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# Potential profitability of pearl culture in coastal communities in Tanzania

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ABSTRACT

Artisanal half-pearl culture has been shown to provide livelihood and economic opportunities for coastal communities in Tanzania that depend directly on exploitation of marine resources. However, these pilot research studies have been supported by donor organisations and the economic feasibility of such development has not yet been assessed. Furthermore, there is little understanding of the costs required to establish pearl farms and the relative impacts of farm size on production, running costs, profitability and risks involved in production. The aim of this study was to develop economic models for subsistence level half-pearl culture in Tanzania. Models were generated for various scenarios relating to farm size and products (i.e. half-pearls and juvenile oyster or 'spat' collection) and they give detail on infrastructure costs, operational costs and income generated for various levels of operation. We concluded that the most profitable model for community-based pearl farming is to culture at least 600 oysters for half-pearl production. However, for communities to be able to run a sustainable and profitable enterprise, development of a sustainable source of oysters is crucial. Farmers can also generate income from collection of juvenile oysters and their subsequent sale to pearl farmers, but this is less profitable than half-pearl farming and requires a longer operational period before profits are made. Like pearl farming, there were major benefits or economies of scale with the largest farms tested providing greatest profit and/or a shorter time required to reach profitability. Our results provide a valuable source of information for prospective pearl farmers, donors, funding bodies and other stakeholders, and valuable extension information supporting further development of pearl culture in Tanzania.



## 1. Introduction

Coastal communities in Tanzania depend primarily on exploitation of coastal and marine resources for their livelihoods (Edward, 2009). Existing livelihood activities include artisanal fishing and mangrove harvesting, agriculture of coconuts and cashews and subsistence farming. However, opportunities for further development of these activities are limited, and this increases exploitation pressures on marine resources which are often harvested using unsustainable methods such as dynamite fishing and beach seining (Andrews, 1998). As a result, natural resources remain in long-term decline against a background of increasing population. To address this underlying dependency on natural marine resources, as well as poverty alleviation, two independent pilot-scale research projects were begun in 2003 to assess the feasibility of developing pearl culture based livelihoods in poor coastal communities at Mafia Island and Zanzibar. They demonstrated that, after basic training, artisanal fishers could routinely produce marketable cultured half-pearls (Fig. 1) and that pearl shell handicraft skills were readily adopted by pearl farmers and other community members (Southgate et al., 2006; Jiddawi, 2008). Production of half-pearls and mother-of-pearl (MOP) handicrafts provides broad income generating opportunities for coastal communities in Tanzania (Southgate et al., 2006; Jiddawi, 2008), and half-pearl culture is compatible with marine conservation efforts (Southgate et al., 2006). As a result of these successes, the World Wide Fund for Nature (WWF) Tanzania Country Office oversaw the Rufiji-Mafia-Kilwa (RUMAKI) Seascape Programme (2005–2012) which was funded by the European Union (EU-ReCoMaP) during the period 2009–2011, to extend artisanal pearl culture activities to another

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**Fig 1.** Half-pearls grown inside the shell of *Pteria penguin* by pearl farmers at Mafia Island, Tanzania. Pearls can be sold in the shell, with shell value based of the number of pearls it contains, or cut from the shell for individual sale. If cut from the shell, the remaining pearl shell can be utilised for mother-of-pearl handicraft and jewellery production.

**Table 1**
Infrastructure and production parameters used to develop economic models for half-pearl and spat farms in coastal Tanzania. Numbers in parentheses are the values used in the models.

| Infrastructure parameters | Production parameters |
|---|---|
| Number of rafts | Cost per nucleus |
| Number of bamboo poles per raft (20) | Average number of nuclei per oyster (3) |
| Number of mangrove poles per raft (12) | Cost of glue per seeded oyster |
| Number of floats per raft (8) | Cost of pearl seeding tools |
| Number of anchors per raft (4) | Time required to seed one oyster (15 min) |
| Number of rolls of rope per raft | Number of seeded oysters |
| Man hours to make one raft (4) | Mortality of seeded oysters (6.25%) |
| Man hours to make anchors (1) | Time to cleaning each oyster (5 min) |
| Man hours to deploy raft (3) | Frequency of oyster cleaning (2 per month) |
| Number of nets per raft (10) | Cost of cleaning equipment (brushes etc.) |
| Cost of nets | Culture period (9 months) |
| Number of oysters per net (8) | Proportion of unsellable pearls (10%) |
| Number of nets per raft (10) | Proportion of sellable pearls (90%) |
| Man hours required to collect oysters | Number of spat harvested |
| Cost of plastic containers | |
| Cost of spat collector materials | |
| Man hours to make spat collectors | |
| Number of spat collectors (50) | |

77 community members at Mafia Island and 54 others in the Kilwa District of mainland Tanzania.

As well as half-pearl production, an associated coastal livelihood opportunity is provided by collection of juvenile pearl oysters or 'spat' that can be retained and grown for subsequent half-pearl production or sold directly to pearl farmers. Spat can be collected by deploying appropriate materials (or 'spat collectors') into the ocean at an appropriate time to provide a settlement substrate for pearl oyster larvae that are later removed as spat (Beer and Southgate, 2000; Southgate, 2008). Spat collection is a major source of income for coastal communities in French Polynesia (Southgate, 2008; Tisdell and Poirine, 2008) and has become an important sector in the pearl culture industry (Tisdell and Poirine, 2008). Spat collection is still at a very early stage as a means of income generation in Tanzania, but it has considerable potential should pearl farming become established.

Although the livelihood benefits and potential of artisanal half-pearl and MOP handicraft production in Tanzania have been briefly reported (Southgate et al., 2006; Jiddawi, 2008), information on the economic viability of these activities is very limited. Information on the set-up and running costs of pearl farms in Tanzania and estimates of potential income generation from pearl production under various scenarios is not currently available. The aim of this study was therefore to develop economic models to assess the feasibility of artisanal half-pearl production and pearl oyster spat collection in Tanzania. Models were developed to represent various scenarios relating to farm size and product (i.e. half-pearls and spat collection). They detailed infrastructure and establishment costs, operational costs and estimated potential income generation from various levels of operation over a 20 year horizon. The outputs from this research provide a valuable source of information for prospective pearl farmers, donors, funding bodies and other stakeholders, and valuable extension information supporting further development of pearl culture in Tanzania.

## 2. Materials and methods

### 2.1. Modelling software and analysis

Economic models were developed using Microsoft Excel and based upon cost-benefit analysis techniques. The modelling software used in this study was adapted from existing software developed by Johnston and Ponia (2003) for analysis of cultured round-pearl production in Pacific island countries (e.g. Tisdell and Poirine, 2008; Hine and Johnston, 2013; https://publications.qld.gov.au/dataset/agbiz-tools-fisheries-aquaculture). For this study changes were made to existing software to account for differences between round pearl and half-pearl production methods and cycles, and differences in inputs, input costs and infrastructure and products (i.e. half-pearl and spat), between the Pacific and Tanzania. The revised software was used to analyse data from inputs related to farming costs (establishment of farm and maintenance), the estimated quantity of half-pearl and spat produced, and value of products (half-pearls and spat). From these data, the software generated information on annual gross revenue, annual production costs, and production costs and revenue per product. Other information generated by this analysis included net present value, annual return and benefit-cost ratio for both half-pearl and spat collection. A discounted cash flow analysis was used to determine the annualised cost structure and likely profitability. The timing and duration of these projects has an influence on the annualised costs and revenues of the project. The single amount calculated using compound interest method is known as present value (PV) of the future stream of costs and benefit. The rate used to calculate present value is known as the discount rate (opportunity cost of funds). All the models developed assumed a project life of 20 years and used a real discount rate of 5 per cent to calculate the net present value (NPV).

Data inputs to the spreadsheet-based models included the costs associated with raft-based farming infrastructure (e.g. bamboo poles, ropes, floats, anchors, etc.), pearl production and husbandry (e.g. oyster nets, pearl nuclei and glue, pearl seeding tools, spat collector materials etc.) and labour (Table 1). Values for all economic parameters (outputs) were calculated from value entered. The summary statistics also provide a breakdown of input costs per product (i.e. per pearl or per spat) which allowed the major input costs to be identified. Another feature of the model is the application of risk analysis (Johnston and Ponia, 2003). Risk and uncertainty are features of most business and government activities and need to be understood to ensure rational investment decisions. The models include a five-point distribution risk analysis that accounts for risk associated with production (e.g. weather events, environmental stressors, disease and predation, pollution, theft, oyster supply, technical skill variability) and revenue streams (e.g. exchange rates, market variability, tourism flows, increased international competition, quality issues associated with product, domestic market competition, global economic shocks etc.) that delivers a cumulative probability distribution of profit (NPV) of a possible 200 annual production outcomes given the risk parameters identified. Development of the risk profile was informed by a decade of research in business skilling with pearl farmers in south Pacific countries and is directly applicable to these scenarios in Tanzania. Values shown in this study are Australian dollars (AUD) and values were calculated from actual costs in Tanzanian Shillings (TZS) using an exchange rate of 1 AUD = 1,506.55 TZS.

### 2.2. Data collection

Data for spat collection and pearl culture were collected from pearl farmers at Mafia Island and in the Mtwara region, respectively. At Mafia Island, three group members work as a cooperative where they perform all activities together as a unit including spat collection, oyster collection, raft making, seeding for pearl production, oyster care, pearl harvesting and marketing. When they make pearl sales, they share the revenue equally. In the Mtwara region, data for cultured half-pearls were collected from a pearl farmer from Mngoji village in the Mnazi Bay-Ruvuma Estuary Marine Park (MBREMP) in Mtwara Rural District. At both sites, production of cultured half-pearls depends on wild-collection of adult black-lip pearl oysters, *Pinctada margaritifera*. However, unlike pearl farmers at Mafia Island, who have access to commercially available nuclei to make their pearls, the farmer at Mngoji village uses plastic hemi-spherical earring buttons as half-pearl nuclei.

The data used in this study to generate economic models were actual operational costs and production data from established spat farming and half-pearl farming activities at Mafia Island and Mtwara, respectively. The infrastructure and production parameters used to develop the economic models are shown in Table 1 with some input values. Infrastructure costs differed between Mafia Island and Mtwara for similar items and these differences were incorporated into the respective models. For example, farming at both sites is raft-based, but farmers at Mafia Island utilise bamboo poles in raft construction while local mangrove poles are used for the same purpose at Mtwara. 'Man hours' were costed at a standard rate of TZS 1430 per hour (=AUD $0.95) for both the half-pearl farm and spat farm models.

### 2.3. Economic models

#### 2.3.1. Half-pearl farm scenarios

Economic models were developed for three different sizes of half-pearl farm in Tanzania. Scenario 1 represents the current farm size at Mtwara and for the purpose of modelling, the farm size was doubled (scenario 2) and tripled (scenario 3). Thus, scenario 1 is a family-owned farm with 200 oysters producing half-pearls; scenario 2 is a family owned farm with 400 oysters producing half-pearls; and scenario 3 is a family owned farm with 600 oysters producing half-pearls.

#### 2.3.2. Spat collection farm scenarios

Economic models were developed for current pearl oyster spat collection methods used at Mafia Island, where one spat collection farm utilises 50 individual spat collectors, composed of 1-m$^2$ of 50% shade cloth held within 6 mm pore size mesh 'onion bags', that are suspended from a bamboo raft at a depth of 2–3 m. Spat collectors are deployed for one year before juvenile oysters are removed for culture. This study determined the economic impacts of varying numbers of spat recruiting to spat collectors. On this basis, economic models were generated for recruitment scenarios of: (1) 10 spat per collector; (2) 25 spat per collector; and (3) 50 spat per collector.

**Table 2**
Output summary and economic indicators generated for the three half-pearl farming scenarios assessed in this study; based on farms with 200, 400 and 600 oysters.

| | Half-pearl farming scenarios | | |
|---|---|---|---|
| | 200 | 400 | 600 |
| *Output summary* | | | |
| Annual production (half-pearl) | 684 | 1368 | 2052 |
| Annual gross revenue | $4275 | $8550 | $12,825 |
| Annual production costs | $963 | $1672 | $2401 |
| Production costs per half-pearl | $1.41 | $1.22 | $1.07 |
| Revenue per pearl | $6.25 | $6.25 | $6.25 |
| *Economic indicators* | | | |
| Net present value | $41,280 | $85,712 | $132,422 |
| Annual return | $3312 | $6678 | $10,626 |
| Benefit-cost ratio | 4.44 | 5.11 | 5.83 |
| *Farm establishment costs* | $702 | $1052 | $1472 |

#### 2.3.3. Assumptions

The economic modelling undertaken in this study made the following assumptions:

- farmers do not pay themselves regular wages or salaries when they work at their farms but use money from pearl sales to support family needs via drawings;
- drawings are not annual and the level of drawings varies from year to year – on this basis drawings were excluded from analyses and the potential profits estimated from our analyses exclude drawings;
- farmers use some locally available materials for farm infrastructure – e.g. bamboo and mangrove poles. In our models such materials were costed (Table 1);
- a single farmer can maintain one raft housing 200 oysters – the model considered that each additional raft with oysters would need another person employed;
- no extra transport (canoe) would be needed for up to three rafts because one canoe can carry up to three people able to service three rafts simultaneously; and
- that 90% of pearls produced are able to be sold at an average price of TZS10,000 (= AUD $6.64) per pearl; these figures are based on average production data from the farm and a 'standard' local pearl price.

## 3. Results

### 3.1. Half-pearl models

The output summary and economic indicators generated for half pearl farming models are show in Table 2. The results indicate that a farm of 200 oysters held on one raft has a net present value of $41,280 and an annual return of $3312 over a 20 year production period. The benefit-cost ratio of such a farm was 4.44 (Table 2) and the capital required to establish the farm was estimated to be $702. The production cost per pearl was estimated at $1.41 and this was composed of nuclei ($0.58) labour ($0.39) and capital ($0.21) as the major input costs (Table 3). While capital and labour are relative flexible, reducing the cost of nuclei could be used as a means of improving profitability. Fig. 2 shows discounted cumulative cash flow for a 200 oyster half-pearl farm for 20 years of production. The

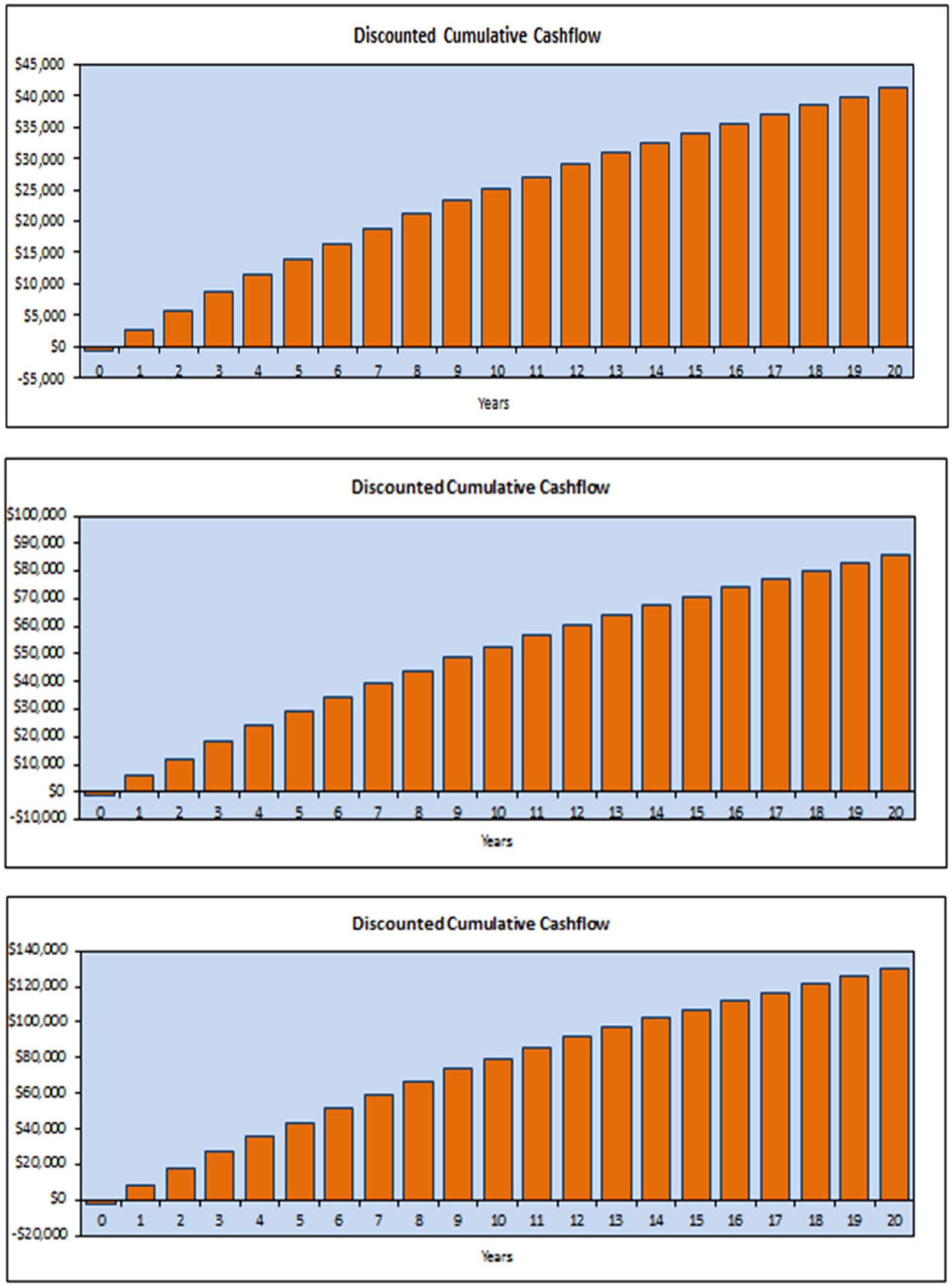


**Fig. 2.** Discounted cumulative cash flow for a 200 oyster half-pearl farm (top), a 400 oyster half-pearl farm (middle) and a 600 oyster half-pearl farm (bottom) over a 20 year production period. Values shown are Australian dollars (AUD) based on an exchange rate of 1 AUD = 1,506.55 Tanzanian Shillings (TZS) at the time of the study.

**Table 3**
Relative contributions of the different components of half-pearl production costs from pearl farms holding 200, 400 or 600 oysters.

| Component | Cost per pearl | | |
|---|---|---|---|
| | 200 | 400 | 600 |
| Capital | 0.21 | 0.16 | 0.15 |
| Operating costs | 0.15 | 0.07 | 0.04 |
| Farm | 0.05 | 0.04 | 0.03 |
| Farm labour | 0.39 | 0.34 | 0.30 |
| Other costs | 0.03 | 0.02 | 0.02 |
| Nuclei | 0.58 | 0.58 | 0.53 |
| **Total** | **$1.41** | **$1.21** | **$1.07** |

farm shows a positive discounted cumulative cash flow in the first year of production and a steady annual increase over the 20 year production cycle to a value of $41,280 in year 20 (Fig. 2).

A half-pearl farm utilizing 400 oysters generated an estimated net present value of $85,712, an annual return of $6678 and a benefit-cost ratio of 5.11 over a 20 year production period (Table 2). The capital required to establish this farm was estimated to be $1052. Production costs per pearl, from a farm with 400 oysters were also dominated by the cost of nuclei ($0.58) followed by farm labour ($0.34) and investment capital ($0.16) (Table 3). However, the contributions of farm labour and investment capital were slightly lower than for a farm with 200 oysters (Table 3), giving some indication of the effects of economies of scale. Discounted cumulative cash flow for a 400 oyster half-pearl farm over a 20 year production period indicates that profits will again be made in the first year of farm operation (Fig. 2). Discounted cumulative cash

**Table 4**
Risk analysis for three half-pearl farming scenarios assessed in this study based on farms with 200, 400 and 600 oysters. Further detail of the risk assessment for the 600 oyster farm is shown in Fig. 3.

| | Half-pearl farming scenarios | | |
|---|---|---|---|
| | 200 | 400 | 600 |
| Risk profile | 73% | 58% | 35% |
| Lowest return | −$568,297 | −$388,816 | −$155,150 |
| Highest return | $48,125 | $127,120 | $233,390 |

**Table 5**
Cash flows for half-pearl farm with 600 oysters over a production period of 20 years.

| Year | Annual Cash Flow | Discounted Cash Flow | Discounted Cumulative |
|---|---|---|---|
| 0 | −$1472 | −$1472 | −$1472 |
| 1 | $10,742 | $10,230 | $8758 |
| 2 | $10,742 | $9743 | $18,502 |
| 3 | $10,742 | $9279 | $27,781 |
| 4 | $10,742 | $8837 | $36,618 |
| 5 | $10,742 | $8417 | $45,035 |
| 6 | $10,742 | $8016 | $53,051 |
| 7 | $10,742 | $7634 | $60,685 |
| 8 | $10,742 | $7270 | $67,956 |
| 9 | $10,742 | $6924 | $74,880 |
| 10 | $9336 | $6595 | $81,475 |
| 11 | $10,742 | $6281 | $87,756 |
| 12 | $10,742 | $5982 | $93,737 |
| 13 | $10,742 | $5697 | $99,434 |
| 14 | $10,742 | $5425 | $104,859 |
| 15 | $10,742 | $5167 | $110,026 |
| 16 | $10,742 | $4921 | $114,947 |
| 17 | $10,742 | $4687 | $119,634 |
| 18 | $10,742 | $4464 | $124,098 |
| 19 | $10,742 | $4251 | $128,349 |
| 20 | $10,807 | $4073 | $132,422 |

flow is greater for the 400 oyster farm than the 200 oyster farm and this pattern continues throughout the projected 20 year production period.

A larger 600 oyster pearl farm was estimated to have a net present value of $132,422, an annual return of $10,626 and a benefit-cost ratio of 5.83 (Table 2). The capital required for a farm of this size was estimated to be $1472. Pearl production costs for a farm this size included nuclei ($0.53), farm labour ($0.30) and investment capital ($0.15) as the major contributors (Table 3). Discounted cumulative cash flow for a 600 oyster half-pearl farm over a 20 year production period showed that profit will again be made in the first year of farm operation and this will be larger than those predicted for farms with 200 oysters and 400 oysters (Fig. 2). A superior discounted cumulative cash flow to both the 200 and 400 oyster farms was also estimated throughout the projected 20 year production period (Fig. 2). The risk profile for a given farming scenario is determined as the point where the cumulative probability distribution curve intersects the zero profit line (Fig. 3). Therefore, a 600 oyster farm showed a 35% probability of making zero profit or less (or a 65% probability of making a profit greater than zero) with a lowest potential return of −$155,150 and highest potential return of $233,390 (Fig. 3, Table 4). Smaller pearl farms with 200 and 400 oyster showed higher probabilities (73% and 58%, respectively) of making zero profit (or losses) with increased potential negative returns and inferior potential highest returns (Table 4). Annual cash flow, discounted cash flow and discounted cumulative cash flow for a half-pearl farm with 600 oysters over a 20 year production period is shown in Table 5.

**Table 6**
Output summary and economic indicators generated for the three spat collection farming scenarios assessed in this study; based on collection of 10, 25 and 50 oysters per collector.

| | Spat collection scenarios | | |
|---|---|---|---|
| | 10 | 25 | 50 |
| *Output summary* | | | |
| Annual production (spat) | $475 | $1188 | $2373 |
| Annual gross revenue | $333 | $831 | $1663 |
| Annual production costs | $826 | $794 | $1273 |
| Production costs per spat | $1.74 | $0.67 | $0.54 |
| Revenue per spat | $0.70 | $0.70 | $0.70 |
| *Economic indicators* | | | |
| Net present value | −$4845 | $366 | $3827 |
| Annual return | −$493 | $37 | $390 |
| Benefit-cost ratio | 0.40 | 1.05 | 1.31 |

**Table 7**
Relative contributions of the different components of spat production (per spat) for spat collection farms collecting 10, 25 and 50 spat per collector.

| Component | Cost per spat | | |
|---|---|---|---|
| | 10 | 25 | 50 |
| Capital | 1.64 | 0.63 | 0.51 |
| Repair/Maintenance | 0.07 | 0.03 | 0.02 |
| Farm labour | 0.03 | 0.01 | 0.01 |
| **Total** | **$1.74** | **$0.67** | **$0.54** |

## 3.2. Spat collection models

The output summary and economic indicators generated for spat collection farming models are shown in Table 6. Under the assumption made by this model, a community-based spat collection farm composed of one raft with 50 spat collectors, each collecting 10 spat every year, that are cultured in a single nursery raft before being sold to pearl farmers has large negative cash flows during the first 20 years of production and would require more than 20 years to pay back the investment capital and start making profit (Fig. 4). Economic indicators of such a farm for a production period of 20 years show a net present value of −$4845, an annual return of −$493, a benefit-costs ratio of 0.4 (Table 6) and a negative cash flow throughout the projected 20 years of production (Fig. 4). Major production costs per spat, included capital ($1.64), repair and maintenance ($0.07) and farm labour ($0.03) (Table 7).

A similar spat collection farm composed of one raft with 50 spat collectors, each recruiting 25 spat each year was predicted to require 15 years of production to break even and start making profit (Fig. 4). The economic indicators of this spat collection farm modelled for a production period of 20 years indicated the net present value to be $366, an annual return of $37 and a benefit-costs ratio of 1.05 (Table 6). Production costs per spat, were made up primarily of capital ($0.63), repair and maintenance ($0.03) and farm labour ($0.01) (Table 7). This farm has lower production costs per spat than the smaller spat collection farm (Tables 6 and 7).

A more successful spat collection farm recruiting 50 spat per collector each year will require 4 years of production to pay back the investment capital and begin making profit (Fig. 4). The economic model for such a farm over a production period of 20 years indicated the net present value of $3827, an annual return of $390 and a benefit-costs ratio of 1.31 (Table 6). Such a farm showed a risk profile with 54% chance of making zero profit or less with the lowest return of −$1060 and highest return of $1036 (Fig. 5). This risk assessment compared well to those for the two smaller spat collection farm models which showed risk profiles of 87% and 76%, respectively (Table 8). Production costs per spat, were made up pri-

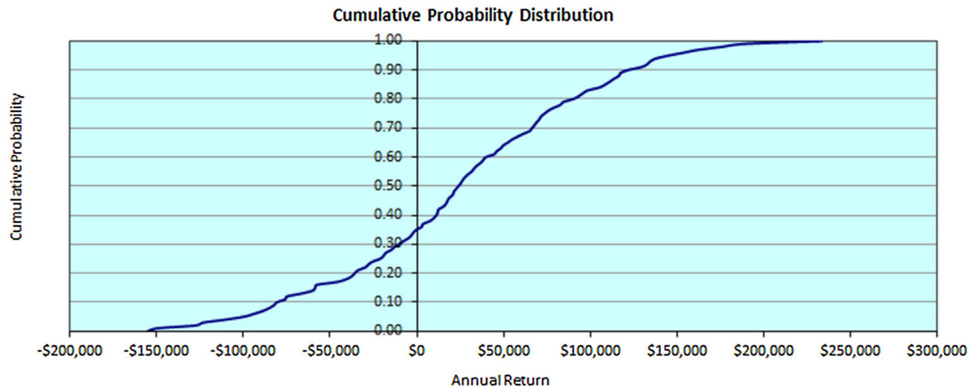


**Fig. 3.** Risk assessment for a 600 oyster half-pearl farm. The point at which the cumulative probability distribution curve intersects the zero profit line indicates that this farm has a 35% chance of making zero profit or less, with a lowest potential return of −$155,150 and highest potential return of $233,390 for 20 years of production. Values shown are Australian dollars (AUD) based on an exchange rate of 1 AUD = 1,506.55 Tanzanian Shillings (TZS) at the time of the study.

**Table 8**
Risk analysis for the three spat collection farming scenarios assessed in this study; based on collection of 10, 25 and 50 oysters per collector. Further detail of the risk assessment for the 50 spat per collector scenario is shown in Fig. 5.

| | Spat collection scenarios | | |
|---|---|---|---|
| | 10 | 25 | 50 |
| Risk profile | 87% | 76% | 54% |
| Lowest return | −$1695 | −$1429 | −$1060 |
| Highest return | $227 | $463 | $1036 |

marily by capital ($0.51), repair and maintenance ($0.02) and farm labour ($0.01) (Table 7).

## 4. Discussion

All three half-pearl farming scenarios modelled in this study (200, 400 and 600 oysters) recovered investment capital and made profit (break-even) in the first year of production. Our results indicate that pearl farms with 600 oysters grown using three rafts is the best of the three models tested as it generates superior revenue in the first year of production than farms with 200 and 400 oysters. This farm type could be appropriate for family operated ventures and cooperatives whose members work together and share revenue after sale of products. Cooperatives may be ideally composed of three farmers because the experience of current pearl farmers in Mtwara indicates that 200 oysters can be managed by one person but a greater number of oysters will need additional employees to manage them.

Smaller farms of 200 or 400 oysters could be best suited to individuals and small families. Although both farming models break-even in their first year of production, they generate less revenue than would be required to support a large family. Also, the level of income generated is unlikely to be sufficient to allow some savings to support future farm re-investment and operation. Experience from an existing family operated farm, with 200 oysters, shows that pearl sales provide sufficient revenue for family needs with a little left over to be saved for emergencies and future farm operation (M. Mkwamba, pers. comm., 2014). Our results indicate that there is scope for farmers tending small pearl farms to reinvest in pearl farming infrastructure and increase farm size over time. This is likely to be an attractive use of income from pearl farming given the relatively low capital requirements of small pearl farms. The same pearl farmer also reported that he managed to construct a new house using revenue from pearl sales that was accumulated over a two year period when he had no large financial responsibilities with the family (e.g. children were not in school).

Although the results of this study indicate that farms with 600 oysters offer the best option for pearl farming in Tanzania, there are some issues that prospective pearl farmers and funding organizations need to consider. The first is the relatively high investment capital required to establish and operate such a farm, estimated at $1472. This is a large sum of money by local standards which few prospective pearl farmers in Tanzania could manage. This sum would also be difficult for many communities to generate unless supported by a donor funding organization. On this basis, it may be better for farmers to establish themselves in pearl farming with smaller scale farms that enable them to generate the capital required to expand their farms over time.

The second issue that needs to be considered is the availability of oysters to new farms. Currently, pearl farming at Mafia Island, Zanzibar and Mtwara is based on collection of wild oysters (Southgate et al., 2006) and studies have indicated that this approach may be unsustainable in places where wild collection is not properly managed (Southgate, 2008). For example, Sims (1993) reported that over-harvesting of *Pinctada margaritifera* reduced wild stocks to below a self-sustaining level in the Cook Islands and Kiribati. Currently, adult oysters are scarce in some areas of Tanzania due to prior unsustainable collection for food and shells (mother-of-pearl). The shell business has now ceased, but oysters are still collected as a source of protein. If not properly managed, wild collection of oysters in Tanzania could lead to a similar situation to those experienced in the Cook Islands and Kiribati. Wild collection of adult oysters for half-pearl culture is an unsustainable practice especially where many farmers may have to share the resource. Establishment of reliable spat collection programs will therefore be an important basis for future development of community-based pearl culture in Tanzania, and prior research has reported that it is possible to collect sufficient *P. margaritifera* spat to support pearl culture activities at some sites along the Tanzanian coast (Ishengoma et al., 2011).

Another issue to be considered by prospective pearl farmers is risk. Our modelling showed that while the potential annual return of a 200 oyster pearl farm was estimated at $3312 there is a high chance (73% of the time) of making a zero profit or loss. The potential annual return of a 600 oyster pearl farm was estimated at more than three times that of the 200 oyster farm ($10,626) while the risk of a zero profit or loss was more than halved (35%). So while larger pearl farms have clear advantages over smaller farms in terms of reducing the risk of making a zero profit or loss, our results indicate that half-pearl farming in Tanzania could still be a risky venture. It is important to note, however, that the farmer from Mtwara involved in this study had made annual profits from his 200 oyster pearl farm for ten consecutive years. Our results indicate, however, that

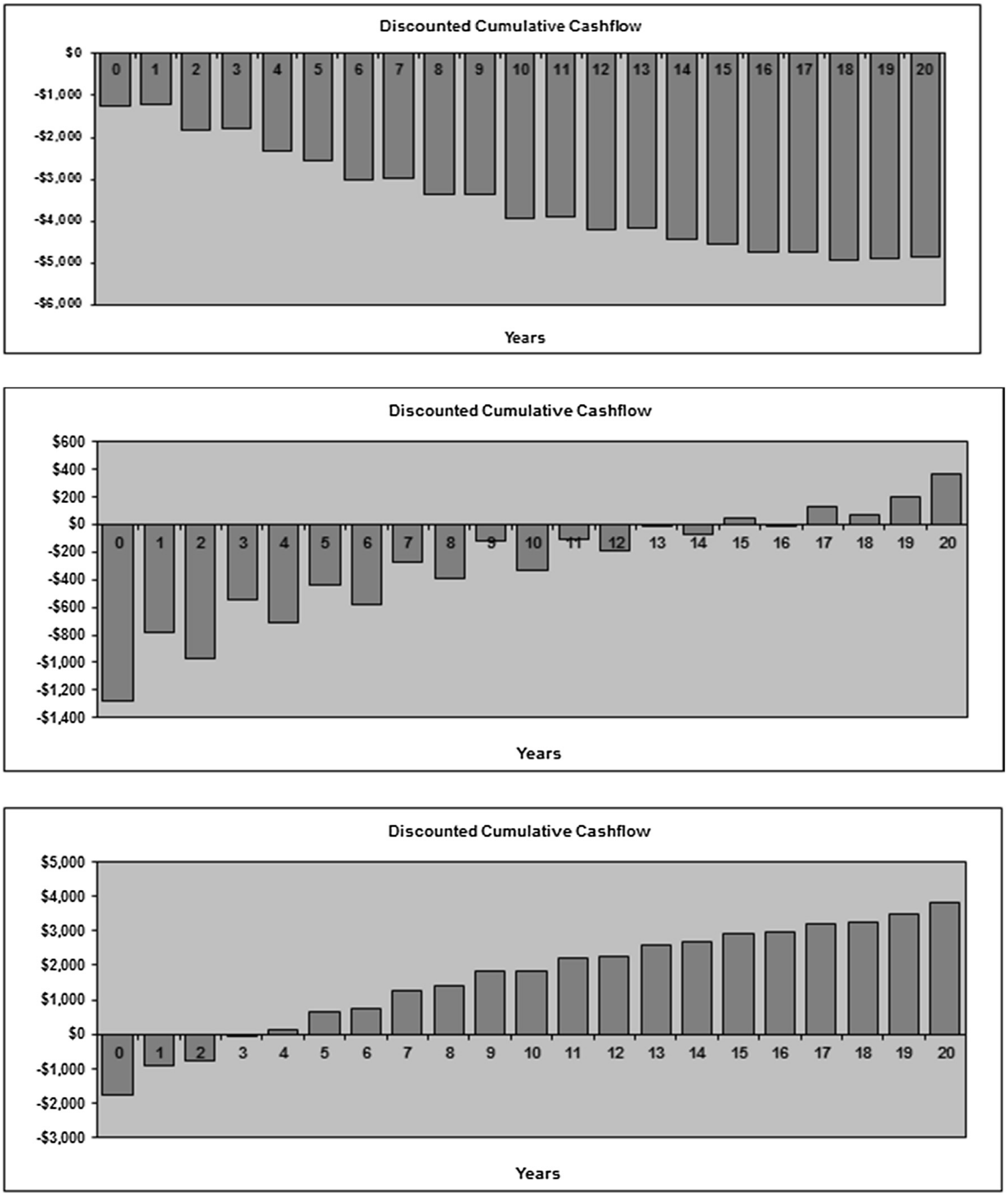


**Fig. 4.** Discounted cumulative cash flow for spat farms collecting 10 spat per collector (top), 25 spat per collector (middle) and 50 spat per collector (bottom) over a 20 year production period. Values shown are Australian dollars (AUD) based on an exchange rate of 1 AUD = 1,506.55 Tanzanian Shillings (TZS) at the time of the study.

increasing farm size above 200 oysters will not only improve annual returns but reduce the risk of zero profit. In Pacific island countries, risk profiles for pearl farms and spat farms generally improve as the experience and skills of farmers improve. Improved technical and husbandry skills that increase production, improve production efficiency and product quality, and improve sales and marketing, for example, result in a shift in the cumulative probability distribution to the right (Figs. 3 and 5), which in turn reduces the chance of making zero profit or loss.

Economic modelling of three scenarios of community-based spat collection not surprisingly showed that the best option was that recruiting the greater number of spat (50 per collector). However, this farming scenario still required 4 years to break-even and to begin making profit. The profitability of such a venture is sensitive to market price, spat collection success, mortality rate due to diseases and predation, storms and theft, and few farmers would have the means to be able to run such a farm at a loss for three consecutive years before making profit, because of underlying poverty and lack of capital for investment. While it is possible for financial institutions to provide loans to farmers, they would need registered properties to use as bonds, which most prospective farmers do not have. Farmers own land and local houses in their villages but these are unregistered and do not qualify as bonds with financial institutions in Tanzania. Rapaport (1996) reported that when community members in French Polynesia acquired loans to invest in pearl farming, many failed to pay back their debts because of lack of

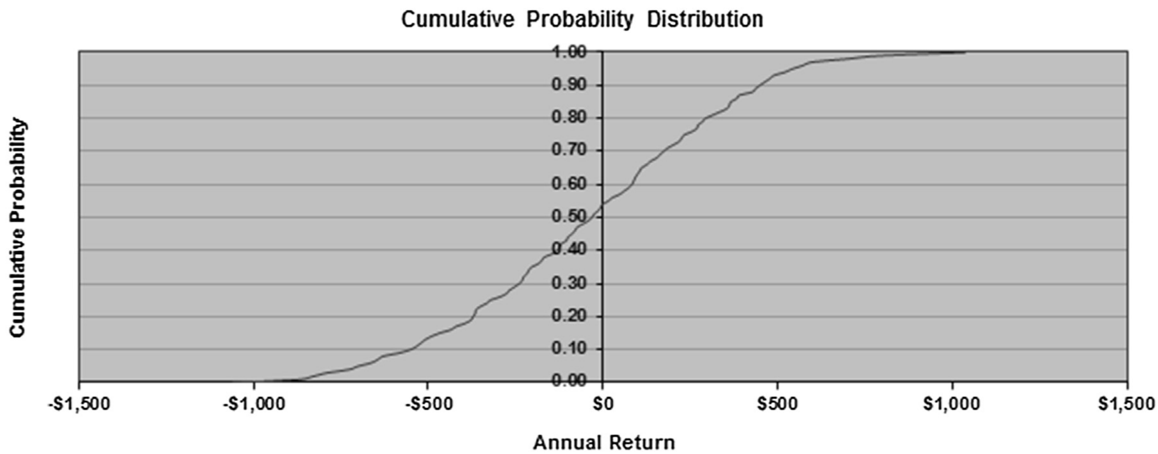


**Fig. 5.** Risk assessment for a spat farm collecting 50 spat per collector. The point at which the cumulative probability distribution curve intersects the zero profit line indicates that this farm has a 54% chance of making zero profit or less with a lowest potential return of −$1060 and highest potential return of $1036 over 20 years of production. Values shown are Australian dollars (AUD) based on an exchange rate of 1 AUD = 1,506.55 Tanzanian Shillings (TZS) at the time of the study.

financial and business knowledge relating to budget management. If provided with loans, Tanzanian half-pearl farmers would require concurrent training in basic business skills that would better equip them to manage a pearl farm budget.

Recruitment of pearl oysters to spat collectors is influenced by several factors including reproductive seasonality, location, spat collector type, immersion time and depth, weather phenomena etc. Farmers could increase spat collection success through deployment of appropriate spat collectors (e.g. Gervis and Sims, 1992; Haws, 2002; Southgate, 2008) to the ocean to coincide with periods of natural recruitment (Coeroli et al., 1984; Southgate, 2008). Spat collection success may also be enhanced when spat collectors are deployed in areas with large numbers of adult oysters and where flushing of sea water is low (Tisdell and Poirine, 2000).

Tanzania is fortunate to enjoy significant tourism and gemstone production industries. The former generates a large potential domestic market for pearl products. Furthermore, the tourism market is stratified from back-packers through to high-end safari tourist, and this provides an excellent opportunity to market pearl products of varying quality, ranging from pearl handicrafts through to high-value pearl jewellery items. However, the size of the potential domestic market for pearl products in Tanzania is unknown and this should be a priority for future research. Tanzania's gemstone industry has well established domestic and international networks that may be beneficial should large-scale pearl production become established in the country.

## 5. Conclusions

The economic models developed by this study are primarily aimed to assist farmers, potential investors and funding organizations in Tanzania to understand the economic requirements, costs and benefits, and risks involved in half-pearl production, and to help develop a sustainable and profitable enterprise. They can also be used to estimate the impact of various management decisions. For example, the farmer may wish to know how drawing wages will affect his profit, or how the use of more expensive pearl nuclei will affect production costs and profit. Under the assumptions made by the models, this study concludes that it is most profitable for individuals and community groups to culture at least 600 oysters for half-pearl production. For communities to be able to run a sustainable and profitable enterprise that involves a number of community members in half-pearl culture, development of a sustainable source of oysters is crucial. However, spat collection in Tanzania is less profitable than half-pearl farming and requires a longer operational period before profits are made. Like pearl farming, there were major benefits or economies of scale with the largest spat farms tested providing greatest profit and/or a shorter time to reach profitability.

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## References

Andrews, G., 1998. Mafia Island Marine Park, Tanzania: implications of appling a marine park paradigm in a developing country. Case studies: destructive fishing practices and collection methods. Proceedings: International Tropical Marine Ecosystems Management Symposium, 267–279.

Beer, A.C., Southgate, P.C., 2000. Collection of pearl oyster (Family Pteriidae) spat at Orpheus Island, Great Barrier Reef (Australia). J. Shellfish Res. 19 (2), 821–826.

Coeroli, M., De Gaillande, D., Landret, J., AQUACOP, 1984. Recent innovations in cultivation of molluscs in French Polynesia. Aquaculture 39, 45–67.

Edward, P., 2009. Settlement adaptation to a changing coastline: archaeological evidence from Tanzania, during the first and second millennia AD. J. Isl. Coastal Archaeol. 4 (1), 82–107.

Gervis, M., Sims, N., 1992. The Biology and Culture of Pearl Oysters (Bivalvia: Pteriidae). ICLARM, Metro Manila, Philippines/ODA, London, England.

Haws, M., 2002. The Basic Method of Pearl Farming, a Layman's Manual. Hawaii Sea Grant.

Hine, D., Johnston, B., 2013. Building better pearl aquaculture businesses in Fiji. SPC Fish. Newsl. 142, 37–38.

Ishengoma, E.B., Jiddawi, N.S., Tamatamah, R.A., Mmochi, A.J., 2011. Wild black-lip pearl oyster (*Pinctada margaritifera*) spat collection in Tanzania. West. Indian Ocean J. Mar. Sci. 10, 49–57.

Jiddawi, N., 2008. Pearl farming in Zanzibar. SPC Pearl Oyster Inf. Bull. 18, 18–19.

Johnston, B., Ponia, B., 2003. Pacific Pearl Economic Model. Economic Models for Aquaculture and Agriculture Commodities. Queensland Department of Primary Industries and Fisheries, Brisbane and Secretariat of the Pacific Community, Noumea.

Rapaport, M., 1996. Between two laws: tenure regimes in the Pearl Islands. Contemp. Pac. 8 (1), 33–49.

Sims, N.A., 1993. Pearl oysters. In: Wright, A., Hill, L. (Eds.), Nearshore Marine Resources of the South Pacific. FFA/ICOD, Canada, pp. 409–430.

Southgate, P.C., Rubens, J., Kipanga, M., Msumi, M., 2006. Pearls from Africa. SPC Pearl Oyster Inf. Bull. 17, 16–17.

Southgate, P.C., 2008. Pearl oyster culture. In: Southgate, P.C., Lucas, J.S. (Eds.), The Pearl Oyster. Elsevier, Oxford, pp. 231–272.

Tisdell, C., Poirine, B., 2000. Socio-economics of pearl culture: industry changes and comparisons focussing on Australia and French Polynesia. World Aquacult., 30–60.

Tisdell, C., Poirine, B., 2008. Economics of pearl farming. In: Southgate, P.C., Lucas, J.S. (Eds.), The Pearl Oyster. Elsevier, Oxford, pp. 473–496.