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Economic Analysis of Eucheumoid Algae Farming in Kenya

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Abstract—Two commercial eucheumoids (brown *Eucheuma denticulatum* and brown *Kappaphycus alvarezii*) were grown in pilot farms of 0.1 ha for 6 weeks (42 days) at two sites (Gazi and Kibuyuni) in southern Kenya. This was done to determine their net yield and economic viability and included sensitivity analysis to determine the effects of decreased farm gate prices and increased operating costs on the return of investment (ROI) and payment period in eucheumoid farming. The average net yield varied from 880 to 1209 kg dry wt for *E. denticulatum* and 600 to 1150 kg dry wt for *K. alvarezii* per crop. No significant difference in net yield was observed between the two morphotypes. However, a higher yield ($p<0.05$) was obtained for plants grown at Gazi (1071 ± 65 kg dry wt) than those at Kibuyuni (793 ± 93 kg dry wt). The total initial investment required for a 0.1 ha seaweed pilot farm (capital investment and operating costs) for one crop was estimated at Kshs 11 253 (Kshs 75=US$ 1), with labour (both hired and family labour) accounting for about 52% of the total production cost. The average annual income per 0.1 ha farm was Kshs 7549 for *E. denticulatum* and Kshs 49 126 for *K. alvarezii*. The rate of return on investment in farming *E. denticulatum* ranged from 15-63% and 122-380% for *K. alvarezii*. The pay back period was shorter for the latter (0.3 to 0.7 years) than the former (1.2 to 2.7 years). Economic sensitivity analysis showed that, even if the farm gate price was decreased by 20% and operating cost was increased by 20%, *K. alvarezii* farming would still be a profitable and attractive venture in Kenya, but not *E. denticulatum* because of negative economic indicators.

INTRODUCTION

The economic importance of seaweeds and their dwindling supply led to the farming of commercial seaweeds, particularly *Eucheuma denticulatum* (Burman) Collins and Hervey and *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva in the late 1960s (Doty, 1987). Cultivation of these red seaweeds was pioneered in the Philippines to alleviate pressure on over-harvested natural wild stock (Doty, 1987).

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Tropical *Kappaphycus* and *Eucheuma* seaweeds are farmed for their phycocolloid, carrageenan, used in food, pharmaceutical and cosmetic industries (McHugh, 2003). There is a great demand for carrageenans, partly due to the growth in consumption of convenience foods and low-fat meat products which has opened up new markets for these phycocolloids (McHugh, 2003). Owing to the increasing global demand for carrageenans, the seaweed industry has encouraged the commercial cultivation of eucheumoids in certain tropical countries such as Indonesia, Fiji, Kiribati, Tanzania and Mozambique (Ask *et al*., 2003; McHugh, 2003). *Kappaphycus alvarezii* farming is at a pilot-scale stage in Brazil (Paula & Pereira, 2003) and Mexico (Muñoz *et al*., 2004), among other countries.

Commercial eucheumoid cultivation has become a major source of livelihood to thousands of coastal inhabitants in developing countries (Hurtado-Ponce *et al*., 2001; Ask *et al.*, 2003). It is a high-yielding investment with a return ranging from 78% to over 100% per annum, which is well above the opportunity cost of some activities such as fishing (Padilla & Lampe, 1989; Luxton & Luxton, 1999). An annual net income ranging from US$ 2662 (Samonte *et al*., 1993) to US$ 5948 (Firdausy & Tisdell, 1991) has been obtained from a one hectare eucheumoid farm. It has been reported that the high income from eucheumoid farming has significantly contributed to an increased standard of living for coastal families in Tanzania and the Philippines (Mshigeni, 1994; Hurtado-Ponce *et al*., 1996). The export of dried seaweeds is a source of foreign exchange for seaweed growing countries such as Indonesia (Firdausy & Tisdell, 1991), Tanzania (Lirasan & Twide, 1993; Mshigeni, 1994), Fiji and Kiribati (Luxton & Luxton, 1999), and the Philippines (Hurtado & Agabayani, 2002). Eucheumoid farming is deemed suitable for coastal communities because it is labour intensive and requires low capitalisation (Doty, 1987; Padilla & Lampe, 1989).

Despite the socio-economic importance of eucheumoid farming in developing countries, the economics of the farms are poorly known (Doty, 1987). There has been no economic assessment of the variability in yields and profit among and within seaweed farms (Smith, 1987). Few studies have investigated the economics of eucheumoid culture. For example, the costs and revenues of *Kappaphycus* farming have been reported in the Southeast Asian region, particularly in Indonesia (Firdausy & Tisdell, 1991) and the Philippines (Samonte *et al*., 1993; Hurtado-Ponce *et al*., 1996). However, most of these reports are based on data collected through interviews with practising seaweed farmers which do not reflect the actual yields and production costs (Hurtado *et al*., 2001). Alih (1990) estimated the costs and revenues of *Eucheuma* and *Kappaphycus* farming among farms in Tawi-Tawi, the Philippines, whereas Doty (1987) examined investment requirements for a one hectare *Eucheuma* farm in Malaysia. There is a small but growing literature on the economics of eucheumoid farming, mainly in Asia as mentioned earlier. The literature on the economic feasibility of eucheumoid farming and associated farming techniques in tropical locations is mainly based upon Asian case studies, presumably because eucheumoid farming started in Asia (Namudu & Pickering, 2006).

In Zanzibar, Tanzania, although eucheumoid farming has become well-established since the early 1990s, only a few unpublished reports have been attempted on the cost and return analysis of this activity. For example, Msuya *et al.* 2007 reported a comparative economic analysis of two seaweed farming methods in Tanzania. The potential economic revenues from seaweed farming vary from place to place (Doty, 1987), hence the operational economics in the Western Indian Ocean areas such as Tanzania and Madagascar cannot be based reliably upon Southeast Asian case studies. The costs and revenues of seaweed farming also vary according to the farming methods and the environmental conditions (Hurtado *et al*., 2001). Coastal communities in the Western Indian Ocean region are culturally and economically quite different from their counterparts in Asia. Thus each region and country must make its own estimates of costs and returns for eucheumoid farming (Smith, 1987).

Several studies have suggested that eucheumoid farming could be developed in Kenyan waters (Yarish & Wamukoya, 1990; Lirasan & Twide, 1993; Wakibia *et al*., 2006).

There is currently an ongoing pilot scale commercial eucheumoid cultivation in southern Kenya (M. De San of ReCoMaP, pers comm.). Seaweed farming has been reported to be a low capital investment venture with high rates of return (Smith, 1987; Hurtado-Ponce *et al.*, 1996). However, the economic viability of seaweed farms needs to be studied and quantified before undertaking commercial seaweed farming in Kenya (Oyieke, 1998). A pilot farm would be desirable to obtain reasonably accurate estimates, particularly of the annual yield and income from the sale of seaweed (Smith, 1987). Therefore, this study was performed to determine the economic viability of *E. denticulatum* and *K. alvarezii* farming in 0.1 ha pilot farms in southern Kenya.

MATERIALS AND METHODS

Study sites

The study was conducted at two coastal sites (Gazi Bay and Kibuyuni) in southern Kenya where there is an ongoing experiment on seaweed cultivation (see Wakibia *et al.*, 2006). The sites were chosen to represent a range of environmental conditions on the Kenyan coast. Gazi Bay (4°25'S, 39°30'E) is a shallow mangrove system which receives freshwater from nearby rivers. However, both a shoreward wind and tidal currents mix water in the Bay, leading to seawater with near oceanic salinity (Kitheka, 1996). The seaweed pilot farms were established on a sandy flat covered with about 20-30 cm of water at the lowest tide and 3.8 m at the highest tide. Kibuyuni (4°38'S, 39°20'E) is a large intertidal reef flat covered by a belt of the seagrass *Thalassodendron ciliatum* (Forsskål) den Hartog. The eucheumoids were planted on a reef-flat covered with 10 cm of seawater at the lowest tide and 3.2 m at the highest tide.

Culture technique and seaweed production

Two morphotypes from two species: brown *Eucheuma denticulatum* and brown *Kappaphycus alvarezii* collected from Zanzibar, originally from Bohol in the Philippines, were used in this study. The fixed off-bottom rope technique as described by Lirasan and Twide (1993) was adopted to culture the two morphotypes (see Wakibia *et al.*, 2006). The fixed off-bottom technique is commonly used for eucheumoid cultivation because of the ease of installation, simple farm maintenance and low cost of the material required. At each site (Gazi and Kibuyuni), two 0.1 ha pilot farms were established, each containing 420 polypropylene ropes (5 m long, 4 mm diameter) of each morphotype. The ropes were stocked with 25 healthy seaweed cuttings, each weighing about 100 g wet weight. The cuttings were tied to the rope using plastic straws ('tie-ties') at intervals of 25 cm. Once stocked, the ropes with cuttings were weighed and installed. The seaweed farms were maintained at least twice a week by removing epiphytes and tightening loose stakes, ropes and cuttings. After six weeks (42 days), the stocked ropes were untied, water drained by shaking for 30 seconds, and the fresh wt of the harvested material was determined. All stocked seaweed material was removed for weighing. Net yield or production (fresh weight) was calculated as the difference between the initial weight (about 1045 kg for the 0.1 ha) and the final weight at the end of the culture period. The harvested plants were sun-dried on mats for three days. About eight kg fresh wt of harvested materials yielded one kg of dry wt. The productivity study was conducted in February-March (period of low growth) and August-September (period of high growth) and net yield values were averaged for each morphotype. The average wt was multiplied by ten to get productivity values per hectare. Data on net yields (two duplicates, period of low and high growth) were analysed by General Linear Model Procedures (GLM) followed by the determination of differences among individual mean values by the Least Significant Difference (LSD) test at $p<0.05$. Statistical analyses were performed using MS Excel and SPSS.

Economic analysis

The aim of the eucheumoid farmer is to maximize profit. The total revenue that the farmer receives from selling the product is given by the quantity that is sold multiplied by the price per unit. The profit is therefore the difference between the total revenue received from the sale of eucheumoid and the total cost of production. The level of profit depends on the inputs that the farmer contributes to yield output. Maximum profit is achieved when each input is fully utilized (Henderson & Quandt, 1980). This means, the eucheumoid farmer can increase the profit as long as the addition to the revenue from the employment of an additional unit of input exceeds its cost. The additional inputs can therefore be applied up to the point when profit starts decreasing with respect to further application of inputs.

An analysis of the costs of production and revenues that accrue from the sale of two eucheumoids was carried out to evaluate the economic viability of their cultivation at the two coastal sites (Shang, 1990). Economic viability is determined at the point where the eucheumoid farmers can break even and make a profit. This condition is met when a change in revenue from the sale of eucheumoids equals a change in the unit cost of production. Data on production costs and projected sales revenues were gathered so that the cost of production and revenue from the pilot farms could be estimated. Data presented in this study are therefore based upon the actual costs and production figures obtained in a 0.1 ha pilot farm and projected to one year with five crops. The total investment requirements (farming costs) were expressed in terms of capital assets and operating costs. The capital assets included: polyethylene ropes (4 mm), floating baskets, waterproof sheets, gunny bags, a digging bar, a bull hammer, and a knife. The operating costs consisted of cash expenses (seaweed cuttings, plastic straws, hired labour and miscellaneous expenses) and non-cash expenses such as family labour and annual depreciation. Family labour was treated as a non-cash expense, computed as man-days devoted in the pilot farms at Kshs 145 man-day^{-1} of 5 hours (average low tide working time day^{-1}). Since family labour was a non-cash expense, it was considered as equivalent to the opportunity cost of labour spent fishing or working in the agricultural farms. In the cost and revenue analysis, the straight-line method of annual depreciation (Shang, 1990) was used and capital assets were assumed to have no residual value at the end of their useful life.

The revenue from seaweed was based on the market price (farm gate price) and the average yield obtained in the pilot farms during the low- and high-growth periods for each morphotype at each site. The farm gate prices of seaweeds were pegged at Kshs 20 and Kshs10 kg^{-1} dry wt for *K. alvarezii* and *E. denticulatum*, respectively, based on the prevailing Tanzanian prices (D. Rogers, per. comm.). However, the prices were computed at a conservatively higher rate of 25% above the Tanzanian farm gate prices to cater for total investment costs incurred here, unlike the former situation where seaweed farmers were provided with supplies and materials. These pegged prices were similar to the prevailing price in Fiji (US$ 0.27=Kshs 20.25) during the study period (M. Namudu, pers comm.). Global trends in the seaweed market indicate that the price of seaweed from Indonesia, Malaysia and the East African coast is 20% cheaper compared to the price of seaweed from the Philippines. Seaweed prices peaked at a historic high of US$ 3,000 per ton in 2008 but have normalized since then (http://www.zuozuo.com/jelly-news-163.html). The costs of equipment, materials, supplies and other inputs were based on market prices at Mombasa.

Standard economic indicators used to evaluate investment feasibility in the present study were the payback period and return on investment (ROI), according to Shang (1990). The payback period is the time taken (years) to gain a financial return equal to the total initial investment. It is the most widely used project selection factor when risks involved are relatively high (Shang, 1990). The payback period was calculated by dividing the total initial investment by the sum of the annual net income of the pilot farm and annual depreciation (from capital assets). The return on investment is another popular investment appraisal technique that examines the whole project. The ROI was calculated by dividing the annual net income from the pilot farm by the total initial investment. Economic sensitivity analysis was also performed to determine the

Table 1. Net yield (kg dry wt) and projected annual productivity (t dry wt ha^{-1} yr^{-1}) of two commercial eucheumoids grown in 0.1 ha pilot farms at two sites in southern Kenya.

Period (2008)	Site and morphotype			
	Gazi		Kibuyuni	
	Brown *E. denticulatum*	Brown *K. alvarezii*	Brown *E. denticulatum*	Brown *K. alvarezii*
February-March (yield)	983	940	880	600
August-September (yield)	1209	1150	1010	682
Mean yield	1096	1045	945	641
Productivity	54.8	52.3	47.2	32.1

ROI and payment period of both morphotypes at the two sites under two different situations: a 20% decrease in farm gate price and a 20% increase in operating costs according to Hurtado and Agabayani (2002). The currency used in the computations was the Kenyan shilling (Kshs 75=US$ 1, in 2008).

RESULTS

Production

The net yield and projected productivity values of the two commercial morphotypes grown in 0.1 ha pilot farms are presented in Table 1. The average net yield varied from 880-1209 kg dry wt for *E. denticulatum* and 600-1150 kg dry wt for *K. alvarezii*. No significant difference in net yield was observed between the two morphotypes. However, higher yields were obtained for plants at Gazi (1071±65 kg dry wt) than those at Kibuyuni (793±93 kg dry wt) ($p<0.05$). The high yield at the Gazi site resulted in a projected annual productivity of more than 50 t dry wt ha^{-1} yr^{-1} for both species while the same morphotypes yielded productivity values ranging from 32-47 t dry wt ha^{-1} yr^{-1} at Kibuyuni (Table 1).

Costs and revenues

The total initial investment in a 0.1 ha seaweed pilot farm was estimated at Kshs 19 553 (Table 2). This amount covered the capital assets and the initial operating cost for the first cropping. The stakes were free as they were cut in a local

Table 2. Initial investment and annual depreciation for a 0.1 ha pilot farm of commercial eucheumoids in southern Kenya (Kshs 75=US$ 1 in 2008).

Item	**Quantity**	**Unit cost**	**Total cost**	**Economic life (years)**	**Annual depreciation**
Capital assets					
Polyethylene rope (4 mm)	12	475	5700	3	1900
Floating basket	2	200	400	0.5	800
Water proof sheet (m2)	20	50	1000	1	1000
Gunny bag	20	15	300	0.5	600
Digging iron bar	1	400	400	5	80
Bull hammer	1	400	400	5	80
Knife	2	50	100	3	33
Subtotal			8300		4493
Operating cost (1 crop)			11 253		
Total initial investment			19 553		

Table 3. Comparative cost and revenue analysis of two eucheumoids grown at two sites in southern Kenya. (Kshs 75=1US$ in 2008).

Item	Site and morphotype			
	Gazi		Kibuyuni	
	Brown *E. denticulatum*	Brown *K. alvarezii*	Brown *E. denticulatum*	Brown *K. alvarezii*
Quantity (kg dry wt)	1 096	1045	946	641
Revenue (Kshs)a	13 702	26 131	11 824	16 026
Operating costs				
Cash expenses				
Seaweed cuttings (1050 kg)	2100	2100	2100	2100
Plastic straws (7 rolls)	1750	1750	1750	1750
Hired labour				
Staking (10 man-days)	1450	1450	1450	1450
Tying cutting (12 man-days	1740	1740	1740	1740
Miscellaneous (10%)b	704	704	704	704
Subtotal	**744**	**7744**	**7744**	**7744**
Non-cash expenses				
Family labour(18 man-days	2610	2610	2610	2610
Depreciation	899	899	899	899
Subtotal	**3509**	**3509**	**3509**	**3509**
Total production cost	**11 253**	**11 253**	**11 253**	**11 253**
Net income (average 1 crop)	2449	14 878	571	4773
Net income (5 crops year-1)	12 243	74 388	2 855	23 864
Return on investment (%)	63	380	15	122
Payment period (years)	1.2	0.3	2.7	0.7

[a]Estimated farm gate prices for 1 kg of dried *Eucheuma denticulatum* and *Kappaphycus alvarezii* were Kshs 12.50 and Kshs 25.00, respectively.

[b]10% of Seaweed cuttings, plastic straws ('tie-ties') and hired labour.

forest. The annual depreciation was Kshs 4493, computed by a straight-line method based on the estimated economic lives of the various supplies and materials. The same total initial investment was used for both sites because they are close to each other (about 10 km apart) and all supplies and materials were bought from the same city, Mombasa.

The comparative costs and revenues of *E. denticulatum* and *K. alvarezii* grown at 0.1 ha pilot farms are presented in Table 3. The projected total operating cost was Kshs 11 253 consisting of cash and non-cash expenses based on averages obtained from two harvest periods, February-March (period of low growth) and August-September (period of high growth). Labour was the most important operating cost, with the hired labour and family labour together accounting for 52% of production costs for the 0.1 ha seaweed farms. Labour costs included staking, tying seaweed cuttings, cleaning, harvesting and drying plants.

The annual net income per 0.1 ha farm was highest for *K. alvarezii* (Kshs 74 388) grown at Gazi followed by *K. alvarezii*

Table 4. Sensitivity analysis of return on investment (ROI) and payback period (years) for two commercial eucheumoids grown at two sites in southern Kenya.

Case	Site and morphotype			
	Gazi		Kibuyuni	
	Brown *E. denticulatum*	Brown *K. alvarezii*	Brown *E. denticulatum*	Brown *K. alvarezii*
No adjustment				
Return on investment (%)	63.0	380.0	15.0	122.0
Payback period (years)	1.2	0.3	2.7	0.7
20% decrease in farm gate price				
Return on investment (%)	-7.0	247.0	-46.0	40.0
Payback period (years)	6.4	0.4	-4.4	1.6
20% increase in operating costs				
Return on investment (%)	5.0	323.0	-43.0	64.0
Payback period (years)	3.6	0.4	-5.0	1.1

(Kshs 23 864) at Kibuyuni, while the lowest value of Kshs 2855 was obtained for *E. denticulatum* at the latter site (Table 3). The average annual income per 0.1 ha was Kshs 7549 and Kshs 49 126 for *E. denticulatum* and *K. alvarezii*, respectively. Consequently, the return on investment (ROI) followed the same trend. However, the trend was reversed for the payback period with the shortest payback time of 0.3 years observed for *K. alvarezii* at Gazi and the longest (2.7 years) for *E. denticulatum* at Kibuyuni (Table 3). The higher net income and return on investment for *K. alvarezii* than *E. denticulatum* was due to farm gate price differences, with the former species fetching Kshs 25 kg^{-1}, whereas the latter species was worth Kshs 12.50 kg^{-1}. However, both *K. alvarezii* and *E. denticulatum* at Gazi yielded a higher net income and ROI, and shorter payback period, than their counterparts at Kibuyuni, probably due to differences in site characteristics. Although the net income and ROI for the two morphotypes at both sites were positive, the pilot farms planted with *E. denticulatum* registered low profitability levels, particularly the low value of Kshs 2855 obtained for plants grown at Kibuyuni.

Table 4 presents a sensitivity analysis of return on investment (ROI) and payback period (years) for the two commercial eucheumoids under different circumstances. The economic indicators (ROI and payback period) of farming both morphotypes at the two sites would respond to decreases in farm gate prices of 20% and increased operating costs of 20%. In the case of decreased farm gate prices, the return on investments (ROIs) would drop by 35% and 67% for *K. alvarezii* grown at Gazi and Kibuyuni, respectively, whereas at both sites *E. denticulatum* farming would register negative ROIs. Consequently, the payback period would increase by 0.9 and 5.2 years for *K. alvarezii* grown at Kibuyuni and *E. denticulatum* grown at Gazi, respectively. There would be little change in the payback period for *K. alvarezii* grown at Gazi while negative values would be observed for *E. denticulatum* grown at Kibuyuni. In the second case, if the operating cost were to increase by 20%, *K. alvarezii* at both Gazi and Kibuyuni would show lower ROI with a corresponding higher payback period. From the two scenarios, it would appear that eucheumoid farming at both sites would be sensitive to both decreased farm gate price and increased operation costs, but the sensitivity is higher for the decreased price compared to increased operating costs. Therefore, at all pilot farms, an increase in operation costs of 20% would still be economically viable, with the exception of *E. denticulatum* grown at Kibuyuni (Table 4).

DISCUSSION

Productivity

The amount of seaweed produced in this study would scale up to an estimated annual yield of 32-55 t dry wt ha^{-1} yr^{-1} based on the mean weight per harvest and five harvests per year. This estimated yearly production was low in comparison to the extrapolated *K. alvarezii* production of about 100-110 t dry wt ha^{-1} yr^{-1} at Kiribati in the central Pacific (Luxton & Luxton, 1999) where a high density planting method was used. The average seaweed production obtained in the present study was comparable to those reported by Braud and Perez (1978) in Djibouti waters (32 t dry wt ha^{-1} yr^{-1}) for *E. denticulatum* and 48 t dry wt ha^{-1} yr^{-1} for *K. alvarezii* (*E. cottonii*) in Indonesia (Firdausy & Tisdell, 1991). However, the yield reported here was higher than published estimates of 10-30 t dry wt ha^{-1} yr^{-1} for commercial eucheumoid farms (Doty, 1987; Alih, 1990) and the projected yield of 27.9 t dry wt ha^{-1} yr^{-1} for *K. alvarezii* in the Philippines (Hurtado-Ponce *et al.*, 1996) and 21 t dry wt ha^{-1} yr^{-1} in Hawaii (Glenn & Doty, 1990). However, the annual productivity data of eucheumoids reported in this investigation should be treated with caution as several authors have pointed out that scaling-up small experiments to estimate potential commercial yields can result in overestimates for larger operations (Hanisak & Ryther, 1984; Doty, 1987).

The eucheumoid production obtained on Gazi pilot farms was significantly higher than that of plants farmed at Kibuyuni (see results). The differences in yields may be attributed to site characteristics, particularly the water motion, among other factors. Water movement was significantly higher at Gazi than at Kibuyuni ($p<0.05$; Wakibia *et al.*, 2006). In addition, strong tidal currents reaching velocities up to 0.6 m s^{-1} were reported at Gazi Bay (Kitheka, 1996). A higher relative growth rate was also obtained at Gazi than at Kibuyuni (Wakibia *et al.*, 2006). It seemed that the greater water movement at Gazi supplied inorganic nutrients for the growth and production of eucheumoids. The high yield of 100-110 t dry wt ha^{-1} yr^{-1} for *K. alvarezii* at Kiritimati and south Tabuaeran farming areas in Kiribati was attributed to high water movement at both sites (Luxton & Luxton, 1999). Water motion has been recognised as a prime factor in eucheumoid growth and productivity (Doty, 1987; Glenn & Doty, 1992). It is thought to increase seaweed growth rates, and thus production, by decreasing the thickness of the unstirred layer of water around the algal surface, thereby enhancing the availability of nutrients and more uniform conditions of irradiance, temperature and salinity (Doty, 1987). The low eucheumoid production at Kibuyuni was probably due to low water movement and also the presence of grazers and epiphytes which were observed to lower the yield of *K. alvarezii* in the Philippines (Hurtado-Ponce *et al.*, 2001).

Costs and revenues

Eucheumoid farming requires few supplies and materials as indicated in this study. The total initial investment required for a 0.1 ha seaweed pilot farm in this study was Kshs 11 253 (US$ 260) and this would scale up to US$ 2600 ha^{-1}. Uan (1990) estimated a slightly lower investment requirement of US$ 1638 for a one hectare *K. alvarezii* seaweed farm in Kiribati. However, the author did not include labour cost as operating costs. The total investment required for a one hectare eucheumoid farm in the Philippines varied from US$ 721 (Hurtado-Ponce *et al.*, 1996) to US$ 1994 (Samonte *et al.*, 1993). Doty (1987) reported that a capital investment of US$ 3285 was required for a one hectare Eucheuma farm in Sabah, Malaysia. However, a higher investment need of US$ 5247 was estimated for a one hectare *K. alvarezii* farm in Indonesia (Firdausy & Tisdell, 1991).

Among the operating costs, labour (both the hired labour and family labour) was the most important cost item, accounting for about 52% of the total production cost in the present study. Family labour input was valued at the hired labour wage rate. Labour accounted for 40% and 60% of the total cost of production in one hectare *K. alvarezii* farms in the Philippines (Hurtado *et al.*, 2001) and Indonesia (Firdausy &

Tisdell, 1991), respectively. Thus, eucheumoid farming is a relatively labour-intensive activity, suited to developing countries where labour is relatively abundant and cheap. In some studies (Alih, 1990; Uan, 1990), the operating costs were considered low, since it was assumed that seaweed farmers use their own family members. However, labour is one of the most important considerations in economic analysis and should always be included as a cost item in the cost and revenue calculations (Shang, 1990).

Eucheumoid farming is considered an attractive livelihood for coastal communities with high returns (Doty, 1987; Padilla & Lampe, 1989; Hurtado-Ponce *et al.*, 1996; Hurtado-Ponce *et al.*, 2001). In the present study, the net income from a 0.1 ha pilot farm would translate into an average annual income of Kshs 75 490 and Kshs 491 260 for *E. denticulatum* and *K. alvarezii*, respectively on one hectare seaweed farms. The average farm size would be about 0.5 ha because every household would depend on its members for labour and the investment required to start the venture could be accommodated within their limited financial resources. It would be expected that most households at the sites would manage a 0.5 ha pilot farm planted with both *E. denticulatum* and *K. alvarezii*. This would provide a yearly income of about Kshs 283 375 (US$ 3778) or a monthly income of Kshs 23 615 (US$ 315) for each household, which is more than twice the average monthly household income of Kshs 9904 (US$ 132) they earn from fishing and other livelihoods (Wakibia *et al.*, 2010). Luxton and Luxton (1999) reported a similar annual income of US$ 3726 for a family unit from a 900-1000 m^2 *K. alvarezii* farm in Kiribati. A lower annual income of US$ 2662 was obtained for a one hectare *K. alvarezii* farm in the Philippines (Samonte *et al.*, 1993). However, Firdausy and Tisdell (1991) reported a higher annual net income of US$ 5948 from a one hectare farm of *K. alvarezii* in Indonesia. This investigation showed that eucheumoid farming can potentially become a major source of income for Indonesian coastal fishing communities.

In the present study, the return on investment (ROI) in farming *K. alvarezii* was higher than 100% with a payment period of less than a year, whereas the ROI for *E. denticulatum* was less than 100% and the payment period was more than a year, implying that the culture of the former species was more profitable than the latter. It also took a shorter time to recover the initial investment in farming *K. alvarezii* than *E. denticulatum*. In the Philippines, Alih (1990) obtained payback periods of 0.7 and 1.6 years, and returns on investments of 150 and 61% for *K. alvarezii* and *E. denticulatum*, respectively. Results of the present study yielded a higher ROI for *K. alvarezii* than the values of 243% and 150% obtained by Samonte *et al.* (1993) and Alih (1990), respectively, in the Philippines, and the 123% ROI for *K. alvarezii* farming in Indonesia (Firdausy & Tisdell, 1991). However, the ROI for *K. alvarezii* obtained in this investigation was lower than the returns on investment reported for *K. alvarezii* in the Philippines (1002% ROI; Hurtado-Ponce *et al.*, 1996) and in Kiribati (900% ROI; Luxton & Luxton, 1999).

The economic indicators (ROI and payment period) reported in this study should be regarded with caution because the costs and revenue were calculated free of uncertainties and risks such as 'ice-ice' syndrome, the El Niño phenomenon and farm gate price fluctuations, among other negative factors. For example, an El Niño weather pattern was observed to reduce *K. alvarezii* production by 60% in Kiribati (Luxton & Luxton, 1999), whereas farm gate price stability was reported to be a critical problem in eucheumoid production in the Philippines (Padilla & Lampe, 1989; Alih, 1990; Hurtado-Ponce *et al.*, 1996). In 1998, an El Niño weather pattern occurred in the Western Indian Ocean region, including the Kenyan coast. Economic sensitivity analysis was undertaken by reducing farm gate prices by 20% and increasing the operating costs by 20% in order to determine their effects on economic indicators. A 20% decrease in farm gate price would reduce the ROI of *K. alvarezii* farming by 35-67% and increase the payment period by 33-129%. The payback period and ROI for *E. denticulatum* at both sites would all be negative under these circumstances, with the exception of the pilot farm at Gazi. The scenario of increasing operating costs by 20% would not be as severe as a reduction in farm gate prices, though the ROI for *E. denticulatum* would deteriorate to low or negative values. The farming of *E. denticulatum*, particularly at Kibuyuni, would be more prone to a decrease in farm gate price and an increase in operating costs than the culture of *K. alvarezii.*

Results of this study indicate that seaweed farming would be more prone to farm gate price fluctuations than the costs of inputs, suggesting that Tanzanian seaweed buyers should stop their tendency of supplying farmers with materials such as ropes and tie-ties, while paying low prices for dried seaweeds (pers. obs.). Rather, seaweed processors should devise a way of increasing farm gate prices and encouraging seaweed farmers to buy their own inputs. This could promote entrepreneurship in seaweed farming, as only interested farmers would take up the activity. It would be better to have a few active members rather than a whole village in which most of the members are not committed to seaweed farming. For example, in Tabuaeran Island, Kiribati, eleven seaweed farmers accounted for about 17% of the Island's *K. alvarezii* production (Luxton & Luxton, 1999). In Zanzibar, some fishermen are supplied with farming inputs, particularly the monofilament cultivation ropes but instead they use them for fishing purposes (pers. obs.).

Interested villagers may have a problem raising capital to start farming but, in this scenario, the seaweed buyers could provide a credit facility that would be repaid with delivered product. Micro-credit schemes should also be promoted to empower seaweed farmers. The micro-credit schemes could be in the form of an informal credit system, such as the "merry-go-round" in which members contribute KShs 100 every month and the total receipts are paid to one member on a rotational system (Wakibia, 2005). Seaweed farmers could also become members of formal micro-finance institutions at the study sites such as Choice International and the Kenya Women Finance Trust (Wakibia, 2005).

Sensitivity analysis showed that the culture of *K. alvarezii* remained profitable even within the two adverse scenarios that were tested; it appeared to absorb both the farm gate price and operating cost shocks. Development of seaweed farming in the Western Indian Ocean region may nevertheless be difficult because the seaweed price never completely covers the real operational costs. In fact, the labour cost is never incorporated when pegging farm gate prices. Therefore, seaweed buyers and processors should incorporate labour at the minimum daily wage for the Western Indian Ocean region in the total production costs when setting farm gate prices, to encourage villagers to embark on eucheumoid cultivation. The carrageen processors should also base their eucheumoid farm gate prices on the quality rather than the quantity of dried seaweed material (the current method). Higher prices should be offered to seaweed farmers with high quality carrageenan-containing material (Wakibia, 2005).

In conclusion, eucheumoid cultivation, particularly that of *K. alvarezii*, appears to constitute a potentially viable aquaculture venture at both sites in Kenya and could provide a good source of livelihood for poor coastal communities. There is a market for eucheumoids from Kenya, as there are investors who are currently developing seaweed farming in Shimoni (M. De. San, pers comm.). Seaweed farming, however, needs to be promoted by the Kenyan government and the donor community to develop a sustainable seaweed industry that will be economically and ecologically suited to the coastal areas of Kenya.

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