CULTURED PEARL FARMING AND PRODUCTION IN THE FEDERATED STATES OF MICRONESIA

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The current production of cultured pearls from the black-lipped pearl oyster (*Pinctada margaritifera*) in the Federated States of Micronesia (FSM) includes mostly beaded as well as blister and nonbead-cultured pearls in a wide array of colors. Pearl farming is carried out on four islands, with plans for commercial production in the near future. The sector is envisaged as a model for economic development and marine conservation. To successfully compete in the marketplace, pearl farmers in the FSM should focus on producing high-quality cultured pearls and explore market differentiation strategies such as the "Micronesian Blue" product. Gemologically, the FSM cultured pearls are indistinguishable from those of French Polynesia that are produced using the same mollusk species.

In Micronesia, a group of more than 2,000 small islands in the western tropical Pacific Ocean, *P. margaritifera* oyster shells have been used by local populations and sold to itinerant traders since the 18th century (Clarke et al., 1996). Martin (1996) noted that in the 1800s, German divers gathered 50 tonnes of oysters from Chuuk Lagoon. The Japanese occupation of Micronesia (1914–1944) prompted further interest in pearl oyster resources, and shells were fished and a trial cultured pearl farm established in nearby Palau. In 1986, the FSM gained sovereignty after nearly 40 years as a U.S.-administered trusteeship. That year, 8,595 kg of black-lipped oysters were harvested in Chuuk Lagoon (Smith, 1992). Until 1987, however, there were no serious efforts to develop a cultured pearl farming industry in the area (Clarke et al., 1996). In the past 25 years there have been numerous attempts to establish commercial and community-based pearling operations. Current efforts are promising, and a variety of cultured pearl colors, including "Micronesian Blue," are beginning to reach the international market (figures 1 and 2).

Black cultured pearl production from the *P. margaritifera* mollusk was valued at more than US$100

Figure 1. These earrings contain "Micronesian Blue" cultured pearls (~10.5 mm in diameter). Photo courtesy of Natsuko Shiraki, © Hasuna Co. Ltd., Tokyo.

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Figure 2. These bracelets are made with baroque-shaped cultured pearls (~7.3–9.0 mm) from the FSM. Photo courtesy of Natsuko Shiraki, © Hasuna Co. Ltd., Tokyo.

million in 2009 (Müller, 2009). This mollusk has a wide geographic distribution, including the Pacific Ocean, Indian Ocean, Red Sea, and off the coast of Mexico (Strack, 2006). However, commercial cultivation of this mollusk only takes place in French Polynesia, the Cook Islands, and Fiji, and is just beginning to emerge in the FSM. The industry as a whole is only 50 years old; the first successes in French Polynesia were reported in 1961 (Domard, 1962).

Pearl farming and associated economic activity has brought considerable development to remote regions of French Polynesia and the Cook Islands (Southgate and Lucas, 2008). At its peak in 2000, the French Polynesian cultured pearl sector employed 7,000 people (Murzyniec-Laurendeau, 2002). In recent decades, a number of other developing Pacific countries—through government and donor-funded projects—have attempted to emulate these successes in culturing black pearls from *P. margaritifera*. These include Kiribati, the Marshall Islands, Papua New Guinea, the Solomon Islands, and Tonga (Strack, 2006; Southgate and Lucas, 2008). The FSM is an ideal candidate for pearl farming projects because of its ecological similarity to the islands of French Polynesia. The country is highly dependent on foreign aid through the U.S. Compact of Free Association agreement, receiving a projected US$92.2 million in 2011 ("The Federated States of Micronesia…," 2010). Clearly, the production of high-value cultured pearls could foster indigenous economic development.

This article reviews various initiatives since 1987 to establish a Micronesian cultured pearl industry and evaluates the viability of community-based farming projects and marketing opportunities for "development pearls." It examines the implications of recent developments in the global black cultured pearl industry for the nascent FSM industry. The hatchery production of juvenile oysters is highlighted, as are a number of pearl oyster husbandry techniques and factors that influence the quality of the resulting cultured pearls. Finally, gemological characteristics of the bead-cultured pearls are presented. One of the authors (LC) visited the FSM pearl farms in October 2011, whereas another author (MI) has been working in the FSM on developing pearl farming and other aquaculture activities since 2001.

HISTORY AND INDUSTRY STRUCTURE

In 1987, the Pacific Fisheries Development Foundation and Pohnpei Research Division began evaluating the feasibility of a domestic cultured pearl industry. Since then a number of pilot projects and initiatives in the FSM have been started by local government, donors, and private citizens. Survey work and a feasibility study were briefly carried out on Ahnt Atoll but ceased in 1991 (Clarke et al., 1996). The primary focus of subsequent efforts was on Nukuoro Atoll, the only island in the FSM known to have a sufficient population of wild spat, thus eliminating the need for costly hatchery production of juvenile oysters. In 1994, Australia and the Pohnpei state government began funding a local project, and by 1995 there were 3,000 oysters seeded with round nuclei and 100 shells implanted with blister nuclei (Clarke et al., 1996). Low retention rates were attributed to the "poor condition of the oysters, the rudimentary working conditions and the relative inexperience of the local staff" (Clarke et al., 1996; p. 4). These factors, along with others detailed later in this article, have posed serious challenges to donor-funded community pearl farms in the FSM.

The Nukuoro farm was eventually incorporated in 2009 as Nukuoro Black Pearl Inc. (Leopold, 2011). The first significant harvest was sold locally in 2002, with 800 cultured pearls bringing US$10,000 (Sehpin, 2002). Three years later, financial irregularities were reported at Nukuoro (Sehpin, 2005). That same year saw the development of a bioeconomic model for small-scale pearl farms that was based on production and financial data from the Nukuoro farm, along with another farm in the Marshall Islands (Fong et al., 2005). However, pearl cultivation ceased in 2009. According to the Nukuoro municipal government, the oysters were left in the lagoon, and 10,000–20,000 have now reached an operable size but cannot be implanted due to lack of funding.

At present, pearl culturing takes place on four of the FSM's 607 islands, all within the state of Pohnpei: Pakin, Pohnpei (Nett Point), Pingelap, and Pweniou (a tiny islet off Pohnpei Island; figure 3). The first two farms each have 10,000 oysters, whereas the latter ones each have 3,000 oysters. All of these farms are in preparation for commercial pearl cultivation. Municipal government recently discontinued cultivation on a fifth island (Mwoakilloa) pending additional investment.

The waters in the FSM region, especially near Pohnpei, are rich in nutrients from nearby coastal mangrove forests. Water temperatures near Pohnpei's Nett Point farm vary between 27°C and 30°C, and salinity ranges from 35.0 to 35.5 parts per thousand. Testing at various sites within the Pohnpei lagoon has revealed that water currents, nutrient availability, and shelter vary greatly from site to site. Appropriate sites for pearl farming have been chosen taking these factors into account. The healthier the oyster, the lower the probability of disease, complications, or mortality and the higher the likelihood of harvesting high-quality cultured pearls.

The most encouraging efforts in support of pearl culturing in the FSM involve a project at the College of Micronesia (COM) Land Grant Program, which supplies hatchery-grown spat and technical assistance to the four operations mentioned above. In 2001, work began on a demonstration and training hatchery at the program's facilities at Nett Point on Pohnpei. The aim of the hatchery was to supply high-quality spat to islands that have insufficient natural oyster populations (Ito et al., 2004). This project has received funding from the U.S. Department of Agriculture (USDA), the U.S. Department of the Interior's Office of Insular Affairs, and the COM program. The ultimate goal is to "develop a self-sustaining pearl industry, integrating

Figure 3. This map shows the location of past and present cultured pearl operations in the FSM. The hatchery that produces oyster spat is located at Nett Point on Pohnpei. The brood stock for this hatchery was initially collected from Ahnt, Pohnpei, and Pakin Islands. Pearl farms are presently in operation on Pakin, Pohnpei, Pingelap, and Pweniou (just off Pohnpei) Islands. Former farms on Mwoakilloa and Nukuoro are no longer producing any cultured pearls. Illustration by Augustin Hiebel.

both community-based and commercial pearl farming operations" by 2016 (Ito, 2006). Investors have visited the FSM to explore the possibility of a large-scale commercial pearl farm, and such an enterprise would ensure the long-term viability of the hatchery, which is still being subsidized.

Another project has received two rounds of funding from the Center for Tropical and Subtropical Aquaculture (CTSA) to investigate the development of pearl farming in the FSM (Haws, 2004), as well as to make hatchery production more efficient and to determine the spawning seasons of black-lipped pearl oysters (Haws et al., 2004). Most of the hatchery-based work was attempted in the Marshall Islands. This project has been discontinued due to a lack of funding. There was no overlap with the COM-based project, and the activities described in this article all stem from work at COM designed to produce cultured pearls marketed under the "Micronesian Blue" label.

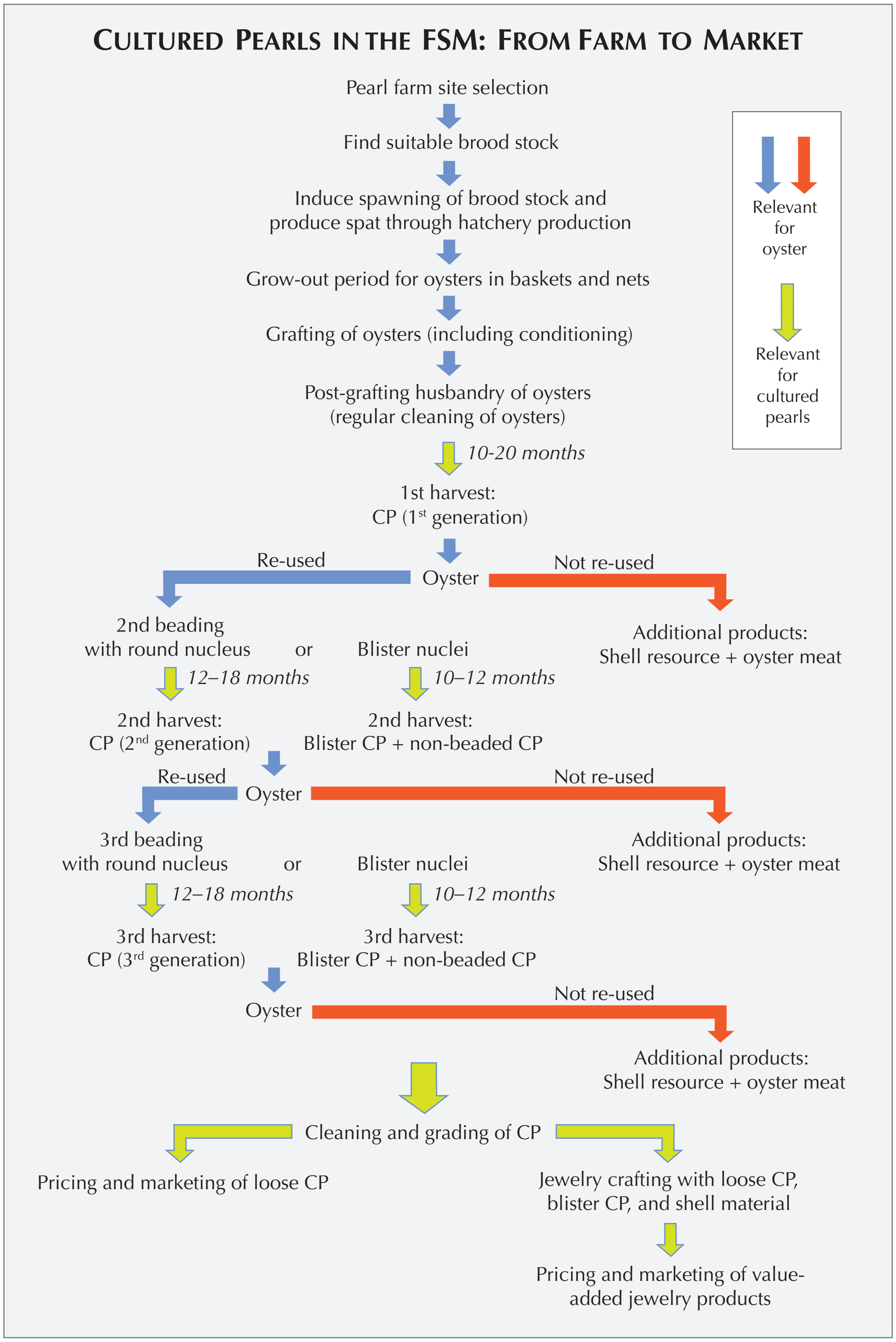


Figure 4. This diagram illustrates the different steps in setting up a pearl farm and obtaining cultured pearls (CP) in the FSM. It shows the potential of using the same oyster several times in the production of cultured pearl products and what resources can be obtained from this process. The periods indicated are from the time of seeding to the time of harvest. Modified after Haws (2002).

PEARL FARMING

The entire FSM pearling procedure, from farm site selection to marketing of the cultured pearls, is presented in figure 4.

Spat Production. Whereas the French Polynesian industry has relied on the collection of wild spat, the emerging FSM cultured pearl sector—apart from Nukuoro—relies on hatchery production using mature oysters (i.e., "brood stock"). Many Pacific islands have seen overfishing and a significant depletion of wild oyster stocks. Winds, currents, hydrology, and the placement of spat collectors and substrates also play major roles in determining the number of spat that can be collected in the wild. Surveys have been conducted around the islands of Ahnt, Pakin, and Pohnpei to determine the feasibility of wild spat collection, but the populations were far too low. To address the shortage of wild spat in Micronesia, two hatcheries were set up in 2001: at Nett Point operated by COM (mentioned above) and on the southern part of Pohnpei Island run by the Marine and Environmental Research Institute of Pohnpei (Haws, 2004).

The key to high-quality hatchery-based spat production is careful selection of mature brood stock oysters collected in the wild. The brood stock strongly influences the color and quality of the cultured pearls. Brood stock for the Nett Point hatchery were collected by one of the authors (MI) and collaborators during multiple transect dives on the islands of Ahnt, Pohnpei, and Pakin from 2001 through 2004.

Whether spat is collected in the wild or produced in a hatchery, oyster reproduction follows very specific cycles that must be taken into account. Interestingly, the FSM seems to have no distinct spawning seasons. However, there are roughly two periods, March–June and September–December, when oysters release eggs and sperm and fertilization can take place. As in French Polynesia, this corresponds to seasonal changes in ocean water temperature and nutrient content (Southgate and Lucas, 2008). Full moon is usually a very good time to induce spawning in the hatchery setting, and this is done by stressing the oysters, such as by a rapid change in water temperature. Spawning in the wild is also induced by a change in environmental factors, though much less rapidly. One episode of spawning in a hatchery can yield 1–2 million oyster larvae per 1,000 liter tank. These larvae are fed various types of algae (figure 5), and they eventually develop into spat. Meanwhile, the water conditions are closely monitored. The combination of algal feed and water conditions is critical to producing strong, high-quality spat. Around day 17–19, spat collectors (e.g., 30 × 50 cm pieces of shade cloth attached to ½ in. PVC pipe frames, known as "Christmas tree" collectors) are placed in the tanks. Approximately 500–2,000 spat accumulate on the 60–70 collectors deployed in each tank. The spat are left there for 42–46 days, until they reach a size of 2–5 mm in antero-posterior shell length. Following this stage, they are transferred from the hatchery tanks into oceanic spat collectors or pearl oyster nets for nursery grow-out.

Figure 5. At the Nett Point hatchery, four species of algae are typically used to feed oyster larvae: Cheatoceros *(yellow),* Pavlova *(yellow-brown),* Rhodomonas *(orange), and* Tetraselmis *(green). Photo by L. Cartier.*

In Brief

- Efforts to produce black cultured pearls in the Federated States of Micronesia (FSM) date back to 1987.
- Farms on four islands in the state of Pohnpei (Pakin, Pohnpei, Pingelap, and Pweniou) are preparing for commercial pearl cultivation, with a total of 26,000 hatchery-reared oysters.
- These farms are projected to yield 6,500 cultured blister pearls and 2,000 loose bead-cultured pearls in 2012, with increasing production in the future.
- The cultured pearls show a range of colors; those with particularly distinct blue overtones are most prized, and branded "Micronesian Blue."

Nursery and Husbandry. Baskets with juvenile oysters are taken to the pearl farm (e.g., figure 6), and left on the seabed in shallow waters to reduce predation. Spat mortality is initially assessed by onsite counting approximately four months after fertilization, and the baskets are examined every six weeks for predators. Carnivorous snails and crabs are major causes of spat mortality. The young oysters are later transferred to lantern baskets (figure 7). When they are between 1.5 and 2.5 years in age they are removed from the baskets, drilled, and hung on chaplet lines (see figure 8). In most areas of the FSM, netting is not required at this stage because predation is less of a threat. Biofouling, the settling and growth of animals and plants

Figure 6. This photo shows the farming operation near Pweniou Island off Pohnpei. Photo by L. Cartier.

on the oysters, must be removed in 1–2 month intervals to ensure the proper health and growth of the pearl oysters (figure 9). Once the shell is deemed sufficiently large (10–12 cm in diameter) and healthy, the oyster can be grafted to induce the formation of a cultured pearl.

Grafting. The grafting operation requires a host and a donor oyster, and a skillful technician (e.g., Hänni, 2007). Whereas the donor oyster (which is sacrificed) is selected for the quality of its mantle, the host oyster is chosen for its vigor (Haws, 2002). An international grafting technician regularly visits the FSM to train locals in grafting techniques for both round and blister cultured pearls, with the aim that by 2013 they can meet the requirements of a nascent cultured pearl industry. The nuclei consist of Mississippi mussel shell material and range from 5.5 to 13.0 mm in diameter.

Figure 7. Two-year-old oysters in lantern baskets are examined at the Pweniou pearl farm. Inside the basket, technicians found two predatory snails. Photo by L. Cartier.

Typically, the first-generation operation is carried out to produce a loose cultured pearl. Cultured blister pearls are sought in older generations of pearl oysters, which can be regrafted two or three times. For the production of bead-cultured pearls, the seeded oysters are kept in the water between 10 and 20 months. An oyster deemed unsuitable for regrafting may then be seeded to produce several cultured blister pearls (figure 10). In this case, the oyster is left in the water 10–12 months. Because a pearl sac is already present, such oysters are very likely to bear "keshi" nonbead-cultured pearls as well. This strategy maximizes the resource: Rather than sacrificing the oyster, it is reused to produce cultured blister pearls that can be manufactured into simple jewelry.

PRODUCTION, PROCESSING, AND MARKETING

Loose cultured pearls and blister products are harvested several times a year, but the output remains small. Production from the COM project in the FSM during the past decade was around 15,000 round cultured pearls and 3,000 cultured blister pearls. The majority of them came from the Nett Point farm on

Figure 8. Grafted oysters are attached to ropes using the "ear-hanging" method, forming chaplets. Photo by L. Cartier.

Pohnpei. They were sold as samples from the COM project to selected Japanese jewelry designers and shops for promotional purposes.

The four farms linked to the COM program are projected to yield 6,500 cultured blister pearls and 2,000 loose bead-cultured pearls in 2012, with a steady expansion in the coming years. The cultured blister pearls are expected to come from Pohnpei (3,000 pieces), Pakin (2,000 pieces), and Pweniou (1,500 pieces), and they will be sold on the local and international markets. As pearl farming moves toward commercial operation in the near future, round cultured pearls will also enter the international market.

The FSM produces far fewer dark cultured pearls than French Polynesia, because it uses lighter-colored brood stock. They are cleaned and processed with nothing more than sea salt and a polishing cloth. Most cultured blister products are crafted into jewelry and sold locally. Two charity sales in Pohnpei in 2010 led to revenues of US$6,000 and $13,500. The entire local market in the FSM is estimated at only US$100,000 per year, and the country drew just 20,000 tourists in 2010. If the pearl sector is to grow, it must expand beyond the local market. Nearby Guam, for instance, is an important tourist destination.

The FSM pearl industry must also find suitable niches worldwide and generate greater income through marketing differentiation (Fong et al., 2005). Although not yet commercially available on the international market, "Micronesian Blue" cultured pearls are being sold at charity sales and were used in two Japanese jewelry collections. The FSM products are also being marketed as "development pearls" because of their contributions to the local economy and marine conservation. Additional marketing strategies are being examined to avoid the failures of numerous donor-funded projects to promote community-based pearl farming over the past three decades (Ito, 2011a).

QUALITY: THE KEY TO PEARL FARM VIABILITY

The greater the proportion of high-quality cultured pearls in a harvest and the lower the oyster mortality rates, the more likely a farm will be profitable. Haws (2002) calculated that 95% of a farm's earnings come from just 2% of the cultured pearls. Le Pennec et al. (2010) estimated that for 2,000 grafted oysters, only 3% yield "beautiful" cultured pearls; improving this rate to 4% would considerably increase farmers' incomes. Conversely, Fong et al. (2005) projected that for a farm with 25,000 seeded oysters, a 5% increase in mortality would raise production costs per cultured pearl by nearly 21%.

Figure 9. Regular cleaning of oysters, as shown here on Pakin Island, is vital to maintaining their health. This step also creates jobs for local villagers. Photo by L. Cartier.

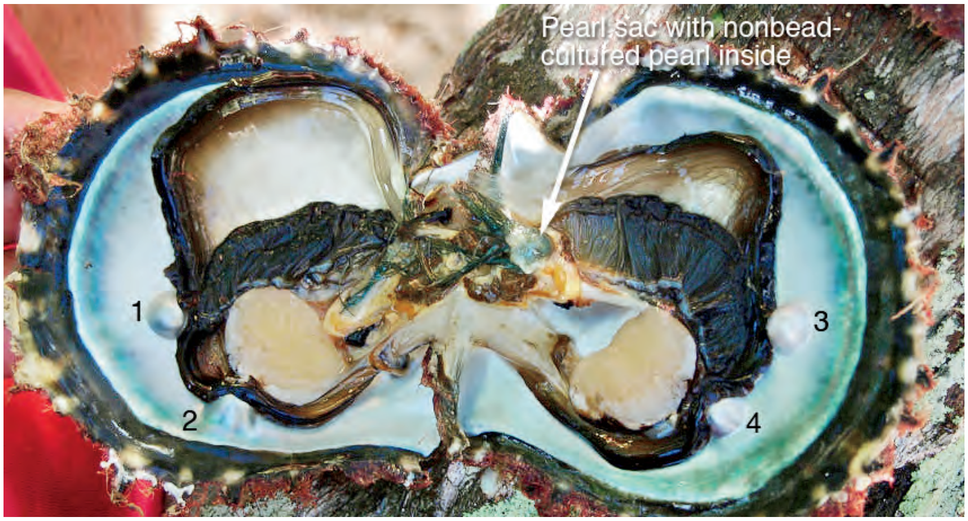


Figure 10. An oyster that yielded a first-generation cultured pearl was regrafted to produce four cultured blister pearls. The remaining pearl sac produced a nonbead-cultured pearl. Photo by L. Cartier.

Le Pennec et al. (2010) noted that out of 1,000 oysters grafted in French Polynesia, 250–300 saleable cultured pearls (25–30%) are typically produced in the first generation. In a study of the Nukuoro farm and another farm in the Marshall Islands, Fong et al. (2005) found that 10,725 marketable cultured pearls (42.9%) were produced from a harvest of 25,000 first-seeded oysters. This success rate is surprisingly high given that mortality rates should be similar to those in other areas of Micronesia (see below) and that the two farms were not commercially successful. The lack of an industrywide grading system for cultured pearls also makes such comparisons difficult.

Improving Cultured Pearl Quality. Murzyniec-Laurendeau (2002) showed that in a sample harvest of 271,000 *P. margaritifera* cultured pearls from French Polynesia, circled goods (cultured pearls with concentric rings or grooves visible on the surface) accounted for 23% of the volume but only 6% of the value. If formation mechanisms of circled cultured pearls can be better understood, practices can be adapted to minimize their production in favor of more valuable cultured pearls. There is a surprising lack of collaboration between gemologists and scientists researching biomineralization, aquaculture, and oyster genetics. Greater synergy across disciplines would advance cultured pearl production and quality.

A three-year research project was initiated by COM in 2007 to understand how grafting techniques could be optimized to improve quality (Ito, 2009). The study also investigated formation mechanisms of circled cultured pearls and disproved the widely held idea that they result from nucleus rotation in the pearl sac (see also Caseiro, 1993). Ito (2009, 2011b) argued that if this were the case, nonlinear patterns should be found on circled cultured pearls. However, Ito's (2011b) study of 4,011 samples found no evidence for this, and proposed a mantle cell proliferation mechanism of circled cultured pearl formation.

A great deal of experimentation has gone into understanding the optimal conditions for oysters and how the quality of harvested cultured pearls can be improved through certain pearling practices. A trial project was initiated by COM in 2005 to investigate the circling phenomenon in cultured pearls, and this study also offered an overview of mortality and rejection rates (figure 11). These rates were higher than in a normal pearl farming context, because the aim was scientific experimentation rather than commercial success; the total success rate was only 28%. Nucleus rejection rates for second-generation grafting of these trial oysters decreased to 10–15%, which is good by international comparison.

The harvesting success rates and qualities are highly dependent on farm site, nursery expertise, skills of the grafting technicians, and whether pearl farming was carried out for experimental or commercial purposes. The following practices are recommended in the FSM: Waiting until the oysters reach a good size (10–12 cm in shell diameter) before grafting, maintaining low stocking densities of oysters, extending the period between grafting and harvest, and regularly (every 6–8 weeks) removing any biofouling from the oysters.

ECONOMIC CONSIDERATIONS AND DEVELOPMENT STRATEGIES

The average price (at export) of black cultured pearls in French Polynesia has fallen by a factor of four in

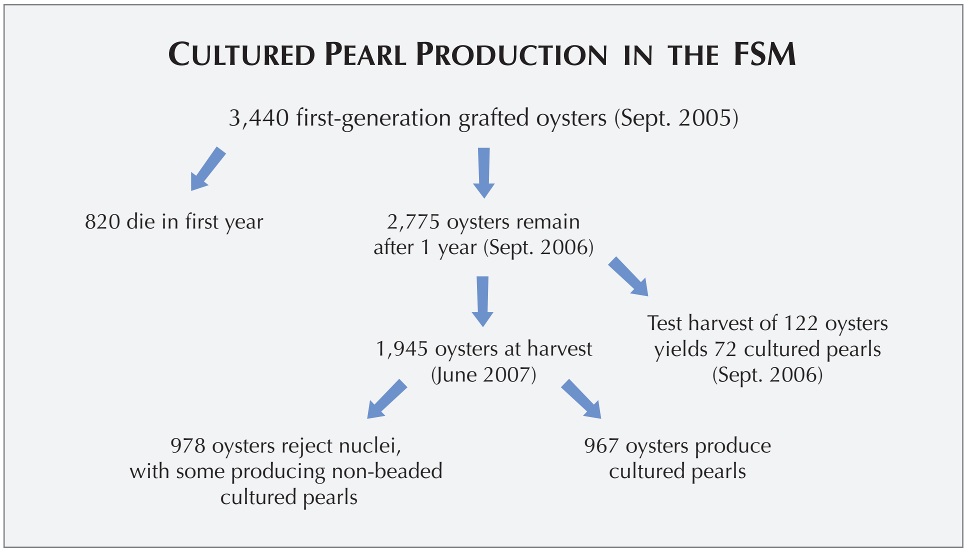


Figure 11. This chart shows the oyster mortality and rejection rates for a 2005–2007 trial project in the FSM. These figures are higher than those in other pearl farming regions, but do not reflect current rates in the FSM, which are much lower.

the past decade, from 1,800 CFP francs (US$19.68) to 460 CFP francs (US$5.03; Talvard, 2011). However, this depreciation is also the result of diminishing quality in the output of many pearl farms. Government authorities continue to carry out quality control of exported cultured pearls, and those of very low quality are destroyed. However, both the average size and average quality of these cultured pearls are lower than a decade ago. Such developments in the French Polynesian industry—which accounts for more than 95% of the world's black cultured pearls—are bound to also affect minor producers such as the Cook Islands, Fiji, Mexico, and the FSM.

A number of reports have noted the lack of large (>13 mm) high-quality black cultured pearls in the international market (Shor, 2007; Torrey and Sheung, 2008; Italtrend, 2010) and the fact that the average price of these larger goods has not decreased. Some reports suggest an overproduction of small black cultured pearls of low to medium quality, but obviously this cannot be generalized to include all types and qualities of these goods at present.

For two farms in the FSM and the Marshall Islands, both with 25,000 seeded oysters, Fong et al. (2005) calculated the average cost of producing a cultured pearl to be US$19.15. This was over a 20-year period, and both farms examined for that study have since ceased operation. In French Polynesia, as elsewhere, large pearl farms (>200,000 oysters) benefit from economies of scale (Poirine, 2003). Poirine and Kugelmann (2003) calculated with data from 2000 that the average cost per cultured pearl in French Polynesia for a large-scale farm was 902 CFP francs (US$9.93), compared to 1,889 CFP francs (US$20.79) for a small-scale farm of <25,000 oysters. Although pearl farming still has the potential to bring economic development to remote coastal communities, the long-term viability of these farms may be at risk due to challenging market factors, not to mention environmental and climate considerations.

Do small-scale farms have a future? The revenue models presented by Johnston and Ponia (2003) and Fong et al. (2005) do not reflect the economically unfavorable evolution of the black cultured pearl market in the past decade. The assumptions of their models render all small-scale pearl farms unprofitable if the recent global slump in black cultured pearl prices is taken into account. Yet other research in French Polynesia and the FSM suggests that there is a future for small-scale pearl farms that adopt alternative strategies, including:

- Maximizing revenue by marketing oyster meat and oyster shell resources (as jewelry or as raw material for medicinal purposes)
- Reducing spat costs through innovation in hatchery production
- Reducing oyster mortality
- Emphasizing cultured pearl quality over quantity
- Strategizing market differentiation through branding (e.g., Fiji)
- Adopting value-added activities such as jewelry crafting and developing synergies with tourism
- Emphasizing technology so that dependence on costly international assistance is minimized
- Making pearling a seasonal activity for local people, complemented by income from fishing, farming, or tourism

Technology Transfer. Even with these strategies, the transfer of technology to local inhabitants is essential. In several countries, the production of cultured blister pearls has been envisioned as an economic development strategy, and donors have funded such projects using *P. margaritifera* in Kiribati (Teitelbaum, 2007), Tanzania (Southgate et al., 2006), and Tonga (Teitelbaum and Fale, 2008). Yet none of these has achieved sustained commercial success, domestically or abroad. Typically, these types of internationally funded projects emphasized farming methods and handicraft-making techniques without training locals in sales and marketing (Ito, 2011a).

In contrast, current efforts in the FSM focus on training locals in all aspects of cultured pearl production and marketing. This ensures that the skills necessary for a pearl farming sector can be sustained locally without long-term foreign aid. Micronesians, not foreigners, are training local workers as technicians at the COM project's Nett Point hatchery on Pohnpei. This is widely regarded as a positive step in the development of aquaculture because it fosters local expertise and community collaboration, making the sector more likely to succeed. Overall, the project has four aims:

1. Standardizing hatchery and ocean grow-out protocols to realize mass spat and seedable oyster production
2. Training local technicians in hatchery-subsequent husbandry practices and grafting techniques
3. Training locals in basic jewelry manufacturing methods
4. Incorporating pearl farming into an integrated aquaculture and marine protected area development project and an ecosystem-based community fisheries management plan, with the goal of promoting alternative livelihood opportunities and local marine conservation

This project in the FSM is unique in the sense that the local grafting technicians being trained also have pearl farming and cultured pearl grading skills, and are themselves capable of training others. Indigenous youths who have learned basic jewelry design and manufacturing techniques (figure 12) then process the cultured blister pearls for sale locally and regionally (in Guam, for instance). Cultured blister pearl jewelry has recently sold in the local market for an average of US$20 per piece, an encouraging development (figure 13).

Figure 12. In a workshop on Pakin Island, local youths are taught how to drill shells containing cultured blister pearls so that they can be processed into jewelry. Photo by L. Cartier.

Management: The Key to a Successful Industry. After five decades of black cultured pearl farming and trading in French Polynesia, it has become clear that the management of both production and marketing is critical to ensuring long-term success. The striking differences in the industry development and

Figure 13. These pieces of cultured blister pearl and shell-derived jewelry, manufactured by indigenous youths, are sold in the local market. The diameter of the shell is ~10 cm. Photo by M. Ito.

government regulation between Australia (the main producer of white South Sea cultured pearls by value) and French Polynesia (the dominant source of black cultured pearls) have been examined by several authors (Tisdell and Poirine, 1998; Poirine, 2003; Müller, 2009). While French Polynesia, in Müller's words, adopted a "laissez-faire" approach to marine concessions, production, and trade, Australia chose to enforce strict quotas on output. Although the FSM pearl industry is unlikely to attain such international importance, questions regarding how the sector should be managed will need to be addressed as the sector develops.

While Poirine (2003) advocated economic regulation of the (Polynesian) cultured pearl sector through an auction system of limited marine concessions, another model has emerged in the FSM. Because most indigenous spat must be grown in a hatchery (Nukuoro notwithstanding), scientists control the oyster supply. Any pearl farm involved in the COM project that does not adhere to strict environmental and other guidelines must return its oysters to the Nett Point hatchery. The oysters remain the property of the hatchery, ensuring scientific oversight of the sector. Additional management models are currently under development.

Marine Conservation. Sound pearling practices have a positive impact on local fish stocks, since fry thrive around oyster farms and commercial fishing within these areas is prohibited (Pae Tai – Pae Uta, 2003). Unlike the extraction of many other gem resources, the cultivation of pearls depends directly on responsible environmental management. Low stocking densities have a positive influence on the health of oysters and are more likely to lead to high-quality harvests (Southgate and Lucas, 2008). Very high stocking densities can lead to mass mortality of oysters, as demonstrated on the island of Manihiki and the subsequent demise of the Cook Islands cultured pearl industry (Macpherson, 2000; Southgate and Lucas, 2008).

Pearl farming is one of the most profitable forms of aquaculture. With limited environmental impact and a high-value resource that can be produced in remote atolls, it has often been described as an ideal business model for developing Pacific coastal communities (Sims, 2003). In regions such as the FSM, which depend on artisanal fishing and subsistence farming and enjoy few if any alternative opportunities, pearl farming may reduce human pressures on the environment and generate cash income for local communities. Through alternative economic opportunities, such as pearl farming, pressures on rapidly diminishing fish stocks can be reduced. The income lost by abstaining from fishing in certain areas—Pakin or Pweniou islands, for instance—can be recouped by income from pearl farming. Marine protected areas (MPA) with no-fishing zones have been established in some parts of Pakin and Pweniou. In Pakin, for example, the model has been extended to become an integrated MPA in which pearl farming is carried out but fishing is not allowed. This innovative approach ensures that fish stocks can recover and gives locals access to alternative sources of income.

GEMOLOGY OF MICRONESIAN CULTURED PEARLS

Materials and Methods. For this study we examined 18 *P. margaritifera* cultured pearls obtained from Pohnpei's Nett Point farm by author LC (figure 14). The samples ranged from 3.86 to 13.00 ct, and measured approximately 8.1–12.1 mm in diameter. The selection was chosen to best represent the range of possible colors and qualities from the FSM's current cultured pearl production; three samples were of the "Micronesian Blue" variety.

In addition to visual examination and close microscopic inspection, all samples were analyzed by X-radiography using a Faxitron instrument (90 kV and 100 mA excitation) and Fuji film. On three samples (FSM_15, FSM_16, and FSM_17), we also measured

Figure 14. A range of colors and overtones were observed in the cultured pearl samples from the FSM (8.1–12.1 mm in diameter). Photo by M. S. Krzemnicki, © SSEF.

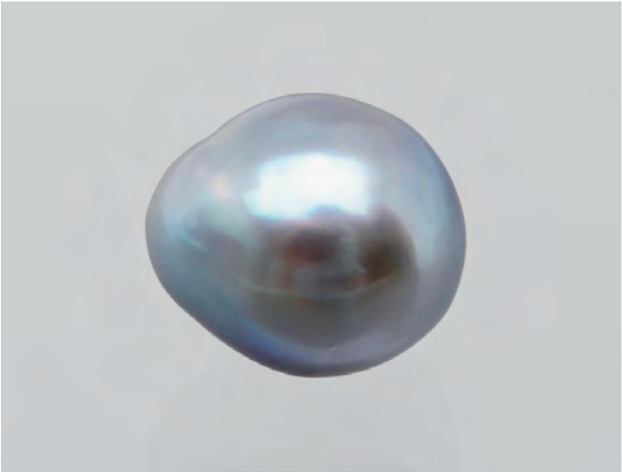


Figure 15. This light gray sample (8.4 mm in diameter) displays distinct blue and purple overtones characteristic of "Micronesian Blue" cultured pearls. Photo by M. S. Krzemnicki, © SSEF.

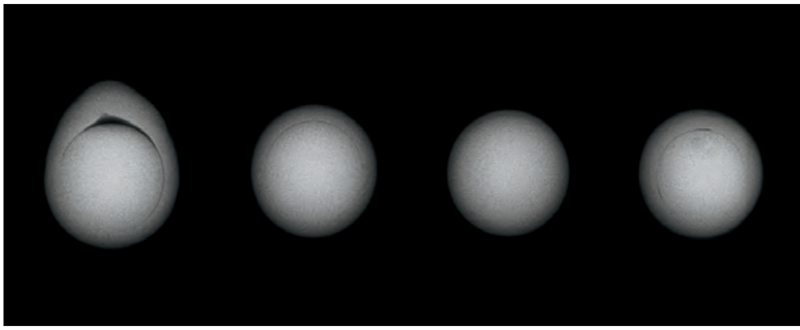


Figure 16. These X-radiographs of four bead-cultured pearls from Micronesia show varying nacre thicknesses, described here from left to right. Sample FSM_4 shows a small triangular cavity at the interface between the bead and nacre. FSM_10 has a medium nacre overgrowth (~1 mm), while FSM_14 shows a rather thin nacre layer (~0.5 mm), and FSM_16 has a thicker nacre overgrowth (~1.5 mm). Images by M. S. Krzemnicki, © SSEF.

UV-Vis reflectance spectra using a Varian Cary 500 spectrophotometer with a diffuse reflectance accessory. Furthermore, all 18 pearls were examined with a long- and short-wave UV lamp. Luminescence spectra of three cultured pearls (FSM_15, FSM_16, and FSM_18) were collected with an SSEF-developed UV-Vis spectrometer (based on an Avantes spectrometer) coupled with a luminescence accessory consisting of a mounting with three 365 nm LED lamps.

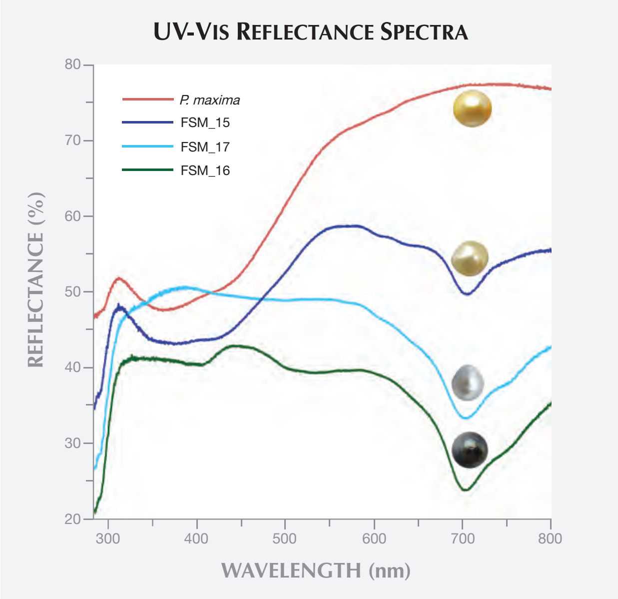
Results and Discussion. The cultured pearls' shape varied greatly from perfectly round to semi-round, button, drop, baroque, and circled. The color range included white, yellow, light gray to dark gray and brownish gray, and black (again, see figure 14). Most showed moderate to distinct overtones, with interference and diffraction colors dominated by green, purple, and particularly distinct blue hues (e.g., figure 15). The color distribution was partially uneven, especially in those showing circled features and surface imperfections such as dots, indentations, and bumps.

As the cultured pearls were taken directly from the production site prior to processing, the moderate to high luster represents their original state rather than their polished appearance. This was especially obvious under high magnification, which revealed fine fingerprint-like structures caused by the regular stacking of the aragonite platelets of the nacre.

X-radiographs (e.g., figure 16) revealed a distinct bead nucleus in the center of each sample, surrounded by nacre with a thickness of 0.5–3.9 mm. The off-shaped cultured pearls in particular showed distinct variations in nacre thickness, whereas the round to semi-round samples had typical (for *P. margaritifera* cultured pearls) nacre thickness of 0.8–1.4 mm.

UV-Vis spectra revealed a trough in reflectance at about 700 nm (figure 17), which is characteristic

Figure 17. The UV-Vis reflectance spectra of three P. margaritifera *cultured pearls from the FSM are compared to the spectrum of a yellow cultured pearl from* P. maxima. *The* P. margaritifera *samples show a distinct trough in reflectance at 700 nm that is characteristic for this species, but not seen in the* P. maxima *sample. The spectra are shifted vertically for clarity.*



of the color pigments (porphyrins) in the shell and cultured pearls of *P. margaritifera* (Miyoshi et al., 1987; Karampelas et al., 2011). Interestingly, even the reflectance spectrum of the yellow cultured pearl (FSM_15) showed this feature. This is in contrast to yellow cultured pearls from the gold-lipped pearl oyster (*P. maxima*), which look very similar but do not show this trough. This supports the use of UV-Vis spectroscopy for separating yellow to "golden" cultured pearls from these two species (see also Elen, 2002).

The samples showed inert to distinct yellow reactions to long-wave UV radiation, and distinctly weaker fluorescence to short-wave UV. Often the reaction was not uniformly distributed, but correlated to the lighter gray surface regions of the cultured pearls. The luminescence spectra of three cultured pearls characterized by distinct yellow fluorescence (FSM_18), moderate yellow fluorescence (FSM_15), and essentially no reaction (FSM_16) to the long-wave UV lamp all revealed two broad luminescence bands that correlated in intensity with the visual strength of their fluorescence (figure 18). By comparison, gray to dark cultured pearls from *Pteria sterna* from the Sea of Cortez in Mexico show additional spectral features above 600 nm that correspond to the red luminescence commonly observed in them (Kiefert et al., 2004; Sturman, 2009).

Figure 18. The luminescence spectra of three cultured pearls from P. margaritifera *with distinct yellow (FSM_18), moderate yellow (FSM_15), and nearly no fluorescence (FSM_16) to long-wave UV radiation are compared to the spectrum of a brown* Pteria sterna *cultured pearl from Mexico, which fluoresced strong red to long-wave UV radiation. The strong luminescence intensity below 400 nm for all samples is due to the excitation wavelength of the LED light source.*

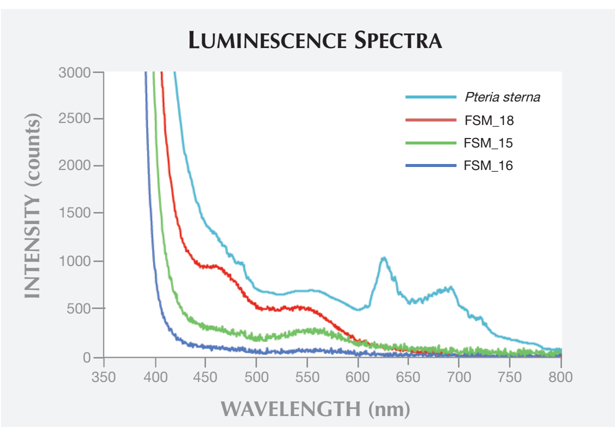


Figure 19. Blue overtones in "Micronesian Blue" cultured pearls (here, 12 mm in diameter) may be diagnostic of these products in the marketplace. Photo courtesy of Yuhei Hosono, © Le Collier, Tokyo.

Based on their observed and measured characteristics, our Micronesian samples were similar in many respects to cultured pearls produced in French Polynesia using the same species. The blue overtones, in some cases quite distinct, may serve to distinguish the "Micronesian Blue" cultured pearls in the international market (e.g., figure 19).

CONCLUSION

Pearl oyster farming is still in its infancy in the FSM, yielding small quantities of cultured pearls compared to the massive production in French Polynesia. Pearling activities and production are expected to expand in the FSM in the near future. Technical assistance through the COM program should ensure the supply of high-quality *P. margaritifera* oysters to support the nascent industry, as well as the adoption of responsible production practices.

Demand for the FSM's cultured pearls appears to be growing as they reach the international market, especially in Japan, where samples from initial harvests have been sold to selected jewelry designers who are marketing them as Micronesian cultured pearls. For the industry to succeed, a market differentiation strategy must be adopted. The decision to brand a portion of the production as "Micronesian Blue" cultured pearls is an important step in that direction.

Figure 20. This necklace features Micronesian cultured pearls (8.5–13.3 mm) of various colors. Photo courtesy of Yuhei Hosono, © Le Collier, Tokyo.

The FSM's cultured pearls come in a wide spectrum of colors and overtones (e.g., figures 14 and 20). Gemological and analytical instrumentation cannot conclusively separate these cultured pearls from those produced by *P. margaritifera* in French Polynesia and other areas. However, they are easily separated from *Pteria sterna* cultured pearls through UV-Vis reflectance spectroscopy. In addition, yellow cultured pearls from the FSM can be separated from yellow South Sea samples cultivated in the *P. maxima* oyster.

Through the careful selection of suitable brood stock, "Micronesian Blue" cultured pearls may become a high-value niche product on the international market in the near future. With an emphasis on quality and limited production, the FSM pearl sector has a realistic chance of economic success without foreign aid.

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