Economic Modeling of Round Pearl Culture in Fiji and Assessment of Viable Farm Size

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ECONOMIC MODELING OF ROUND PEARL CULTURE IN FIJI AND ASSESSMENT OF VIABLE FARM SIZE

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ABSTRACT Round pearl culture is an increasingly important industry in Fiji. Significant barriers to entry include high capital outlay and technical requirements, and a high turnover of small to medium size farms has limited industry growth. This study developed a viable-scale farm model for round pearl culture in Fiji to assist new or potential entrants understand costs, risks, and production levels required for success. Major production costs were labor (51%), oyster stock (18%), and pearl nuclei (10%). At steady state, median annual profitability was determined to be $156,362, but inclusion of price and production risk factors reduced annual profitability to $29,463. The model farm achieved an internal rate of return of 36% with a benefit–cost ratio of 1.8 and payback period of 5 yr. Farms holding 100,000 oysters and producing more than 8,000 pearls are deemed of viable scale. At this scale, farms can attract overseas pearl seeding technicians, apply economies of scale, and invest profits into future development. Given the average rural household income in Fiji is $5,800, round pearl culture offers significant economic opportunity and delivers socioeconomic benefits for rural communities in upstream (oyster stock supply) and downstream (handicrafts, jewelry, and tourism) activities.

KEY WORDS: Fiji Islands, pearl farming, pearl economics, pearl oyster, pearl farm profitability

INTRODUCTION

The black-lip pearl oyster Pinctada margaritifera has a broad Indo-Pacific distribution from East Africa and the Red Sea to eastern Polynesia (Wada & Témkin 2008). Since the mid-1970s, it has supported cultured pearl production in French Polynesia and the Cook Islands, which today is valued at around $170 million per annum. Pearl culture provides opportunity for export income and is the second largest contributor to gross domestic product in French Polynesia after tourism. It also supports socioeconomic benefits and employment in remote rural locations. On this basis, pearl farming is the Pacific region’s most valuable and highest priority aquaculture activity (SPC 2007). Based on the success of pearl culture in Polynesia, recent years have seen development of pearl culture in western Pacific countries such as the Fiji Islands (Fiji), which, since 2000, has developed a round pearl export industry valued at approximately $13 million per annum (Bolatagici 2016). The developing cultured pearl industry in Fiji has quickly gained a reputation for high-quality pearls with a unique range of colors (Southgate et al. 2008, Kishore & Southgate 2016). There is considerable opportunity for further expansion of the industry in Fiji and this is strongly supported by the Fiji Islands government.

Round pearl production involves insertion of a single round nucleus into the gonad of a host pearl oyster, accompanied by a piece of the nacre secreting mantle tissue from a donor oyster (Taylor & Strack 2008). This skilled operation, generally called “seeding” or “grafting,” is usually conducted by experienced overseas technicians, but not all oysters presented by the farmer are appropriate for pearl production and maybe rejected by the technician. Even after seeding, it is still common for oysters to reject the nucleus during subsequent culture, an occurrence referred to in the industry as a “vomit”. Successful seeding results in proliferation of the grafted mantle tissue around the nucleus to form the pearl sac (Kishore & Southgate 2016), which begins nacre secretion onto the nucleus. A period of 18–24 mo is usually required to produce a cultured pearl with appropriate nacre thickness (Blay et al. 2014). Once a pearl is harvested by a technician, a second nucleus can be inserted into the existing pearl sac to produce a second pearl. This “reseed” process can be carried out up to four times assuming appropriate-quality pearls continue to be produced by the oyster. During the pearl culture period, oysters are tied to a rope using fishing line in series to form a “chaplet” (Southgate 2008, Kishore & Southgate 2016). Chaplets are then suspended from a longline holding the oysters in suspended culture where they are periodically cleaned of fouling (Southgate 2008).

The grading of pearls is determined by the five characteristics of shape, size, luster, color, and surface perfection (Matlins 2001, Strack 2006). Quality of a cultured pearl relies on the skill of the technician and his/her seeding technique (Cochennec-Lauerau et al. 2010, Ky et al. 2014). These skills influence the post-operation mortality of oysters, the nucleus rejection rate, and the quality (color and grade) of the resulting pearls, reflecting appropriate selection of host oysters and saibo tissue from donor oysters (Scoones 1996, Wada & Komaru 1996, O’Connor 2002, Mamangkey et al. 2010). Pearls are the only gem without an internationally recognized grading system and, therefore, pearl grading is considered subjective (Matlins 2001, Strack 2006). The Tahitian system grades pearls from A to D, with descending quality, and is the common grading system for most cultured pearls produced in the south Pacific. Table 1 outlines the grading system used for round pearls.

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In terms of overall production, the proportion of A-grade pearls in a harvest might only be around 3%, and it is generally acknowledged that around 5% of pearls produced by a pearl farm in the Pacific generate around 95% of farm revenue (Haws 2002). The potential financial reward of round pearl farming is coupled with significant risk, from factors other than pearl quality. Production of round pearls is commonly characterized by high capital investment; extended cash flow lags following establishment; significant exposure to production risks such as cyclones, disease, and theft; and requires a high level of technical input. According to the Ministry of National Planning in Fiji in 2009, the main constraints preventing further sustainable commercial development of this sector include (1) lack of technical expertise, (2) lack of appropriate technology and infrastructure, (3) lack of ability to access appropriate markets and capital, (4) declining fishery resources, and (5) export standards compliance. A major impediment to further development of this industry in Fiji is lack of knowledge relating to establishment and operational costs of pearl farms, potential profitability compared with other rural activities, and inherent production and financial risks. Whereas the larger foreign-backed farms could overcome some of these barriers, smaller locally owned operations may struggle to establish and maintain a sustainable operation because of these factors. There are currently four operational round pearl farms in Fiji that export their product (Johnston et al. 2014).

Few studies have investigated the economics of pearl farming worldwide, yet such information is of vital importance for long-term viability. For example, economic modeling recently demonstrated that potential profitability from half-pearl culture is far greater than that from spat collection and sales of pearl oysters to pearl farmers (Saidi et al. 2017). The aim of this study was to determine establishment and operational costs of active cultured round pearl farms in Fiji through a series of workshops attended by industry stakeholders. Workshops were held in 2013 and 2015 and yielded pearl farm economic data. The resulting information was used to develop whole-farm economic models for round pearl production in Fiji, incorporating risk analysis, and provided a basis for determining minimum viable pearl farm size. The information generated will assist the Fijian government in policy development for the sector, facilitate business establishment and industry expansion, and assist regional agencies and donor research organizations in prioritizing funding and research activities.

### MATERIALS AND METHODS

#### Generating Inputs for the Economic Model

The information needed for the modeling was generated through a series of workshops with pearl farmers and other stakeholders, and one-on-one interviews.

#### Development of the Economic Model

The economic model was developed using cost–benefit analysis methodology incorporating a discounted cash flow framework over a 20-year period to ensure the model achieved a steady state, given the complexity of the production system (Johnston & Ponia 2003). The approach estimates the benefits and costs of an investment, or potential investment, to identify whether the benefits outweigh the costs of undertaking the investment. This method is also applied when choosing among a range of investment or project options (Nas 2016).

The economic model for round pearl culture uses a number of financial indicators to assess viability of the investment in this venture. The present value (PV) of the future stream of costs and benefits is calculated using the compound interest method. The rate used to calculate that PV is the discount rate. Subtracting the future value of costs from the future value of benefits is the net PV (NPV), represented by the following equation (Ronald et al. 2012):

\[
NPV = -INV + \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t} + \frac{SV_n}{(1+i)^n}
\]

where

- INV is the initial investment;
- NCF is the net cash flow (annual revenues less total fixed and variable costs, including capital costs);
- \(n\) is the number of years for the life of the investment;
- \(i\) is the discount rate; and
- SV is the salvage value.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Shape</th>
<th>Luster</th>
<th>Size (8–20 mm)</th>
<th>Surface perfection</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Round</td>
<td>Very high luster</td>
<td>Often larger than pearls in other grades</td>
<td>Very minor or no imperfection, usually less than 5% of the total surface</td>
<td>Very bright and attractive color</td>
</tr>
<tr>
<td>B</td>
<td>Round to semi-round, semi-baroque</td>
<td>High luster</td>
<td>Variable, but generally larger than pearls of C and D grades</td>
<td>Minor surface imperfections, usually less than 30% of the total surface</td>
<td>Brightly colored</td>
</tr>
<tr>
<td>C</td>
<td>Baroque</td>
<td>Variable (medium) luster</td>
<td>Variable</td>
<td>Notable surface imperfections that may include blemishes, dents, bulges, and circles</td>
<td>Variable</td>
</tr>
<tr>
<td>D</td>
<td>Uneven shapes/presence of circles</td>
<td>Dull</td>
<td>Variable</td>
<td>Major surface imperfections, more than 60%</td>
<td>Variable</td>
</tr>
</tbody>
</table>

### TABLE 1.

The NPV was used to derive an equivalent annual return (EAR), or annual profit, for the pearl farm using the following equation:

$$\text{EAR} = \frac{i \times \text{NPV}}{1 - (1 + i)^n}$$  \hspace{1cm} (2)

For this modeling exercise, the discount rate was set at 6%, a reflection of the long-term domestic bond market in the country at the time of the modeling (cbonds.com). The internal rate of return (IRR) provides an indication of the sensitivity of the project to changes in the discount rate and is another financial indicator used in this study. The IRR defines the discount rate i at which the NPV in Eq. 1 is set to zero. More simply, the IRR represents the maximum rate of interest that could be paid on all capital invested in a project. If all the funds were borrowed and interest charged at the IRR, the borrower would break even, i.e., recover the capital invested in the project.

Annual benefits were estimated using revenues generated from the sale of pearls both internationally and domestically. Average prices across grades and types of pearls were estimated from a number of interviews with existing pearl farmers in Fiji. Sale of value-added products such as jewelry and handicrafts were not included in the analysis. All capital, variable, and fixed costs were also estimated based on data collected from a range of business skills workshops and one-on-one interviews with pearl farmers in Fiji.

Finally, the stochasticity of the project was explored using the Monte Carlo analysis. The critical and uncertain parameters of farm yield and average pearl price had five-point probability distributions applied, using data collected from the workshops, informing the assessment of risk for the “viable-scale” round pearl farm. The equation for the Monte Carlo simulation, sampling underlying distributions for price and yield, is as follows:

$$p_i = \left[ y_j + \frac{y_{j+1} - y_j}{a_k - a_{k-1}} \times \left( RY_j - a_k \right) \right]$$

$$\times \left[ p_l + \frac{p_{l+1} - p_l}{b_m - b_{m-1}} \times \left( RP_l - b_m \right) \right] - TC$$  \hspace{1cm} (3)

where

$$j[k(\text{RY}_i)] \text{ and } l[m(\text{RP}_j)]$$

Profit is denoted as $\pi$; $y$ and $p$ represent the two distributions of yield and price, respectively; $a$ and $b$ represent the probability distributions for $y$ and $p$, respectively; $RY$ represents the random number for yield; $RP$ represents the random number for price; and $TC$ represents the total annual cost of the pearl farming operation. The values $j$ and $k$ represent the distribution intervals, or “bins,” for yield and its associated probability distribution, where $j + 1$ and $k + 1$ are the upper limits of the bin. Similarly, $l$ and $m$ represent the same for the price distribution and its associated probability distribution, respectively. The sampled results for price and yield were then multiplied to generate a revenue sample from which all annual costs were deducted to produce an EAR. The simulation runs 10,000 iterations.

The round pearl whole-farm tool developed in Excel was used in business skills workshops in Fiji and incorporated a risk analysis model developed internally by the authors using Visual Basic language. This supported the distribution among target coastal communities, associated government agencies, and organizations, without requiring additional commercial risk analysis software. Incorporation of internal risk analysis software within the spreadsheet model greatly enhances the extension capability of the program throughout the Pacific, improving adoption and application.

Various methods have been used to assist estimation of input risk distributions with a degree of confidence to reflect the risky environment of pearl farming. There were varying degrees of success. To improve the understanding of risk, and adoption of the model as a business tool, a separate Excel tool was developed to better assist the development of the price and production risk distributions. A “Pearl Farming Risk Calculator” was developed, both as a training tool and to improve autonomous risk assessments by pearl farmers. The risk calculator categorizes the price and production risk from severe to low as shown in Table 2.

As an example, production risks that were identified as “significant” during the workshops, delivering a “poor” to “average” production result included category 3–4 cyclones, significant flood events that reduced salinity to <25, chronic disease of oyster stock, and problems with oyster availability. Each was assigned a probability of occurrence and combined to provide the probability in the related distribution.

**Modeling Oyster Flow**

Modeling was based on the French Polynesian chaplet-based culture method (Southgate 2008). One of the major challenges encountered in developing the economic model was the dynamic and complex nature of the progression of oysters through the farming operation over time (Fig. 1). Modeling was based on the categories of oysters on farm as outlined in Table 3.

Given that there are six categories of oysters on the farm at any one time (Table 3), further complexity is added when considering other factors that determine whether an oyster is reseeded. When an oyster enters the reseeding shed for the first time, a range of decisions will follow, which determine its flow through the farm during its life (Fig. 1). If oyster condition is unsuitable for reseeding, it is rejected and reconsidered at the next reseeding event, or discarded. Seeded oysters are placed back out on the farm (Taylor & Strack 2008) for 18 mo before pearls are harvested at the next reseeding event. The seeding operation creates a level of mortality because of the stress caused by the operation (Gervis & Sims 1992), which is considered in the modeling. If an oyster survives on the farm, and assuming

<table>
<thead>
<tr>
<th>Risk category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe</td>
<td>Delivers “zero” to “poor” production or a minimum to poor price</td>
</tr>
<tr>
<td>Significant</td>
<td>Delivers “poor” to “average” production and price outcomes</td>
</tr>
<tr>
<td>Moderate</td>
<td>Delivers “average” to “good” production and price outcomes</td>
</tr>
<tr>
<td>Low</td>
<td>Delivers “good” to “maximum” production and price outcomes</td>
</tr>
</tbody>
</table>
nucleus retention, it will be returned to the seeding shed for pearl harvest. The technician will again open the oyster to remove the pearl from the developed pearl sac. Further decisions based on the condition, quality of pearl harvested, and nucleus rejection are made at this time to determine whether the oyster is reseeded with another nucleus, rejected, or discarded. This process will continue through the oyster’s life on the pearl farm until it dies naturally or is discarded. A discarded oyster can be harvested for its meat and mother-of-pearl (shell) (Chand et al. 2011).

Flow of oysters through the production system drives related elements of the modeling, including the number juvenile oysters needed to maintain the desired farm scale, the number of nuclei required for seeding, and the number of seeding operations. In Fiji, two annual seeding events occur in March and September. The production system achieves a steady state at approximately the 10-y point beyond which the proportions of first, second, third, and fourth harvest pearls are stable.

**Components of the Economic Model**

**Physical Parameters**

The scale of the model is set by entering a figure for the number of juvenile oysters that will enter the production system at inception of the farming project. The economic model calculates the number of preseedable and seeded oysters, estimating the total number of oysters required on the farm at any point in time. Other physical parameters set in the model include details of farming infrastructure, e.g., longlines, including rope, anchors, buoys, and chaplets (Southgate 2008). Information entered in this section of the model informs the capital requirements section of the economic model and sets area and density measures for the farm.

**Farm Labor**

Farm labor is divided into four categories in the economic model:
Technical assistants—casual or part-time labor hired to assist seeding technicians during biannual seeding events. Payment is based on a weekly wage.

Cleaning labor—casual or part-time labor hired to regularly clean oysters on the farm. Biofouling is a significant issue that increases operational and economic costs associated with pearl production and requires a significant proportion of farm labor to control (Pit & Southgate 2003, de Nys & Ison 2008, Bertucci et al. 2016).

Permanent staff—full-time labor hired to perform key farm duties, i.e., farm manager.

Owner—drawings of the owner are accounted for in the farms total labor costs.

Seeding Technician Labor

Seeding technicians are brought in for biannual seeding events and are paid in numerous ways. The economic model allows for three options, including payments based on a percentage of gross revenue received at harvest, a set value per oyster seeded with an optional bonus, or a set wage that can also include additional payment to cover travel, food, and accommodation. The most common form of technician payment in Fiji uses a set price per seeded oyster with an optional bonus based on pearl quality targets. Generic parameters are set in the model, including the number of technicians required, seeding operations completed per day, harvest operations completed per day, and the average number of days a seeding technician is required per year.

Marketing

The marketing section of the economic model sets out the breakdown of the harvest in terms of the types (shapes) of pearls harvested (Table 4), size of pearls harvested, and their quality based on the Tahitian grading system. The model provides additional capacity for users to describe pearls using the basic shape categories of cultured pearls based on the Akoya system (Lintilhac 1987, Strack 2006, Taylor & Strack 2008, Kishore & Southgate 2015). Also considered in this section of the model are the marketing costs, including advertising, auction, brokerage, and commission costs.

Additional Operating Costs

This section of the economic model accounts for any additional operating costs not captured in the wider modeling exercise. These include fuel and oil; electricity; repairs and maintenance; accounting and legal, office, and administration; government fees and charges; phone; travel; vehicle registrations; and insurances.

Capital Expenditure

Capital costs of round pearl farms are divided into nine main components: (1) land and buildings; (2) vehicles and machinery; (3) longlines, buoys, and anchors; (4) culture units; (5) watercraft and associated equipment; (6) diving equipment; (7) laboratory and associated equipment; (8) seeding equipment; and (9) miscellaneous (e.g., tools). Capital equipment bought at farm inception is replaced at predetermined periods over the 20-y life of the farming project. Replacement costs are estimated as the amount of money required to replace capital items, net of its salvage or trade-in value. The initial year of capital purchase is year-0, and the model assumes that all

---

**TABLE 3.**

Farmed pearl oyster categories.

<table>
<thead>
<tr>
<th>Oyster category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spat and juveniles</td>
<td>Oysters that range from spat (small oysters taken from collectors in the wild) to a size that is almost ready for seeding. Age ranges from 1 to 24 mo.</td>
</tr>
<tr>
<td>Preseedable</td>
<td>Oysters that have moved through the nursery phase on farm and are ready to be seeded at the next seeding or grafting event (commonly held twice a year). Age ranges from 24 to 36 mo.</td>
</tr>
<tr>
<td>Seeded (first)</td>
<td>Oysters that have undergone their first seeding operation.</td>
</tr>
<tr>
<td>Seeded (second)</td>
<td>Oysters that have had their first pearl removed and a second larger nucleus implanted during seeding.</td>
</tr>
<tr>
<td>Seeded (third)</td>
<td>Oysters that have had their second pearl removed and a third larger nucleus implanted during seeding.</td>
</tr>
<tr>
<td>Seeded (fourth)</td>
<td>Oysters that have had their third pearl removed and a fourth larger nucleus implanted during seeding.</td>
</tr>
</tbody>
</table>

**TABLE 4.**


<table>
<thead>
<tr>
<th>Shape</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round and semi-round</td>
<td>A round pearl is one that is of perfect, or close to perfect, spherical shape (considered rare and valuable), whereas a semi-round pearl looks round to the eye, appears symmetrical, but has some minor flaws where diameter varies by 2%–5%.</td>
</tr>
<tr>
<td>Semi-baroque</td>
<td>Includes drop shapes (commonly described as teardrop shape—the neck or extension at one end of the pearl is generally caused by the incision by the grafting technician), pearl shapes, and oval and button shapes (a pearl that has a flat surface on one side and is rounded on the remainder).</td>
</tr>
<tr>
<td>Baroque</td>
<td>Pearls that have a distinctly irregular shape and are asymmetrical.</td>
</tr>
<tr>
<td>Circles</td>
<td>A symmetrical pearl that has one or more parallel furrows running around the pearl perpendicular to its long axis (evidence suggests the shell's byssus creates the phenomenon).</td>
</tr>
<tr>
<td>Keshi</td>
<td>A non-nucleated pearl with many unique shapes that is created when the nucleus is vomited.</td>
</tr>
</tbody>
</table>
relevant capital is sold and proceeds enter the cash flow as a revenue stream in year-20.

RESULTS

Farming Parameter Inputs for the Economic Model

The information in this section describes outputs from workshops attended by Fijian pearl farmers and industry stakeholders and provides details of inputs used in the economic modeling exercise. All monetary values are expressed in U.S. dollars.

Physical Parameters

An establishment phase of 9 mo was factored into the modeling that assumes first seeding occurred in September of the first year. A production period from seeding to harvest was selected at 18 mo and the production method used was based on chaplets (Southgate 2008). Critical to the economic model is determination of the number of juvenile oysters present at the beginning of the farming operation; this was set at 60,000. An additional input requirement was to set the number of oysters required for each seeding event; this was set at 15,000 (excluding older oysters returning for reseeding operations). Tables 5 and 6, respectively, outline the physical parameters related to oyster numbers and the production infrastructure required to support them.

Seeding and Mortality

The economic model sets a number of seeding parameters relating to progression of oysters through the production system, including seeding mortalities, retention rates, and number of saleable pearls resulting from a seeding event. Table 7 shows the parameters used in the modeling. It is not until year-3 that any pearls are harvested, and it is not until midway through the farm’s life that pearl production achieves a steady state (Fig. 2).

Cost Inputs for the Economic Model

Juvenile Requirements

New juveniles are required each year to replenish the farm’s oyster stocks. The number of juveniles required is based on the estimated number of preseedable oysters required at future seeding events, with a correction for losses. An expected survival rate was set at 60%, i.e., if 10,000 oysters are required at seeding and only 60% are expected to survive to seeding, then 16,667 \((10,000 \times 0.6)\) would be required to achieve the desired target. Juveniles are sourced from external spat collection operators and supplied at a cost of $1.00 per juvenile. The number of juveniles required annually over the life of the farm is shown in Figure 3.

TABLE 5.

Farm oyster numbers at steady state.

<table>
<thead>
<tr>
<th>Oyster category</th>
<th>Number of oysters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of oysters on farm</td>
<td>112,906</td>
</tr>
<tr>
<td>Number of juvenile oysters</td>
<td>60,000</td>
</tr>
<tr>
<td>Number of preseedable oysters</td>
<td>15,000</td>
</tr>
<tr>
<td>Number of seeded oysters</td>
<td>37,906</td>
</tr>
</tbody>
</table>

TABLE 6.

Longline infrastructure and associated oyster numbers.

<table>
<thead>
<tr>
<th></th>
<th>Seeded</th>
<th>Preseedable</th>
<th>Juvenile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of longlines</td>
<td>38</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Total length of longlines (m)</td>
<td>3,800</td>
<td>800</td>
<td>100</td>
</tr>
<tr>
<td>Number of oysters per longline</td>
<td>998</td>
<td>1,875</td>
<td>60,000</td>
</tr>
</tbody>
</table>

Nuclei

The modeled dynamic production system estimated the number of nuclei required at each seeding event from first implant through to numbers required for a fourth implant. Estimated cost of nuclei over this period is shown in Table 8. The total number of nuclei required annually and their cost is shown in Figure 4.

Marketing

Marketing of Fiji pearls is split into two market segments, with A-grade and B-grade pearls, across all shapes, sold to international buyers. Pearl size also influences price and the average size of Fijian pearls from first to fourth pearls, i.e., first seed of an oyster to its third reseed that produces a fourth pearl is shown in Table 9. Many harvested pearls are of low quality, and high-quality flawless round pearls represent only around 5% of saleable pearls (Kishore & Southgate 2016). The highest average price used in the model was $650 for an A-grade 14-mm round pearl, whereas the lowest price was $8 for a B-grade 10-mm baroque pearl. Across all pearl sizes, 25% A-grade and 50% B-grade pearls were assumed for this model. The remaining 25%, graded C and D, are sold domestically. The average wholesale prices for various pearl shapes and sizes used in the model are shown in Table 10.

Seeding Technicians

For this modeling exercise, a flat rate of $2.56 per operation was used to cover all costs, including the seeding operation, airfares, accommodation, food, visas, and any taxes a technician may incur. On an annualized basis, the model round pearl farm spends $67,812 per year ($7.77 per saleable pearl) on seeding technicians, and this represents the largest portion of annual operating costs at 35.45% (Fig. 5).

Other Labor

The remaining labor component of the model farm consists of six permanent employees paid $80 for a 40-h working week
(average wage rate in Fiji is $2.00 per hour), equating to an annual cost of $23,040 (allowing for 4 wk of holiday). In addition, the model assumes the owner will draw $7,500 per annum. In the Pacific, labor is treated as a non-value good, assuming that drawings will only be realized when the business generates sufficient profit (Johnston & Pickering 2003). This approach underestimates the true cost of labor. If the enterprise returns a profit solely based on unpaid labor, then the decision to undertake that enterprise would be based on false economies (Johnston & Pickering 2003).
Other Operating Costs

All miscellaneous costs used in the model are shown in Table 11.

Capital Expenditure

Capital costs of the pearl farm comprised three main components: land and buildings, production infrastructure and equipment, and vehicles and machinery. A small parcel of land is purchased for storage of equipment, office space, and other onshore activities. The remainder was allocated to infrastructure such as living quarters and a pearl seeding facility. The total cost of land and buildings is $20,050. Additional equipment and infrastructure required for the model farm are listed in Table 12 and are purchased second hand. The residual value, representing the total cash salvaged at the end of the project from the sale of capital items, was $21,515.

Economic Model Output Summary and Economic Indicators

Farm Output Summary

The Fijian viable-scale pearl farm produced 8,723 saleable pearls annually. Of the saleable pearls produced, 32% were round, 21% were semi-baroque, 33% were circles, and 14% were baroque. Annual gross revenue from the sale of pearls totaled $347,634 ($39.85 per saleable pearl), whereas annual production costs totaled $191,271 ($21.93 per saleable pearl) (Table 14).

Net Present Value

Net present value over the 20-y life of the project, using a discount rate of 6%, was $1,793,465. As shown in Figure 6, the model indicates that it would take 5 y to recoup the original investment in the project.

Annual Profitability

Measurement of pearl farm profitability was based on EAR (EAR = annualized NPV) and IRR. The results of the analysis are shown in Table 15 with some additional economic indicators. Equivalent annual return was $156,362, IRR was 36.12%, benefit–cost ratio was 1.83, and payback period was 5 y (Table 15).

Risk Analysis

Risk analysis focused to two key parameters, price and production, and five-point distributions were used for both variables (Table 16). In both distributions, the average point is derived from the outcomes already described in the farm output summary. Minimum production is zero because in Fiji, cyclones...
and disease could potentially wipe out annual pearl farm production. Pearl farmers indicated that a “poor” production result would be approximately 10% of expected production levels, hence 872 saleable pearls. The “maximum” point in the distribution of pearls was set at 10,000 as the pearl farmers indicated that the model’s expected outcome of 8,723 pearls would be difficult to exceed in both number of pearls produced and the number of years that it might occur. The “good” point in the distribution for production was estimated as the midpoint between the “average” point and the “maximum” point.

The average price for a saleable pearl from the viable-scale pearl farm was $39.85. This was used to set the “average” point in the distribution. The maximum price to be received for a saleable pearl was set at $50.00, based on stakeholder inputs. Remaining distribution points were based on midpoints between the “average” and the “maximum,” and the “average,” and the “minimum.” Probabilities were determined following stakeholder input to identify and categorize risks from severe to mild and their probabilities of occurrence. Simulation output is the EAR. The highest EAR was $295,406, whereas the lowest was –$190,765 (Fig. 7). The average EAR produced by the simulation was $29,463. Incorporation of production and price risk reduced the expected EAR from $156,362 per annum to $29,463. The probability of the viable-scale pearl farm making a loss (where the distribution intersects the Y axis; Fig. 7) is approximately 42%.

**DISCUSSION**

The aim of this study was to determine establishment and operational costs for round pearl culture in Fiji and to estimate a viable-scale farm size. Development of a viable-scale whole-farm model was initiated to serve as a guide to industry participants, stakeholders, government departments, research organizations and donors, regional extension agencies, and non-governmental organizations, describing the inputs required to establish and maintain a viable round pearl farm in Fiji. Economic information pertaining to pearl farming in the south Pacific is sparse, providing little or no guidance in the development of a farming profile. On this basis, the information generated in this study is vital for sustainable development of the Fijian cultured pearl industry. It will assist in the establishment of new farms, expansion of current farms, and will inform development of a policy framework by the government of Fiji to support industry expansion. To provide some context, the largest farm in Fiji, J. Hunter Pearls (Fiji), seeded approximately 100,000 oysters in 2016 (Justin Hunter, personal communication). The second largest, Civa Fiji Pearls, seeded only 7,000 oysters in 2015 (Claude Prevost, personal communication). The results of this study suggest that a viable-scale farm requires an annual seeding of a minimum of 30,000 oysters per year.

Only one prior study (Fong et al. 2005) discusses the economic feasibility of black-lip round pearl culture in the Pacific (Republic of the Marshall Islands and the Federated States of Micronesia). The motivation for their study was to stimulate private-sector economic development with a view to reducing reliance on foreign aid and government support (Fong et al. 2005). The basis for their economic modeling was a pearl farm containing 25,000 seeded oysters at any point in time, which is similar to the scale of the Fijian pearl farming model developed in the present study. Similar to the present study, south Pacific is sparse, providing little or no guidance in the development of a farming profile. On this basis, the information generated in this study is vital for sustainable development of the Fijian cultured pearl industry. It will assist in the establishment of new farms, expansion of current farms, and will inform development of a policy framework by the government of Fiji to support industry expansion. To provide some context, the largest farm in Fiji, J. Hunter Pearls (Fiji), seeded approximately 100,000 oysters in 2016 (Justin Hunter, personal communication). The second largest, Civa Fiji Pearls, seeded only 7,000 oysters in 2015 (Claude Prevost, personal communication). The results of this study suggest that a viable-scale farm requires an annual seeding of a minimum of 30,000 oysters per year.

**TABLE 11.**

<table>
<thead>
<tr>
<th>Cost item</th>
<th>Annual cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel, oil, and electricity</td>
<td>$3,150</td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>$4,538</td>
</tr>
<tr>
<td>Training</td>
<td>$1,000</td>
</tr>
<tr>
<td>Travel</td>
<td>$5,000</td>
</tr>
<tr>
<td>Lease fees</td>
<td>$2,500</td>
</tr>
<tr>
<td>Vehicle expenses</td>
<td>$400</td>
</tr>
<tr>
<td>Sundries</td>
<td>$450</td>
</tr>
<tr>
<td>Total</td>
<td>$17,038</td>
</tr>
</tbody>
</table>
Fong et al. (2005) used a 20-y time frame but with a higher discount rate of 8%. Some of the key findings from their study were an upfront capital investment of $202,076, producing an NPV of $102,944 with an IRR of 9.6% (Fong et al. 2005). This capital investment is nearly twice that reported here for the Fijian viable-scale farm, but it included more than $100,000 for land and buildings, including living quarters for technicians and 12 laborers. The estimated Fijian investment in similar items in the present study was $23,000 in wages for six laborers, with seeding technicians building in the cost of hotel accommodation or similar. Although the capital investment is higher in the Fong et al. (2005) model, the analysis showed that it is profitable, but margins were smaller because of the significant costs of labor and seeding that represented 66% of the total production cost, compared with 51% in the present Fijian model. With an NPV of $102,944, and using the 8% discount rate, the EAR for the Fong et al. (2005) model farm was $10,485. The NPV for the Fijian model, using a 6% discount rate, was considerably higher at more than $1.7 million with an EAR of $156,362. Recalculation of the Fijian model using the same discount rate as the Fong et al. (2005) model (8%) only reduced the EAR by 7.7% to $144,309. An IRR of 36.12% in the Fijian model developed in the present study indicates that an investor could borrow the capital required at that interest rate and still break-even. In addition, the Micronesian model of Fong et al. (2005) had a 4-y lag before any cash inflow is realized compared with 3 y for the Fijian model developed in the present study.

The Micronesian pearl farming model (Fong et al. 2005) and the Fijian model developed in the present study have similar production costs of $19.15 per pearl in Micronesia and $21.93 per pearl in Fiji. The average price per pearl across all grades, shapes, and implant number for the Fijian model is $39.85, whereas the average price across first to third implants was approximately $21.42 in Micronesia. Fong et al. (2005) stated that the market prices used were conservative, with a 50% discount, based on saleable pearl quality from two farms in the region and international pearl prices at the time. The Fijian pearl pricing matrix used in the present study is based on actual sales data from all Fijian pearl farmers who attended workshops and follow-up one-on-one interviews. Fijian pearl farmers and the Government of Fiji have invested significantly to differentiate their product, from that of mass-produced (measured in tonnes) pearls from French Polynesia through color and quality (Anon 2007). Targeted marketing campaigns by Fijian stakeholders and tight controls over the quality of exported pearls sold in the international marketplace (Johnston et al. 2007).
et al. 2014) meant that no discounts were applied to Fijian pearl prices.

Fong et al. (2005) recognized that low potential profitability could be reduced by training locals in pearl seeding techniques to reduce reliance on specialist and costly overseas technicians. A similar approach has been trialed in Fiji with at least two farms; both demonstrated limited success and poor pearl yield and quality. The Fijian pearl industry is likely to be reliant on overseas pearl seeding technicians for many years into the future, although training of local seeding technicians is a desirable development and is likely to be an increasingly important consideration in a number of Pacific nations.

### Considering Risk for Pearl Farming in Fiji

Future development of the round pearl farming sector in Fiji is unlikely to attract significant new entrants, and farms that do establish are likely to have some level of foreign interest. The Fijian viable-scale farm model developed in this study sets the bar high in terms of production compared with current farming effort and provides a robust blueprint for round pearl farming in Fiji. At the expected production level where everything goes to plan, the Fijian model generates a significant annual income of $156,362. The Fijian model has a payback period of 5 y and generates a benefit–cost ratio of 1.82. That is, for every dollar invested in the project, $1.82 is returned. These results do not take into account the riskiness of the activity. Profit margins are susceptible to the significant risks including disease events, destructive cyclones, theft, and fluctuating market prices. A pearl farm, although potentially facing losses in some years, must compensate for those potential losses with consistent cash flows in other years. The potential impacts of risks were accounted for in this study using stochastic modeling (Monte Carlo simulation), which showed that the Fijian viable-scale pearl farm could still generate an average income of $29,463 and realize losses in 4 in 10 y despite facing significant risks. Although 81% is a significant drop in the EAR, it represents significant profit, above all costs, for an operation in the context of other aquaculture and agricultural practices in Fiji. For example, according to the most recent survey in 2008 to 2009 by the Fiji Bureau of Statistics, the average annual rural household income is approximately $5,800.

### Constraints to Pearl Farm Establishment in Fiji

The common denominator for the stifled expansion of the Fijian cultured pearl industry since 2000 was a lack of access to capital to establish effective operations, grow their businesses, and survive the early years when cash flow is lacking. New entrants do not often have the scale to attract technicians or purchase resources at reasonable market prices because they lack the necessary capital.

### TABLE 16. Production and price distributions with associated cumulative probabilities.

<table>
<thead>
<tr>
<th>Description</th>
<th>Production (no. of pearls)</th>
<th>Cumulative probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Poor</td>
<td>872</td>
<td>15</td>
</tr>
<tr>
<td>Average</td>
<td>8,723</td>
<td>65</td>
</tr>
<tr>
<td>Good</td>
<td>9,200</td>
<td>85</td>
</tr>
<tr>
<td>Maximum</td>
<td>10,000</td>
<td>100</td>
</tr>
<tr>
<td>Description</td>
<td>Price per pearl</td>
<td>Cumulative probability (%)</td>
</tr>
<tr>
<td>Minimum</td>
<td>$29.70</td>
<td>0</td>
</tr>
<tr>
<td>Poor</td>
<td>$34.78</td>
<td>15</td>
</tr>
<tr>
<td>Average</td>
<td>$39.85</td>
<td>65</td>
</tr>
<tr>
<td>Good</td>
<td>$44.93</td>
<td>85</td>
</tr>
<tr>
<td>Maximum</td>
<td>$50.00</td>
<td>100</td>
</tr>
</tbody>
</table>
cannot buy in bulk. Commonly, small pearl farming operations rely on larger operations for support, access to skilled technicians and resources, and imparting knowledge and skills. In French Polynesia, many pearl farms are grouped in relatively close proximity, forming economic interest groups, or Groupement d’Intérêt Economique (Hisada & Fukuhara 1999); however, Fijian round pearl farms are spatially dispersed, which limits potential benefits relating to scale and resource sharing. This is complicated further by the lack of clear title and tenure for marine farming areas that are often subject to traditional access rights. Interestingly, the four current round pearl exporting farms have some degree of foreign investment and support, which assists access to resources, but most importantly, capital. Indigenous Fijians find it difficult to access capital from local lending institutions, particularly for aquaculture businesses. In Fiji, a business is required to have appropriate insurances, their business accounts certified, and some level of collateral appropriate to the size of their loan.

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