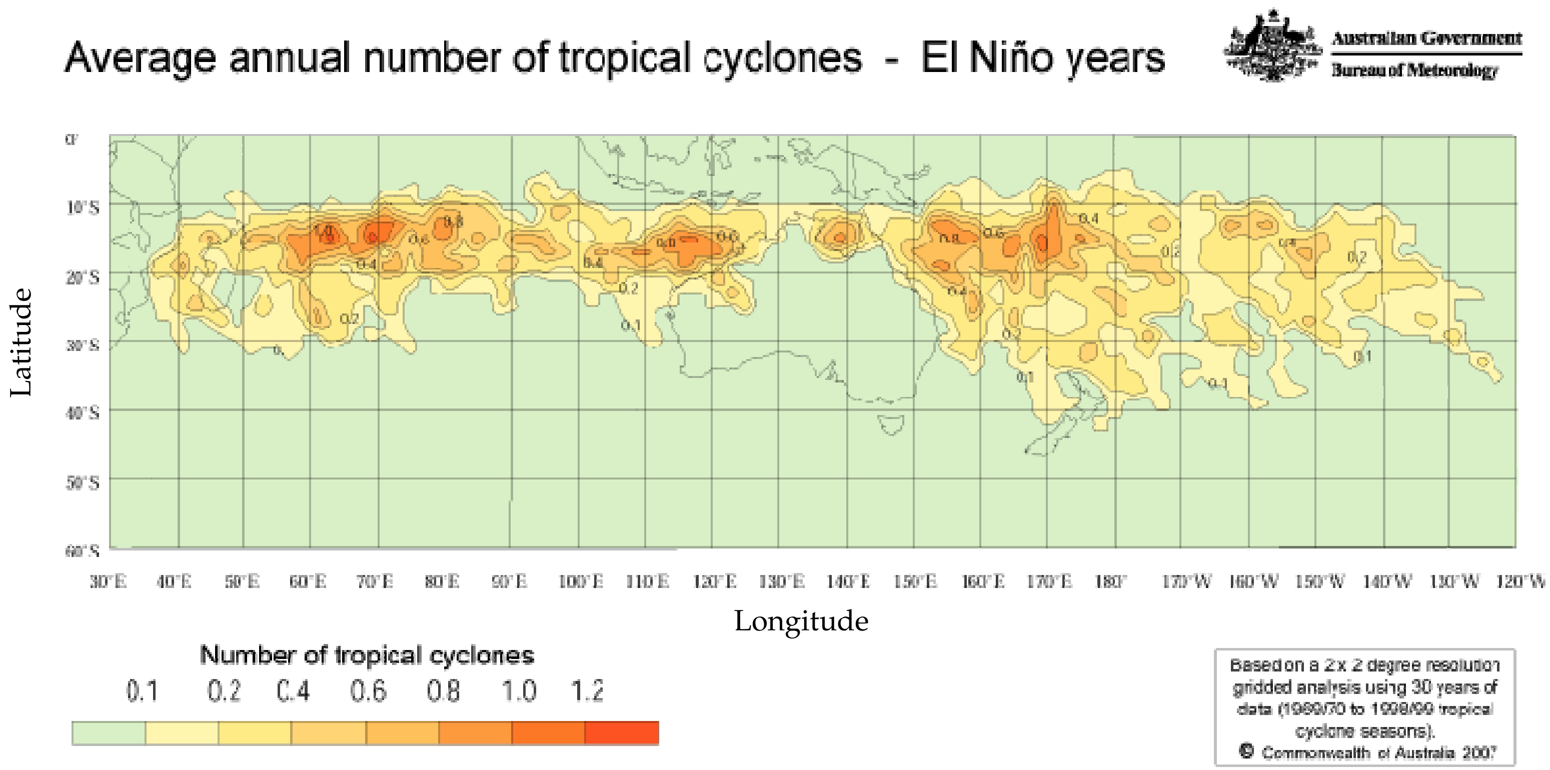

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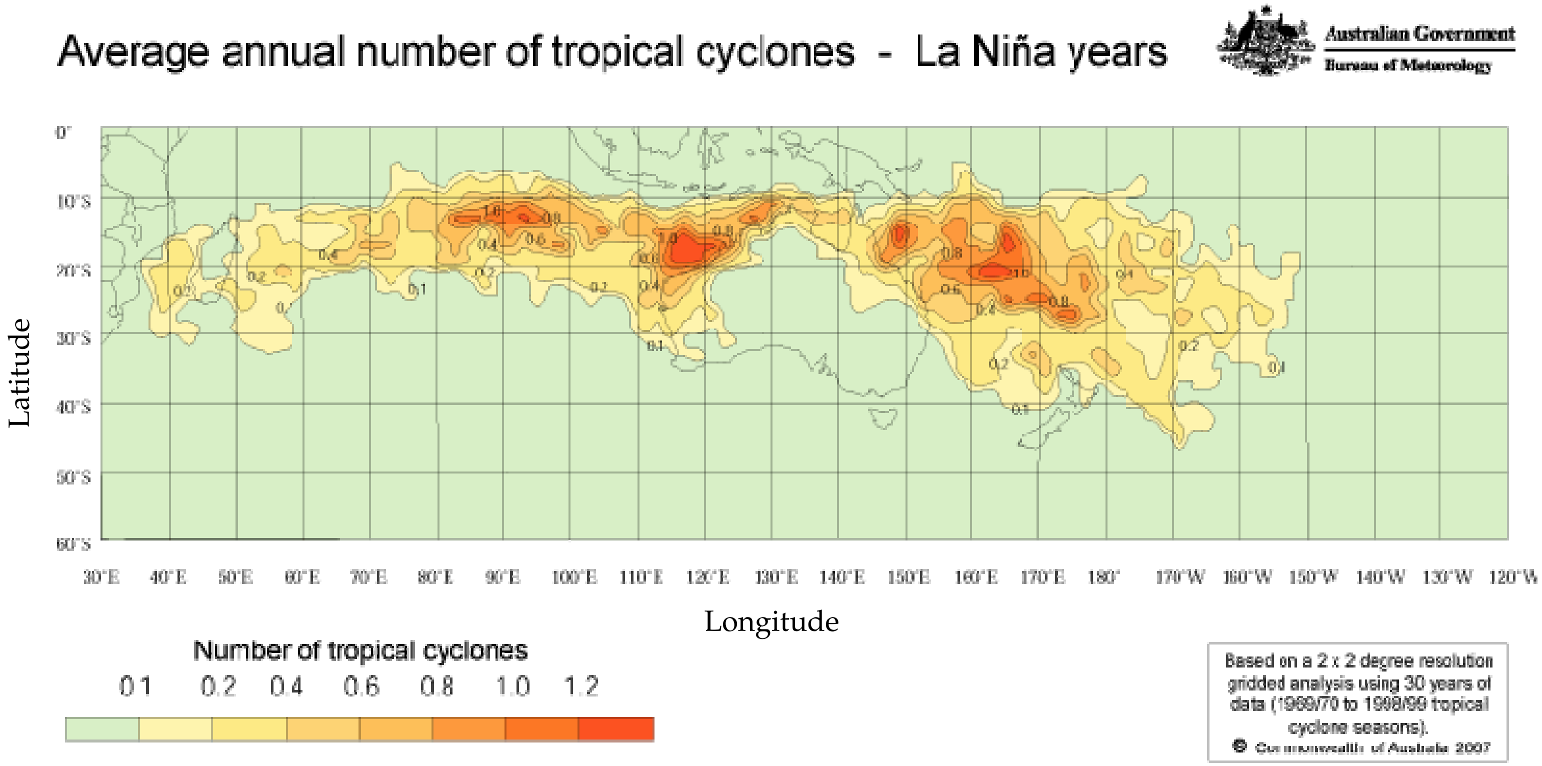

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Report to:

WorldFish Center

Abundance, Size Structure and Quality of Silver-lip Pearl Oysters in the Solomon Islands

FINAL

June 2008

The Ecology Lab Pty Ltd

Marine and Freshwater Studies

Abundance, Size Structure and Quality of Silver-lip Pearl Oysters in the Solomon Islands

June 2008

Report Prepared for:

WorldFish Center

Jalan Batu Maung

Batu Maung,

11960 Bayan Lepas,

Penang,

Malaysia

Report Prepared by:

The Ecology Lab Pty Ltd

4 Green Street

Brookvale, NSW, 2100

Phone: (02) 9907 4440

Report Number – 55/0607A

Report Status – Final 4 June 2008

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SUMMARY

The European Union has funded a project entitled 'Stimulating investment in pearl farming in the Solomon Islands'. The objective of this project is to provide offshore pearl companies with sufficient information to determine the potential for long-term investment in pearl farming in the Solomon Islands. The WorldFish Centre sub-contracted The Ecology Lab Pty to:

- participate in underwater visual census and remote video census of the major historical fishing grounds for silver-lip pearl oysters (*Pinctada maxima*) in the Solomon Islands;
- analyse data from these surveys and calculate the abundance of silver-lip pearl oyster stocks, the number of sustainable quotas of silver-lip pearl oysters that could be allocated for pearl farming and the proportion of oysters at each site with the preferred silver nacre; and
- prepare a report describing the results of the surveys and analyses performed.

Divers equipped with surface-supplied compressed air (hookah) conducted visual censuses of silver-lip oyster stocks on eight historical fishing grounds: Malaita, Marau Sound, Mboli Passage, Sandfly Passage, Telina Island, Kia and Waghina. These censuses were based on a hierarchical sampling design with four randomly-positioned transects being swum at three separate sites within each location. Individual sites with these locations were based on interviews with fishers who had previously taken part in commercial pearl collection. Based on those interviews, all locations had and still do support silver-lip pearl oysters, but exploitation was best developed at Kia and Waghina.

Silver-lip pearl oysters were found on 33 of the 96 transects surveyed, yielding a total of 117 oysters. Waghina, Kia and Mboli Passage (Narula Passage) had the largest populations, with mean densities of 1.23 ± 0.38, 1.03 ± 0.27 and 0.66 ± 0.27 pearl oysters per $400m^2$ transect. Pearl oysters were not found at Mbili Passage and Telina and were scarce (i.e. had an average density of <0.1 per 100 m long transect) at Malaita, Marau Sound and Sandfly Passage.

Pearl oysters varied in length from 164 to 278 mm and in width from 31 to 69 mm. 93% exceeded 175 mm in length and would thus generally be considered too large for pearl culture. The overall length range of the oysters at Kia was slightly smaller than that at Mboli Passage and Waghina, but the average length of oysters did not differ significantly among these locations.

The majority of oysters examined had high grade external shell characteristics; of the subset sacrificed for internal investigation 58% of them had gold mantle margins, 36% off-white margins and the remaining 6% had white margins.

Silver-lip pearl oysters were more abundant on coral rubble, gravel/rubble, sand/rubble and sand/shell/coral mixtures with swift water flow, than on mud, coarse sand and gravel habitats.

The remote video census was hampered by operational problems, hence the number of transects surveyed was not consistent across locations. In some instances, the images recorded were difficult to interpret. A total of nine "possible" live pearl oysters and two dead silver-lip pearl oysters were sighted across the video transects analysed. The identity of the "possible" oysters, however, could not be determined, because the objects were

overgrown by other biota. The maximum average number of "possible" live oysters found per transect was one, suggesting that these animals are also scarce at depths of 35-50m.

The low densities of silver-lip oysters observed in the underwater and remote visual censuses suggest that stocks have not recovered to sustainable levels since fishing was prohibited in 1994. The lack of small animals suggests that recruitment may have consistently failed during this period.

As pearl oysters change from male to female as they age, most of the oysters found during the current and previous surveys undertaken in the Solomon Islands are likely to have been female. The current assumed bias in the sex ratio may be partly responsible for a reduction in reproductive output and resulted in impaired, if not total recruitment failure.

If historical over-exploitation has led to poor recruitment, recovery of the populations is likely to remain either be very slow or non-existent. It should be noted that some of the black-lip pearl oyster stocks in the Cook Islands and French Polynesia, subjected to intense fishing during the late nineteenth and early twentieth centuries, had not recovered from over-exploitation by the 1980s. The fact that stocks in the Waghina region of the Solomon Islands have been subjected to three phases of exploitation suggests that some degree of recovery of fished stocks has occurred in the past. An alternative explanation for this phasing is that changes in fishing method over that period have enabled divers to access stocks in progressively deeper water.

In conclusion, exploitation of silver-lip pearl oysters for pearl culture is not an ecologically or commercially viable option at present, because of the paucity of the stocks and unfavourable size of the majority of oysters. If the silver-lip pearl oyster stocks in the Solomon Islands do eventually recover from the last phase of commercial exploitation, management strategies that protect the recovered population will need to be implemented to prevent overfishing prior to any further exploitation.

1.0 INTRODUCTION

1.1 Background and Aims

Pearl oysters are highly valuable commodities that are either fished or farmed throughout the Indo-Pacific region for their shells, pearls and meat. This resource has proved to be a valuable source of employment and export income for small, less-developed countries, particularly French Polynesia and the Cook Islands. In French Polynesia, the production and value of pearl oysters increased from 575 metric tons and US$37.77 million in 1990 to a peak of 11,364 metric tons and US$158.78 million in 2000 (SPC 2007). In the Cook Islands, the value of pearl oyster production over the same time period increased from NZ$4.9 million to NZ$18.4 million. At the peak of production, approximately 7000 and 450 people were employed in the industry in French Polynesia and the Cook Islands, respectively. Although production of pearl oysters in these regions has subsequently declined, the most recent figures indicate that production in the Cook Islands was valued at NZ$3.2 Million in 2004 and that from French Polynesia had a value of US$126.5 million in 2005. In the Cook Islands and French Polynesia, production is based entirely on cultivated black pearl (*Pinctada margaritifera*) stocks. Small-scale production of black pearl oysters also occurs in Solomon Islands, Fiji Islands, Marshall Islands, Tonga and the Federated States of Micronesia (SPC 2002). Silver-lip pearl oysters (*Pinctada maxima*), also known as white-lip or gold-lip pearl oyster) are farmed in Australia and Papua New Guinea, but not in the South Pacific.

The European Union has recently funded a project entitled 'Stimulating investment in pearl farming in Solomon Islands'. The primary objective of this project is to provide offshore pearl companies with sufficient information to determine the potential for long-term investment in pearl farming in Solomon Islands. Information on the following aspects is currently being compiled for this project:

- Publications on the availability and culture of black-lip pearl oysters in Solomon Islands;
- Availability and quality of silver-lip pearl oyster resources in Solomon Islands;
- Availability of suitable habitats and environmental conditions for the growth of black-lip and silver-lip pearl oysters in Solomon Islands and pearl-producing regions of the South Pacific;
- The investment climate in the Solomon Islands;
- Policy guidelines for the development of environmentally and financially sustainable pearl farming in the Solomon Islands; and
- Offshore pearl companies most likely to consider investing in pearl farming in Solomon Islands.

In February 2007, The WorldFish Center commissioned The Ecology Lab Pty Ltd to provide various consultancy services for the EU project including:

- Assist WorldFish staff conduct interviews with coastal communities to identify and map the historical major fishing grounds for silver-lip pearl oysters in Solomon Islands;

- Collaborate with WorldFish staff to develop sampling designs to obtain precise and accurate estimates of the density and size structure of silver-lip pearl oysters at up to 10 sites throughout Solomon Islands;
- Participate in underwater surveys at selected sites to obtain estimates of abundance, and sub-sample the oysters there to estimate size structure and nacre colour;
- Analyse data from the UVC and video surveys, and the sub-sampled oysters, at all sites to calculate:
  1) the abundance of silver-lip pearl oyster stocks at each site, and across all sites,
  2) the number of sustainable quotas of silver-lip pearl oysters that could be allocated for pearl farming within and across all sites, and
  3) the proportion of oysters at each site with the preferred silver nacre.
- Prepare a report on the abundance, size structure and variation in nacre colour of silver-lip pearl oysters in Solomon Islands, and the recommended number of sustainable fishing quotas that could be allocated for pearl farming based on data collected at all sites; and
- Prepare a manuscript for the Journal of Shellfish Research on the abundance, size structure and variation in nacre colour of silver-lip pearl oysters in Solomon Islands based on the UVC and video data, and sub-sampling, at all sites.

This report focuses on the abundance, size structure and variation in nacre colour of silver-lip pearl oysters in Solomon Islands, and the recommended number of sustainable fishing quotas that could be allocated for pearl farming based on data collected at all sites.

1.2 Existing Information

1.2.1 History of Exploitation

Natural pearl oyster populations in Solomon Islands have been exploited for at least two centuries (Colgan 1993). Three species: silver-lip (*Pinctada maxima*), black-lip (*Pinctada margaritifera*) and brown-lip pearl oysters (*Pteria penguin*) were exploited commercially for the nacre or mother–of–pearl (MOP) in their shells. The MOP was initially exported unprocessed to Japan, however, in 1990 button factories were established in Honiara (Richards *et al.* 1994).

Small-scale commercial exploitation of gold-lip pearl oyster began in 1916 and was carried out by Japanese hard hat divers based at Aratoba Island near Waghina until 1922 (Gauld 1975 in Colgan 1993). In 1968, the fishery at Aratoba Island was re-opened by the Palmer family based on Gizo. Fishing was done by hookah divers and Hamilton Channel, Waghina, Kia, Rob Roy Channel and Popu Passage were the major areas fished. A large silver-lip pearl oyster bed was also found at Ngella, but was decimated soon after by a disease outbreak (Gauld 1975 in Colgan 1993). Silver-lip pearl oysters were also found in Marau Sound. Attempts were also made to collect spat, but only black-lip pearl spat settled-out. At the peak of its operation, the Solomon Islands Mother of Pearl Company formed by the Palmer family employed 22 divers. The fishery was terminated in 1972 because of declining stocks resulting from overfishing, increased operational costs and a decline in MOP prices on world markets. In 1987, a pearl fishery employing divers of I-Kiribati origin commenced operations at Waghina (Colgan 1993). In 1994, the export of wild-caught black-lip and silver-lip pearl oysters was banned due to overexploitation (Kile 2000). In the decade prior to this, the annual exports of black-lip and silver-lip pearl shell varied between 15 and 44 tonnes and between 6 and 25 tonnes, respectively (Richard *et al*. 1994). The export statistics provided to the Solomons Islands Fisheries Division by MOP traders in Honiara indicate that most of the pearl shell exported came from the Waghina area (Colgan 1993).

1.2.2 Pearl Oyster Cultivation

There have also been several attempts to establish a pearl culture industry. The Palmer family, assisted by Stan Hynd, a CSIRO scientist, cultured pearls between 1968 and 1972, but ceased production due to problems with spat collection and breeding techniques (SPC 2002). In 1994, the International Centre for Living Aquatic Resource Management (ICLARM now the WorldFish Center) and the Fisheries Division of the Solomon Islands Government (now the Ministry for Fisheries and Marine Resources) commenced a large-scale black-lipped pearl oyster spat collection programme with a view to investigating pearl culture. The study involved the assessment of spatial and temporal variation in abundance of spat settling on artificial collectors deployed at 24 sites spanning 500 km of 'open' reef systems in the Solomon Islands (Friedman *et al*. 1998). This study showed that wild black-lip oyster spat collected in 'open' reef systems could form the basis of a culture industry, provided that predation can be controlled. The growth and survival of juveniles has also been assessed in lantern nets suspended from longlines at depths of 3-4 m at nine shallow water sites throughout the Solomon Islands and at depths of 9-12 m and 35-45 m within an area of the Gizo Lagoon (Friedman and Southgate 1999).

In 1996/1997, the WorldFish Center in collaboration with the Australian Centre for International Agricultural Research and the Solomon Islands' government initiated a program to culture high-quality black pearls in a sustainable manner in the Solomon Islands. A pilot farm was established near Gizo in the Western Province of the islands. The first crop of cultured pearls from the farm was auctioned for more than US$29,000 in September 2000 and the second crop auctioned in June 2004 raised over US$18,000 (WorldFish Center 2007). A report has recently been produced on past research and development on black-lip pearl oysters in Solomon Islands (Hawes and Messia 2007).

1.2.3 Previous Surveys of Pearl Oyster Stocks

In 1988, potential silver-lip pearl oyster resources in the Santa Isabel region were surveyed by three divers employed by Solomon Taiyo Ltd. A total of 49 silver-lip oysters were found over the two week survey with the majority coming from Kia and Port Praslin Passage. Most of these oysters were considered unsuitable for farming, because they were larger than 200 mm DVM (Nichols 1988 in Colgan 1993). In 1990, a six-day long survey conducted off Kia by two divers yielded 46 silver-lip oysters, most of which were again too large for pearl culture (Batty and Kile in Colgan 1993). In December 1990, a week-long survey of pearl oyster grounds at three depths targeted by commercial divers was carried out primarily in the Waghina area, but with two additional dives at Kia (Colgan 1993). The substratum and conspicuous benthic organisms found at each site were also noted. Only two oysters were found in the Waghina area at depths of 34-36 m and 28-31 m respectively, whereas ten individuals were found at Kia at depths between 39 m and 51m. These stock levels indicated that, at the time, there was no potential for commercial fishing or pearl culture in the Waghina area. Suitable habitat for silver-lip pearl oysters in the form of "garden bottom" characterised by sponges, soft corals and whip corals was fairly common, being recorded at approximately half the sites sampled at Waghina.

In 1993, ICLARM and the Solomon Islands Fisheries Division surveyed the abundance of black-lip pearl oysters around population centres on Guadalcanal, Malaita, Florida Islands, Russell Islands, New Georgia and Gizo and interviewed local villagers about the status of the stocks (Richards *et al.* 1994). The maximum abundance observed was 12 oysters per diver hour, but most encounter rates were in the order of 2-3 oysters per diver hour. The interviewees claimed that oyster stocks had declined considerably over the previous ten years.

In June 2004, The Nature Conservancy and Department of Fisheries and Marine Resources of the Solomon Islands Government conducted a "broad-brush" assessment of commercially important species, including pearl oysters, in the main archipelago. Sixty-six sites, stretching from Choiseul and Shortland Islands in the northwest to the Three Sisters and San Cristobal in the southeast, were surveyed over a 6 day period. Thirty-five sites were located in coral reef habitats on parts of islands exposed to direct wind and wave action. The other sites were generally in sheltered lagoons and bays. At most sites, both shallow (5-10 m deep) and deep (18-30 m) habitats were surveyed. In the shallow habitat, six 50 m long x 2 m wide transects laid over the terrace or slope in shallow habitats were surveyed per site. In the deep habitat, five 50 m long x 5 m wide transects laid parallel to the reef crest and over soft sediments or rubble were surveyed per site.

Black-lip (*Pinctada margaritifera*) and brown-lip (*Pteria penguin*) pearl oysters were collected in shallow and deep habitats and at sheltered and exposed locations, but no silver-lip pearl oysters were found. Black-lip pearl oysters were found in 36.4% of the shallow habitats and 4.8% of the deep habitats surveyed, whereas brown-lip pearl oysters were found in only 6.1% of the shallow habitats and 12.7% of the deep habitats surveyed. In the shallow habitat, similar total numbers of black-lip (39) and brown-lip (41) pearl oysters were found. However, in the deep habitat, brown-lip pearl oysters (40) were an order of magnitude more abundant than black-lip oysters (4). Black-lip oysters were equally abundant in sheltered and exposed locations, but brown-lip oysters were more abundant in sheltered locations. The respective average densities (no./ha) of black lip and brown-lip oysters was 9 and 11 in shallow habitats and 0.4 and 4 in deep habitats. In the shallow habitat, the mean number of black-lip oysters per transect was two-three times greater in Mbili Passage in Marovo Lagoon (Western Province), Falabulu Island in Langalanga Lagoon (Malaita) and Gavutu in Ngella (between Malaita and Guadalcanal) than at the other sites. Most of the black-lip oysters found in this habitat were large animals, with a DVM > 12 cm. The greatest density of brown-lip oysters was found at Airasia in Are' Are Lagoon.

2.0 STUDY METHODS

2.1 Preliminary Investigations and Site Selection

2.1.1 Pre-Survey Visit to Island Communities

An essential part of the study was a visit to communities, selected on the basis of their location in relation to previous exploitation of silver-lip pearl oysters. All sites were visited at least two weeks before the main survey took place. At each community, meetings were held to inform people of the study, to ask permission to work in customary waters and to conduct interviews regarding historical distribution of pearl oysters, likely current distribution (and, hence prospective sampling sites) and occurrence of any recent or ongoing exploitation. During each interview, the study team sought to have at least one person present who could speak/translate pidgeon and the local dialect. A questionnaire (Appendix 1) was used to structure the interviews and a minimum of five local people who expressed personal experience of pearl oyster fishing were interviewed. Where possible, scientists undertook brief dives at likely sites using snorkel and/or scuba.

2.1.2 Current Exploitation

In order to assess the likelihood of stock recovery, it is essential to have some knowledge of any recent or ongoing exploitation. This was addressed by interviews with local communities, as described above. In addition, project participants from Solomon Island Fisheries examined centralised records in Honiara for any evidence of seizures of pearl oysters over the past five to ten years.

2.1.3 Site Selection

Eight major fishing grounds for silver-lip pearl oysters were identified during the course of preliminary interviews with coastal communities. Scientists also undertook brief dives at likely sites using scuba and/or snorkel. The grounds selected were those included the following:

- Malaita Island, Kau (9°S 161°E);
- Marau Sound (9° S 160°E) at the eastern end of Guadalcanal;
- Mboli Passage (9°S 160°E) a narrow division between two small islands, Nggela Sule and Nggele Pile (formerly part of the Florida Islands) situated between the major islands of Guadalcanal and Malaita;
- Sandfly Passage (8° 59.869′ S, 160° 6.059′E) which separates Mbokonumbela Island from Nggela Sule in the Florida Island Group;
- Mbili Passage (8°40.574′S, 158° 11.534′E) an eastern entrance to Marovo Lagoon, including the area enclosed by Sanihulumu Island;
- Telina Island (8°31.168′S, 158° 11.534′ E) in Marovo Lagoon off the northern coast of Vangunu Island;
- Kia (7° 34′S, 158° 37′ E) at the western tip of Isabel Island; and
- Waghina Island (7• 26'S, 157• 42' E) situated SE of Choiseul Island.

The relative position of each location is shown in Figure 1. Malaita and Marau were surveyed in April 2007, as were some transects at Mboli Passage (Narula Passage). Sandfly Passage, Mbili Passage and Telina were surveyed in May 2007 and Kia and Waghina were surveyed in October 2007. The sites selected for investigation within each location were places that the interviewees reported as historically and/or currently most favourable for silver-lip pearl oysters. A local fisher or fisheries officer accompanied the survey boat to assist with specific local knowledge and finding the recommended sites.

2.2 Underwater Visual Census

At each location, three sites were surveyed by pairs of divers towed very slowly beneath a small outboard boat and supplied with air via hoses from a compressor in the boat ("hookah" system). Pearl oysters were collected by the divers from four randomly-positioned 4 m wide transects. The latitude and longitude at the beginning and end of each transect, time and duration of the dive, maximum bottom depth and the type of substrata found along each transect were recorded (Appendix 1). Position and depth were taken from a Hummingbird 737 combination GPS/Echo sounder. Transects varied in length from 69 to 725 m and in maximum depth from 12.4 to 40.5 m, with the average being 305 m long and 27.3 m deep. It should be noted that these lengths are derived from straight line interpolations between transect start and finish points. As far as was possible divers were towed in a straight line and we have assumed that each diver adhered to a 2 m wide transect.

Oysters found by the divers were placed in mesh bags and returned to the boat. On the surface, the length and width of each pearl oyster shell was measured to the nearest millimetre using callipers and recorded. The quality of the shell exterior was assessed visually as being either high grade, of suspect quality or unwanted. The criteria used in this assessment were related to the Australian standard of B FAQ and C respectively (Hart and Friedman 2004). At each site up to ten, haphazardly selected shell were sacrificed to allow the colour of the margin and centre of the nacreous layer to be assessed. Ten pearl oysters from three locations were taken at (Kia, Waghina and Mboli) but only five were collected at Marau, while only a single shell was available from Malaita. All of these shells were photographed and have been archived at the Nusa Tupe Research Station of the WorldFish Center.

2.3 Remote Video Census

Remote video censuses were undertaken at Malaita (Kau), Marau, Sandfly Passage, Kia and Waghina. The system comprised a Deep Blue Pro II colour video camera mounted onto an aluminium sled and connected to a Sony VRD-VC30 DVD recorder and a 45M068X LCD screen. Two water-proof laser pointers were attached to the camera and aligned in parallel, 160 mm apart. These spots were readily viewable under all lighting conditions and allowed dimensional calibration of the images. Tows were initially planned for 30 minutes, but at Malaita and Marau this was found to be optimistic. In practice a series of 10 minute tows was found to be most effective in allowing straight line navigation, minimum disruption from encounters with irregular bottoms and ensuring data security. After Marau, we attempted to obtain three ten minute tows from each of three locations. Where possible we targeted a depth range deeper than the dive tows, typically 40-50 m. At those locations where video treansects were made, the GPS co-ordinates (latitude and longitude), duration of tow, bottom time, depth range surveyed and length of each transect were noted (Appendix 2).

A number of operational problems were encountered during the censuses, including strong currents that exceeded optimal imaging speed, irregular terrain that resulted in snagging and/or flipping of the camera and battery failure, the last of which resulted in the loss of data. Problems were also encountered when some of the video material from Malaita and Sandfly Passage was transcribed onto DVD. Operating this complex electronic equipment from a small boat was demanding when rain fell. The number of transects surveyed at each location and the quality of the images consequently varied markedly (Appendix 2).

On return to Australia, DVDs were viewed on a computer screen using the software package Power-DVD. The quality of the video material varied, with some sections being either difficult or impossible to analyse, because the camera had been towed too fast or had been positioned too high above the substratum or the water was silty and visibility was poor. The types of substrata observed along each transect were recorded and any organisms resembling pearl oysters were counted and measured. Measurements were taken relative to the 160 mm distance between the two laser spots projected from the camera, when these were visible.

2.4 Statistical Methods

The survey was designed so that nested analyses of variance could be used to assess the significance of variation in the density of silver-lip pearl oysters among and within fishing grounds. Due to the absence of pearl oysters on some fishing grounds and their scarcity at others, these analyses were restricted to Mboli Passage, Kia and Waghina, where pearl oysters were relatively abundant. In these analyses, location was considered a fixed factor, whereas sites and transects were random factors. These analyses were based on densities of oysters per 400 m^2 transect (i.e. they were standardised to compensate for differences in the length of transect surveyed). Data were checked for homogeneity of variances using Cochran's *C* Test prior to doing the nested ANOVA. Student Newman Keuls (SNK) tests were used to identify which levels of significant factors differed. Further details of these analytical procedures are available in Underwood (1997). One-way analysis of variance was used to compare the mean lengths of oysters among the three locations.

2.5 Estimates of Population Size

The size of the silver-lip oyster populations at Kia, Mboli Passage and Waghina, the fishing grounds with the most abundant stocks, were estimated as follows:

1. First, raw counts per transect were corrected for sampling error on this type of sea floor by multiplying by 2.7. This is based on the assumption that collecting efficiency during the survey was similar to that for Australian divers working over similar habitats (i.e. 37%) (Hart and Friedman 2004), in practice the efficiency of the divers used, who were inexperienced in pearl survey my have been less than this resulting in an underestimate of abundance;
2. Second, corrected counts per 400 m^2 transect were multiplied by 25 to give estimates per hectare; and
3. Finally, densities per hectare were multiplied by estimates of the total habitat area available at each locality derived from MaxSea digital bathymetric charts.

These calculations were based solely on the density estimates derived from underwater visual census, because of the uncertainty about the identification of oysters on the remote video censuses.

3.0 RESULTS

3.1 Recent and Ongoing Exploitation of Pearl Oysters

The results of the interviews undertaken with island communities are summarised in Appendix 3. The key information obtained from each community about recent and ongoing exploitation and the current distribution of silver-lip oysters is outlined below.

3.1.1. Recent and Ongoing Exploitation

The respondents indicated that small amounts of shell are still collected at Marau, Mboli Passage, Sandfly Passage and Maramasike (Malaita). These are used locally as jewellery and/or shell money. They also mentioned that there is a local market for oyster shell at Maramasike (Malaita) and that some of the divers at Kia are collecting silver-lip oysters and storing them near their houses in the hope that the fishery will be re-opened. The respondents at Waghina indicated that big harvests of pearl oysters have occasionally been made since the ban and the shell sold to illegal exporters.

3.1.2 Current Distribution

The Waghina community indicated that plenty of silver-lip oysters are available and that the best places to find them are throughout Hamilton Channel, in the narrow channel at Ngosele and in the channel running from Kia towards Waghina.

The respondents from Kia indicated that silver-lip oysters can still be found at shallow depths and that they occur on a variety of substrata, including mud and broken coral. They also mentioned that oysters can be found in the small channel at Kakadeke at depths of 10-20 m.

According to the Marovo (Telina/Mbili) community, silver-lip oysters can be found in almost every channel between the islands, at depths greater than 20 m and sometimes occur in good numbers. Silver-lip oysters were also reported to occur on stony substrata in Mbili Passage and in nearby 30 m deep channels.

At Marau, silver-lip oysters were reported to be widespread and present in lagoons, passages and open water. The shallow Suukitahi Passage, the slopes of the passes between the islands and an area NE of Taiaru Reef were reported to be good fishing sites.

The interviewees at Ngella, indicated that shell is taken from the water at the northern end of Mboli Passage and in the area to the east and west of the passage where it spills out into the open sea. At Mboli Passage itself, shell collecting begins part way up the passage (from Honiara end) and extends right up to the mangroves. It was reported that no shells occur at the southern part of Mboli Passage nor where it opens to the sea. At Sandfly Passage, shell is taken in the bays and slopes to north and south, rather than in the centre which is deep. The favoured locations are around Mbike Island and the promontory to the north of this (Hanipana Pt), Roderick Dhu Bay and Haroro Bay. The respondents also mentioned that shell occurred in Hanesavo Harbour and the passage running NE/SW to the E of Mangalonga Island, to the NW of Sandfly Passage.

Three collecting areas were identified on the east and west sides of the northern mouth of Maramasike Passage.

3.2 Underwater Visual Census

3.2.1 Abundance

Silver-lip pearl oysters were found on 33 of the 96 transects surveyed, yielding a total of 117 oysters. Waghina, Kia and Mboli Passage (Narula Passage), had the largest populations, with mean densities of 1.23 ± 0.38, 1.03 ± 0.27 and 0.66 ± 0.27 pearl oysters per $400m^2$ transect, respectively (Figure 2). Pearl oysters were not found at Mbili Passage and Telina 1 and were scarce (i.e. had an average density of <0.1 per 100 m long transect) at Malaita, Marau Sound and Sandfly Passage. Oysters were found in a variety of habitats, including mud, sand, gravel, coral rubble and various mixtures thereof. The greatest densities were found on transects composed of coral rubble, gravel/rubble, sand/rubble and sand/shell/coral (Appendix 1).

Significant differences in the density of pearl oysters were evident among some of the sites at Kia and Waghina, but not among those at Mboli Passage (Figure 3). Differences in density among locations were not significant (Table 1). Given the low power of the ANOVA test and relatively high proportion of transects with no oysters it is difficult to draw any firm conclusions about differences at the scale of sites and lack of difference at the scale of locations.

3.2.2 Population Size Structure

The pearl oysters collected varied in length from 164 to 278 mm and in width from 31 to 69 mm. The mean (± S.E.) length and width was 219 ± 2.2 mm and 49 ± 0.8 mm, respectively. More than 80% of oysters were between 191 and 240 mm long and 36 to 60 mm wide (Figures 4a and 4b, respectively).

The mean, median, minimum and maximum length and widths of pearl oysters at Mboli Passage, Kia and Waghina are presented in Table 2. Although the overall length range of the oysters at Kia was slightly smaller than that at Mboli Passage and Waghina (Figure 5), the average length of oysters was not significantly different among the three locations (Table 3a). The width range of the oysters at Kia (31 - 60 mm) was also slightly smaller than that at Mboli Passage 2 (35 - 69 mm) and Waghina (31 - 67 mm) (Figure 6), but differences in mean widths among locations were not significant (Table 3b). It is, however, worth noting that the size frequency distribution of the oysters from Mboli Passage was positively-skewed (0.713), whereas that for Kia was negatively-skewed (-0.731) and that for Waghina was close to symmetrical (-0.088) (Figures 5 and 6).

3.2.3 Quality and Colour of Shell and Nacre

Most (87.3%) of the pearl oysters examined had high grade for external shell (Grade 1). The shell quality of the remainder was suspect (Grade 2), but no unwanted (Grade 3) shells were encountered. Figure 7 shows that a larger proportion of suspect shells were collected from Mboli Passage than from Kia and Waghina. Of the subset of shell that were sacrificed to assess nacre, all had white nacre in the middle, though the margins of the nacreous layer, were a mix of white, off-white or gold in colour (Plate 1). Shells with a white margin were scarce, comprising only 6% of the oysters examined, with all of these individuals being collected at Kia. Approximately 36% of the shells had off-white margins while the remaining 58% had gold margins. Oysters with gold margins predominated at Kia, Waghina and Marau, but those with off-white margins did so at Mboli (Figure 8).

3.3 Remote Video Census

Eleven objects that could be "possible" pearl oysters were sighted across the video transects analysed. Two of these were dead silver-lip pearl oyster shells lying open on the seabed. "Possible" oysters that appeared to be alive were seen on only nine transects, with only one specimen being evident per transect. Three "possible" oysters were found along the set of transects surveyed at Kia and Waghina, whereas two "possible" oysters were observed off Malaita and Sandfly Passage. The identity of the "possible" oysters could not be confirmed, because the objects were overgrown by other biota. These animals were found on silty sand, living reef, a mixture of coral sand and rubble and on coral sand with live coral rubble. Only seven of the "possible" oysters could be measured relative to the laser guides; the five live specimens varied in length from 68 - 116 mm, whereas the two dead specimens were 36 mm and 140 mm long. Overall this yields a maximum video census estimate of 8 possible oysters per 400 m^2.

Ten types of benthic substrata were distinguished during the analysis of remote video transects. The primary components identified were silty sand, coral sand, dead reef, low rubble, coarse rubble, medium rubble, heavy rubble and living reef. The substratum at two sites off Malaita was dominated by silty sand, except for one of the transects at Site 1, which was composed of dead reef. The substratum at Site 3, Malaita was characterised by coral sand. The substratum at Sites 1 and 2, Sandfly Passage were also dominated by silty sand, but that off Site 3 consisted of either coral sand, a mixture of coral sand and rubble or living reef. The substratum at Site 1, Kia consisted of silty sand or silty sand plus low rubble, while that at Site 3 was composed of either silty sand or silty sand plus heavy rubble. The substratum at Site 2, Kia was quite different, consisting of either coarse sand and medium rubble, coral sand and living coral or living reef. The substratum at Waghina consisted of a mixture of coral sand and various grades of rubble.

3.4 Estimates of Population Size

The total area of potential pearl oyster habitat at Kia, Mboli Passage and Waghina was estimated to be approximately 2000, 1250 and 4163 hectares, respectively (Figures 9 - 11). These areas were estimated to support a total of 136,000 ±, 42,016, 55,688 ± 14,598 and 345,529 ± 141, 353 silver-lip pearl oysters, respectively. It should, however, be noted that oysters < 175 mm, the size preferred by pearl farmers, comprised about 3.6% of the total, with total estimates being 1114 (4.3%) at Kia, 0 in Mboli Passage and 6,910 (5.4%) at Waghina.

3.5 Number of Sustainable Quotas

The first step in a sustainable quota management system for silver-lip oysters is the setting of an annual total allowable catch (TAC). The latter is normally based on the information that is available about the abundance, size structure, recruitment, growth, reproduction, and mortality of the species. For the silver-lip oyster fishery to be sustainable, the loss of biomass due to natural mortality plus fishing mortality must not exceed the increase in biomass due to recruitment of smaller individuals into the fishery, growth and reproduction. Given the small size of the silver-lip oysters stocks (and large size of individuals within the stocks) at present and lack of information on recruitment, growth, reproduction and mortality, it is not feasible to determine a TAC or allocate sustainable quotas to potential fishers at this time.

On the other hand it may feasible to gather some silver-lip pearl oysters to establish a hatchery with a view to restock habitats in future. This could entail collection of small numbers (say, < 100) of mature females, which constitute the majority of the existing stock, and importation of some males into Solomon Islands.

4.0 DISCUSSION

The current surveys undertaken by divers indicated that silver-lip pearl oysters were present at six of the eight historical fishing areas sampled and that densities at Waghina, Kia and Mboli Passage (Narula Passage) were considerably greater than those at Malaita, Marau Sound and Sandfly Passage. However, the maximum average density within any one location was less than 1.25 animals per 400 m^2 and none of these stocks could be considered commercially significant. The highest density recorded per 400 m^2 transect was 12.4 and occurred on Transect 1, Site 2, Mboli Passage (Appendix 1). The remote video censuses indicated that pearl oysters may also be present in deeper water at Kia, Waghina, Malaita and Sandfly Passage, however, even here the "possible" pearl oysters were present at low densities. The low densities of silver-lip oysters observed are consistent with previous surveys undertaken in Kia and Waghina in the late 1980's and early 1990's (Colgan, 1993). While those surveys used different sites and different methods and are not strictly comparable, they recovered approximately 50 shells in a week of diving. The current survey suggests that stocks have either recovered little since fishing was prohibited in 1994 or that they did recover, but have subsequently been depleted by natural mortality or illegal fishing.

There is certainly evidence that natural mortality can reduce silver-lip pearl oyster stocks, with Ngella being decimated by disease in the early 1970s (Gauld 1975 in Colgan 1993) and reports of a "red tide" causing heavy mortality of silver-lip oysters at Kia in 1971 (Colgan 1993), but it is not known whether these have caused large-scale natural mortality in recent years. No anecdotal evidence of disease was offered in interviews with local villagers, who did however confirm that fishing of pearl oysters has taken place at both Waghina and Kia Passage since exploitation was prohibited. Illegal exports of silver-lip and black-lip pearl oysters from these locations have been intercepted by Fisheries, however, it is not known how much shell was collected (J. Leqata pers. comm.).

The population structure that we observed was biased towards large individuals, with an overall median size of 210 mm. Pearl farmers in Western Australia prefer oysters around the 125 mm size class to those in the 150-160 mm size classes for round pearl production (Fletcher *et al.* 2006) and will not harvest pearl oysters larger than 175 mm DVM. We found no shell smaller than 160 mm and overall only 4.2% were less than 175 mm DVM. The majority of oysters found during the current survey were beyond the limit currently considered most suitable for pearl farming. Previous surveys had also indicated that most of the oysters found were >200 mm in DVM and too large for pearl culture (Nichols 1988 and Batty and Kile 1990 in Colgan 1993).

The simplest explanation for the presence of small populations of large individuals, in the current survey is a persistent failure of reproduction, spat settlement and/or recruitment over the past decade. The reproductive success of many marine invertebrates is episodic, with a low background level of recruitment occasionally being interrupted by very good years (Gaines et al. 1985; Dye 1990; McShane and Smith 1991; Hughes and Tanner 2000). The size frequency distributions of some of the fished silver-lip oyster populations in Australia suggest that recruitment is also episodic in some populations of pearl oysters (Hart and Friedman 2004). In broadcast spawners, the distribution and abundance of adults has a profound influence on individual reproductive success (Levitan *et al.* 1992). The reduction in abundance and greater spacing of adult oysters brought about by exploitation is a factor that may have contributed to poor reproductive success and low larval production. In some heavily exploited broadcast spawners, recruitment may rely on either natural or human induced refuge populations that act as reservoirs for larval production (Clareboudt 1999).

Prolonged recruitment failure in populations of silver-lip pearl oysters is likely to affect the sex ratio. Pearl oysters are protandrous hermaphrodites (i.e. they change sex from male to female as they mature) and most of the oysters found during the current and previous surveys undertaken in the Solomon Islands are likely to have been female. In Western Australia, animals develop into males at a length of 110-120 mm, but by the time they reach 170 mm approximately 50% of individuals are female and by the time they reach 190 mm they are >9 years old and all female (Fletcher *et al.* 2006). The temporal/size aspects of sex change in animals at Solomon Islands is not known, and gonads samples were not taken in this or earlier surveys, but the dominance of old, large individuals in all of the surveys undertaken to date suggest that sex ratio may be a potential barrier to population growth and is worthy of further investigation. The susceptibility of pearl oyster stocks to such recruitment over-fishing has been noted previously (Sims 1992).

If over-exploitation, resulting in low density and a biased sex ratio, has caused a marked decline in the number of recruits, recovery of the fished population is likely to either be very slow or non-existent (Jennings *et al*. 2003). The three phases of exploitation to which stocks in the Waghina region have been subjected implies that some degree of recovery of fished stocks has occurred in the past. The phasing could also simply reflect a change in fishing method, with divers in the latter phase using hookah equipment to access stocks in deeper water. If the silver-lip pearl oyster stocks in the Solomon Islands eventually recover from the last phase of commercial exploitation, fisheries management strategies will need to be implemented to protect the recovered populations to prevent recruitment overfishing prior to any further form of exploitation. One option for doing this would be to establish a network of spawner sanctuaries within defined fishing zones or fully-protected, permanent marine reserves (Tegner 1993; Peterson 2002). If healthy stocks can be located in other regions of the Solomon Islands, the possibility of facilitating the recovery of depleted populations by means of stock enhancement programmes should be investigated. Stocks could be enhanced by either releasing juveniles raised in hatcheries, transplanting juveniles from naturally occurring stocks into areas where recruitment is low but conditions for growth and survival are good or by using translocated broodstock to enhance larval production (Bell *et al.* 2005).

However, it is possible to reduce populations to points at which recovery is barely possible. In some of the atolls in the Cook Islands and French Polynesia, where black-lip pearl oysters were subjected to intense fishing during the late nineteenth and early twentieth centuries, stocks had not recovered from over-exploitation by the 1980s (Intes 1984; Sims 1990). The situation at Suwarrow in the Cook Islands, in fact, became so bad in the early 1990s that oysters were imported from Penrhyn to assist in the recovery of this population (Dalzell and Adams 1996). Sims (1992) suggested that rapid water exchange and loss of planktonic larvae through passages in the reef probably contributed to the lack or recovery of black-lip pearl oyster populations in the open atoll systems of the Cook Islands. In more "open" coral reef systems, such as those of Solomon Islands, dispersal of larvae from unexploited stocks and refuge stocks beyond the depths in which most divers operate, could lead to recovery of some stocks, albeit at a slow rate.

The present survey indicated that silver-lip pearl oysters occurred on a variety of benthic substrata, including mud, sand, gravel, coral rubble and various mixtures thereof, but were generally more abundant in areas characterised by coral rubble, gravel/rubble, sand/rubble and sand/shell/coral and with a fast flow of water over them. Silver-lip pearl oyster spat select a hard surface for initial attachment (Gervis and Sims 1992; Wells and Jernakoff 2006) and individuals found on soft sediments are thought to have been displaced to these habitats after detachment of their byssus (Gervis and Sims 1992) or to be attached to broken shells, coral fragments or pebbles embedded in the sediment (Hynd 1957 in Colgan 1993).

The largest area of good habitat appears to be through Hamilton Channel at Waghina and it is this that probably makes it the best potential site from silver-lip, even though it currently has a low population density. However, the economic production of pearls is dependent on the availability of suitable culture sites, reliable sources of oysters, funding to establish and operate the farm, grafting technicians and a market for the pearls. The layman's manual on basic methods of pearl farming indicates that it is not profitable to hire a grafting technician unless there are at least 3,000 pearl oysters of the right size and condition in which to implant nuclei (Haws 2002). As the three major fishing grounds surveyed in the Solomon Islands were estimated to contain between 1,392 and 8,638 silver-lip pearl oysters of an appropriate size, it would appear that there are insufficient stocks at present to support a viable pearl production industry based on the harvest of wild shell and that it is inappropriate at this stage to make any quota available for commercial operations.

5.0 CONCLUSIONS

The interviews with coastal communities provided information on the location of historical and present day fishing grounds for silver-lip pearl oysters and some areas of Solomon Islands where silver-lip oysters have recently been observed. The underwater visual censuses undertaken at the eight historical fishing grounds indicated that the density of silver-lip pearl oysters was generally low and that most animals were larger than the size considered suitable for pearl farming. The sub-samples that were examined had high quality shell with white nacre in the middle of the interior and gold, white, or off-white margins. Kia, Mboli Passage and Waghina, the three major fishing grounds surveyed, were estimated to contain between 1,392 and 8,638 silver-lip pearl oysters of an appropriate size for pearl farming. The paucity of the stocks examined and unfavourable size of the majority of oysters suggest that commercial exploitation of wild silver-lip pearl oysters for pearl culture is not an ecologically or economically viable option at present.

6.0 ACKNOWLEDGEMENTS

This report was written by Drs Theresa Dye, Marcus Lincoln Smith, Ian Hawes and Jon Leqata. Transects were surveyed by Francis Kera, Ian Hawes, Alex Meloty, Patrick Mesia., Ronnie Posada, Peter, Rex, Anne-Maree Schwarz, Mason Tauku, Regon Warren and Marcus Lincoln Smith. Ian Hawes examined the nacreous layers of the shells and Jon Leqata confirmed reports of recent illegal harvesting.

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TABLES

Table 1. Results of analysis of variance comparing densities of silver-lip pearl oysters among and within the fishing grounds at Mboli Passage, Kia and Waghina.

Table 2. Mean (± S.E.), median, maximum and minimum shell lengths and widths of the silver-lip oysters collected at Mboli Passage (n = 28), Kia (n = 46) and Waghina (n = 37).

Table 3. Results of analysis of variance comparing (a) lengths and (b) widths of silver-lip pearl oyster shells found at Mboli Passage, Kia and Waghina.

Table 1. Results of analysis of variance comparing densities of silver-lip pearl oysters among and within the fishing grounds at Mboli Passage, Kia and Waghina.

Data: Untransformed
Cochran's *C* = 0.315, ns

Source of variation	SS	DF	MS	F	P	F versus
Fishing grounds = FG	1.995	2	0.998	0.380	0.697	Sites(FG)
Sites(FG)	15.580	6	2.597	3.170	0.017	Residual
Residual	22.090	27	0.818			
Total	39.665	35				

Table 2. Mean (± S.E.), median, maximum and minimum shell lengths and widths of the silver-lip oysters collected at Mboli Passage (*n* = 28), Kia (*n* = 46) and Waghina (*n* = 37).

(a) Shell lengths

Location	Shell Lengths (mm)			
	Mean (± S.E.)	Median	Minimum	Maximum
Mboli Passage	218±4	213	185	278
Kia	221±3	225.5	167	255
Waghina	217±4	217	164	268

(b) Shell widths

Location	Shell Widths (mm)			
	Mean (± S.E.)	Median	Minimum	Maximum
Mboli Passage	48±2	46.5	35	69
Kia	50±1	52	31	60
Waghina	50±1	47	31	67

Table 3. Results of analysis of variance comparing (a) lengths and (b) widths of silver-lip pearl oyster shells found at Mboli Passage, Kia and Waghina.

(a) Shell lengths

Source of Variation	SS	df	MS	F	P
Between Locations	339.851	2	169.925	0.307	0.736
Within Locations	59823.122	108	553.918		
Total	60162.973	110			

(b) Shell widths

Source of Variation	SS	df	MS	F	P
Between Locations	196.248	2	98.124	1.387	0.254
Within Locations	7638.779	108	70.729		
Total	7835.027	110			

FIGURES

Figure 1. Google Earth image showing the relative position of the fishing grounds surveyed in the Solomon Islands.

Figure 2. Mean (± S.E.) densities of silver-lip pearl oysters per 400 m^2 transect at each fishing ground.

Figure 3. Mean (± S.E.) densities of silver-lip pearl oysters per 400 m^2 transect at the sites surveyed at Mboli Passage, Kia and Waghina.

Figure 4. Frequency distribution of (a) lengths and (b) widths of silver-lip pearl oysters combined across the eight fishing grounds.

Figure 5. Length frequency distribution of silver-lip pearl oysters found at (a) Mboli Passage (b) Kia and (c) Waghina.

Figure 6. Width frequency distribution of silver-lip pearl oysters found at (a) Mboli Passage (b) Kia and (c) Waghina.

Figure 7. Percentage of shells from Mboli Passage, Kia and Whagina classified as having either high or suspect external shell.

Figure 8. Proportion of shells collected from Kia, Waghina, Mboli Passage, Marau and Malaita with white (white bar), gold (pale grey bar) and off-white (dark grey bar) margins along the nacreous layer of the shell.

Figure 9. Extract from MaxSea chart showing potential habitat for pearl oysters at Kia.

Figure 10. Extract from MaxSea chart showing potential habitat for pearl oysters in Mboli Passage.

Figure 11. Extract from MaxSea chart showing potential habitat for pearl oysters at Waghina.

Figure 1. Google Earth image showing the relative position of the fishing grounds sampled in the Solomon Islands. 1. Kau, Malaita; 2. Marau; 3. Mboli Passage; 4. Sandfly Passage; 5. Mbili Passage; 6. Telina; 7. Kia; and 8. Waghina.

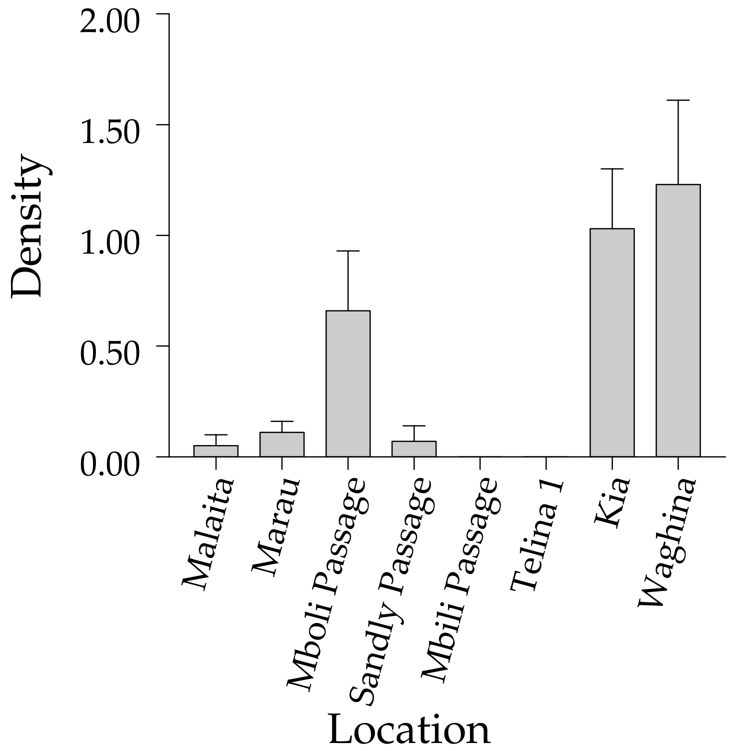

Figure 2. Mean (± S.E.) densities of silver-lip pearl oysters per 400 m^2 transect at each fishing ground.

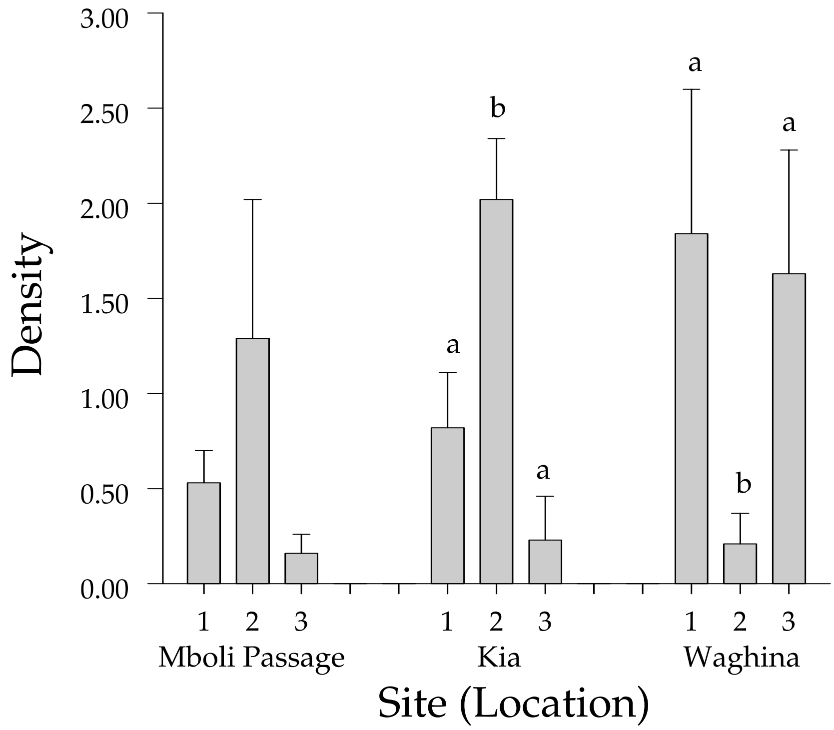

Figure 3. Mean (± S.E.) densities of silver-lip pearl oysters per 400 m^2 transect at the sites surveyed at Mboli Passage, Kia and Waghina (different symbols above bars indicate that densities differ between sites).

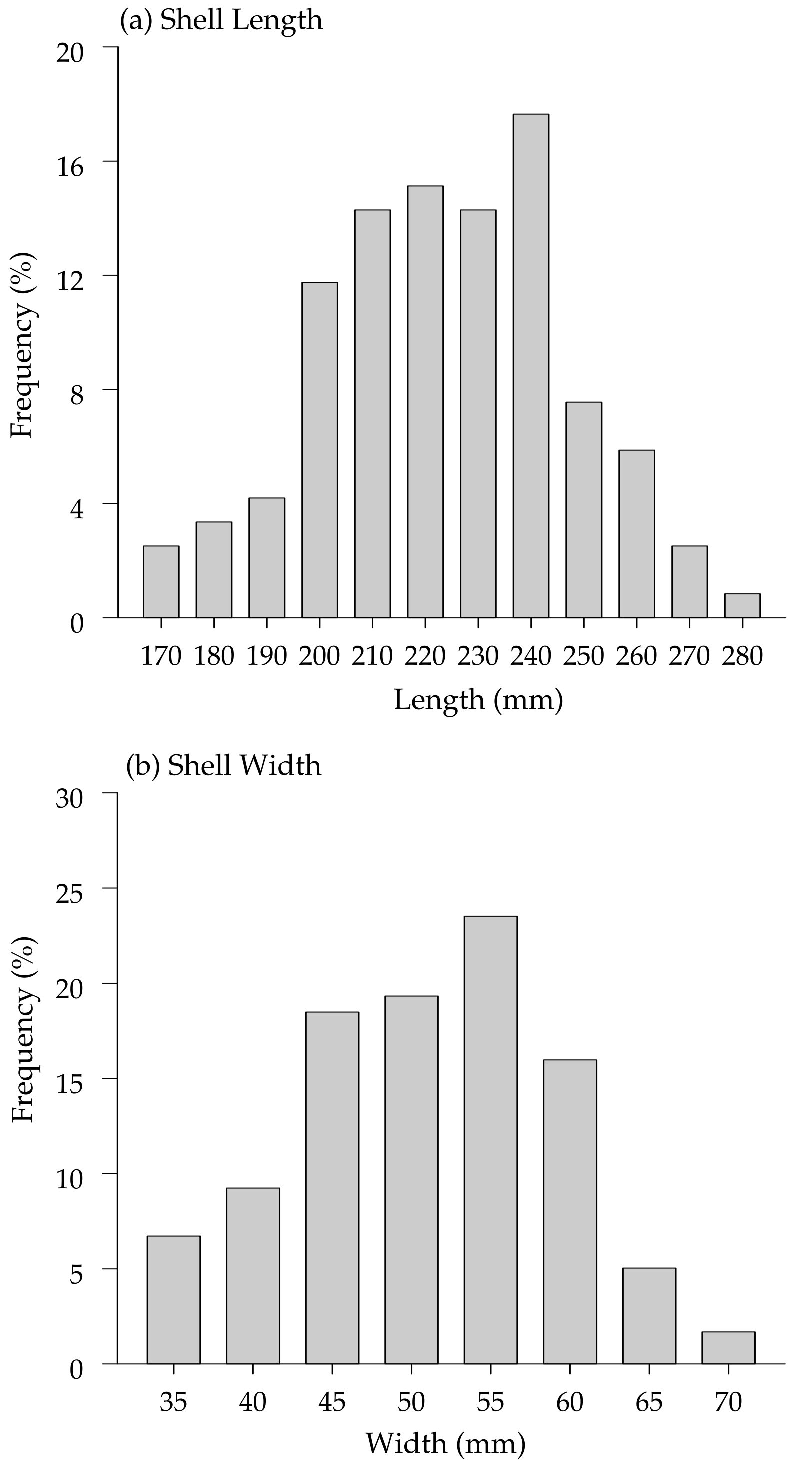

Figure 4. Frequency distribution of (a) lengths and (b) widths of shells of silver-lip pearl oysters combined across the eight fishing grounds *(n* = 119).

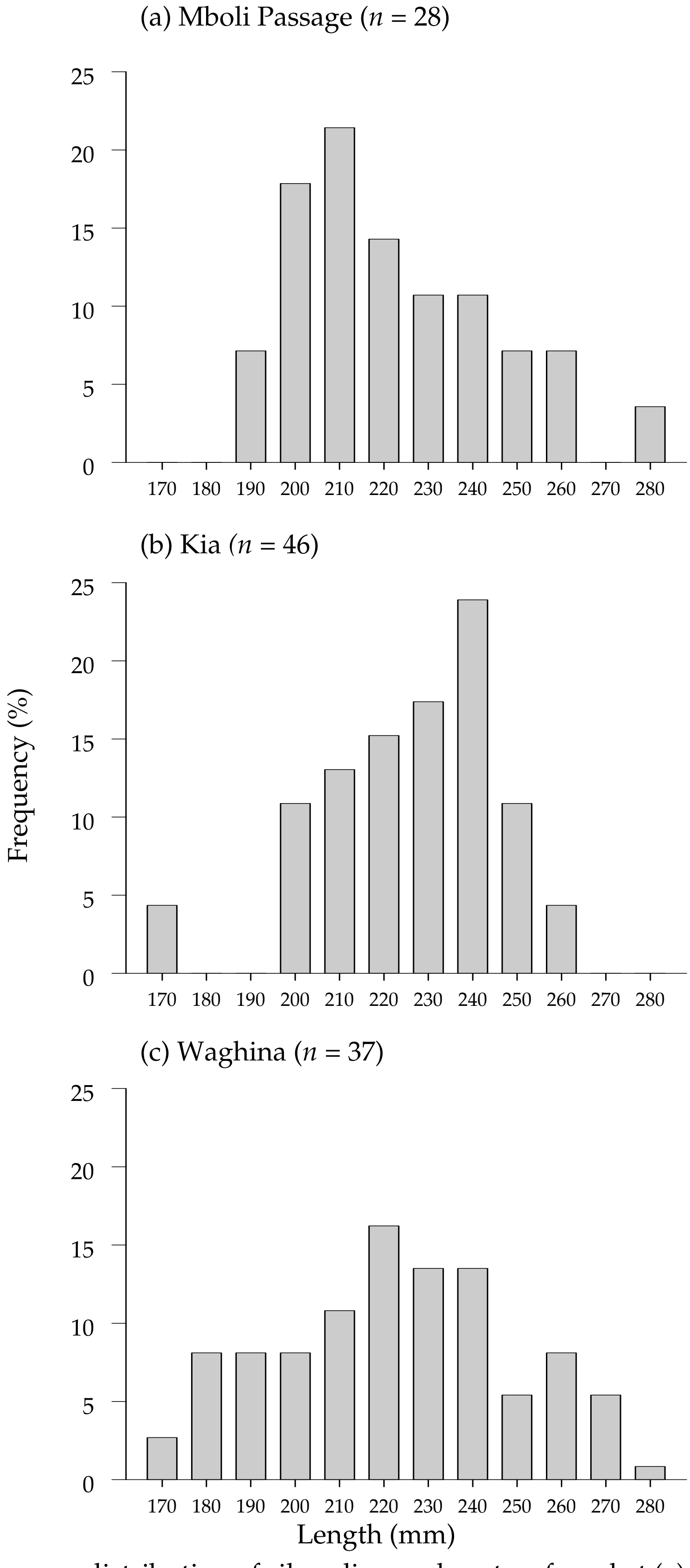

Figure 5. Length frequency distribution of silver-lip pearl oysters found at (a) Mboli Passage (b) Kia and (c) Waghina.

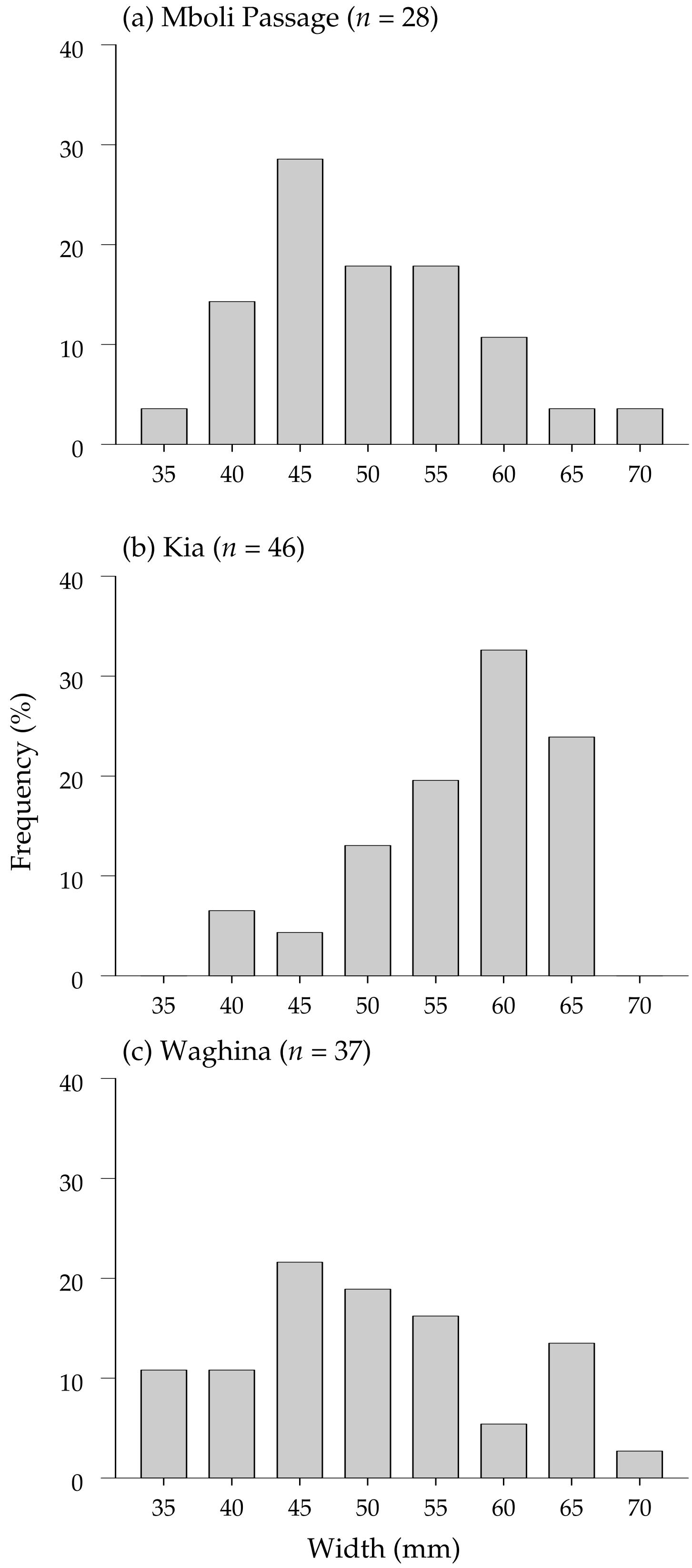

Figure 6. Width frequency distribution of silver-lip pearl oysters found at (a) Mboli Passage, (b) Kia and (c) Whagina.

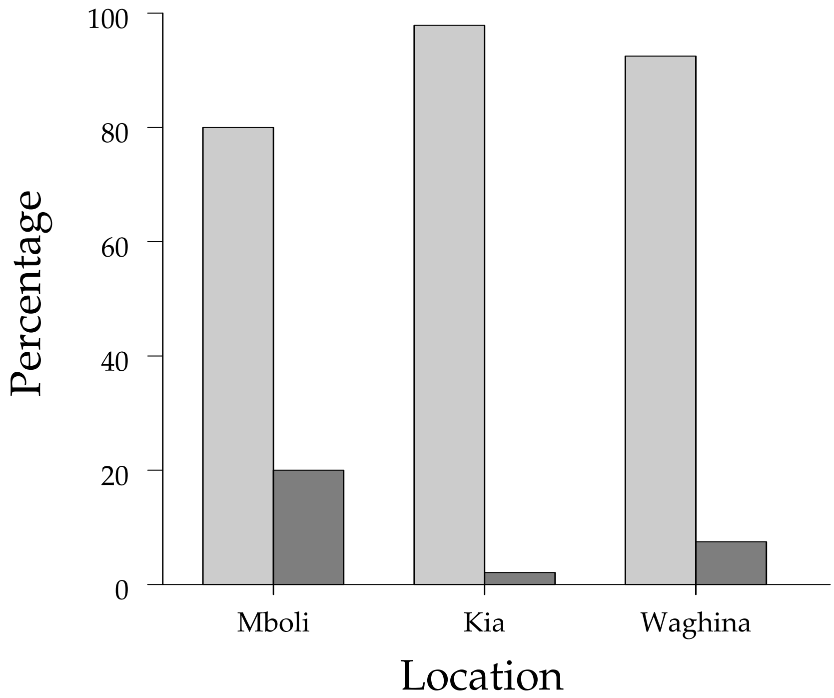

Figure 7. Percentage of shells from Mboli Passage, Kia and Waghina classified as having either high (light bars) or suspect (dark bars) external shell.

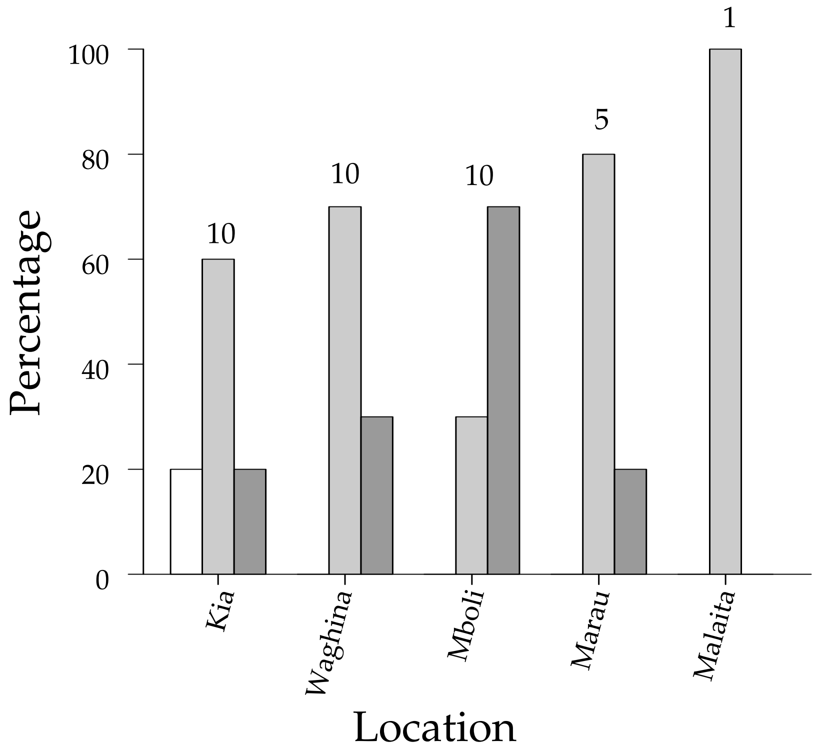

Figure 8. Proportion of shells collected from Kia, Waghina, Mboli Passage, Marau and Malaita with white (white bar), gold (pale grey bar) and off-white (dark grey bar) margins along the nacreous layer of the shell. Numbers above bar indicate sample size per location.

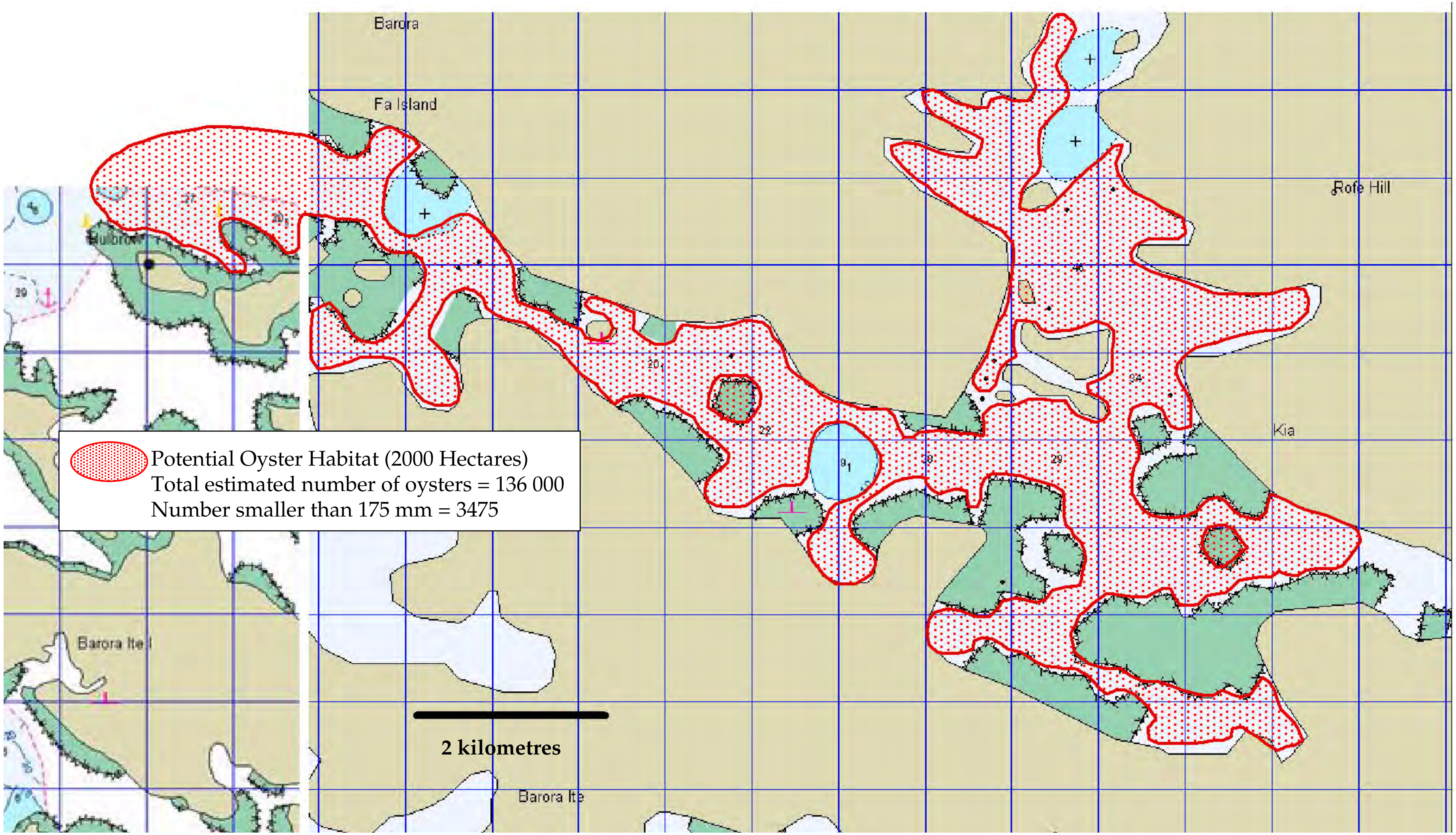

Figure 9. Extract from MaxsSea chart showing potential habitat for pearl oysters at Kia. Note that grid lines are displayed at approximately 926 metre intervals (each square = 87 hectares).

PLATES

Plate 1. Pearl oyster shells with (a) white, (b) gold and (c) off-white margins along their nacreous layers.

(a) White nacreous margin

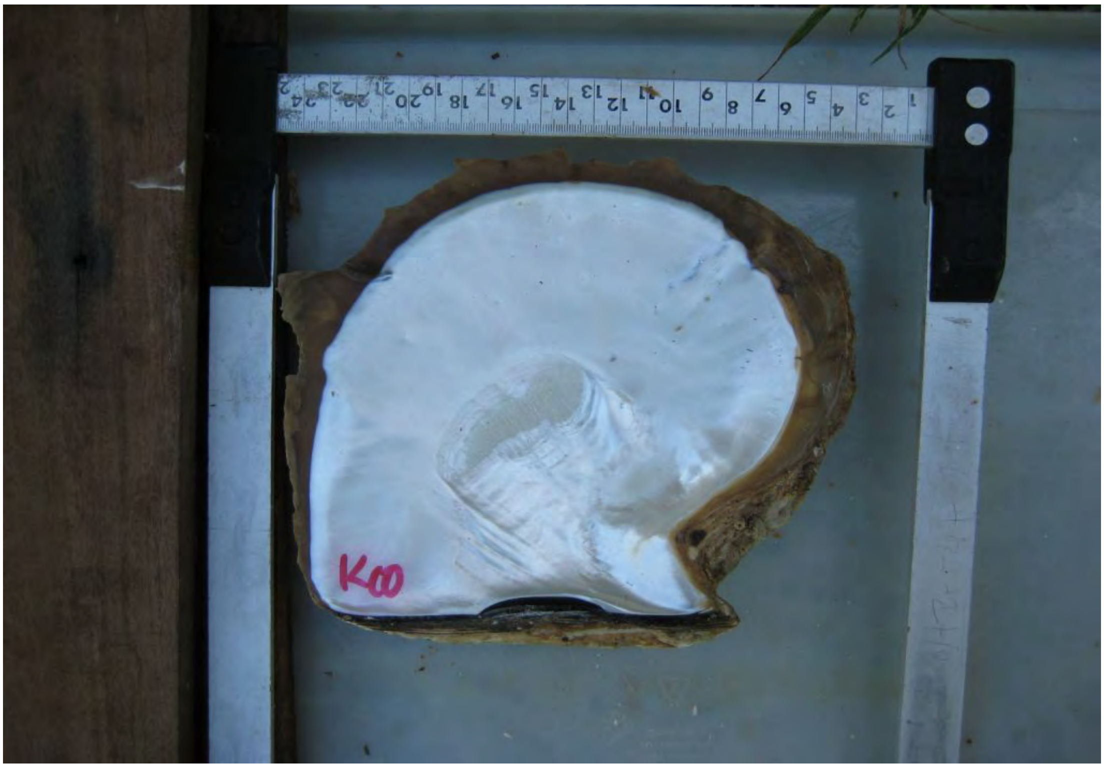

Plate 1. Pearl oyster shells with (a) white, (b) gold and (c) off-white margins along their nacreous layers.

(b) Gold nacreous margin

Plate 1 continued.

(c) Off-white nacreous margin

Plate 1 continued.

APPENDICES

Appendix 1. Questionnaire used in structured interviews of island communities.

Appendix 2. Details of transects divers were towed along during the underwater visual census.

Appendix 3. Details of remote video transects undertaken at Malaita, Marau, Sandfly Passage, Kia and Waghina.

Appendix 4. Summary of the results of interviews with island communities.

Appendix 1. Questionnaire used in structured interviews of island communities.

1. Was capture of white-lipped pearl oysters an important activity around here? How important was it as a source of money to the local community?

Very important | Quite important | Not important

2. How many people used to be involved in this activity? Did they make their living from this?

1 or 2 | 2-5 | >5 | Full living | Part living | No

3. Was it local people that did the fishing?

Local | Outsiders

4. What sort of places did they fish in?

Lagoon | Passage | Open water

5. Were some areas better than others?

Yes | Not sure | No

6. What sort of equipment did they use to collect shells?

Mask | Hookah | SCUBA | Dredge

7. How deep did they have to dive for shells?

10 m | 10-20 m | 20-30 m | >30 m

8. Which areas were the most favoured by fishers? Can you show me on this map?

9. Do people ever swim or dive in these places now?

Yes | No

10. Does anybody fish for white-lip pearl oysters at the moment?

Yes several | One or two | Nobody

11. Are they local people or from outside?

Local | Outsiders

12. What do they do with the oysters that they catch?

Use locally | Sell locally | Sell to outsiders | Move to another place

13. Where do they usually dive for the oysters? Can you show us on this map?

14. Do they dive in deep water or shallow?

10 m | 10-20 m | 20-30 m | >30 m

15. If oysters had been moved from one place to another, would you be able to let us know?

Yes | No | Unsure

16. Can you show is these places or help us place them on the map?

17. Has anybody from fisheries ever been along to check on the status of the pearl oysters?

No | Not recently (when) | Recently (when)

18. We are hoping to come back with some divers to look at the status of the pearl oysters. Would you be happy for us to look in your waters?

Yes | No

19. After the ban on the harvest of white lip have you seen oysters in?

Place dived before | New places

20. Can you show us on the map or give us the names of these places?

21. How deep have you seen white lip oysters?

10 m | 10-20 m | 20-30 m | >30 m

22. What are the best times to dive for shell?

1^{st} quarter | 2^{nd} quarter | 3^{rd} quarter | Last quarter

23. Was the inside of the shells damaged by many scars?

All shells scarred | Biggest shells scarred | No shells scarred

Appendix 2. Details of transects swum by divers during the underwater visual census (lat, latitude; long, longitude; min, minute or minimum; m, metre; avg, average).

Location and GPS datum	Site	Transect	Date	Time: start	Lat: start min	Long: start min	Time: end	Lat: end min	Long: end min	Bottom Time (min)	Max depth (m)	Depth (m): min/avg/ range	No. oysters collected	Transect length (m)	Bottom type
Malaita	1	1	18-Apr	9:30	21.673	20.501	9:51	21.636	20.507	12	30.5		0	69	sand/rubble
9° S 161° E	1	2	18-Apr	11:01	21.373	20.456	11:20	21.445	20.45	10	28		0	134	coral/sand
	1	3	18-Apr	11:35	21.751	20.462	11:52	21.804	20.478	10	34		0	102	sand
	1	4	18-Apr	12:14	21.946	20.945	12:34	21.871	20.945	10	31.1		0	139	rubble
	2	1	19-Apr	9:41	21.246	22.437	9:57	21.229	22.275	10	29.4		0	298	sand/rubble
	2	2	19-Apr	10:09	21.229	22.368	10:27	21.214	22.275	10	27.7		0	172	sand/rubble
	2	3	19-Apr	10:56	21.306	22.505	11:16	21.239	22.43	12	32.8		1	185	sand/rubble
	2	4	19-Apr	11:34	21.259	22.441	11:52	21.229	22.286	10	31.8		0	289	sand/rubble
	3	1	19-Apr	2:39	19.585	20.007	3:56	19.632	20.004	11	26.5		0	87	coral/sand
	3	2	19-Apr	4:12	19.551	20.171	4:30	19.582	20.092	10	29.3		0	155	sand/rubble
	3	3	20-Apr	9:16	19.678	19.953	9:37	19.618	20.018	13	30.9		0	163	rubble
	3	4	20-Apr	9:55	19.6	20.023	10:14	19.559	20.161	12	28.9		0	263	sand/rubble
Marau Sound	1	1	23-Apr	8:56	49.785	49.644	9:14	50.057	49.72	11	27.2		0	522	coral/sand channels
9° S 160° E	1	2	23-Apr	9:35	50.426	49.496	9:55	50.534	49.599	10	30.2		0	274	coral at start then sand
	1	3	23-Apr	10:05	50.523	49.615	10:27	50.626	49.692	10	31.7		1	237	coral, sand
	1	4	23-Apr	11:34	50.067	49.964	11:54	49.968	49.885	10	35.3		1	233	sand/rubble/coral
	2	1	23-Apr	12:16	50.183	48.844	12:43	50.187	49.174	20	22		0	602	fine sand grading later to mud
	2	2	23-Apr	14:58	49.732	48.582	15:23	49.977	48.666	20	16.3		1	479	coarse clean sand
	2	3	23-Apr	15:47	48.635	48.257	16:13	49.018	48.338	20	16.7		2	725	coral at start then sand
	2	4	23-Apr	16:27	49.4	48.367	16:51	49.011	48.329	20	12.4		0	724	sand/rubble
	3	1	23-Apr	9:34	49.408	49.417	9:53	49.458	49.442	10	30		0	206	sand
	3	2	23-Apr	10:04	49.456	49.399	10:21	49.358	49.344	11	31.4		0	415	sand
	3	3	24-Apr	11:07	49.491	49.365	11:27	49.602	49.406	10	29		0	438	sand
	3	4	24-Apr	11:44	49.398	49.307	12:00	49.531	49.339	10	31.2		0	506	sand
Mboli Passage	1	1	30-Apr	8:37	6.678	17.148	8:58	6.633	17.3	15	19.7	18	1	290	sand
9° S 160° E	1	2	30-Apr	9:21	6.959	16.987	9:44	6.76	17.03	15	20.4	18	1	377	mud/small stones
	1	3	30-Apr	10:01	6.384	17.617	10:23	6.241	17.778	15	19.4	16	4	396	sand
	1	4	30-Apr	11:37	6.097	17.849	11:57	5.918	17.983	15	14	12	2	412	coral rubble
	2	1	30-Apr	14:03	4.745	18.381	14:30	4.967	18.422	15	18	14	13	418	coral rubble
	2	2	1-May	8:17	5.67	18.141	8:31	5.627	18.284	10	16	14	5	273	sand and rubble
	2	3	1-May	8:50	5.788	18.066	9:11	5.674	18.225	15	18.9	16	0	359	gravel
	2	4	1-May	9:28	5.883	18.052	9:50	5.708	18.215	15	20.9	14	1	440	sand, some gravel
	3	1	1-May	11:08	7.289	17.322	11:28	7.173	17.183	15	18.1	17	0	333	mud
	3	2	1-May	11:42	7.404	17.245	12:04	7.243	17.141	15	21.5	19	1	354	mud/shell/rock outcrop
	3	3	1-May	13:50	7.751	16.986	14:12	7.655	17.118	15	23	17	0	300	mud
	3	4	1-May	14:25	7.62	17.252	14:46	7.739	17.166	12	24.9	22	1	271	mud

continued

Appendix 2 continued.

Location and GPS datum	Site	Transect	Date	Time: start	Lat: start min	Long: start min	Time: end	Lat: end min	Long: end min	Bottom Time (min)	Max depth (m)	Depth (m): min/avg/ range	No. oysters collected	Transect length (m)	Bottom type
Sandfly Passage	1	1	5-May	9:05	59.159	5.895	9:20	59.1	5.908	10	32.6	29	0	112	mud, coral plates
8° 59' S, 160° 06' E	1	2	5-May	9:45	58.977	5.508	10:09	58.962	5.608	10	28.7	26	0	185	mud, coral plates
	1	3	5-May	12:29	58.638	5.796	12:52	58.794	5.784	11	29.8	26	0	290	mud
	1	4	5-May	2:23	59.143	5.848	2:43	59.252	5.914	10	30	28	0	235	mud, coral plates
	2	1	5-May	3:38	2.479	6.512	3:58	2.396	6.44	10	29.3	26	0	202	sand, coral heads, coral rubble
	2	2	7-May	9:11	1.622	7.21	9:33	1.691	7.092	11	36.6	30	0	251	40% plate coral, 60% coral sand
	2	3	7-May	9:50	1.757	7.244	10:11	1.762	7.147	11	29.7	27	0	178	80% plate coral, 20% sand
	2	4	7-May	10:37	1.891	7.308	10:55	1.906	7.188	10	30.9	27	0	221	60% coral, 40% sand
	3	1	6-May	9:11	0.948	8.103	9:31	1.025	8.18	10	29.7	25	0	200	60% sand 40% coral, coral reef at end.
	3	2	7-May	14:04	1.383	7.56	14:22	1.481	7.652	10	31.7	26	2	248	30%coral 7%fine sand
	3	3	7-May	14:56	1.714	7.822	15:17	1.603	7.799	10	28	24	0	210	sand, with coral at end only
	3	4	7-May	16:15	1.558	7.562	16:35	1.46	7.629	10	32.9	29	0	219	30% plate coral, 70% sand with coral shrapnel
Mbili Passage	1	1	9-May	11:56	40.258	11.069	12:18	40.329	10.89	12:30	29.6	18-30	0	353	all sand
08° 41' S 158 12' E	1	2	9-May	12:30	40.317	11.198	12:55	40.416	10.923	17	23.3	17-22	0	536	40% sand +coral rubble; 30%sand;
	1	3	9-May	13:09	40.258	10.881	13:26	40.092	10.824	10	26.5	24	0	325	all sand
	1	4	9-May	14:55	39.86	10.694	15:16	40.067	10.837	17	23	20-22	0	464	85% sand; 15% coral
	2	1	9-May	15:48	37.073	9.948	16:07	36.977	9.897	10	29.9	27	0	201	all mud
	2	2	9-May	16:21	36.914	9.891	16:39	36.819	9.852	10	28.2	25	0	190	60% mud; 40% reef
	2	3	9-May	17:01	36.936	9.831	17:18	36.851	9.765	10	28.8	27	0	198	all mud
	2	4	10-May	9:11	36.797	9.529	9:34	36.638	9.443	10	34	32	0	334	100% fine mud
	3	1	10-May	10:21	41.238	11.357	10:36	41.235	11.282	4	20.2	11-17.5	0	137	100% fine mud
	3	2	10-May	12:51	41.31	11.349	13:13	41.376	11.181	15	22.6	21	0	331	100% fine mud
	3	3	10-May	13:29	41.498	10.937	13:50	41.433	11.082	10	24.6	22	0	291	100% fine mud
	3	4	10-May	14:24	41.617	11.424	14:43	41.495	11.342	11.5	18.6	15	0	271	80% mud 20% coral reef
Telina	1	1	11-May	7:35	31.171	3.712	7:52	31.074	3.623	12	21.2	20	0	243	100% mud I dead shell
08° 31'S 158° 04'E	1	2	11-May	8:09	30.939	3.399	8:28	30.855	3.386	10	32.7	30	0	157	100% mud
	1	3	11-May	8:55	31.06	3.658	9:15	30.968	3.755	11	29	26	0	246	100% mud
	1	4	11-May	9:40	30.702	3.951	10:03	30.684		12	36.9	33	0	150	100% mud
	2	1	11-May	10:33	31.105	4.23	10:56	31.256	4.023	10	23.6	19	0	471	100% mud
	2	2	11-May	11:22	31.037	4.769	11:42	30.924	4.75	10	31.6	31	0	212	10%reef 90% coral sand
	2	3	11-May	13:22	31.135	4.884	13:40	31.135	4.884	11	31.4	23	0	220	80% mud 20% reef
	2	4	11-May	13:54	31.327	5.133	14:16	31.273	4.951	17	24.6	23	0	348	80% mud 20% sand
	3	1	11-May	14:46	31.574	5.492	15:07	31.461	5.767	12	21.8	18	0	545	90% mud 10% reef
	3	2	11-May	15:37	31.543	5.975	15:59	31.486	5.767	16	21.9	19	0	395	90% mud 10% reef
	3	3	11-May	16:15	31.532	6.248	16:38	31.43	6.057	17	26.3	23.5	0	398	100% mud
	3	4	11-May	17:02	31.224	5.771	17:22	31.309	5.869	10	29	26	0	239	90% mud 10% reef

continued

Appendix 2 continued.

Location and GPS datum	Site	Transect	Date	Time: start	Lat: start min	Long: start min	Time: end	Lat: end min	Long: end min	Bottom Time (min)	Max depth (m)	Depth (m): min/avg/ range	No. oysters collected	Transect length (m)	Bottom type
Kia	1	1	2-Oct	9:35	34.03	22.951	9:54	34.122	23.084	12	22	21	5	298	90%sand/shell 10% coral rock
7° 34' S, 158° 37' E	1	2	2-Oct	10:09	34.108	23.093	10:28	34.136	23.238	12	23	21	1	271	90%sand/shell 10% coral rock
	1	3	2-Oct	10:41	34.136	23.238	10:53	34.236	23.352	12	26.2	23	2	279	80%sand/shell 20% coral rock
	1	4	2-Oct	11:08	34.238	23.357	11:27	34.304	23.557	12	25.5	23	2	387	90%sand/shell 10% coral rock
	2	1	2-Oct	16:33	33.537	22.635	16:52	33.672	22.852	12	30.7	29	9	470	100%gravel/rubble
	2	2	2-Oct	17:12	33.699	22.94	17:22	33.833	23.123	10	32.5	29	9	418	100%gravel/rubble
	2	3	3-Oct	9:17	33.467	22.487	9:34	33.369	22.291	12	26.9	23	5	403	100%gravel/rubble
	2	4	3-Oct	9:47	33.367	22.24	9:58	33.247	22.086	12	26.9	22	10	360	90%gravel/rubble, 10% rock
	3	1	3-Oct	10:34	33.427	20.732	10:50	33.438	20.854	10	31.5	30	0	225	80%mud, 20% reef
	3	2	3-Oct	11:04	33.436	20.854	11:23	33.493	20.977	10	34	30	0	249	80%mud, 20% reef
	3	3	3-Oct	11:33	33.501	20.972	11:43	33.464	21.097	10	29.8	28	0	240	70%mud, 30% reef
	3	4	3-Oct	12:06	33.389	21.171	12:25	33.431	21.341	11.5	24.8	22	3	322	50% sand/shell 10% reef, 40% mud
Waghina	1	1	16-Oct	8:44	26.896	42.375	9:03	26.808	42.504	10	35.0	33	3	288	40%sand 60% coral cobble/garden
7° 26' S, 157° 42' E	1	2	16-Oct	9:12	26.843	42.908	9:30	26.872	43.004	10	35.0	32	2	184	coral rubble garden
	1	3	16-Oct	9:43	26.773	42.946	10:00	26.813	42.98	10	34.2	32	4	97	30% sand, 70% coral rubble garden
	1	4	16-Oct	11:40	26.838	42.714	12:00	26.816	42.57	10	33.2	32	3	268	coral rubble garden
	2	1	16-Oct	12:38	28.486	41.764	12:55	28.212	41.925	11	24.1	18	1	587	70% coral rubble garden, 30% sand,
	2	2	16-Oct	15:18	28.629	41.655	15:36	28.416	41.775	12	22.0	17	0	452	80% coral rubble garden, 20% sand
	2	3	16-Oct	15:46	28.059	41.928	16:03	27.904	41.954	12	21.5	17	2	291	100% coral rubble garden
	2	4	16-Oct	16:15	28.711	41.547	16:32	28.89	41.391	12	22.2	20	0	438	70% coral rubble garden, 10% sand, 20%rock
	3	1	17-Oct	9:04	25.066	39.413	9:25	25.212	39.334	10	35.0	28	6	307	100% coral rubble garden
	3	2	17-Oct	9:50	25.331	39.474	9:50	25.389	39.6	10	31.7	29	8	255	100% coral rubble garden
	3	3	17-Oct	10:18	25.428	39.669	10:18	25.525	39.832	10	32.4	30	0	349	50% coral rubble garden, 50% sand
	3	4	17-Oct	11:34	25.114	39.722	11:58	24.985	39.584	8	40.5	35	5	348	100% coral rubble garden
	4	1	17-Oct	15:12	29.098	43.929	15:30	28.969	43.796	13	27.3	15	0	342	50% coral rubble garden, 50% sand
	4	2	17-Oct	15:40	28.914	43.884	15:50	28.833	43.909	10	34.0	29	0	157	80% coral rubble garden, 20% sand
	4	3	17-Oct	16:16	28.181	43.527	16:38	28.049	43.424	10	37.0	33	3	309	80% coral rubble garden, 20% sand

Appendix 3. Details of remote video transects undertaken at Malaita, Marau, Sandfly Passage, Kia and Waghina.

Location and GPS datum	Site	Transect	Date	Time: start	Lat: start min	Long: start min	Time end	Lat: end mon	Long: end min	Bottom Time (min)	Depth range (m)	Transect length (m)	Problems encountered
Malaita	1		18-Apr	15:05	21.81	20.43	15:15	21.96	20.429	10	NR	277.8	
9° S 161° E	2		20-Apr	11:51	20.588	21.568	12:35	20.936	21.83	44	NR	803.5	
	3		20-Apr	14:42	19.474	20.202	15:22	19.711	19.775	40	NR	896.8	
Marau Sound	1		25-Apr	13:20	49.711	50.331	13:50	49.497	50.21	30	NR	454.1	
9° S 160° E	2		25-Apr	14:11	48.837	49.178	14:35	48.908	49.288	24	NR	240.6	
Sandfly Passage	1	1	8-May	8:25	59.808	5.709	8:35	59.959	5.755	10	38-41	292.0	
8° 59' S, 160° 06' E	1	2	8-May	8:35	58.959	5.755	8:45	58.805	5.708	10	38-29	297.9	
	1	3	8-May	8:57	58.928	5.76	9:07	59.056	5.752	10	36.5-41	237.5	
	1	4	8-May	9:07	59.056	5.752	9:18	59.195	5.712	11	41.8-41	267.6	
	1	5	8-May	9:19	59.191	5.705	9:29	59.263	5.611	10	42.2-45.3	217.6	
	2	1	8-May	9:53	0.537	5.821	10:02	0.504	5.726	9	38-22.2	184.2	
	2	2	8-May	10:13	0.433	5.616	10:23	0.517	5.603	10	40-39.3	157.4	
	2	3	8-May	10:23	0.517	5.603	10:33	0.589	5.55	10	39-36	164.9	
	2	4	8-May	10:34	0.589	5.55	10:38			4	33.9-20		
	2	5	8-May	10:49	0.508	5.46	10:59	0.55	5.587	10	49.5-51	245.0	
	3	1	8-May	11:23	1.006	7.551	11:33	0.974	7.674	10	44.7-46.7	232.7	
	3	2	8-May	11:34	0.972	7.679	11:43	0.927	7.797	9	46.6-46.4	231.4	
	3	3	8-May	12:22	0.804	7.783	12:32	0.95	7.834	10	46.4-46.4	286.0	
	3	5	8-May	12:33	0.949	7.834	12:40	1.033	7.812	7	45.5-31	160.7	
	3	5	8-May	12:47	1.033	7.783					43.8		fouled at start
	3	6	8-May	12:59	0.936	7.73	13:09	0.898	7.607	10	44.6-48	235.7	
	3	7	8-May	13:11	0.91	7.595	13:21	0.797	7.566	10	48.5-52.8	215.9	
Kia	1	1	4-Oct	10:08	*33.999*	22.065				2	NR		not recording
7° 34' S, 158° 37' E	1	1	4-Oct	10:24	33.984	22.965				6	NR		low battery termination
	1	1	4-Oct	11:08	33.983	22.973	11:23			15	NR		new battery - low but working
	1	2	4-Oct	11:27	34.064	23.109	11:42	34.123	23.441	15	NR	619.4	
	1	3	4-Oct	11:43	34.123	23.441	11:58	34.214	23.63	15	NR	385.8	
	1	4	4-Oct	12:00	34.214	23.63	12:15	33.931	23.414	15	NR	657.3	battery issue, no record
	2	1	4-Oct	12:27	33.494	22.531	12:42	33.592	22.73	15	NR	408.0	
	2	2	4-Oct	12:43	33.606	22.67	12:53	33.549	22.56	10	NR	227.9	
	2	3	4-Oct	12:55	33.549	22.56	1:00	33.465	22.435	5	NR	277.3	battery issue, no record
	3	1	4-Oct	1:16	35.49	20.73	1:26	33.446	20.86	10	NR	252.2	new DVD
	3	2	4-Oct	1:27	33.446	20.06	1:29	nr	nr	2	NR		
	3	3	4-Oct	1:37	33.385	21.182	1:47	33.436	22.274	10	NR	1670.0	transcription error
Waghina	1	1	18-Oct	8:40	*29.223*	44.135	8:55	29.083	44.133	15	NR	259.3	
7° 26' S, 157° 42' E	1	2	18-Oct	8:57	29.08	44.12	9:12	29.078	43.987	15	NR	244.3	
	1	3	18-Oct	9:14	29.071	43.983	9:29	28.951	44.001	15	NR	224.7	did not record
	2	1	18-Oct	9:49	29.075	41.444	x	x	x	x	NR		abandoned
	2	1	18-Oct	9:59	29.053	41.41	x	x	x	x	NR		abandoned
	2	1	18-Oct	10:14	28.527	41.738	10:26	28.329	41.831	12	NR	404.5	stop and start again when stuck
	2	2	18-Oct	10:28	28.329	41.831	10:37	28.191	41.897	9	NR	282.9	
	2	3	18-Oct	10:45	18:53	41.961	10:55	14:25	21:59	10	NR	354.2	
	2	4	18-Oct	11:05	26.899	41.998	11:13	x	x	8	NR		abandon - flipped
	4	1	18-Oct	12:05	26.316	42.108	12:20	26.488	42.28	15	NR	448.6	
	4	2	18-Oct	12:25	26.488	42.28	12:40	26.462	42.459	15	NR	332.2	did not record
	4	3	18-Oct	12:50	26.451	42.417	13:03	26.518	42.517	13	NR	221.6	

Appendix 4. Summary of the results of interviews with island communities.

Waghina

Waghina emerged as the main historical centre for the gold-lip fishery. Historically, that is in the 1970-1980 and briefly in 1990 prior to the ban, mother of pearl diving was an important economic activity for many people. For many it was a full-time job. Local fishing was concentrated in the passage off of Kia, Hamilton Passage, from Tenbe to Tema, with considerable depths being dived for shell. Indeed towards the end of the fishery hookah divers were operating to 70 m to collect shell, and many suffered decompression sickness as a result. Since the ban, occasional big harvests have still been made, with shell sold on to illegal exporters. MFMR have never had any involvement with the fishery, though we understand they did intercept one illegal shipment.

Diving was best in the main passage (Hamilton Channel) but, due to currents, is only feasible at neap tides (first and last quarter). Shell can be found on stony bottoms. Divers also worked Kia and Ngosele Passage, in similar fast flowing channels, though at Ngosele shell were also found on the muddy bottoms on the N side of the passage. In Ngosele, the best areas are in the narrow channel, and in Kia the best area is reported as the channel running towards Wagina from Kia town.

The dominant substrate where shell are found is crushed coral, and shells can be heavily colonised, with older shell scarred on the inside. Best quality shell, ie least scarred, was found on sandy areas of lower flow, and smaller shell were least scarred. Shell was generally easy to find, and the divers report that there is plenty out there at the moment, though immediately after the ban very few could still be found.

Kia

MoP was of lesser importance to Kia than to Waghina, where most local divers were mask divers only, and few had access to hookah gear. It was important to a few people, and of low importance to many. Most divers were Gilbertese from Wagina, and local people involved full time in the industry were usually canoe operators. Breath-hold divers still encounter shell, at shallow depths and on a variety of substrates from mud to broken coral. Historically, most activity was in the fast flowing channels, which could only be worked on neap tides. Swirling areas were the best places to fish, as shell seemed to be concentrated there, with fewer shells in the channel centres. Close to inflows from mangrove areas was also good and close to the groups of small islands. The small channel at Kakadeke also holds goldlips at 10-20 m. Nowadays, when breath-hold divers encounter goldlip they will often collect them and bring them into shore, to keep close to their houses in case they become saleable again. Shell are found on sand, mud, coral rubble, seagrass, even rock walls. As at Wagina, small shell was less scarred and better quality than large shell.

Marovo (Telina/Mbili)

Not such an intense industry here, but of some value to some people in the past. Goldlips are seen in almost every channel between the islands, at 20 m plus, and at times in good numbers. The shell is on sand/mud and rarely are badly scarred. Some locals still use shell for carving (inlay/jewellery). Telina is in an area of quiet currents and can be worked at any tidal condition. Mbili Passage, where a strong exit/entrance current exists with a stony substrate is also reported to support GL, including in nearby 30 m deep channels. Fisheries have been involved here in that they came to advocate the deployment of BL spat collectors, though nothing came of this, and there is no fisheries involvement yet with goldlip.

Marau

In Marau the pearl oyster industry was important to the economies of many people, though for all it was a partial living only. A mix of mask, hookah and SCUBA diving has been undertaken there, more or less dominated by the local people. Shell is still collected in small amounts and is used and sold locally, mostly for jewellery and shell money; it has traditional values for this. The shells are widespread and people report taking them from lagoons, passages and open water. Depth limits result in the slopes of the passages being fished rather than the central areas. Good locations include the shallow Suukitahi Passage, the slopes of the passes between the islands. A new area was recently discovered NE of Taiaru Reef.

Ngella

Two main areas were identified to us, Sandlfy Passage and Mboli passage. Mboli Passage reported the shell as providing a partial living to many people and that it was important. Both mask and hookah diving were carried out, by locals as well as outsiders, though commercial buyers dominated the outside influence. Some shell is still taken here for local use. Shell are found in the passage itself, but some interviewees said also in the water at the northern end of the passage, to both east and west where it spills out into the open sea; others reported that these were not good areas. Mboli Passage itself is the only site now fished, with shell beginning part way up the passage (from Honiara end) just past a rocky point favoured by sunbathing crocs. Small shell are found right up to the mangroves. No shell are apparently found at the southern part of the passage, nor where this opens to the sea, but it might be worth a quick look to confirm this.

Sandfly passage is deep in the centre and most shell is taken in the bays and slopes to north and south. Here interviewees suggested that shell was moderately to highly important to the community, though fishing was by mask only by those that were spoken to. This limited divers to shallow water. Some people still take shell here for local use. The favoured locations were all around Mbike Island and the promontory to the north of this (Hanipana Pt) and the shallow water area to the north of this might be worth a look. Two Bays, Roderick Dhu Bay and Haroro Bay were also identified as good sites. Respondents here also reported that shell are to be found in two passages NW of Sandfly, Hanesavo Harbour and the passage running NE/SW to the E of Mangalonga Island.

Maramasike (Malaita)

This preliminary survey was undertaken by Fisheries staff and was less comprehensive than those undertaken by WorldFish staff. A picture emerges of a breath-hold capture industry that was of moderate importance to a few people. Only locals were involved, and breath-hold depth limits apply. Currently there are no commercial activities, though oysters are still seen and when caught, there is a local market for shell. Not clear form responses, but this may again be for shell money and jewellery. Three villages were canvassed, and three areas are identified on the east and west sides of the northern mouth of Maramasike Passage, but with insufficient detail to define sites at this stage.

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 5. Solomon Islands: The Investment Climate for Pearl Farming

Prepared by:

A.V. Hughes
Vonavona Lagoon
PO Box 59,
Gizo
Solomon Islands

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Contents

1. Governance and political stability

1.1 Constitutional government

The constitution of Solomon Islands was adopted at independence in 1978 after a country-wide consultation process. Its broad structure is similar to those of other former British dependencies. Currently the head of state is the British monarch, represented by a governor-general elected by the SI parliament. The constitution establishes the national government and requires it to make legislative provision for establishment and operation of provincial governments, of which there are currently eight. An elected municipal government of the capital, Honiara, is established under a separate law.

A draft replacement constitution now under review by a constitutional congress provides for a non-executive president as head of state, and for a federal structure with state governments replacing the present provincial governments. The draft new constitution is expected to be ready for adoption by the end of the present parliament in 2010.

The fifty-member single-chamber national parliament is elected every four years. All adult Solomon Islanders are eligible to register as voters and vote in a first-past-the post ballot. Elections since Independence have usually produced a substantial turnover in parliamentary membership. Recent governments have been seeking to make their tenure of office more secure by channelling development grants to constituencies through members of parliament, particularly those who support the government.

Parliament elects a prime minister who forms a ministerial government from members of parliament. The need to maintain political support in parliament has led to creation of more ministerial posts than efficient administration requires, and the preservation of solidarity within the government and its parliamentary supporters is a constant preoccupation of the prime minister and an inner political caucus.

1.2 Judicial system

The formal judicial system comprises magistrates, courts, the High Court of SI, and a Court of Appeal. The judiciary is constitutionally independent and is generally thought to be free of political influence, though at provincial level this may be harder to sustain.

Governments have on the whole submitted to the rule of law when required to do so, but not without visible internal strains. Generally in SI there is a high level of respect for the legal machinery and the use of due process. Very public controversy over the filling of the Attorney General’s position in 2006-7 by a close friend of the prime minister led to a parliamentary vote of no confidence and change of government in November 2007.

The judicial process is generally regarded as slow but fair. The enforceability of civil judgements is a weak area. The system of native courts that apply customary law to disputes between Solomon Islanders is effective in some areas but not others, depending on the degree of confidence placed in the traditional system by people of the area. The interface between customary law and the statute law enforced by the formal court system is under strain as monetisation and commerce penetrate more deeply into people’s lives.

1.3 The public service

The national public service has undergone substantial expansion and qualitative change since independence. It has suffered from increasingly direct political interference in its management and has been severely weakened by corruption in departments dealing with taxation, contracting, licensing, access to forests and marine resources and transactions in public land. Efforts are now under way to re-establish codes of professional ethics and raise standards of administrative and technical competence.

The departments with which an investor would mainly be dealing (investment registration, taxation, employment, immigration, lands, fisheries, provincial government) are all ostensibly aiming to promote and assist legitimate investment, but they vary in experience, effectiveness and speed of doing business. Investors should ensure that documents are carefully prepared and presented, and sufficient time allowed for processing and discussion of any difficulties with relevant officials. Any suggestion that additional unofficial payments would facilitate processing should be rejected.

1.4 Political parties and factions

Before and since independence, officials and political leaders have been conscious of the risks posed to nation-building by the potential for inter-island conflict. Deliberate efforts have been made to avoid forming political parties on ethnic or island bases. As there are few other themes that could unite people outside the kinship of their own extended families or land-holding groups, political parties have generally been weak, taking the form of short-term clusters around a potential or actual prime minister in expectation of tangible rewards. These allegiances have been fragile, depending on the perceived benefits of the sharing-out of political power and financial patronage, and often attacked.

This environment produces frequent speculation about the stability of the government in office, and has several times led to a change of government during the life of a parliament—the most recent being that in November 2007. From an investor's viewpoint, however, there are few discernible policy differences among the various political groupings. The differences are mainly about who should be prime minister and in charge of patronage, while external relations with China/Taiwan and Australia are also a matter of debate. Major shifts of policy affecting or relating to foreign investment seem unlikely. All parties claim to be in favour of decentralised investment, creation of rural jobs and income opportunities and increased export earnings. Pearl farming scores well all round.

1.5 Provincial governments

Sub-national or island-level governing bodies, earlier known as local councils and more recently as provincial assemblies, have been established for almost fifty years, to exercise powers and functions devolved and delegated to them by the national government. These governments are elected by all adults on the same electoral roll as the national parliament. In the last twenty years provincial governments have been chronically under-resourced and under-performing in provision of services and infrastructure, and in stimulating or supporting development. Rivalry with national politicians and the difficulty of staffing services in remote locations have been key factors in this decline.

Despite its present weaknesses, effective sub-national government at island level is crucial to providing a secure environment for rural business. Steps are being taken now with international assistance to rebuild competent provincial government able to maintain close touch with rural communities. In the background are the constitutional review process and the possibility that provinces may become states in a federal system.

In any case, commercial investors in rural locations will need to maintain good working relations with provincial or state government at political and official levels. Timely consultation in planning, legal compliance and transparency of dealings are critical.

1.6 The ethnic conflict of 1998-2003

The ethnic [1] fragmentation of the country acts as a brake on economic development, but politically it has also tended to act as a stabilising factor—it has been difficult to build a critical mass of support for radical policies that would be positive or negative for development. This appearance of multi-ethnic stability suffered a severe blow in 1998-2003 with the eruption of violent conflict and subsequent establishment of gun-rule in Honiara, Guadalcanal and parts of Malaita, and intermittently in Western Province.

Known as 'the tensions', the upheaval was specifically triggered by extremist elements from Guadalcanal, who tapped into a pool of dislike and mistrust over inward migration and settlement, particularly from Malaita, and resulting unresolved disputes over land that had grown up in North Guadalcanal over several decades. Successive governments had failed to intervene in any significant way despite being asked many times to do so.

The disastrous outcome included an estimated two hundred violent deaths, physical and mental suffering and loss of property for many thousands of people, the collapse of the ethnically-split police as a disciplined force, and the overthrow of the elected government in an armed coup in June 2000. Though a peace process was initiated by civil society and external assistance, and a general election was successfully held in late 2001, it was not until June 2003 that the rule of armed gangs and their leaders was ended (next section).

The most sustained violence occurred in Guadalcanal between persons from that island and from Malaita, the latter armed and assisted by Malaitan police. At the same time more widespread violent incidents and the broad psychological trauma of the conflict had a destabilising effect in other parts of the country. The damage to ethnic 'neighbourliness' and sense of nationhood has been substantial. Continued population growth and migration from the more populated and resource-poor islands (Malaita, Reef Islands) to those with more space and possibility of work (Guadalcanal, Isabel and the New Georgia group) mean that the risk of further ethnic violence cannot be ignored.

Investors in rural areas need to be aware of this history. They need to actively foster good relations with neighbouring communities, maintain an ethnic composition in their workforce that minimises friction, and be alert for signs of tension in and around their investment so as to identify its causes and organise ways of alleviating them. There are several examples in the tourism sector of investments that have successfully done this, and they are worth studying. They tend to be on a similar scale to a potential oyster farm.

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[1] In current Solomon Islands' usage 'ethnic' more often refers to island or language group identity than to race.

1.7 The role of RAMSI

In March 2003, under the terms of a resolution of the Pacific Forum (the Biketawa Declaration) the SI Prime Minister requested external assistance to deal with armed lawlessness and associated mounting social and economic distress. The Regional Assistance Mission to Solomon Islands (RAMSI), organised and largely funded by Australia, arrived in June 2003. This put an immediate end to the rule of armed gangs and in the following months large quantities of small-arms were surrendered and destroyed. The basic functions of government were progressively restored, public services resumed near-normal levels of activity and the 'peace process' accelerated.

In 2004-6 a large number of aid-funded activities were put in place with the aim of rebuilding national capacity to deliver services, build and repair infrastructure and maintain law and order. Many components of these programs represent long-term commitments, and linkages to normal bilateral and multilateral aid programs involving other donors have been and are being developed. A transition from emergency intervention to deeper-rooted, longer-term building of local capabilities is occurring.

RAMSI itself will be reviewed early in 2009. Public confidence in national capacity to maintain law and order was destroyed in 1998-2003, and remains very low. A contingent of Australian and other regional police remains in support of the SI police, and a military rapid-response presence is maintained in the background. It is widely hoped and expected in SI that the core assistance programs underpinning public security, policing and containment of violent crime will be extended for a further ten years, in the context of a coherent plan to develop national capacity to re-assume responsibility for security during that period. The current SI government and governments of key RAMSI countries have been signalling their potential support for such an agreement.

2. Currency and financial stability

2.1 Currency and exchange rate

The national currency is the Solomon Islands dollar (SBD). The current official exchange rate is about SBD7.70 to USD1.00, or SBD7.00 to AUD1.00**.** The exchange rate against USD is set by the Central Bank in its daily transactions with the commercial banks, which then deal with the public in a range of currencies by applying competitively-set margins to the CBSI rate.

The Central Bank determines the value of the SBD by reference to a basket of currencies that reflects the composition of SI's external trade. Exchange rate policy is agreed between CBSI and the government. Broadly the policy aim has been to maintain a level of external reserves equivalent to three months' imports of goods and services, and protect the competitiveness of domestic production and rural-based export industries.

Faced since the mid-1980s with mounting government budget deficits and erosion of external reserves by resulting import expenditures, the SBD was progressively depreciated from parity with AUD at Independence in 1978 to around SBD7=AUD1 today. Since 2004 the external reserves have been boosted by heavy grant-funded inflows associated with RAMSI and other aid programmes, creating a surplus on the overall balance of payments, but the authorities have not increased the exchange value of the SI currency—which would have increased consumption of imports and undermined local production and exports. Recently the level of reserves has been heading back to the CBSI's target zone of three months import cover. The prospect of declining export receipts from the logging of natural forest (offset in part by lower logging-related imports of fuel, machinery and skilled personnel) and higher domestic inflation threatening export competitiveness suggest the likelihood of future pressure on the exchange rate.

2.2 Financial system and interest rates

The formal institutions making up the financial system include the Central Bank of Solomon Islands (CBSI), three commercial banks (ANZ, Bank of South Pacific and Westpac), the PNG-based Credit Corporation and several hundred credit unions. CBSI has the normal currency issuance, external reserves management, and financial institution and system supervisory responsibilities of a central bank.

The commercial banks operate branches in Honiara and provincial centres, and ATMs are available at or near most of the ANZ and Westpac branches. ANZ operates mobile bank facilities along parts of the road systems of North Guadalcanal and North Malaita.

Currency in circulation and demand deposits with banks are presently around SBD900m, and savings and time deposits around SBD450m. Domestic lending, almost entirely to the private sector, is around SBD1000m and net foreign assets (external reserves) are about SBD700m, equivalent to USD90m.

The banking system is reasonably liquid, and able to handle expected domestic demand for financing of commercial development. The banks have access to head office funding if needed. Interest rates at commercial banks are in the range of 1-4% for term deposits, depending on term and amount; and 13-18% for loans, depending on term and amount, the security available, and the reputation and business prospects of the borrower.

Domestic inflation, estimated by the Central Bank on the basis of Honiara retail prices, has recently been accelerating under the impact of imported fuel and food price rises. The annual rate of inflation is now in the range of 12-15% and may be going higher. The annual rate should drop back into single figures after the main 'drivers' of the current trend stabilise, though it is not likely that the recent fuel price rises will be reversed.

2.3 Exchange control and suspicious transactions reporting

The Central Bank operates exchange control regulations under which authority to approve and process routine trade transactions is delegated to commercial banks. Authorised exporters are allowed to retain funds offshore to pay for imports to minimise inward and outward transaction costs.

Capital movements require Central Bank approval, which is readily given on proof of legal status and availability of funds, eg repatriation of declared dividends or of capital on sale of an investment. Anti-money-laundering legislation requires banks to report suspicious transactions, and customers may be required to provide proof of their identity and nature of transactions.

2.4 Government finance

The national government obtains just over half of its annual budget from domestic tax revenues and the balance from external sources, almost all as grants. Domestic revenues have grown strongly in recent years as the effectiveness of tax collection has improved and the level of taxable income and expenditure flows in the economy has increased. Both these factors are connected to the impact of foreign assistance under RAMSI and other aid programmes. No systematic analysis of the economic and fiscal impact of the upsurge in aid-funded expenditures has been published, but it has certainly been very significant, particularly in the urban sector. The other striking driver of revenue growth has been the expansion of log exports in volume and value (along with clear evidence that both have long been substantially understated by the exporters) roughly doubling between 2005 and 2007.

The government has recently released a statement of medium-term fiscal strategy which envisages a much tighter budgetary future. This is attributed mainly to the expected contraction of natural forest logging over the next five years as the remaining commercially attractive stands of timber are exhausted, and logging-based activity shrinks. The Honiara service economy, the rural areas where logging has been taking place and the government will all experience a fall in money income. At the same time expenditure pressures on the budget will increase, largely driven by population growth, government commitments to accelerate development of rural areas, and the demands of the political and official payrolls as the cost of living rises.

Though the government budget is expected to become more stringent, an incoming investor is not likely to be directly affected by fiscal tightening. As explained in section 7 below, the current scheme of investment incentives contains no grants or other payments by government that might be cut back. Pressure to create and maintain an environment conducive to investment will be kept up by domestic and external advice, and the improvement of economic infrastructure will continue under various aid programmes.

The economic and social value attributed to potential investment in pearl farming will be enhanced by the contraction of natural forest logging, which has caused immense damage to the natural environment and community relationships, while corrupting substantial elements of the political and official machinery of government.

2.5 External aid

Solomon Islands has increased its dependence on external assistance in recent years and this looks set to continue. The re-emergence in SI and elsewhere of donor funding of parts of the government recurrent budget is a recognition that effective public services have to be assured in order for investment-driven growth to occur on a sustainable basis.

The Australian regional aid programme is being significantly increased in size and SI will be a major recipient through the bilateral programme and RAMSI. New Zealand will also maintain and strengthen its aid to SI, directly and through regional bodies.

The rivalry of China and Taiwan for the allegiance of Pacific states has enabled SI governments to obtain substantial untied (and only very lightly accountable) aid from Taipei, usable for political purposes shunned by other donors. Though this rivalry is likely to recede and presumably vanish under any foreseeable Beijing-Taipei scenario, there is no reason to think that substantial Chinese aid will not continue to be available.

The World Bank Group is opening a country office in SI so as to make its money and advice more readily accessible, and the Asian Development Bank is paying increasing attention to SI's situation and needs. The European Union seems uncertain about its long-term relations with the Pacific, but for the present the EU's development agencies, including the EIB, are actively engaged and committed to multi-year programmes in SI.

All this is positive for commercial investment. It provides assurance that regional and international agencies will be physically present in SI, arguing the case and providing resources for better infrastructure and services, trade expertise in key institutions and a regulatory regime that attracts quality investment and assists it to commercial success.

3. Land tenure

Land in Solomon Islands is held either under customary tenure, or under a system of registration of land and defined interests therein established by the Land and Titles Act. By far the greater part of Solomon Islands is customary land, and customary rights commonly extend to neighbouring reefs and inshore fishing grounds

3.1 The registered tenure system

Rights of ownership, occupation and use of registered land are recorded in the Land Register, maintained by the Registrar of Titles, and land boundaries are recorded in the Registry Map maintained by the Surveyor-General. The system covers about 10% of the land in Solomon Islands. This includes all the urban centres, several hundred parcels of land in rural areas formerly known as alienated land, a small number of parcels converted from customary tenure by a process known as land settlement, and a growing number of parcels acquired by the Commissioner of Lands for purposes of development or other public purposes. All land on the register has gone through a process of title and rights investigation before being registered, and the interests in registered land recorded on the Land Register are the subject of indemnity by the government.

The principal forms of registered interest are the perpetual estate, fixed term estate, lease and charge. Rights of way and easements such as access to water and other natural assets are also registrable as encumbrances on the registered right to occupy and use the land.

a) *a perpetual estate* broadly corresponds to a freehold interest in European usage. The perpetual estate in a parcel of land can only be held by the Commissioner of Lands or by a Solomon Islander (as defined in the Land and Titles Act), a company at least 60% owned by Solomon Islanders, and certain other limited classes of persons. Broadly speaking, 'government land' is held by the Commissioner as perpetual estate, and in coastal parcels the title extends to the high-water mark. The Commissioner may transfer the perpetual estate to eligible person(s) and may make this subject to payment of premium, rent and performance conditions.

b) *a fixed-term estate* may only be granted by the Commissioner of Lands, and for not more than 99 years. It is generally similar to a leasehold interest in European usage. There is no restriction on who may be granted a fixed-term estate, and almost all urban land and large tracts of rural land (eg for plantation forestry and agriculture) is held in this way, subject to rent and development conditions.

c) *a lease* may be granted by owners of perpetual and fixed-term estate other than the Commissioner of Lands (who may grant periodic tenancies but not leases). The nature of a registered lease and the conditions that may be attached are generally similar to leaseholds in European usage. A lease may be for any period up to the life of the estate interest, but the written consent of the Commissioner is required for a lease to a non-Solomon Islander.

d) *a charge* in respect of a registered parcel of land corresponds to a mortgage in European usage. Charges may be created and registered as encumbrances on estates, registered leases or other charges. Commercial lenders are accustomed to the use of a registered charge as security for lending to owners of fixed-term estates and leases, particularly in urban areas, and the process is well established.

3.2. Customary tenure

Non-Solomon Islanders (as defined in the Land and Titles Act) cannot legally own interests in customary land, so any proposed formal investment on customary land will involve its conversion to registered land. Problems of definition of customary land rights and boundaries so as to facilitate development by traditional owners, and efforts to convert customary rights to a form in which they can be registered and dealt in under the registered title system, have been going on intermittently for more than forty years, and no proven system is yet in place.

Customary use rights encompass all the uses of the land and its resources traditionally practised by groups of horticultural island-dwellers fairly lightly scattered through SI. The ‘bundle of use rights’ that best describes customary ownership is commonly claimed by a kinship group (or tribe) of several hundred persons, tracing descent from a named ancestor ten or more generations ago. Such claims may have been subject to dispute as to precise boundaries by neighbouring descent groups, sometimes for long periods.

Monetisation, education and the physical and financial impact of commercial logging of the natural forest have injected deeply disruptive forces into customary society. Traditional leadership in many areas has crumbled under these pressures leaving tribal governance in disarray. The traditional structures in Isabel and Shortlands appear to be in better shape than elsewhere, but everywhere caution, tact and patience is needed in approaching the possible use of customary land for commercial investment.

Machinery exists under the Land and Titles Act (Parts IV and V) for the conversion of customary to registered ownership of land. Properly done, these involve painstaking inquiry into traditional use rights and the degree of understanding and readiness among those concerned to convert to the registered system. Part V provides for the Commissioner or a Provincial Assembly to acquire a registered perpetual estate in a parcel of customary land (whereupon it ceases to be customary land) and then to transfer the perpetual estate to the original customary right-holders. They can then deal in it as registered land, for example by subdividing it and granting leases to themselves or outside investors for residential or other purposes.

There has been a recent upsurge of activity under Part V in connection with government plans to establish large-scale enterprises in remote rural areas, but the sustainability of the outcome is far from certain. There have also been smaller acquisitions for private development (via transfer by the Commissioner or the Provincial Assembly to local developers). If all goes smoothly in such cases the process should take about six months, but here too the longer-term outcomes of existing acquisitions are not yet clear because of questions about the quality of the investigative process.

As well as going through a 'due diligence 'check and the appropriate formal procedures for acquiring a registered interest in land, a prospective investor would want to be thoroughly assured of local acceptance of the proposed investment through a painstaking process of getting acquainted with local leaders and communities and reading up local history. Commercial investment on unregistered land by a non-Solomon Islander would be insecure and is not recommended.

3.3 Relevant location of government-owned and other existing registered lands

In these circumstances it probably makes sense, at least while proving the commercial feasibility of a pearl industry investment, to explore the possibility of using land that is already registered, and has been or is now in use for some form of economic activity.

Such lands exist in the following locations:

- Shortlands (Ballalae airstrip), Gilbertese resettlement, close to Bougainville
- Vaghena, Gilbertese resettlement, Kagau (airstrip), access to Manning Strait
- Manning Strait islands
- Suavanao (airstrip)
- NW Isabel coastline, Allardyce Harbour
- Reef islands southeast of Gizo, including Nusatupe (Gizo airport, WorldFish base) tourist resorts and Gilbertese resettlement
- South Vona Vona lagoon (Munda airport)
- NW Marovo lagoon reef islands (Ramata) (airstrip)
- The major part of the Marovo lagoon appears to have been extensively affected by sediment run-off from logging on New Georgia and Vangunu
- SW Marovo lagoon (Uepi, Seghe) (Seghe airstrip)
- Russell Islands (Yandina airstrip)
- Sandfly Island and passage (Maravari)
- Marau Sound, East Guadalcanal (airstrip) (shell jewellery, corals, Ian Gower) (Tavanipupu resort)
- Santa Ana (East Makira)

These locations will be indicated on the map of SI included in the brochure. Visits will be arranged to some of the most accessible sites where it is believed conditions may make pearl farming technically feasible.

3.4 Reefs

Land as defined in the Land and Titles Act includes land covered by water (though not minerals or 'substances in or under land' that are usually obtained by mining or surface working). Most interests in registered land are defined to end at the high-water mark, but if customary rights extend over reefs adjacent to customary land being acquired by the Commissioner or Provincial Assembly for transfer of the perpetual estate to the customary owners, in the manner already described, it appears that those rights could be included in the perpetual estate and be subsequently leased to an investor.

4. Transport and telecommunications

4.1 Land transport

There are no road bridges between islands, and most of the potential mariculture sites are not on the intra-island road systems that do exist on North Guadalcanal and Malaita and to a lesser degree on Makira and Choiseul.

4.2 Sea transport

Frequent and busy shipping services operate between Honiara and ports in Russell Islands (Yandina) and Western Province (Marovo ports, Munda, Noro, Gizo and Shortlands). Isabel is also well served, Choiseul and the eastern provinces less so. Vessels in service include several landing barges and express passenger craft. There is strong competition for freight business and rates are keen.

Transhipment of freight from rural ports to remote locations is mainly done by 6-8m fibreglass open boats or large wooden canoes powered by 25-60hp outboards.

4.3 Air services

The government-owned airline Solair operates three 20-seat Twin Otter STOL aircraft and one 8-seat Islander. There are two scheduled flights most days to Western Province, going on twice a week to Choiseul and Shortland, daily flights to Auki and Malaita and twice a week to Makira. Fares are competitive with other domestic operations in the region, but the aircraft have limited cargo capacity and care is needed to ensure that urgently needed spare parts, for example, don’t get off-loaded in favour of surfboards. A locally-based helicopter is used mainly by minerals prospectors but is also available for other charter work.

4.4 Telecommunications

The national telecommunications provider Solomon Telekom Limited (trading as ‘Our Telekom’) is a licensed monopoly, majority owned by the national superannuation fund. It provides landline services at Honiara and urban centres, mobile phone services at the larger centres and satellite links for international communications. Though the business is very profitable, user costs are high by international standards and service quality and technical support are not highly regarded by customers.

Public opinion for some time has favoured opening the sector to competition. External advice (eg, World Bank, ADB) agrees, and the government is now committed to it. The expectation is that this will lead to lower prices and better services, as has been the case in other Pacific island countries with a similar telecommunications history. With the existing links, at locations within 25km of main centres (equivalent to an hour's journey by fast boat) an investor would be able to establish voice and internet communications.

5. Security of investments

5.1. Physical security

In rural locations in SI physical security depends on a combination of factors. Regular patrolling by the police is simply not available. An investor with portable assets to protect needs to take clear and non-provocative precautions against theft that are understood and accepted by neighbouring communities. Physical demarcation of boundaries by agricultural-type fencing, constant presence on the property of employees whose duties include regular inspection of perimeter fences etc, secure lock-up of offices, laboratories and storage of portable tools, outboard motors and other valuable items are obvious precautions, as is not keeping large amounts of cash on the property.

Oysters growing in a demarcated reef area as part of a pearl farming project would be the subject of common knowledge and interest in the area, and an important component in the security arrangements would be the attitude of people in neighbouring communities. Strangers are readily spotted and reported. If local residents feel they have a stake in the commercial success of the pearl farm and thus an interest in its physical security—which includes not stealing its stock themselves—this greatly reduces a significant area of risk.

5.2. Security of registered leaseholds

Registered leasehold interests in land, including land below the highwater mark, eg adjacent areas of reef, will be legally secure provided the appropriate procedures under the Land and Titles Act have been followed. As already mentioned, persons registered as owners of interests recorded in the land register are indemnified against loss arising from rectification of any defect discovered in their title. They are entitled under the general law of SI to assert and defend their rights to occupy and use land in ways appropriate to their registered interest.

It is still the case, though, that good relations with local communities are crucial to successful operations in rural areas. It would be impracticable to make and operate an agricultural or maricultural investment in a rural setting in a hostile social environment. It will be necessary to make sure that local communities know and understand what is proposed, that the operation is designed to provide as much participation for local people as is reasonable and practicable, business transactions with them are transparent, on fair terms as to prices and quality, and are properly recorded.

When the business grows, the local stakeholders will need to feel that they can share part of that growth. If the business experiences harder times, aspects of these can be fairly shared too provided the reasons are understood. This will not be news to persons who are already successful investors in other Pacific islands, but it is important not to lose sight of this aspect of security in promoting the prospect abroad.

5.3. Protection against expropriation

There no history in SI (or the Pacific islands generally) of expropriation of commercial investment. Governments have shown a clear understanding of the damage such action would do the country's chances of attracting further investment. SI subscribes to the APEC principles on non-expropriation and is a member of the Multilateral Investment Guarantee Agency, part of the World Bank Group of institutions, which provides financial guarantees against expropriation of foreign commercial investments by host governments. There is no significant expropriation risk to a possible pearl farming investment that is conducted in a commercially and legally conventional manner.

6. Forms of co-investment

6.1 Partnerships and incorporated joint ventures

There are several legal forms of joint enterprise, in which two or more persons share the costs and benefits of the business in ways they decide and record in a formal agreement. Professional groupings (lawyers, doctors, accountants) often take the form of partnerships, in which responsibility for group income, expenses and profits is shared according to a detailed partnership agreement. That does not seem to fit the likely circumstances of a potential pearl farm in SI. A possible preliminary period of collaboration and knowledge transfer between WorldFish at Nusatupe and an incoming investor in pearl oyster farming would most likely lead to the investor moving to a separate location to establish the commercial operation.

A form commonly used for business ventures in SI involving substantial fixed investments and the sharing of costs and benefits between public and private sector entities is the formally incorporated joint venture. There is no obvious public sector co-investor for a private investor to team up with, but there is a possibility of an established mariculture business joint-venturing with an incoming pearl farm investor. In that case the formal structure of their collaboration would be developed by them with their own legal and accountancy advisers

6.2 Specific terms of lease

As noted earlier, the participation of local communities stakeholders, particularly the kinship group or groups owning rights to land and/or reef areas to be included in the oyster farm and shore base, may be crucial to a successful long-term investment. This may be initially achieved by the terms of the lease to the pearl farm owner/operator, which would be implemented after the Commissioner of Lands had acquired the perpetual estate and transferred it to the appropriate kinship group(s).

Here, a rent structure may be negotiated that recognises the high risk and relatively long lead time that characterises a pearl oyster project, but provides for a significant increase in rents as and when commercial viability is achieved. Payment of an agreed share of gross sales and/or gross or net profits (with deduction before ‘net’ clearly defined) may be agreed on top of an ‘unimproved value’ fixed rental payment . There are many precedents for such successful agreements in the field of tourist hotel and resort development, and competent independent advice to the kinship group(s) concerned could readily be arranged.

6.3 Participation through out-grower operations

Depending on the form of operation chosen, which will depend on the method of oyster culture that appears to investors to be best suited to SI circumstances, participation in the pearl farming project may take the form of collection and sale of juvenile oysters to a central farm, where they are grown to seedable size, implanted with the prospective pearl nucleus and all being well are harvested after about two years. Outgrower rearing of oysters to seedable size and the seeding of oysters in outgrower farms seems likely to be a later development, but could come earlier if the scientific, land tenure and commercial factors affecting viability come together in a favourable way. Any of these forms of participation require clear definitions of oyster sizes and conditions, standards and methods of caring for the growing oysters, and transfer techniques and valuation methodology if oysters are to be relocated before harvesting of pearls. A prospective investor is likely to have relevant experience and preferences that would be critical in deciding the form of local participation in the risks, costs and benefits of any operation.

7. The investment approval process

The initial procedure for obtaining the necessary approvals for investment in SI has been much simplified by the Foreign Investment Act, 2005. Previously applications for investment approval were considered by a Board, which was often the cause of delays and accusations of undue influence. Now the initial step in the process only involves registration of the proposed investment, before more complex issues are addressed.

If a company is to be incorporated in SI to undertake the pearl farming the necessary application and registration processes under the Companies Act should be initiated and the company's name and details given in the application for investment registration.

A prospective investor applies under s.15 of the Foreign Investment Act providing the basic information required by s.16, describing the proposed investment activity and its location, if known at that stage. The Registrar checks completeness of the application and acknowledges receipt. Within five days the Registrar must reply approving or refusing the registration or giving notice that he is taking advice, for which a further five days is allowed. According to ministry staff these time limits are being successfully applied.

Pearl farming is not listed as a restricted or prohibited activity, and approval within the initial five-day time period appears most probable. A certificate of registration would then be issued by the Registrar giving details of the approved investment. Detailed changes (business name, address) may be made to the specification at the request of the investor, but if major changes are proposed a new certificate would be required.

A certificate may be cancelled by the Registrar if the proposed activity has not started within twelve months of the investor receiving the certificate or if the investor engages in a reserved or prohibited activity or breaks the law relating to investment. If the certificate is cancelled the investment activity must cease.

The Act also establishes an Investment Facilitation Committee, to be appointed and overseen by the Minister. The committee had not been activated at the time of preparing this brief. The committee is designed as a review board for decisions of the Registrar, and is itself subject to review by the High Court of SI in matters of law.

8. Taxation and incentives

8.1 Direct taxation: business tax

Resident corporations (companies) and individuals are taxed on their global income. Non-residents are taxed on income derived in Solomon Islands. The profits of resident corporations are taxed at 30%, non-residents at 35%. In calculating profit, deductions from income are allowed only for costs incurred in producing that income.

Capital expenditure is not normally a deductible expense (depreciation is deductible at prescribed rates). However, 100% deduction of capital expenditure is allowed for certain agricultural, livestock and scientific purposes, and it should be possible to make a good case for the same treatment to apply to development of pearl farming. Tax losses can be carried forward for up to five years provided there is no change of shareholder control.

8.2 Direct taxation: personal income tax

Employers are required to deduct personal income tax (PAYE) from their employees' wages and remit the proceeds to Inland Revenue. Individuals are taxed on an incremental scale. (In this section $ means SBD) Above a personal allowance of $7800 per year, income is taxed at 11% for the next $1-$15,000, 23% for the next $15,001-$30,000, 35% for the next $30,001-$60,000, and income above $60,000 is taxed at 40%.

These rates were set some years ago. With the fall in the value of money the real rate of personal tax is sufficiently high to induce significant concealment of income and tax evasion. Moreover a recent increase in the legal minimum wage has moved it above the personal tax-free allowance. This presumably unintended outcome needs rectification.

Income tax is also collected through a withholding tax, deductible from payments to residents and non-residents for a range of services and on dividends. There is reason to think that in practice this tax is less than fully collected both in urban and rural areas. Nevertheless it forms part of the formal tax structure and would apply to pearl farming.

A pearl farm investor would presumably devise a combination of personal residence and employment arrangements to minimise tax payable in SI while complying with the law

8.3 Indirect tax

Goods tax is charged on the wholesale value of locally manufactured goods, and on imports, where it is charged at 15% of a notional wholesale price calculated as 130% of the sum of CIF value and any import duty payable. There are a number of categories of imported goods exempt from goods tax, including scientific and research equipment. It will be worth requesting exemption from goods tax for any such equipment and other specialised imports required for pearl oyster development.

Sales tax is charged on sale of fuel, travel, professional services and a range of other services. It does not apply to marine or agricultural products. A pearl oyster farm will have to pay sales tax on many of its purchases but is unlikely to be selling goods or services that would require it to charge and collect sales tax and remit the proceeds it Inland Revenue.

Import duties are charged on a wide range of imports, but duty rates have been greatly reduced over the last ten years as part of trade liberalisation policy. When a schedule of technical and scientific equipment and other specialised imports is available, an investor should request exemption from import duty on the initial importation as a valuable form of assistance to undertake the investment. Such exemption is possible and seems likely here if the case is well put; note though that requests are as a matter of principle treated sceptically because of a history of abuse of ministerial powers of duty remission.

8.4 Incentives

The government has recently moved to regularise the granting of incentives for new and additional investment, by moving the function from the former Investment Board to the Inland Revenue Division. There an Exemptions Committee considers requests and makes recommendations to the Commissioner of Inland Revenue.

Within the limits of the tax law, guidelines to the Commissioner are laid down by the Minister of Finance. These stress that government revenue should only be forgone by the grant of tax exemptions if there are clear net economic and financial benefits expected from the proposed investment. Pearl farming's investment cost and benefit profile is unusual and will require careful explanation to the tax authorities, but it should be possible to make a good case for tax incentive treatment that fits the likely profile.

The government has indicated that it wants to reduce the importance of specific exemptions and concessions as incentives to investment by creating a 'more level playing field' for all businesses. Personal tax rates and thresholds are generally regarded as out of date and uncompetitive, with change long overdue. It seems likely though that an investment incentive in the form of a multi-year business tax holiday would remain, to enable capital invested to be recouped faster than would otherwise be the case (see 8.3).

The most likely and useful business tax incentive available to a pearl farm investment appears to be a tax holiday (exemption from business profits tax) for a period of up to 10 years, the actual period to be decided on basis of the projected performance of the business. This would be assessed by the Exemptions Committee and put forward to the Commissioner. A well-argued case should be able to obtain the maximum exemption.

9. Licence under the Fisheries Act, 1998

A pearl oyster farm will require a licence as a 'fish processing establishment' under the Fisheries Act. There should be no difficulty in obtaining this from the Aquaculture Division of the Ministry of Fisheries, once the proposal has been registered under the Foreign Investment Act. Under the 2005 Regulations a fee of SBD10,000 is payable for each species farmed. If both gold and black-lip shell are farmed it is likely that two fees will be payable.

10. Labour laws

10.1 Foreign workers

Work permits under the Employment Act and residence permits under the Immigration Act are required for foreign employees, including the investor himself/herself. Though the number of foreign workers is not likely to be large, an organisation diagram and job descriptions for the positions to be filled will need to accompany the request for work permits, to be sent to the Commissioner of Labour. The application forms contain a checklist of information required, including a description of the special skills that make it necessary to employ foreign workers, and the biodata of persons for whom permits are being sought. Evidence of training programs or other ways to be used to build up local capacity to replace foreign workers is required. Permits are issued for periods up to two years for fees of SBD150-SBD1100.

10.2 Wage structure and legal minimum wage

Wages in formal jobs in rural areas range from \$30-50 per day for semi-skilled to \$100-\$150 per day for skilled workers. The recently revised legal minimum wage in agriculture, which includes mariculture is \$3.80 per hour or about \$30 per day.

An oyster farm could expect to recruit all its unskilled and semi-skilled workers locally and not be involved in transporting them to and from annual leave. Workers housed on site would receive free basic housing, water sanitation and lighting. Supervisory and junior management pay in rural-based formal employment is in the range \$30,000-\$100,000 a year, plus free housing, water and electricity.

Workers in formal employment will be required to pay income tax (mentioned earlier) and contribute to the national provident (superannuation) fund, NPF, to which employees contribute 5% and employers 7.5% of pay. This is deducted from pay and the total remitted quarterly to NPF.

11. Provincial government business licensing

Licensing of businesses is one of the functions devolved to provincial governments. Their chronically weak financial condition has from time to time led provincial governments to impose unrealistically heavy licence fees (claimable as a pre-payment of business income tax but a heavy imposition on businesses—other than natural forest logging—not yet at the stage of making taxable profits). These moves have triggered protests to national and provincial governments by non-logging business operators and the subsequent reduction of the proposed fees. There is now a move within the national government to relieve provincial governments of this function and to compensate them for loss of business licence revenue through the national-provincial grant system.

12. Environmental impact assessment

The Environment Act, 1998, requires that any development—defined (despite a printing error in the relevant schedule) in a way that clearly includes the farming of oysters and associated land-based activities—should be the subject of an application for development consent under the Act. In considering the application the Director of Environment may require the preparation of a public environmental report or an environmental impact assessment, which would be published. After periods for public reaction to such report or assessment have elapsed the Director may issue the development consent with or without conditions, or may refuse consent.

Given the need for environmental care in the rearing of oysters and the relatively small scale of the shoreside installations required, it is unlikely that environmental objections would arise in this case. Nevertheless an investor should be seen to comply with the requirements of the Environment Act. The administrative and technical arrangements for implementation of the law are still untested, and a potential investor will need to take care that the legal provisions intended to protect the environment are understood and applied in the project.

13. Contacts on investment matters

1. Foreign Investment: Director, Investment Division, Derek Aihari, tel.22856
2. Taxation: Inland Revenue Exemptions Committee, Joseph Dokekana, tel. 22556
3. SI Chamber of Commerce and Industry: CEO Daniel Tuhanuku, tel.39542
4. Fisheries: Chief Aquaculture Officer Simeon Alekera, tel.30564
5. Lands Division: Commissioner of Lands, Joseph Pinita, tel. 23989
6. Labour: Deputy Commissioner of Labour, David Kaumae, 26811
7. Environment: Director of Environment, Fred Peter Siho, tel. 23031
8. Legal services: Primo Afeau, tel. 25600; Andrew Radclyffe, tel. 24095
9. Chartered accountants: Morris and Sojnocki, tel. 21851; Misi and Associates, tel. 30372
10. Banks: ANZ tel. 21111; Bank South Pacific tel. 21874; Westpac tel.21222

See 2008 Telephone Directory Yellow Pages and 2008 Solomon Islands Trade Directory for more accounting, legal, professional and technical services.

GILLETT, PRESTON AND ASSOCIATES INC.

Marine Resource Assessment, Development and Management

Stimulating Investment in Pearl Farming in the Solomon Islands

Pearl Farming Policy and Management Guidelines

Report to The WordFish Center

Garry L. Preston

August 2008

Stimulating Investment in Pearl Farming in the Solomon Islands

Pearl Farming Policy and Management Guidelines

G. L. Preston

30 October 2008

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1. EXECUTIVE SUMMARY

Pearl farming has been demonstrated to be technically feasible in Solomon Islands, and the Government is keen to see the development of a commercial pearl farming industry which provides rural income and employment, and generates foreign exchange and other benefits at the national level. The Worldfish Center has been supporting the Government in this regard, through a range of research and development activities of which this study forms a part. The present report reviews experience with the development and management of pearl farming industries in other countries, especially Pacific Island countries, in order to derive lessons that may guide management of the industry in Solomon Islands.

The report concludes that a management framework for the industry should be established at an early stage, to avoid problems that have occurred elsewhere. These problems include pearl oyster disease and mass mortalities which have severely curtailed pearl production, and which could have been prevented or mitigated by better husbandry practices; and loss of product value through inadequate quality control and the entry of low-grade pearls onto the market. The management framework needs to address these issues, and ensure that the pearl farming industry develops in a way that provides maximum economic and community benefits, and minimises negative environmental and social impacts.

The findings of this report are being used to support the formulation of the proposed management framework, which will initially consist of two primary elements:

- a pearl farming policy statement for consideration by Government and which, when adopted, will provide overall guidance to the management of the industry;
- a pearl farming regulation, which lays down specific requirements and restrictions on pearl farm operators, and which can be adopted by the Government either under existing fishery legislation, or under new legislation currently being prepared.

Key proposed policy goals include:

- generation of national revenue and foreign exchange through increased exports;
- economic diversification;
- creation of jobs;
- developing new skills for Solomon Islanders; and
- providing rural communities with income-earning opportunities.

Proposed policy initiatives to be used in achieving these goals include:

- consideration of tax concessions for new pearl farming investors for an initial period of ten years;
- issuance of long-term (ten year renewable) licences to approved pearl farming operations;
- issuance of work permits for foreign workers having skills not available in Solomon Islands, notably senior managers and seeding technicians;
- continuation of the existing ban on export of wild-caught pearl shell;
- management of the industry to ensure good farm husbandry practices, minimise the risk of pearl shell disease and mortality outbreaks, and mitigate against the transfer of parasites and pathogens;
- environmental regulation of other industries which may have impacts on pearl farming operations;
- regulation of pearl exports to prevent marketing of low-grade or inferior-quality pearls by small-scale producers who may eventually enter the industry.

The regulatory approach proposed focusses on the following primary controls:

- location of farm sites, and restrictions on their relocation once approved;
- limits on the total number of pearl oysters held under culture at any one farm site;
- limits on stocking densities of pearl oysters, expressed as numbers of oysters per unit of volume occupied by the farm;
- minimum spacing between farm sites;
- restrictions on the importation and translocation of live pearl oysters;
- regulation of the use of noxious or polluting substances;
- minimum standards for waste disposal processes and procedures, including from hatcheries;
- implementation of environmental management plans and codes of practice;
- restrictions on the transfer of licences.

It is proposed that Government give priority to pearl farming investment proposals that include:

- the degree to which local communities are likely to benefit from the project in terms of employment, collection and processing of spat, lease payments, training and skills development, and other advantages;
- the likely benefits to Solomon Islands in terms of exports and foreign exchange earnings;
- the commitment of the investor to environmentally responsible operations, as evidenced by the environmental management plan or code of practice for the project.

Forms of support that Government may be able to provide to prospective pearl farmers include:

- provision of historical information held by the Government that may be relevant to pearl farming operations;
- access to hatchery and/ or analytical laboratory facilities in which the Government has an interest;
- jointly financed or executed pearl farming research activities;
- community extension and training activities by Government in support of pearl farming development.

As the Solomon Islands pearl industry develops, the Government should establish and participate in consultative mechanisms that will ensure full and open dialogue between commercial pearl farmers, participating communities, and relevant government agencies. The Government needs to work closely with the industry to ensure that pearl farming management arrangements remain appropriate to the needs and development of the sector, and to ensure that the interest of all participants are fully protected.

2. BACKGROUND

Past research suggests that black-lip and possibly white-lip pearl farming could be technically and economically feasible in Solomon Islands. The WorldFish project '*Stimulating Investment in Pearl Farming in the Solomon Islands*', of which this study forms a part, aims to carry earlier research on pearl oyster distribution, life history and culture in Solomon Islands into an economic development phase by encouraging the engagement of overseas investors in the industry. The project, which is funded by EU-STABEX funds, involves studies of a number of relevant areas, including:

- consolidating information from past research on pearl oysters in Solomon Islands;
- assessing status of white-lip pearl stocks;
- management policy and regulatory guidelines;
- investment and business climate for pearl farming.

These reports are being made available to potential investors who will be invited to visit Solomon Islands to assess pearl farming development prospects from their own perspectives.

The present study concerns management, regulation and licensing of pearl farming activities in Solomon Islands. Experience from other countries shows that a balance needs to be struck between not imposing undue restrictions, burdens, or red tape on commercial operators, and ensuring that the industry develops in a socially and environmentally responsible manner. In particular, aspects of the industry will need to be controlled to ensure that benefits to Solomon Islanders are maximised, husbandry techniques minimise the risk of disease outbreaks among the farmed oysters, and operational practices do not cause environmental damage or social disruption.

The report discusses the major issues that have affected or influenced pearl industry management in other countries, and suggests approaches that would be suitable for Solomon Islands. Information has been gathered from published literature, media, interviews and conversations with relevant stakeholders, and industry documentation, some of which was provided in confidence. The topics covered are those specified in the consultant's terms of reference, viz.:

- carrying capacity for pearl oysters;
- mechanisms to deliver benefits to smallholders;
- access payments to customary owners;
- implementation of culturally sensitive operations;
- regulations to protect investments;
- marketing strategies;
- penalties for violations;
- incentives for investors;
- opportunities for smallholders to progressively increase their involvement in the industry; and
- a framework for the industry to operate in an environmentally and socially sustainable way and establish a reputation for Solomon Islands as a producer of fine pearls.

Discussion of these topics does not exactly follow the order or the headings listed above, but has been organised so as to allow the logical development and argument of ideas and approaches.

The concepts and suggestions presented in the report are then used to formulate two documents for consideration by appropriate agencies in the Solomon Islands Government:

- a pearl farming policy statement, which lays out Government's plans for and expectations from the industry, and identifies a framework for socially and environmentally responsible industry development;
- a pearl farming regulation, which embodies rules and requirements applying to licensed operators, and which will apply to any pearl farming licenses issued by the Government.

Draft licence application and issue forms have also been prepared to assist the administrative process through which the policy and regulation will be implemented.

These documents have been produced after widespread consultation with Solomon Island authorities and it is anticipated, but cannot be guaranteed, that they will formally be adopted by Government after due consideration and reflection. It is further expected that the latter document will be integrated into the review and revision of Solomon Islands fishery legislation which is currently under way.

3. PEARL FARMING IN THE PACIFIC ISLANDS

3.1. Development history

Two species of pearl oyster, the black-lip pearl oyster (*Pinctada margaritifera*) and the white-lip pearl oyster (*P. maxima*)[1] are used in commercial production of farmed pearls in the Pacific islands. *P. margaritifera* is the smaller of the two species, and is found throughout the Pacific Islands region, as well as in the Atlantic and Indian Oceans. *P. maxima* has a more limited distribution, and is only found naturally in the high-island countries west of Fiji, although attempts have been made to introduce it to Palau, Kiribati, Tonga and other countries. Both species occur naturally in Solomon Islands.

Commercial farming of the white-lip pearl oyster originally developed on the northern and western coasts of Australia. In recent years some Australian operators have moved offshore to reduce labour costs and escape the strict Australian regulatory environment, as a result of which new farming operations have spread to Indonesia Vietnam, Cambodia, Philippines and Myanmar. Indonesia has now overtaken Australia as the world's largest producer of *P. maxima* pearls in terms of volume, but lags far behind in terms of value. A single white-lip pearl farm has been operating in Papua New Guinea since about 1995, but there are no others in the Pacific Islands region. Pearls from white-lip pearl oysters are generally more valuable than those from black-lip because of their gold-to-white coloration and larger sizes.

Commercial farming of the black-lip pearl oyster takes place in two Pacific Island countries – French Polynesia and Cook Islands – of which French Polynesia is the most prominent. Pearl farming went through a 25-year development phase in French Polynesia, and continues to be the biggest employer and export earner for the country. However the industry has declined significantly in recent years, mainly due to problems of overproduction and poor pearl quality. In 1998 French Polynesia produced around 5 tonnes of pearls worth over US$ 150

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[1] There are two varieties of *P. maxima*, commonly referred to as gold-lip and silver-lip. It is not known for certain whether only one or both these varieties occurs in Solomon Islands. The term white-lip is used here to include both varieties.

million; in 2002, it exported over 11 tonnes, worth about the same amount. Average pearl prices have fallen from around US$ 35/ gramme to about US$ 14/ gramme in the past ten years.

The government in French Polynesia has spent many years attempting to address the problems of poor pearl quality, but with mixed success. Larger farming operations produce sufficient pearl volumes to organise and run their own marketing networks or participate in auctions, often overseas. Larger operators are generally conscious of quality issues and are able to refrain from marketing low-grade or poor-quality produce. Smaller family farms, however, do not generally have direct access to organised marketing networks and often sell their products indiscriminately by hawking them to visiting buyers or overseas jewellery producers. The sale of low-grade pearls in this way leads to a decline in the reputation and value of all pearls from that source. Negative perceptions of pearl quality may initially relate to an individual farm or farmer, or a given island or area, but will eventually affect the reputation of the country as a whole.

Initially the French Polynesian government established a cooperative to market the pearls produced by smaller farms, pooling the production from over 1,000 small operators and thereby enabling them to participate in volume auctions and marketing networks. Membership in the cooperative gave small farmers access to government services including technical advice, access to seeding technicians, low-cost farming materials and subsidised loans, in exchange for which farmers were obligated to market their pearls through the cooperative. Low-grade pearls were ceremonially destroyed each year during high-profile public events intended to promote or restore overseas confidence in the quality of French Polynesian pearls. However many farmers found ways to hide their poor quality pearls and keep them out of the cooperative marketing network, instead selling them on the black market. This process is said to have been aided by the growing number of local pearl seeding technicians, whose pay expectations were less than those of foreign technicians and who may have been less rigorous in regard to recording and controlling the pearls being harvested.

In subsequent years the French Polynesian authorities have attempted to put in place an industry code of practice, an active pearl marketing campaign that serves the industry as a whole, and a comprehensive system of quality control and certification, in which each approved pearl is sold along with an X-ray demonstrating the nacre thickness, as well as a government certificate of authenticity. These measures may have helped slow down the falling image and value of French Polynesian pearls, but have not completely arrested it, and the industry continues to decline. There is still a great deal of leakage, with large volumes of poor quality pearls continuing to enter the market. This undermines attempts by both government and large-scale producers to maintain the rarity value and exclusive image of their product.

The second most important producer in the Pacific Islands region is Cook Islands, where the industry was catalysed largely by developers from neighbouring French Polynesia who brought technical skills and investment funds to the country. The Cook Islands industry produced about US$18 million worth of pearls at its peak in 2000, but has declined since that time, with production of only about US$2 million in 2005. A major disease outbreak at the end of 2000, attributed mainly to overstocking and poor farming practices, decimated the industry, and it has still not fully recovered. Cook Islands has suffered more development problems than French Polynesia, including, in addition to disease, conflicts among farmers and persistent marketing of low-grade pearls, which has undermined prices in general and given Cook Islands a widespread reputation as a producer of a low-grade product.

Other Pacific Island countries produce black-lip pearls in very small quantities. A handful of farms in Fiji and Papua New Guinea have been discreetly run by private operators over the past 3-4 decades, of which one is currently operating in Fiji. Small donor-funded pilot farms have operated in Marshall Islands, Federated States of Micronesia, and Kiribati. Tonga has been carrying out research on the winged pearl oyster *Pteria penguin* with the intention of eventually establishing a half-pearl industry. Other than Fiji, none of these countries are likely to be significant pearl producers in the near future. Solomon Islands has also produced black pearls at a demonstration farm (see report by Hawes and Mesia, 2007, in this series) but to date has also not been commercialised.

3.2. Farming operations

Black-lip pearl farming is typically carried out as follows. Larval pearl oysters are collected from the wild by deploying strings of collectors on long (100-200m) anchored horizontal mainlines (longlines) suspended by floats a few metres below the sea surface. Juvenile pearl oysters settling on the collectors are referred to as spat. Collectors are cheap and simple to construct, deploy and maintain; originally they were made from twisted up pieces of plastic sheeting, onion bags or bundles of twigs; nowadays they are often made of 'mussel-rope', a special rope manufactured specially for shellfish spat collection, which has its strands deliberately frayed or left hanging from the standing part of the rope.

A typical small-scale collection operation might involve a few hundred individual spat collectors strung along half-a-dozen mainlines. Each individual collector may collect a few spat or a few hundred, depending on the characteristics of the collection area. Spat are allowed to grow to the size where they can be properly handled (at a minimum, about the size of a thumbnail, but usually somewhat larger) and then may be transferred to grow out lines or cages, or simply left to grow on the collector. Different areas have different characteristics in regard to mortality, predation, fouling by other organisms, etc., and this determines to a large degree how early the spat need to be transferred and the handling practices to be followed. Spat collection and grow-out require little specialised equipment or knowledge and can be accomplished by semi-skilled and unskilled operators.

When the juveniles are about 15 cm in dorso-ventral measurement they can be prepared for implantation with an artificial pearl nucleus. The preparation process involves deliberately stressing the shell for several days or weeks before surgery, in order to clear reproductive products from the gonads and make implantation easier. This is often done by dropping the pre-op shell lines to lie in a heap on the seafloor to deprive them of food and oxygen. Weakening the shell in this way reduces its ability to reject the nucleus after surgery, although there is a risk that the shell will be weakened so much that it will not survive surgery at all. After mortality and rejection, a nucleus retention rate of 70% in the implanted shell would be considered good. Research carried out in Australia in the 1990s concluded that better survival and retention rates could be achieved by anaesthetising the shell prior to surgery, rather than stressing them, but anaesthesia is still an uncommon practice in the industry.

Carrying out the implantation operation is a highly skilled profession practiced by experienced seeding technicians. It is a surgical operation in which the shell is partially opened, an incision made in the gonad, and a bead ground from the shell of a particular species of freshwater bivalve inserted. On top of the bead is placed a portion of mantle tissue from another pearl oyster, which has been sacrificed for this purpose. The operated oyster is then returned to the farm where it is hoped that the incision will heal, the inserted piece of mantle will form a pearl sac around the bead, and this will then deposit mother-of-pearl on the bead in an even, uniform and attractive manner to create a pearl. For the first few weeks after seeding the shell is kept inside a mesh bag in case it rejects the nucleus, which in that case can be recovered from the bag and re-used.

A good technician will achieve low rejection rates (30% rejection would be considered good), and a high proportion of good-quality pearls. Pearl price is exponentially related to quality – a grade 1 pearl may be worth 10 or 100 times the value of a grade 2 pearl, so a small increase in the proportion of grade 1 pearls in a harvest makes a huge difference to the profitability of the farm. Pearl seeding technicians are costly, particularly the most skilled ones. The typical cost of implanting pearl nuclei is around US$ 10 per shell. Since a typical mid-sized farm may have 10,000 – 50,000 shells seeded each year, this represents a very substantial investment, and is a major barrier to entry into the industry.

Harvesting of pearls typically takes place about two years after implantation. When a pearl is harvested, it is frequently possible to insert a new nucleus into the pearl sac in the gonad in place of the harvested pearl, thus immediately commencing a second crop. Second and subsequent pearls from the same oyster tend to be of better quality than first pearls because the pearl sac is already established. In addition, larger nuclei can be used, leading to a progressive increase in pearl size and value. Some oysters can produce four or five pearls during their lives, and occasionally even more.

The main difference between black-lip and white-lip pearl farming is in acquisition of shell for implantation. White-lip spat are less abundant and settle less readily on spat collectors than black-lip, hence spat collection is not a major source of young oysters for this species. Traditionally white-lip were collected as young adults from the wild, but hatchery technology for pearl oysters has now developed to the point that juveniles of both white-lip and black-lip can be produced in relatively simple hatchery facilities. Where wild stocks are unable to provide sufficient white-lip pearl oysters for farm operations, hatchery-reared spat are increasingly used.

In general, black-lip pearl farmers prefer wild-collected juveniles over those reared in hatcheries, as they are reputedly more robust and are said to produce better-quality pearls. This is not universally true, however, and some users of hatchery-produced spat appreciate the consistency of size and shape, which makes seeding easier. For wild spat collection to be successful requires a robust natural spawning stock to produce the juveniles, which in turn requires that the natural stock not be excessively harvested, either for shell (which is an export commodity in its own right) or for adults to be used for seeding. In areas where natural stocks have been depleted, pearl farms can contribute to reproductive success by aggregating concentrations of breeding adults, and spat collection operations are often most successful in locations close to existing farms. Nevertheless a rigorous management regime for wild adults is required where spat collection is the basis of a pearl industry, no matter how many shell are being kept under culture, and both French Polynesia and Cook Islands have restricted or banned the collection of adult pearl shell from the wild in islands where pearl farming is practised.

The pearl farming industries of French Polynesia and Cook Islands have evolved to show similar structural characteristics. A small number of large companies produce the majority of the pearls while larger numbers of smaller producers or family farms each produce small numbers of pearls, or simply collect and sell juvenile shell to the larger operators. This segmentation of the industry allows participation at different levels. Large investors with substantial capital, a long time horizon and a low aversion to risk can take the chance to implant large numbers of pearl shell in the hope of substantial economic gain. At the same time small operators with limited capital or those who are new to the industry can collect and sell spat to the larger operators, while also accumulating the adult shells, capital and skills necessary to move into actual pearl culture should they wish.

This industry segmentation is very suitable for a country like Solomon Islands, where there is a need to provide rural dwellers with income-earning opportunities. Because farming of white-lip does not generally involve collection of spat from the wild, there are fewer opportunities for participation by smaller players in the industry and this may make it less suitable as a development option for Solomon Islands than black-lip.

Even in the case of black-lip, however, small farmers will only be able to participate in the industry if there are larger operators present to provide a market for spat and juvenile shell. In addition, a critical mass of shell to be implanted is needed before it becomes economically feasible to bring in a seeding technician. If one or more large operators are in place, each with several hundred thousand shell under culture, then a seeding technician can be hired to implant these shell as well as those of any smallholders in the vicinity. Without this critical mass it becomes difficult and costly to organise for a seeding technician to implant small numbers of shell held in numerous widely scattered locations.

3.3. Marketing

The primary method of marketing pearls is to sell them through auctions or specially organised gatherings of pearl and jewellery buyers, either in consumer countries or, where the volume of product warrants it, in the country of production. Hong Kong is a primary centre for pearl auctions, but they are also held in many other locations.

When selling at auction, pearls are typically organised into lots which may contain several dozen or just a few pearls of varying quality. This arrangement prevents buyers from picking only the best specimens, and leaving the seller with unsold lower-value pearls. Because of the volume of product required to allow parcelling of the pearls into lots, only larger-scale producers can effectively participate in auctions. As noted earlier, there have been efforts to consolidate the production from small farmers through collective marketing arrangements, with partial success.

Smaller farmers may market direct to the jewellery trade, locally or overseas, or to the general public. This often leads to indiscriminate marketing to buyers who may not be sufficiently knowledgeable about pearl quality to judge good from bad. Subsequent problems with the pearls give a bad name to the product and depress demand and prices across the board.

Quality control is therefore a critical issue. In both French Polynesia and Cook Islands the marketing of poor quality pearls has damaged the industry. In some cases this is a result of farmers harvesting too early, leading to pearls with only a thin nacreous layer that subsequently cracks or wears off. In others very low-grade pearls have been sold that would normally have been rejected and destroyed. Pearls are a high-end luxury product and experience in other countries has shown that industry revenues are maximised by marketing only the best-quality product, maintaining the image of rarity and exclusivity, and keeping low-grade pearls off the market altogether, preferably by destroying them.

If the problem of pearl quality can be overcome then there are strong prospects for developing local pearl and pearl shell jewellery products in the country of production, for sale to tourists and other visitors. Local jewellers can add significant value to the base product and provide mementos and souvenirs that attract premium prices from visitors. In other pearl farming countries, retail pearls and pearl jewellery are more expensive when purchased in-country than when purchased overseas, where they tend to be competing with a range of alternative products. Most medium- and large-scale pearl farms work with local or overseas designers to develop their own jewellery lines for sale through retail outlets on the farms themselves, or in local hotels and tourist stores.

In countries with significant amounts of tourism, pearl farms can generate additional revenue and value by organising farm visits and tours that take in operations such as spat collecting and processing. As well as generating additional revenue for the farming operation, tours provide a good way to expose visitors to jewellery products and increase on-farm sales. Where tourism forms part of the pearl farm's activities, proper attention needs to be paid to environmental management to ensure that visitors perceive the farm as a clean and healthy operation which is not polluting or harming the marine environment.

Pearl farms also produce significant amounts of pearl shell, which is in high demand overseas for jewellery, furniture inlays and other decorative purposes. Export of shell is permitted in some countries but may be prohibited where there are concerns about management of wild pearl oyster stocks. Farmed shell are hard to distinguish from wild shell, so allowing the export of farmed shell provides an opportunity for illicitly harvested wild shell to enter the trade.

4. PEARL FARMING IN SOLOMON ISLANDS

4.1. Opportunities and prospects

Pearl farming has several characteristics that make it a particularly suitable form of development for the Solomon Islands:

- it uses species that are native to Solomon Islands, so there will be none of the unwanted environmental impacts that may arise when new species are introduced;
- culture techniques are well-established, and have been shown to be economically feasible and socially and culturally appropriate in other Pacific Island countries;
- pearl farming can be carried out in rural or remote areas, providing development opportunities away from the urban centres;
- spat collection and some aspects of farm maintenance are labour-intensive and low-technology, and can be carried out using unskilled or semi-skilled rural labour. Other activities, such as those involving diving, can also be carried out using local labour after suitable training by the farm operator;
- the products (pearls and pearl shell) are non-perishable, low in volume and high in value, a major advantage in Solomon Islands where domestic transportation links with rural areas are unreliable and quite costly;

These characteristics are favourable for the development of a rurally-based pearl farming industry in which small-scale operators and large investors can profitably participate.

In general black-lip pearl farming has been most successful to date in atoll locations, where geomorphologic features favour the retention of spat and consequently give high levels of spatfall. However black-lip farming has also been carried out successfully in Fiji and Papua New Guinea, which, like Solomon Islands, are high island countries with mainly open reef and lagoon systems. White-lip pearl farming is not associated with atoll locations, and occurs along the coast of Australia as well as other locations in South-East Asia.

Initial questions about the feasibility of pearl farming in Solomon Islands centred around the availability of spat in the wild, since, given the open nature of the reef systems, it was not known whether these would be retained in coastal waters in sufficient numbers to permit commercial farming. However trials carried out by the WorldFish Center indicate that black-lip spat can be harvested in commercial quantities in Solomon Islands, and that saleable pearls can be produced. Previous pearl oyster research data from Solomon Islands is summarised in a companion document to this report (Hawes and Mesia, 2007).

One positive element in this regard is the current moratorium in Solomon Islands on pearl shell exports. The Fisheries Division imposed this in 1994 in response to fears of over-exploitation following high levels of shell exports in prior years. The moratorium is still in place, although some illegal harvesting takes place and illicit export consignments, primarily of white-lip shell, are occasionally intercepted. Surveys have shown that white-lip pearl oyster populations persist in several parts of Solomon Islands, though current numbers are probably too low for a pearl industry based on wild caught shell (see report by The Ecology Lab (2008) in this series). However, production of pearl oyster spat has been successfully demonstrated in Solomon Islands by the WorldFish Center. WorldFish hatchery-reared spat were grown out and seeded to produce pearls without any particular technical difficulties (see Hawes and Mesia 2007).

Other factors that are positive for the development of a pearl-farming industry in Solomon Islands include:

- there are large numbers of potential farming sites;
- based on WorldFish Center trials, pearl oyster growth rates appear to be about 25% faster than in Cook Islands;
- labour costs are generally low (current minimum rural wage of about US$ 5 per day in Solomon Islands, as compared to about US$ 50 per day in French Polynesia).

Although environmental and economic conditions appear favourable, there are several factors that may work against the development of a pearl farming industry in Solomon Islands. In particular, there is a generally poor external perception of Solomon Islands by many potential investors (Government instability or unreliability, ethnic tensions, security of investment, etc.). These issues are often exaggerated, as discussed in a report from this project on the economic and investment climate in Solomon Islands (Hughes 2008).

Even if investors (whether foreign or domestic) were forthcoming, this would not necessarily lead to a situation in which rural Solomon Islanders would be able to participate in the industry. The natural business decision of a commercial pearl farmer would be to carry out spat collection/ production himself along with his pearl seeding and harvesting activities, and to undertake his business in as secretive a manner as possible in order to protect his own competitive advantage. Under these circumstances there would be few flow-on benefits to rural Solomon Islanders apart from a few manual jobs, and no mechanism to support the development of community or family-based farming activities. It is the responsibility of the Solomon Islands Government to implement policy and legislation to ensure that development of a pearl industry is managed in a way to make it attractive to investors, environmentally and economically sustainable and capable of delivering benefits to rural communities.

4.2. Legislation

Several government documents pertain to the management of fisheries aquaculture in Solomon Islands. Chief amongst these are the Fisheries Act (1998), Fisheries Regulations (2002) and the Ministry of Fisheries and Marine Resources' Aquaculture Development Plan.

Responsibility for the management and development of Solomon Islands' marine resources lies with the Ministry of Fisheries and Marine Resources (MFMR). The Fisheries Act (1998) (hereinafter referred to as *the Act*), is the major piece of legislation governing fisheries and fisheries-related activities. The Act is currently (late 2008) under review, but until new legislation is fully adopted will continue to apply to any prospective pearl farming activities. The Act provides the basic legal framework from which other subsidiary controls can be derived but in itself has minimal direct application to the overall control of aquaculture. The Act does not distinguish aquaculture from other fishing methods or fisheries, and the applicability of some provisions to aquaculture control is unclear. The Act does however have certain relevant provisions, as follows:

- Section 31, *Aquaculture Operations*, requires the written permission of the Director of Fisheries, with or without conditions, for the setting up and operation of an aquaculture activity. Conditions that may be specified with a written approval deal with issues such as 'the location of the aquaculture facilities and its operation, the prevention of the spread of communicable fish diseases, the inspection of aquaculture sites and the provision of statistical information'. Contravention of the provisions of this section invokes a penalty of up to SI$ 100,000 on conviction.

- Section 32, *Import and Export of Live Fish*, prevents the import or export of live fish without the Director's permission. The section imposes an assessment on the possible impacts of imported live fish being released into the wild. Contravention of the provisions of this section invokes a penalty of up to SI$ 500,000 on conviction.

Provisions for further aquaculture control come in the form of 'regulation making powers' under Section 59, *Minister's Powers to Make Regulations*, under which the Minister may regulate, in general, any fishery activity in need of or requiring control for management and development purposes. Section 59(1)(xiv) specifically empowers the Minister to regulate the cultivation of seaweed and other aquatic organisms, and Section 59(1)(xv) empowers the licensing of fish farms and regulation of the importation of live fish.

Draft Aquaculture Regulations were developed by the MFMR Aquaculture Division and subsequently included as Part 2 of the draft Fisheries Regulations (2003). They were intended to apply to the farming of a range of species, including *Pinctada margaritifera*, *P. maxima* and *Pteria penguin*. The draft Regulations describe aquaculture licensing procedure and impose penalties upon violation of the licensing requirement. No licence is required for 'any traditional practice of breeding, farming, culturing, taking or holding of live fish or aquatic organism the purpose of which is for subsistence, personal or traditional use only' and 'farming which is done by a local or a local community on a small scale and for subsistence purposes only'. Despite providing a detailed and useful basis for aquaculture management, the Fisheries Regulations 2003 have never been gazetted and are therefore not in force.

Under the provisions of the draft Regulations, any application for a licence should contain the following information:

- details of the species, stage of the life cycle and quantity of the aquatic organism to be bred, farmed, cultured or held;
- plans relating to the construction, development or modification of an aquaculture facility to which the application relates;
- details of the location of the aquaculture facility and of all places, if applicable, at which the applicant intends to breed, hold, rear, process or sell fish or aquatic life;
- details of the gear, tools or equipment that the applicant intends to use to take fish or aquatic life;
- approvals required under any other law, and;
- such other information as may be required by the Director.

The draft Regulations also specify the conditions of the licence that may relate, but are not limited, to:

- the species of fish or aquatic life to be bred, farmed, cultured or held;
- the stages of the lifecycle of fish or aquatic organism at which the same may be kept;
- limitation of the quantity of fish or aquatic life that may be kept or sold;
- the method of water discharge or waste disposal;
- the location of the aquaculture facilities;
- limitation of the use of chemicals or drugs, if any;
- a requirement for the lodgement of a guarantee or security to cover the cost of damage that may be caused by the operation of the aquaculture facility.

The licence is not transferable. The Director may review, vary or alter the conditions of the licence, or temporarily suspend a particular condition. Under specific circumstances, the Director may cancel, revoke or suspend the licence. Any person aggrieved by such a decision of the Director, or the decision not to issue or renew the licence, may appeal to the Minister within 30 days following receipt of the notification of such decision.

In addition to the licensing requirement, all aquaculture facilities and equipment must be built, installed or constructed to standards approved by the Director of Fisheries. For example, all facilities need to have an effluent reservoir in which wastewater is to be treated before discharge. The Regulations also require biological (as opposed to chemical) means of effluent treatment to be used unless circumstances render it costly or impractical. The Director may impose conditions to the aquaculture licence relating to the method of water discharge or waste disposal. After inspection of the facility, the Director may issue a certificate certifying the facility as fit and proper for aquaculture activities. Without this certificate it is prohibited to culture aquatic organisms in the facility.

As noted these draft Regulations are not yet in force, but there is the possibility that they may be gazetted in the near future, as an interim measure until the new Fisheries Legislation is ready. The draft Regulations provide a useful model which has been used during the present study in the drafting of a specific Pearl Farming Regulation for consideration by Government.

Only one commercial aquaculture operation has been licensed in Solomon Islands in the last few years, a land-based prawn farm on Guadalcanal, which is no longer operating. Because of the absence of appropriate licensing mechanisms, this was licensed as a fish processing establishment. The only other aquaculture licence thought to have been issued in Solomon Islands was to ICLARM (now the WorldFish Center) in the early 1990s for community aquaculture projects supported by that organisation based on the grow-out and export of giant clams produced in the WorldFish hatchery.

A revised version of the Fisheries Regulations was prepared in 2003, but for various reasons has never been gazetted. The existing Regulations are likely to be superseded as part of the ongoing review of the Fisheries Act. Like the 1998 Fisheries Act, the new draft Act as it currently stands pays only limited attention to aquaculture. There is a need to strengthen the aquaculture provisions of the new Act prior to its finalisation, and to ensure that aquaculture in general, and pearl farming in particular, are adequately covered in regulations or other subsidiary legislation. Representations and recommendations are being provided to the review team to this effect.

4.3. Policy

The current government's stated policy goal for the fisheries sector is *'the development and sustainable utilisation of sea and marine resources to benefit and contribute to the well being of Solomon Islanders'*. The policy is accompanied by eight expected outcomes and a series of associated strategies, most of which relate to managing and increasing economic benefits from capture fisheries, especially tunas. None of the outcomes or strategies make any reference to aquaculture.

MFMR's Aquaculture Development Plan (hereinafter referred to as *the Plan*) contains a number of statements of policy in regard to aquaculture in general and pearl farming in particular. The Plan recognises that the Ministry lacks knowledge and experience of aquaculture, and that institutional strengthening and human resource development are required. It also acknowledges the absence of appropriate policies and regulations for aquaculture, and urges the development of these. Noting that the WorldFish Center operates the only aquaculture hatchery in Solomon Islands, the Plan recommends against the development of further hatcheries by government, although it encourages government support to the private sector in regard to hatchery development. Section 9 of the Plan states that MFMR will provide information to prospective aquaculture investors in regard to land and sea tenure, licensing, infrastructure and transportation, among other things. In regard to pearl farming, proposed actions by MFMR are:

- Collaborate with WorldFish and EU to attract private investors in Solomon Islands;
- Maintain the ban on the wild shell trade;
- Implement the policies and licensing conditions developed by the EU-funded project;
- Provide extension services for the participation of local communities through Provincial Fisheries Officer, after the establishment of private farms;
- Promote value added pearl oyster products particularly for rural communities in opportunities such as shell carvings or pearl mabe handicrafts.

At present there is no policy or management framework specifically intended for the pearl farming sector. The development of such a framework for an as-yet non-existent industry may be regarded by some as somewhat premature and liable to discourage investors. However in other Pacific Island countries where the pearl industry has developed the absence of any regulatory framework has led to major problems which have had to be addressed once the industry was already in a crisis. As with fisheries management, it is far better to learn from experience, anticipate problem areas and set the 'rules of the game' beforehand, rather than wait until the problems occur.

Properly formulated management guidelines should also be a source of reassurance to legitimate investors with a long time horizon. Bona fide investors will prefer to operate within a framework in which 'the rules of the game' are already in place and clearly spelled out, rather than in an uncertain environment where policy and regulations are ignored until there is a crisis, or are developed according to the whims of government ministers or public servants.

5. ENVIRONMENTAL MANAGEMENT OF PEARL FARMS

5.1. Pearl oyster health

The pearl oyster industry is based entirely on shellfish health. The pearl itself is a product of the immune defences of the pearl oyster, which work to fight off any invasion or irritation of the soft tissues by enclosing it in a pocket of calcium carbonate and protein. Since significant energy is required to lay down this defensive pocket, the most productive pearl oysters are those that are in good health and with access to the energy reserves required.

Pearl farming means that cultured pearl oysters grow in crowded and unnatural conditions, are repeatedly handled, and undergo surgery, all of which present physiological stresses that the oyster would not face in the wild. The energy requirements for pearl production have to be balanced against the need to handle the oysters and grow them in conditions they did not evolve to fit. This balance is easier to achieve if overcrowding and disease can be minimised.

Most disease problems in pearl oysters centre on opportunistic pathogens taking advantage of oysters weakened by the stress of handling, pearl surgery and sub-optimal growing conditions. Mass mortalities have been experienced in Japan, Australia, French Polynesia and Cook Islands. In all cases these appear to have resulted from oysters being weakened by natural events (e.g., high temperature or cyclone-induced changes), sometimes coupled with pearl oyster spawning seasons, or by coral spawning or red tides, both of which deplete the water of oxygen; and then succumb to bacteria or parasites that are normally tolerated without harm. Poor farming and handling practices such as stocking shell too densely or failure to clean the shell of fouling organisms, both of which weaken the oysters by depriving them of nutrients and oxygen, also seem to have contributed to mass mortalities.

Pearl oysters have not yet faced the types of contagious disease agents that have plagued other types of mollusc culture. Although a blessing for the industry so far, this means that there has not been extensive research on pearl oyster pathology, and there is a lack of information documenting normal versus abnormal parasites, pests and diseases for these species.

Once an epizootic occurs in an aquatic habitat, the chances of eradication and control are limited. In fact there are no examples to date of any molluscan disease agent being actively eradicated from an open-water system. The main purpose of environmental and health management is to minimise the risk of disease outbreaks on pearl farms and, if an outbreak occurs on one farm, to reduce the likelihood of it spreading to other farms. This is addressed mainly by regulating the total number of shell that can be held on a farm, their stocking density, the distance between farms, and the transfer of shell from one area to another.

Environmental management also aims to ensure that pearl farming does not have negative impacts on adjacent marine ecosystems or on other economic activities, such as fishing or marine tourism. Pearl farming involves the use of boats and fuel, construction materials for farm lines and over-water structures, cleaning fluids, transfer of shells between locations, and the disposal of pearl oyster fouling waste and diseased or dead shells. Pearl hatcheries may use antibiotics, disinfecting agents and other chemicals, and if an infection occurs can serve to spread disease to wild shell and the natural environment. If not carried out in a responsible and sensitive manner, therefore, pearl farming can have potentially negative environmental, economic and social consequences which can degrade local marine ecosystems, affect other resource users, and cause a nuisance to residents in the area.

5.2. Stocking density

Mature pearl oysters filter water at the rate of approximately 20 litres per hour, or 480 litres per day. If the oysters are not sufficiently separated they will collectively strip the water of oxygen and nutrients and ingest excessive quantities of each other's waste products. A regulatory goal should be to ensure that stocking densities do not exceed one oyster per cubic metre within the water volume occupied by the farm.

On a typical pearl farm, shell are hung on 'chaplets', which are vertical ropes of 2 – 5 metres in length, and carrying 10 – 20 shell, either drilled through the hinge and tied directly onto the chaplet, or in panel nets attached to it. Chaplets are strung along a horizontal mainline which may be up to 220 metres in length (this being the standard length of a coil of rope). In operational terms, achieving a stocking density of one shell per cubic metre of water would require the following:

- a minimum spacing of 10 cm between shells on a chaplet;
- chaplets spaced along the mainline at minimum intervals of one metre;
- mainlines spaced from each other at a distance of 10 metres, and preferably 20 metres or more.

Based on these minimum requirements a typical farm might be stocked as follows:

- 100 mainlines each of 220 metres length, spaced 10 metres apart;
- 220 chaplets hanging from each mainline, spaced at 1m intervals – total 22,000 chaplets;
- each chaplet 2 metres long, and carrying 20 shell spaced at 10 cm intervals – total 440,000 shell.

The volume occupied by the farm would be 440,000 m^3 (1000 m x 220 m x 2 m) giving the required volume:shell ratio of one shell per cubic metre of water. Greater spacing between shells, chaplets or mainlines would further improve (i.e., lower) the stocking density.

To facilitate monitoring, stocking density regulations should be kept relatively simple. In particular no distinction should be made between spat and adult oysters – the same requirement of no more than one shell per cubic metre should apply irrespective of the oyster life stage. In order to minimise the impact of any disease or health problems should they arise, farm sites should be restricted to a maximum of one million shell held under culture at any one location. Shell in excess of this number should be held at a separate location and subject to the provisions of a separate licence.

5.3. Farm size and location

The farm site described in the preceding section would occupy a surface area of 1,000m x 220 m = 220,000 m^2, or 22 hectares. However a more usual farming arrangement would involve the separation of shell into several areas (for examples, zones containing newly-hung spat, pre-operative shell, and seeded oysters) within the main farm site. Greater mainline spacing, which should be encouraged, would add further to the need for space, as also would installations such as over-water seeding sheds. As a result a typical farm site would require a lease area of at least 100 – 150 ha. To reduce the risk of disease outbreaks spreading from one holding to another, regulations should stipulate that farm sites must be separated by at least five kilometres of water.

Most well-run farming sites are situated at least 100 m from adjacent reefs and in water at least 25 m deep, with sediment rather than live corals beneath. These practices distance the shell from benthic predators and parasites and allow free water exchange below the hanging shell. Mainlines are generally suspended at least two metres below the sea surface in order to keep shell out of the most agitated part of the wave zone, and avoid accidental damage from small boats. All these practices should be a regulatory requirement for pearl farmers in Solomon Islands.

Where pearl farming takes place in atolls, especially closed ones, circulation may be limited and currents weak, which may result in the accumulation of pearl oyster waste (faecal products and drop-off by fouling organisms) beneath farm sites. In these circumstances, good health management practices require that mainlines be moved to adjacent areas after 1-2 years, before being moved back after another 1-2 years. This allows alternate sites to lie fallow and regenerate, avoiding excessive build-up of toxic or unhygienic waste products. Where farms are located in areas with stronger coastal currents, or in very deep water, this practice is not necessary. Farms in Solomon Islands will probably correspond to the latter situation, but the option should be retained to require farmers in semi-enclosed areas or low-current situations to relocate their mainlines between two (or more) alternate sites every two years.

5.4. Movement of pearl shells

One of the health risk factors relating to pearl farming is that animals may be transferred from an area where a disease or parasite is present, to an area previously free of the infection. Transfers may occur under a variety of circumstances: pearl farmers may collect spat in one area and grow them out in another; farmers may take shell from an existing farm for purposes of expansion or setting up new farms elsewhere; broodstock may be relocated to or between hatcheries; or a new entrant into the industry may buy shell from an existing farmer to meet his start-up requirements.

At the present time there are few constraints on the movement of biological material within Solomon Islands, whether it be terrestrial or marine. Seaweed is regularly transferred among far-distant farm sites in response to the needs of farmers, and it is likely that pearl farmers would similarly want to move batches of pearl shell from one place to another from time to time. In Australia, Japan, Cook Islands and French Polynesia regulations have been introduced to control the indiscriminate movement of pearl oysters between farming sites. Translocation is still permitted, but only takes place between sites where the health status of the shell population has been studied and monitored or, failing that, after health inspections of the shell to be moved and, sometimes, quarantine of those shell.

The Secretariat of the Pacific Community (SPC) has published guidelines relating to the transfer of biological material between and within countries for aquaculture purposes. The guidelines provide disease inspection, quarantine and risk assessment protocols for a range of species, including pearl oysters. It is recommended that as a minimum the SPC guidelines be adapted for incorporation into Solomon Island’s pearl industry management regulations. In general, local movements of shell within a 25 km radius need not be regulated, to allow a reasonable dispersal of a pearl farmer’s spat collectors and grow-out sites. However any movement of pearl shell over a distance greater than 25 km should require the written permission of the Director of Fisheries. An application for approval of a pearl shell transfer should be accompanied by a full justification, and an explanation of what alternative measures have been considered. Permission for transfer should not be unreasonably withheld, but there should be a proper risk assessment of the proposed translocation before approval is granted. If appropriate, histological examinations of sample of both the shell to be moved and the population at the destination site may be required prior to transfer. If pathogens, parasites or harmful fouling organisms are present in the shell to be moved, but not in the destination population, then this should be taken into account in the risk assessment.

Pearl farmers operating in Solomon Islands could conceivably wish to import shell from other countries. This is currently prohibited under Solomon Islands fishery legislation without the express written consent of the Director of Fisheries and is highly regulated in most other countries. As a matter of principle, the importation into Solomon Islands of live pearl oysters from other countries should not be permitted. Apart from the risk of introducing exotic parasites and diseases, inter-breeding of non-native shell will influence the genetic makeup of the local population and possibly compromise any natural advantages that Solomon Islands shell may have in regard to adaptation to local conditions, pearl colour, growth rates and other characteristics relevant to pearl farming.

5.5. Hatchery operations

Hatcheries are used to supplement or replace the supply of wild-caught juvenile pearl oysters, as well as to permit selective breeding of pearl oysters with favourable traits for pearl farming (colour, high growth rates, disease resistance, etc.). Hatcheries rely on a small number of wild-caught broodstock which are made to reproduce in closed tanks or water systems. The larvae so produced are initially free-swimming, but settle onto solid substrates after about 20 days, and metamorphose into juvenile pearl oysters. Feeding is required in the initial stages, and a pearl oyster hatchery also needs to maintain cultures of live algae for this purpose. Both the pearl oysters and the algal cultures are susceptible to infection and mass mortality caused by bacterial or other infections, so all aspects of the hatchery operation require high standards of cleanliness and disinfection.

The most significant environmental impacts that hatchery operations may have centre around the uncontrolled disposal of used water and waste products into the surrounding waters. This may allow contamination of wild stocks by diseases or infections that may develop in the hatchery, release of non-native algal species or entry of disinfectants and other pollutants into natural waters. A more subtle impact is that, as hatchery produced larvae join the reproductive population in the wild, they may alter the genetic makeup of the wild population.

Pearl oyster hatchery operation requires the culture of algae needed to feed larval and juvenile pearl oysters. Different species of algae are used at various stages of the pearl oyster life cycle, and each hatchery operator has his or her own preferences for the types to be used. Algae are usually obtained as sterile monocultures from overseas laboratories, which are used to inoculate mass cultures within the hatchery. Mass cultures may become infected with bacteria or unwanted algae from time to time, so that they have to be disposed of and replaced, requiring the hatchery to periodically import new starter cultures . There is the prospect of cultured algae escaping into the natural environment unless waste disposal is properly managed.

The primary environmental management requirement for hatcheries is therefore that all water discharge from the facility should be disposed of into an effluent reservoir or sump on land, at least 15m inland from the high tide mark, and well above it. Waste should preferably be treated by chlorination, ultra-violet disinfection or physical filtration to remove pathogens and harmful chemical residues, and should be allowed to settle in the effluent reservoir or sump for several days before draining out. Hatchery waste water should never be discharged directly into the sea, or into rivers, streams or ponds. These measures effectively prevent contamination of the natural environment and wild pearl oyster stocks by the chemical or biological products of the hatchery.

5.6. Other environmental requirements

A number of other measures are suggested to ensure that pearl farming operations safeguard the marine and coastal environment and avoid creating public nuisances. Some of these should be incorporated into regulations or licence conditions as requirements which incur a penalty if not followed. Others are measures that should be encouraged as part of a responsible approach to pearl farming, but are not appropriate for inclusion as regulatory measures.

Measures proposed for inclusion in regulations include the following:

- farm lines must be secured to concrete anchors dropped on a sediment (not coral) seafloor. The practice of tying farm lines and spat collectors to coral heads, common in some countries, should not be permitted;
- over-water structures should be built with minimum excavation and in such a way as to minimise damage to corals and the adjacent environment. Use of anti-fouling paints or building materials treated with toxic chemicals that might leach into the water (such as tanalised timber products) should be prohibited;
- cleaning and removal of fouling organisms from pearl shell under culture should take place on a barge, raft or boat. Fouling and other waste should be taken ashore and disposed of on land, not dumped in the water;
- waste from over-water structures (cleaning products, food refuse, toilet flushing waste and other pollutants) should be taken ashore for disposal, and not dumped in the water;
- containers that may have previously contained industrial chemicals should not be used for floats. Containers that have previously contained food or other non-toxic products should be thoroughly cleaned and labels removed before use;

Licenses should also require the provision of basic data on pearl farming and spat collection operations using standard forms and logsheets that will be developed as part of the licensing process.

Measures that would be good practice, but which are not suitable for inclusion in regulations, include:

- daily operations require the use of fuel and oil. Employees should be trained in spill prevention and precautions taken to ensure spills are avoided;
- use of four-stroke rather than two-stroke outboard engines for pearl farm operations;
- rubbish and litter not to be thrown into the sea;
- animals not to be kept on over-water structures;
- regular information meetings and consultation with stakeholders, including community representatives, landowners, local government officers, and Fisheries Department personnel.

As part of the pearl farming application process, proposers should be encouraged to submit an environmental management plan (EMP) which addresses the above issues and specifies how the requirements will be met. The EMP should describe the physical and operational systems and measures that the pearl farming operation will put in place to ensure environmental management goals are monitored and met, including human resource management measures (staff training, incentives to encourage good practice, performance monitoring, etc).

In addition to licensing under the Fisheries Act, under the 1998 Environment Act pearl farming operations would require a development consent from the Director of Environment, which may in turn require an environmental impact assessment (EIA). By including an EMP which complies with the above requirements and guidelines as part of the project approval documentation, prospective pearl farm investors would not only be demonstrating a commitment to environmentally responsible operations, but may avoid the need for (and cost of) a formal EIA.

5.7. Cultural sensitivity

It goes without saying that pearl farming operations need to develop in a manner that is reasonably harmonious with Solomon Islands cultures and traditions. While economic development will always involve change, there is no reason why this cannot take place in a framework of mutual respect and cooperation between commercial pearl farming operations and local communities. At the very least it will be a requirement for investors to consult with local community representatives and stakeholders, and understand their needs and aspirations. Care should be taken to avoid activities that are inappropriate in areas of cultural importance, such as historically-important sites and tabu areas, or to do things such as dumping of rubbish and waste products in a way that will cause a nuisance to members of the community. Encouraging direct or indirect participation in the industry, as described in the next section, will also go a long way towards cementing good relations between pearl farmers and local communities.

6. COMMUNITY AND SMALLHOLDER PARTICIPATION

6.1. General

There are a number of ways in which local Solomon Islanders can benefit from the establishment of pearl farming operations by a foreign investor. Benefits would primarily accrue to people and communities in the immediate area of the pearl farm, and could include:

- access payments or royalties in regard to a lease over an area of water and adjacent land where pearl farming operations are carried out;
- revenue generated by a shareholding in the company or entity that produces and markets the pearls;
- employment as labourers and, with appropriate training, as divers and possibly in managerial roles on the pearl farm;
- collection of wild shell and their sale to the pearl farm during the period of initial establishment;
- collection and processing (cleaning and re-stringing) of spat, and their sale to the pearl farm;
- eventually, small-scale farming pearl farming, with support and assistance (materials, technical advice, seeding and marketing) from the main farm.

These options are discussed in more detail in the sections below.

6.2. Lease payments and access royalties

Possible arrangements under which leases over areas of water and adjacent land suitable for pearl farming sites are described in more detail in a companion report to this document (Hughes, 2008). That report provides information on land tenure in Solomon Islands and recommends that prospective investors consider basing their operations on registered land, which comprises about 10% of land in Solomon Islands, rather than customary land, which constitutes the remainder. Registered land is considered legally secure whereas land that is not registered can be subject to dispute.

6.3. Shareholding or business participation

Some business operators in rural areas have successfully engendered community goodwill and support by allowing local people to become shareholders in the business and participate in its profits through payment of dividends or other forms of benefit.

In one example a company in PNG (not a pearl farming company) invited local people to buy shares at a cost of 1 kina (about US 30 cents) each. The company declared a dividend of about 10% of the share value twice a year, and also held an annual general meeting during which all shareholders were provided with information on company operations and invited to express their views on aspects of company business. The AGM was accompanied by custom performances and a feast, all paid for by the company. This arrangement generated considerable goodwill among the local community and permitted the company to go about its business without undue obstruction or interference. The low cost of entry allowed even members of the community with little money to buy a few shares and participate in both dividends and the AGM, which ultimately became a much-anticipated community event.

In another example, possibly more relevant to the present case, a pearl-farming company endowed the local community that owned traditional fishing rights over the area where the pearl farm was located with a shareholding which entitled it to 2.5% of the gross sales value of pearls produced by the farm. These funds were distributed to the community according to rules laid down in an agreement signed by the community's traditional leaders. In practice, a proportion of the funds were retained by the traditional leadership, and a proportion spent on community projects or distributed among individuals as agreed internally by community members. The community has the option to increase its shareholding through purchase of additional shares, at a fair cost to be agreed between the company and the community, but this has not so far been taken up.

Both of the companies mentioned above have also undertaken additional activities intended to provide community benefits and maintain goodwill. These have included financing, in full or in part, of community projects such as buildings and infrastructure (toilets, water pipes, solar panels, etc.), contributions to community fund-raising events, providing scholarships for promising local students, and sponsoring youth groups to carry out beach or village clean-ups. As always in such situations there is a need to strike a balance between the company raising ever-increasing expectations within the community and being regarded as a cash cow, and ensuring good community relations.

There are numerous ways in which communities can participate in or benefit from the business activities of a pearl farm based in their locality. Detailed arrangements would need to be worked out through negotiation between the operator and the community, based on the needs and aspirations of the community and the financial realities of the pearl farming operation. Ideally the arrangements put in place should ensure that benefits flow to all community members, rather than just a few landowners or chiefs, although recognition of traditional authority or seniority will also be important. As in the examples above, a mixture of individual shareholding, payments to traditional or community leaders, and projects that benefit the community at large would seem appropriate.

6.4. Employment

Pearl farming is relatively labour-intensive. In the initial set-up phases there will be a need to construct and set anchors, farm lines and buoys, and any over-water structures required.

Much of this work will have to be carried out by SCUBA divers, who will also be needed on an ongoing basis for inspection and maintenance of the underwater parts of the farm. Other ongoing work involves the making and deployment of spat collectors, chaplets, new farm lines, and maintaining boats and outboards. Once the farm has shell under culture, they need to be cleaned every 3-4 months. This involves hauling the shell onboard a boat or barge and scraping or scrubbing off any fouling organisms that have accumulated, then transporting the waste back to shore for dumping.

The amount of labour required at different stages of the farm's operation will depend on the size of the installation and the number of shell under culture. A mid-size farm with 50-100,000 shell under culture may require 4-6 full-time labourers and two SCUBA divers, with additional help needed during busy seasons. It would be normal and appropriate for these workers to be sourced from the local community, including SCUBA divers, who should be trained to professional standards by the company. It would also be normal for Solomon Islanders, preferably from the local community if this is possible, to be employed as foremen or middle-level farm managers. While not an appropriate subject for inclusion in aquaculture regulations, policy should dictate that pearl farmers would not be eligible for work permits allowing foreign staff to work in these positions.

The same is not true in regard to seeding technicians. The entire business operation depends on the qualities and abilities of these individuals, who are in fact not mere technicians but qualified and highly experienced veterinary surgeons. In other countries localisation policies have forced pearl farmers to hire locally trained technicians who have generally performed less well than foreign personnel, resulting in higher levels of shell mortality and pearl rejection, and lower pearl quality. In addition, the decline in pearl quality and increase in black marketing of pearls in French Polynesia and Cook Islands has been attributed in part to the increase in local technicians working in the industry. Solomon Islanders should be encouraged to undertake training as seeding technicians, and to sell their services competitively on the free market. However any attempt by Government to force the localisation of this profession or regulate the use of foreign technicians will damage the pearl farming business and act as a major deterrent to prospective investors. Government policy on pearl farming needs to clearly state that there is no intention to exclude foreign seeding technicians from operating in Solomon Islands in the future.

6.5. Spat and shell collection

In the start-up phase of a pearl farming project there will be a desire to establish a stock of implantable oysters as soon as possible by harvesting young adult shell from the wild, and this represents another income-earning opportunity for local communities. As the farm matures, shell will start to be sourced from spat collection or hatcheries, and the need for adults harvested from the wild will progressively decrease.

Over the longer term, the greatest opportunity for local communities to benefit from pearl farming activities in their area will be through spat collection, which might operate in a number of ways:

- in some situations, individuals or families build and deploy their own spat collectors, check them, harvest the spat when ready, and sell them to pearl farmers at a typical cost of US$ 1 per spat (7-10 cm in dorso-ventral measurement);
- in another situation, the pearl farming company sets its own spat collectors, but engages a women's group from within the community to harvest and process the spat. The collectors are picked up by the company boat and taken to a simple processing

> shed on the shore, where women nominated by the group pick off the spat (around 6-8 cm DVM) and drill them for hanging on grow-out ropes. Around four months later the same process is used to harvest the grow-out ropes and re-hang the shell on chaplets. For each of these stages the women's group is paid about 10 US cents per oyster. The total payment depends on the number of spat collected and processed, but is typically of the order of USD 20,000 per season. The women's group makes the decision about how workers and members will be remunerated, and what (if any) community projects the funds received will support.

As regards Solomon Islands, the latter scenario is probably the most relevant. Under this arrangement there are no capital costs to the women's group as the pearl farming company provides all of the equipment required for processing. As the industry develops, some individuals or groups might progress to the stage where they provide these facilities themselves, and are able to earn higher amounts per spat as a result.

6.6. Small-scale pearl farming

It may be anticipated that, over time, community- or smallholder-based spat collection could evolve to small-scale pearl farming operations in which individuals or community groups retain some of the spat that they collect and use it for on-growing, seeding and eventual harvesting. These additional stages add complexity and cost to the spat collecting operation and therefore require greater organisational, management and technical skills, more capital, and a longer time horizon. At some stage such operations will require separate aquaculture licences and policy must dictate when this occurs. Additionally, the commencement of foreign investment projects may encourage domestic investors to enter the industry, possibly in partnership with existing or new foreign operators. In either case, the result may be a growing number of relatively small-scale entrants to the industry over a period of 5 – 10 years or more.

Experience in French Polynesia and Cook Islands shows that many problems arise when small, inexperienced and unregulated operators start to account for a significant proportion of industry production. Small farms are the primary source of poor-quality and black market pearls and do not have the management discipline or financial capacity to reject low-value product in order to improve the value of better-grade pearls. As discussed above, poor quality control threatens the industry and policy may need to contain mechanisms for regulating sales by small-scale operators.

In other Pacific Island countries, attempts to regulate and manage small farmers to keep inferior pearls off the market have been only partially successful. In a country such as Australia, with significant resources to spend on monitoring, surveillance and enforcement, a regulatory approach to pearl quality may be feasible. However in most Pacific Island countries, including Solomon Islands, it would be naïve to imagine that government regulations or centralised marketing run by a public body would be effective in deterring small farmers from selling low-quality pearls and undermining the industry as a whole.

This situation thus presents something of a quandary. Entry into the real business of pearl farming, rather than just spat collection, could present significant opportunities for Solomon Island communities and domestic investors; but in other Pacific Island countries where smallholders have become a major part of the industry, problems of pearl quality have arisen which have caused the industry to decline.

The most promising way to address this problem in Solomon Islands, if and when it should arise, would seem to be to encourage the development of a 'nucleus-estate' model in which smallholder farms are required to be linked with larger commercial enterprises which can provide them with technical and material support, including marketing. It could be envisaged that the process of spat collection could progressively be upgraded to small-scale pearl farming through a process in which communities or individuals form partnerships with commercial pearl farms. In that case the commercial pearl farm would provide support in the form of materials, technical assistance and, importantly, seeding. In exchange the small farmer would be obligated to have his pearls harvested under the supervision of the commercial operator, and included in that operator's marketing arrangements. The relationship would need to be laid down in clear and immaculate detail under a binding contract that committed both parties to pre-determined and transparent dealings with each other. Similar arrangements would apply in the case of partnerships or joint ventures that might develop between the commercial pearl operation and domestic investors. Licensing of small farms could be a useful stage for the encouragement of the nucleus-estate model.

This is unlikely to be a perfect arrangement in all cases, or universally supported. Smallholders in other countries have entered into arrangements with large-scale operators and subsequently claimed to have been cheated on marketing deals, especially where complex multi-company arrangements permit transfer pricing and somewhat subjective attribution of costs. Conversely, larger operators often lose patience with small farmers whose demands for financial and material support become excessive, who fail to follow proper husbandry or farm maintenance practices, or who persist in trying to market inferior quality pearls despite the marketing agreements in place. However in the absence of better alternatives the nucleus-estate model seems to be the option of choice. This approach is being used in another pearl farming operation in the region but is relatively new and thus has not so far stood the test of time.

In any case this is not likely to be an issue in the near future. It will probably take 5 to 10 years at least before the industry develops to a point where small-scale pearl farming becomes a management issue. However the problems need to be anticipated so that, in the event that an industry does develop, it does not then become undermined by the quality problems that have arisen elsewhere. Government policy on pearl farming needs to recognise the need to control indiscriminate pearl marketing, possibly by licensing marketing as a separate activity to farming itself. Under such an arrangement pearl marketing licences would only be issued to larger-scale operations with sufficient demonstrated production volume to participate in industry auctions and major marketing events.

7. INVESTOR INCENTIVES

The main natural attractions for pearl farming in Solomon Islands have already been identified in section 4.1 as multiple farming sites, high pearl oyster growth rates, and low labour costs. Additional incentives that could be offered by Government or the WorldFish Center are described by Hughes (2008) in an accompanying report and are summarised below.

7.1. Duty and tax relief

Given that pearl farming is an industry that requires long time and investment horizons there are strong arguments for providing full or partial duty relief on the importation of materials and supplies needed to establish the pearl farm, and tax relief for an initial period of ten years. Many other countries offer such concessions for pioneer and rural industries, and for Solomon Island not to do so would reduce the relative attractiveness of the country to foreign investors.

7.2. Employment of seeding technicians

As noted earlier, any pearl farming industry that develops in Solomon Islands will depend on the services of foreign seeding technicians, the majority of whom are Japanese. In other countries regulations requiring localisation of this work has led to a variety of problems for the industry. A clear statement by the Solomon Islands Government that licensed pearl farming operators will be entitled to receive work permits for foreign seeding technicians will be an encouragement to investors with long-term investment horizons.

7.3. The Worldfish facility

One drawcard for a pearl farmer considering an investment in Solomon Islands is the existing WorldFish aquaculture facility at Nusa Tupe, in Western Province. Any investor who could gain access to this facility would immediately short-circuit the process of identifying a suitable culture site and negotiating a lease agreement, and constructing basic operating facilities, including a hatchery. The stock of 2-3,000 adult shell currently being held at the facility could be implanted with nuclei immediately, so that the farm would commence generating revenue in two years rather than the usual 4-5. Spat collection and/ or hatchery production arrangements would still need to be developed so that the size of the farm could be progressively increased, but the existing stock would accelerate the process of achieving positive cash flow and profitability.

A cooperative venture with the WorldFish Center should thus be a significant attraction to any investor interested in exploring pearl farming in Solomon Islands. This should make it possible to leverage a cooperative venture which allows WorldFish and the Solomon Islands Government to continue research on aspects of pearl oyster biology and life history (growth rates, spat collection success, etc) or to access research information obtained by the commercial partner. Ultimately, if initial success was achieved at the WorldFish site, the company would need to negotiate its own site and facilities.

8. FUTURE MANAGEMENT ARRANGEMENTS FOR PEARL FARMING

There is currently an absence of appropriate management legislation and procedures relevant to a pearl farming industry, should it develop in Solomon Islands. A relatively simple initial management framework is proposed during what will hopefully comprise the industry's start-up phase. This is in three parts:

- a Pearl Farming Policy Statement, for government consideration and approval;
- a Pearl Farming Regulation, laying out the rules under which pearl farming must be carried out and including a schedule that stipulates the data to be provided to the MFMR by licence-holders; and
- Pearl Farming Licence application and issuance forms, which stipulate specific terms and conditions for two types of licence:
    - Commercial Pearl Farming Licence, intended for larger-scale operators with significant numbers of shell under culture and who need to bring into Solomon Islands expatriate managers and pearl seeding technicians;
    - Pearl Hatchery Licence, intended to supplement the Commercial Pearl Farming Licence in the event that farmer wishes or needs to operate a hatchery. (This also caters for the possibility that a hatchery operation might develop to service multiple pearl farms);

These documents, which integrate the principles and recommendations presented in this report, have been drafted in late 2008, in consultation with MFMR, the Solomon Islands Attorney General and their advisors. The focus at this stage is on pearl oyster health management, disease control, environmental management and impact mitigation from large-scale operations, and on ensuring community benefits. It is not proposed at this point to regulate spat collection or small-scale pearl farming by local individuals or communities, since both activities will take several years to develop. It would also be premature at the present time to establish regulations relating to pearl marketing and quality control, but controls on all these aspects may be necessary in the future, depending on developments over the next few years. If commercial pearl farming commences in Solomon Islands as hoped, then the regulations should be reviewed after an appropriate period (no more than 5 years) and amended as necessary. Such a review should take place with the full participation of any pearl farmers who may be operating in the country by that time.

The Solomon Islands Ministry of Fisheries and Marine Resources is currently preparing an overall policy framework to guide the development and management of the fisheries sector, and is also reviewing the current fishery legislation with a view to updating and improving it. The draft Pearl Farming Policy Statement, Regulation and Licence documents have been prepared in such a way that they can be adopted immediately, or integrated with only limited amendment into the broader policy and legislative instruments currently being prepared.

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Solomon Islands Pearl Farming Regulation

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A Regulation

To Control the Development of the Pearl Farming Industry in Solomon Islands.

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Division I. Preliminary

1. Short Title and commencement

(1) This Regulation may be cited as the ***Pearl Farming Regulation 2008*** and shall come into operation on such date as the Minister may appoint by notice published in the Gazette..

2. Interpretation

(1) In this Regulation, unless the contrary intention appears:

‘**Act**’ means the Fisheries Act 1998;

‘**chaplet**’ means a length of rope or line, suspended vertically from the mainline of a farm line, on which individual pearl oysters are hung, whether or not in bags, cages or other enclosures;

‘**Director**’ means the Director of Fisheries as defined in Section 2 of the Act;

‘**farm line**’ means an assemblage of lines, ropes, anchors and floats used for the purpose of suspending adult pearl oysters in coastal waters so that they can grow in a manner that is easily accessible for pearl farming;

‘**float line**’ means the line connecting a float to the mainline of a farm line or spat line in order to prevent it from sinking;

‘**hatchery**’ means a facility used for the purpose of propagating juvenile pearl oysters;

‘**mainline**’ means the horizontal part of a farm line or spat line, from which chaplets or spat collectors are hung;

‘**pearl farming**’ means the rearing and culturing of pearl oysters in coastal waters, the seeding of pearl oysters, and the harvesting, processing and marketing of pearls, and includes the process of spat collection;

‘**pearl farming facility**’ means the buildings, structures, underwater lines, floats, rafts, anchors and other infrastructure used for pearl farming, including hatcheries;

‘**pearl farming lease**’ means a lease of land, water, sea or part thereof for purposes of aquaculture, and includes a sub-lease of an existing facility to a third person;

‘**pearl oyster**’ means a bivalve mollusc of the species listed in Schedule 1;

‘**licence**’ means a licence to carry out pearl farming issued under this Regulation.

‘**licensee**’ means the holder of a licence granted under this Regulation.

‘**person**’ means a natural person or a body corporate;

‘**Principal Licensing Officer**’ means such fisheries officer as appointed under the Act;

'**seeding**' means the implantation of artificial nuclei of any type into pearl oysters for the purpose of producing pearls, and includes half-pearls;

'**spat**' means juvenile specimens of pearl oysters after metamorphosis and settlement from their larval stages;

'**spat collector**' means a device, typically made of frayed rope, small-mesh netting, or twigs, and typically no more than 2 metres in length and 50cm in thickness, fixed to a spat line and suspended in the water for the purpose of attracting larval pearl oysters and promoting their settlement and metamorphosis;

'**spat collection**' means the process of deploying spat collectors in coastal waters and subsequently harvesting the spat collected on them, either for the purpose of producing pearls, or for sale to other pearl farmers;

'**spat line**' means an assemblage of lines, ropes, anchors and floats used for the purpose of suspending multiple spat collectors in coastal waters.

(2) This Regulation shall apply to the farming and processing of those species listed in Schedule 1 to this Regulation. The Director may, by notice published in the Government Gazette, amend the schedule whenever necessary.

Division II. Activities requiring a licence

(2) Harvesting of pearl oysters from the wild, or collection of pearl oyster spat, may be practised without a specific licence by:

(a) any licensee holding a licence issued under this regulation

(b) any Solomon Islander;

(c) any village group, community group or community-based organisation.

(2) Unlicensed individuals, groups or organisations collecting adult pearl oysters or their spat may only do so for the purpose of selling the spat so collected to pearl farming facilities or operations in Solomon Islands and licensed under this Regulation.

(3) All other activities relating to pearl farming, including but not limited to growing of spat to adult size, seeding of pearl oysters, harvesting of pearls and operation of hatcheries may only be carried out by holders of a valid licence issued under this Regulation.

Division III. Licensing

3. No pearl farming without a valid licence

(1) No person shall rear, hatch, breed, farm, culture, take or hold pearl oysters for sale or trade, other than the collection of wild pearl oysters for sale to pearl farms, and the collection of spat using spat collectors, without a valid licence issued under this Regulation.

(3) Any person who breeds, farms, rears, cultures, takes or holds pearl oysters for sale or trade, other than the collection of wild pearl oysters for sale to pearl farms, and the collection of spat using spat collectors, without a licence shall be guilty of an offence and liable to a fine not exceeding fifty thousand dollars.

4. Types of licence

(1) An application for a licence shall be made in the prescribed form to the Director.

(2) Subject to these regulations the Director may, on payment of the prescribed fee, grant to an applicant one of the following types of licence:

(a) a **Pearl Farming Licence**;

(b) a **Pearl Hatchery Licence**.

(3) Subject to payment of the prescribed fees, an applicant may apply for one or both types of licence.

(4) The prescribed fees for initial application and renewal of a licence are shown in Schedule 2 to this regulation. The Director may, by notice published in the Government Gazette, amend the schedule whenever necessary.

(5) Every application for a licence shall contain:

(a) details of the type of licence for which the application is made;

(b) details of the species of pearl oysters to be farmed;

(c) plans relating to the construction, development or modification of the pearl farming facility to which the application relates;

(d) details of the location of the pearl farming facility and of all places at which the applicant intends to collect spat and to breed, rear, hold and process pearl oysters;

(e) approvals required under any other law for the time being in operation in Solomon islands;

(f) details of the gear, tools, equipment, chemicals and any noxious agents that the applicant intends to use in connection with the operation of the pearl farming facility;

(g) details of any lease entered into for the purposes of pearl farming;

(h) such other information as may be required by the Director for processing of the application.

(6) Any person who acquires or procures a licence on the basis of false information being supplied in such person's application shall be guilty of an offence and liable to a fine not exceeding fifty thousand dollars, plus cancellation of licence.

5. Period of validity of licence

(1) Licences shall be issued for an initial period of ten years. Licences shall be renewed annually subject to the following conditions:

(a) payment of the prescribed renewal fee;

(b) compliance by the Licensee with the provisions of this Regulation.

(2) At the time of renewal, the term of expiry of a licence shall be extended by a further period of one year, such that the period of validity of the licence is restored to ten years on each renewal.

6. Provision of statistical information

(1) Any licensee holding a licence issued under this Regulation shall be required to provide information on the licensed pearl farming operation to the Director in a form and at a frequency as he may reasonably require in order to:

(a) ensure the effective management of the pearl farming industry in Solomon Islands; and;

(b) monitor compliance by the licensee with the provisions of this Regulation and any special licence conditions that may apply.

(2) Information so supplied may be included in aggregate form into statistical summaries or other public information documents produced by the Director or his agents, provided that such inclusion is done in a manner which prevents detailed identification of the licensee's activities by third parties.

7. Pearl Farming Licence

(1) A Pearl Farming Licence permits the licensee to carry out farming of pearl oysters in coastal waters, including the collection of spat, the growing of juvenile and adult pearl oysters, the seeding of pearl oysters and the harvesting and marketing of pearls. A Pearl Farming Licence does not permit the licensee to operate a hatchery.

(2) A Pearl Farming Licence granted under this Regulation shall be subject to the following conditions:

(a) the licensee is permitted to collect pearl oyster spat from the wild using artificial spat collectors;

(b) the licensee is permitted to purchase wild pearl oysters and their spat from communities or individuals;

(c) the licensee is permitted to purchase farmed adult pearl oysters from another holder of a Pearl Farming Licence or a Pearl Hatchery Licence.

(3) The Director may specify additional conditions in relation to any Pearl Farming Licence issued under this Regulation.

8. Conditions of Pearl Hatchery Licence

(1) A Pearl Hatchery Licence permits the licensee to operate a hatchery for the purpose of causing adult pearl oysters to reproduce in captive conditions, growing in captive conditions the larval and juvenile pearl oysters resulting from such reproduction, and transferring the juvenile pearl oysters to licensed pearl farming operations in coastal waters. A Pearl Hatchery Licence does not permit the licensee to operate a pearl farm.

(2) The Director may specify additional conditions in relation to any Pearl Hatchery Licence issued under this Regulation.

9. Review, variation or alteration

(1) The conditions prescribed in a licence issued under this Regulation may be reviewed, varied or altered by the Director. Any such variation shall be communicated to the Licensee within seven days of such action.

10. Licence to be displayed

(1) A licence issued under this Regulation must be displayed in a prominent place at or within the vicinity of the location prescribed in the licence for the operation of the pearl farming facility.

(1) Any licensee who fails to display the licence at the prescribed location shall be liable to a fine not exceeding ten thousand dollars.

11. Licence not transferable

(1) No licence issued under this Regulation shall be transferable except with the written permission of the Director.

(2) Notice of the sale or disposal of a pearl farming facility operating under a licence issued under this Regulation shall be sent to the Director at least twenty-one days before such transaction is concluded.

(3) Any person who transfers a licence issued under this Regulation without the Director's consent commits an offence and shall be liable to a fine not exceeding one hundred thousand dollars.

(4) Any person who knowingly acquires a licence to which the Director's written permission is not given or is yet to be given commits an offence and shall be liable to a fine not exceeding fifty thousand dollars.

(5) Any licence transferred without the Director's written permission shall be deemed invalid.

12. Register to be maintained

(1) The Director shall maintain or cause to be maintained a register which shall contain particulars of licensees and permit holders and of transfers, variation of licences or permit conditions, expiry, suspension or cancellation of licences or permits.

(2) The register shall be made available on request to any interested person.

(3) The Director may charge a fee for the examination or obtaining a copy of the register by interested persons.

13. Director may cancel licence

(1) The Director may cancel, revoke or suspend a licence in any of the following circumstances:

- (a) where a licensee is grossly in breach of this Regulation or the conditions prescribed in the licence;
- (b) a licence is acquired on the basis of false information;
- (c) a licensee has committed an offence not warranting immediate suspension or cancellation of the licence but has nonetheless committed the same or related offence repeatedly on at least three occasions.

(2) Where a licence has been suspended, revoked or cancelled, the licensee shall be informed by the Director of the suspension, revocation or cancellation within seven days of such action.

14. Aggrieved person may appeal

(1) Any person aggrieved by the actions of the Director in refusing to issue or renew a licence, or in cancelling, revoking or suspending a licence may, within thirty days of receipt of notification of such decision, appeal to the Minister.

Division IV. Pearl farming operations

15. Area and location of pearl farming facilities

(1) Details of the location and surface area of the land and coastal waters to be occupied by the pearl farming facility shall be provided to the Director during the process of applying for a Pearl Farming Licence.

(2) No pearl farming facility shall be situated within 5 kilometres of another pearl farming facility. No licence for a pearl farming facility shall be issued if there is a pre-existing pearl farming facility within five kilometres of the proposed location.

(3) No pearl farming facility shall be relocated over a distance of more than one kilometre without the prior written permission of the Director. Where such a relocation is proposed, the Director may at his discretion require the licensee to submit a new licence application relating to the proposed relocation.

(4) For the purposes of clauses 15(2) and 15(3), distances between pearl farming facilities shall be taken as the shortest distance between them measured over water.

(5) Any changes in the extent of a pearl farming site or its boundaries, which do not involve relocation over a distance of more than one kilometre, whether or not accompanied by a change in lease arrangements relating to the pearl farming facility, shall be notified to the Director within seven days of the changes taking place.

16. Pearl oyster stock size and stocking densities

(1) The maximum number of pearl oysters allowed to be held in coastal waters at any pearl farming facility shall be one million (1,000,000). No pearl farm shall hold more than this number of pearl oysters, irrespective of their age, size, or stage of life.

(2) The limit referred to in clause 16(1) shall not include spat which have settled naturally on spat collectors and which have not yet been harvested.

(3) Notwithstanding the provisions of clause 16(1), the maximum areal density of pearl oysters allowed to be held in coastal waters in any part or sub-area of any pearl farming facility shall be one hundred thousand oysters (100,000) per hectare.

(4) Notwithstanding the provisions of clauses 16(1) and 16(3), the maximum volumetric density of pearl oysters allowed to be held in coastal waters in any part of any pearl farming facility shall be one pearl oyster per cubic metre of water occupied by the farm lines.

(5) For the purposes of this Regulation the surface area, areal stocking density, water volume and volumetric stocking density of the pearl farm shall be calculated according to the methodology described in Schedule 3.

17. Location of farm lines and spat lines

(1) All farm lines and spat lines shall be fixed to the seabed with man-made anchors used specially for that purpose.

(2) Anchors shall be set in areas of sand, mud or other sediment sea floor and shall not be placed in areas of live coral.

(3) Fixing of farm lines and spat lines to coral heads or other natural marine features is not permitted.

(4) No farm lines or spat lines shall be located:

(a) within 100 metres of the coast or of any reef;

(b) in waters having a depth of less than 20 metres;

(c) above areas of living coral.

(5) Farm lines shall be set such that there is a minimum distance of 10 metres between them.

(6) Spat lines shall be set so that there is a minimum distance of 5 metres between them.

(7) Farm lines and spat lines shall be set so that all ropes and lines are at least 2 metres below the surface of the sea.

(8) Buoys and floats used to support farm lines and spat lines shall be clearly marked with the name and licence number of the licensee to whom they belong.

18. Over-water structures

(1) Any over-water structures, including seeding platforms, guard sheds and watchtowers must be built with minimum excavation and in such a way as to minimise damage to corals and the adjacent environment.

(2) The use of anti-fouling paints or building materials treated with toxic chemicals that might leach into the water is prohibited.

(3) Animals, including but not limited to dogs, pigs or chickens, must not be kept on over-water structures.

19. Pollution and waste disposal

(1) Waste from over-water structures, including but not limited to cleaning products, food refuse, toilet flushing waste and other pollutants, must be taken ashore for disposal, and not discharged into the sea.

(2) Cleaning and removal of fouling organisms from pearl shell being held on farm lines, or from spat harvested from spat collectors, shall take place on shore or on a barge, raft or boat. Fouling and other waste must be taken ashore and disposed of on land, and not dumped in the sea.

(3) The use for floats of containers that may have previously contained industrial chemicals is prohibited . Containers that have previously contained food or other non-toxic products must be thoroughly cleaned and labels removed before use;

(4) Appropriate precautions must be taken to minimise the spillage of fuel and oil into the sea or on land during daily pearl farming operations. Employees should be trained in spill prevention and cleanup.

(5) Rubbish and litter must not be thrown into the sea.

Division V. Importation, movement and export of live pearl oysters

20. Importation of pearl oysters prohibited

(1) No live pearl oyster may be imported into Solomon Islands from any other country, irrespective of its size, age or stage of life, without the prior written permission of the Director.

(2) Any person who imports a live pearl oyster into Solomon Islands from another country without the prior written permission of the Director commits an offence and shall be liable to a fine not exceeding one hundred thousand dollars.

21. Movement of pearl oysters

(1) No live pearl oyster may be transported over a distance of more than 25 kilometres within Solomon Islands, or exported from Solomon Islands, without the written permission of the Director, irrespective of its size, age or stage of life.

(2) No pearl oysters known to be infected with contagious diseases or parasites shall be moved over a distance of more than one kilometre within Solomon Islands.

(3) For the purposes of clauses 19(1) and 19(2), distances shall be taken as the shortest straight line distance between the origin and the destination of the pearl oysters being moved, irrespective of whether measured over land or over water.

(4) Any person who transports a live pearl oyster over a distance of more than 25 kilometres within Solomon Islands or exports a live pearl oyster without the prior written permission of the Director, or transports a diseased pearl oyster over a distance of more than one kilometre commits an offence and shall be liable to a fine not exceeding fifty thousand dollars.

Division VI. Pearl hatchery operations

22. Pearl hatchery to be situated on land

(1) Any pearl oyster hatchery must be situated on land, at least 15 metres inland from the high water mark, and 3 metres above the level of mean high water spring tides.

(2) No pearl hatchery may be built, established or operated on platforms, rafts or other structures situated over coastal waters, coral reefs or other emergent features within coastal waters.

23. Facility to have effluent reservoir

(1) Any pearl oyster hatchery for which discharge of water is required must have an effluent reservoir or sump built to a standard approved by the Director.

(2) Waste water from a pearl oyster hatchery must be disinfected or treated by biological, physical or chemical means approved by the Director.

(3) No wastewater from a pearl oyster hatchery shall be discharged directly into a river, stream, creek, pond or sea without first being treated at an effluent reservoir.

(4) Any person who discharges waste directly into a river, stream, creek, pond or sea without treating such waste water in an effluent reservoir commits an offence and shall be liable to a fine not exceeding fifty thousand dollars.

24. Importation of living biological material

(1) No living biological material of any kind, including but not limited to algal cultures, may be imported into Solomon Islands for use within a pearl oyster hatchery without the prior written permission of the Director.

(2) In applying for permission to import living biological material, the licensee must provide a full explanation and justification for the proposed import, including but not limited to details of:

(a) the type and nature of the living biological material to be imported;

(b) the source of the living biological material to be imported;

(c) the purpose for which the living biological material will be used;

(d) the measures to be used to ensure that the living biological material will not enter the natural environment of Solomon Islands.

(3) Any person who imports living biological material into Solomon Islands without the written permission of the Director for use within a pearl oyster hatchery commits an offence and shall be liable to a fine not exceeding one hundred thousand dollars.

Division VIII. Miscellaneous

25. No exemption from applicable laws

(1) Unless otherwise specified, nothing in this Regulation shall exempt any person duly licensed hereunder from compliance with the applicable laws of Solomon Islands.

26. Minimum fine

(1) Any monetary fine to be paid under this Regulation shall not be less than one third of the prescribed sum.

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SCHEDULE 1

List of species to which this regulation applies

(1) This regulation applies to bivalve molluscs of the family Pteriidae, and specifically to the following species:

Pinctada margaritifera – black-lipped pearl oyster
Pinctada maxima – white-lipped, gold-lipped or silver-lipped pearl oyster
Pteria penguin – winged pearl oyster

(2) The Minister for Fisheries may at his discretion amend this schedule to include other species as required.

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SCHEDULE 2

Licence fees

(1) The following fees will apply to licences issued under this regulation:

(a) Initial fee on first issue of licence: SI$ 20,000

(b) Annual renewal fee: SI$ 10,000

(2) Separate fees are payable in respect of each type of licence issued.

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SCHEDULE 3

Method of calculating stocking density

(1) For the purposes of this Regulation the surface area occupied by the farm lines is defined as the average length of the farm lines multiplied by the distance between the farm lines at the extremities of the area occupied by the farm lines.

(2) The areal density of pearl oysters shall be calculated as the number of pearl oysters in the area of the farm lines divided by the surface area of the farm lines, calculated as per clause 1.

(3) For the purposes of this Regulation the water volume occupied by the farm lines in any area or sub-area of the pearl farming facility is defined as the surface area (calculated as per clause 1) multiplied by the average depth of the chaplets or other vertical lines on which the pearl oysters are hung.

(4) The volumetric density of pearl oysters shall be calculated as the number of pearl oysters in the water volume of the farm lines divided by the water volume of the farm lines, calculated as per clause 3.

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Solomon Islands Pearl Farming Policy Statement

The Government of Solomon Islands notes that research carried out over the past 15 years indicates that Solomon Islands is a potentially suitable location for pearl farming. Attributes of the country that are positive for pearl farming include:

- natural presence of three species of commercial interest (*Pinctada maxima*, *Pinctada margaritifera*, and *Pteria penguin*) throughout Solomon Islands;
- demonstrated levels of *P. margaritifera* spatfall sufficient to support commercial pearl farming;
- numerous sheltered coastal lagoons and embayments suitable for pearl farming, widely dispersed throughout the country;
- unpolluted coastal waters, a clean marine environment and suitable climatic conditions for pearl farming;
- a long-standing (since 1994) prohibition on export of pearl shell from the wild;
- abundant unskilled and semi-skilled rural labour available at a cost far below that in other pearl farming locations in the Pacific region;
- rural communities eager to support and participate in pearl farming.

The Government recognises that development of a pearl farming industry in Solomon Islands has the potential to deliver a number of benefits to the country, including:

- generation of national revenue and foreign exchange through increased exports;
- economic diversification;
- creation of jobs;
- developing new skills for Solomon Islanders; and
- providing rural communities with income-earning opportunities;

The Government further recognises that development of a pearl farming industry in Solomon Islands is unlikely to occur without foreign investment by experienced pearl farming operators. The Government wishes to actively encourage such investment by foreign pearl farmers with the necessary technical, financial and marketing expertise to successfully contribute to the development of a pearl farming industry in Solomon Islands. Measures that the Government will take to encourage foreign investment in pearl farming include:

- consideration of tax concessions for new pearl farming investors for an initial period of ten years;
- issuance of long-term (ten year renewable) licences to approved pearl farming operations;
- issuance of work permits for foreign workers having skills not available in Solomon Islands, notably senior managers and seeding technicians;
- continuation of the existing ban on export of wild-caught pearl shell;
- management of the industry to ensure good farm husbandry practices, minimise the risk of pearl shell disease and mortality outbreaks, and mitigate against the transfer of parasites and pathogens;
- environmental regulation of other industries which may have impacts on pearl farming operations;
- regulation of pearl exports to prevent marketing of low-grade or inferior-quality pearls by small-scale producers who may eventually enter the industry.

Other forms of government support may also be available to investors, depending on the nature of the proposed pearl farming venture. These may include:

- provision of historical information held by the Government that may be relevant to pearl farming operations;
- access to hatchery and/ or analytical laboratory facilities in which the Government has an interest;
- jointly financed or executed pearl farming research activities;
- community extension and training activities by Government in support of pearl farming development.

The Government wishes to ensure that pearl farming investors conduct their operations in a manner that is socially and environmentally responsible, and which provides genuine development benefits for the country. Factors that will be taken into account when considering pearl farming investment proposals or negotiating cooperative projects that involve the government include:

- the degree to which local communities are likely to benefit from the project in terms of employment, collection and processing of spat, lease payments, training and skills development, and other advantages;
- the likely benefits to Solomon Islands in terms of exports and foreign exchange earnings;
- the commitment of the investor to environmentally responsible operations, as evidenced by the environmental management plan or code of practice for the project.

As the Solomon Islands pearl industry develops, the Government will establish and participate in consultative mechanisms that will ensure full and open dialogue between commercial pearl farmers, participating communities, and relevant government agencies. The Government will work closely with the industry to ensure that pearl farming management arrangements remain appropriate to the needs and development of the sector, and to ensure that the interest of all participants are fully protected.

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Solomon Islands

Application for Pearl Farming Licence

Fisheries Act 1998, Fisheries (Amendment) Regulations 2005,
Pearl Farming Regulation 2008

Name of applicant..

Address of applicant ....

....

If the application is made on behalf of a company,

Name of company...

Address of company ....

Registered business number..

This application is for (tick one or both): Pearl Farming Licence ☐ Pearl Hatchery Licence ☐

Pearl oyster species to be farmed:..

....

Location of pearl farming facility (*Specify all places where pearl oysters will be collected, bred, reared, held and processed. Attach map if required*)..

....

....

The following documents are attached in support of this application.

Document	**Yes**	**No**	**If no, explain why**
Pearl farming site lease			
Business or joint venture registration details			
Plan of pearl farming site or facility			
Business plan or project description			
Provincial business licence			
Environmental management plan/ code of practice			
Environmental development consent			
List of gear, tools, equipment, chemicals and noxious agents to be used			
Fee ($ 10,000 per licence)			

Any other information that the applicant wishes to be considered (*attach additional pages if required*) ....

....

....

Date..Signature...

Solomon Islands

PEARL FARMING LICENCE

**Fisheries Act 1998, Fisheries (Amendment) Regulations 2005,
Pearl Farming Regulation 2008**

Licence No: ___________ for Pearl Farming/ Hatchery operation (*delete as appropriate*)

The holder of this licence is authorised to operate a pearl farming facility at the location described below for the species listed, and subject to the conditions printed on the reverse of this licence, plus any special conditions specified below.

Name of licensee..

Address of licensee ....

....

Registered business number of licensee ....

Location of pearl farming facility (attach map if required) ....

....

....

....

Species authorised for farming ....

....

....

Fees Paid: ....Receipt number:...

Special conditions ....

....

....

....

....

....

....

The holder of this licence shall comply with and ensure the facility is operated in accordance with the Fisheries Act (1998), the Fisheries (Amendment) Regulations 2005, and the Pearl Farming Regulation 2008.

Date of issue...Date of expiry ....

Authorised at Honiara this (date)...

____

Licensing Officer

Summary of Pearl Farming Licence conditions
(*to be printed on back of licence*)

This summary is provided for convenience and ease of reference. For a full and authoritative list of conditions applying to pearl farming operations, refer to the Pearl Farming Regulation 2008.

Permitted activities

- Deployment and harvesting of spat collectors.
- Purchase of spat from individuals, communities, hatcheries and other licensed pearl farmers.
- Purchase of adult pearl oysters from local fishermen/ communities, hatcheries and other licensed pearl farmers.
- Rearing and seeding of pearl oysters.
- Harvesting, processing and marketing of pearls.

Regulations and restrictions

- Maximum number of pearl oysters to be held on the farming site is one million
- Maximum stocking densities of pearl oysters:
  - one hundred thousand (100,000) shell per hectare;
  - one shell per cubic metre of water occupied by the farm lines.

For methods of calculating stocking densities, see Schedule 3 of the Pearl Farming Regulation 2008.

- Minimum spacing of ten (10) metres between farm lines.
- Minimum spacing of five (5) metres between spat lines.
- No farm lines or spat lines to be attached to coral heads or other natural features.
- No farm lines or spat lines to be set:
  - within one hundred (100) metres of the coast or any reef;
  - in waters having a depth of less than twenty (20) metres;
  - above areas of living coral.
- Farm lines and spat lines to be set so that mainlines are at least two (2) metres below the sea surface.
- Hatcheries to be located on land, at least fifteen (15) metres from the limit of mean high water spring tides, and three (3) metres above it.
- Hatcheries must have an effluent disposal reservoir.

Activities requiring a special permit

- Relocation of pearl farming facility by more than one kilometre.
- Transportation of pearl oysters over a distance of more than 25 kilometres.
- Importation of pearl oysters from overseas, regardless of size, age or stage of life.
- Importation of biological material, including algal cultures

Activities not permitted

- Use of anti-fouling paints or building materials treated with toxic chemicals for over-water structures.
- Keeping of animals on over-water structures.
- Disposal of waste, including fouling waste removed from pearl oysters, into the sea.
- Use of containers for floats if they have previously contained toxic chemicals.

Environmental responsibility

- Operators are expected to show responsibility for the marine environment through the application of their environmental management plan or code of practice. In particular, operators should:
  - take action to minimise spillage of fuel and oil during daily operations;
  - ensure litter and rubbish is not thrown into the sea;
  - ensure staff are properly trained in cleanup of fuel and oil spills, and proper methods of waste disposal.

Other

- This licence must be displayed in a prominent place at or within the vicinity of the pearl farming facility to which it relates.
- Conditions of licence may be reviewed or varied by the Director of Fisheries.
- This licence is not transferable.

This licence may be cancelled if the licensee breaches the licence conditions or the provisions of the Fisheries Act (1998), the Fisheries (Amendment) Regulations 2005, or the Pearl Farming Regulation 2008.