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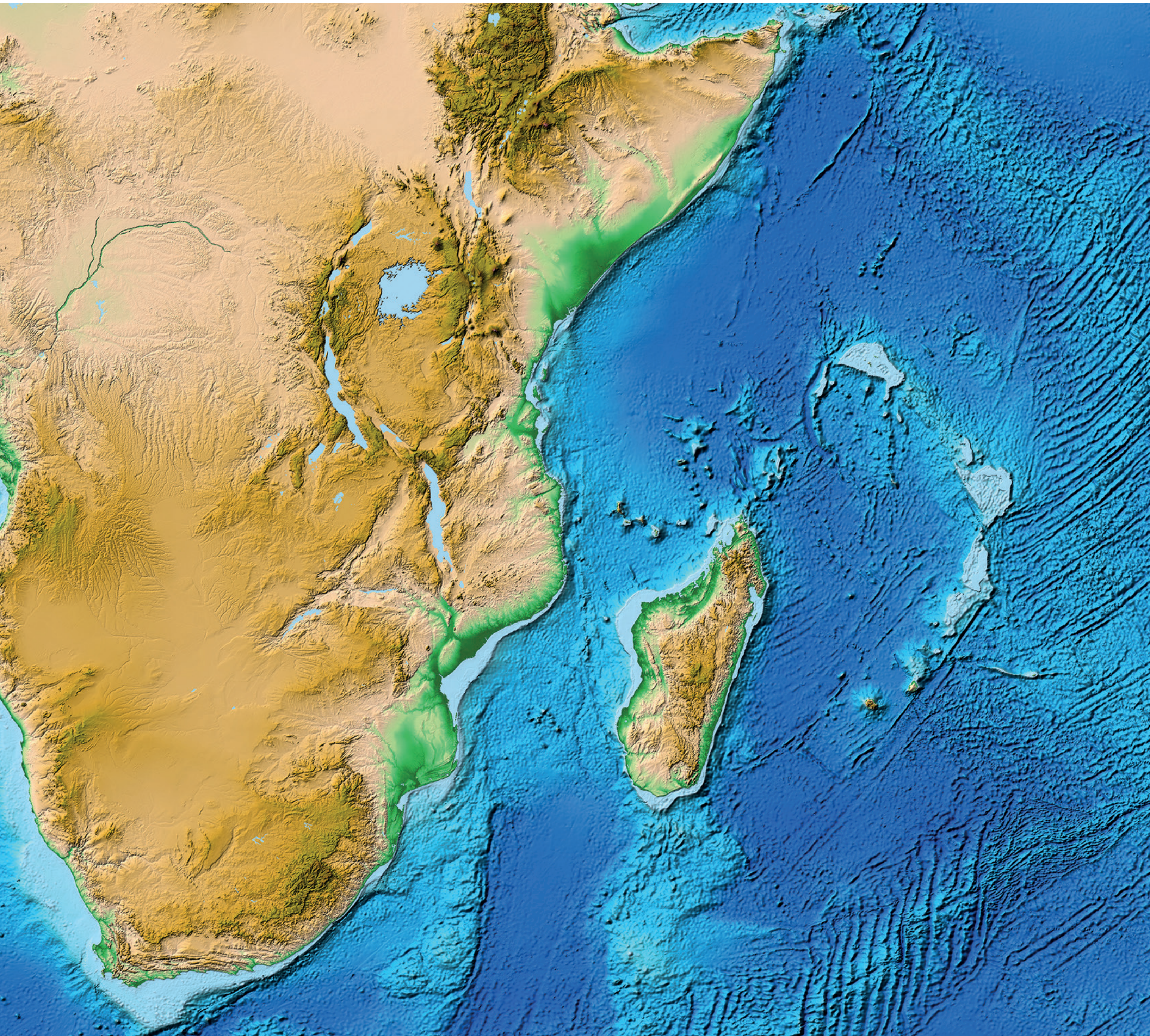

Western Indian Ocean JOURNAL OF Marine Science

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Cover image: Relief model of the WIO surface that integrates land topography and ocean bathymetry. Amante and Eakins / National Geophysical Data Center, NOAA (2009)

Feasibility of extensive, small-scale mud crab (*Scylla serrata*) farming in East Africa

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Abstract
Small-scale farming of mud crabs (*Scylla serrata*) has been suggested as a low investment alternative for generating incomes to resource-poor coastal communities in East Africa. However, it is unclear if the present culture methods are profitable and ecologically sustainable. Here we assess the two dominant culture methods, extensive 'crab-fattening' in cages (cage culture) and grow-out farming of small juveniles in ponds (pond culture) using economic and ecological analyses in Kenya and Tanzania.

Cost-revenue analyses of cage culture showed negative results at all scales in both countries. High labor costs and poor survival and growth make cage culture an unprofitable and unsustainable livelihood in its present form. Pond culture showed a positive return at prices above $US 3.4 kg^{-1}, which is achievable in Kenya and Mozambique, but not in Tanzania. Analyses also showed that larger ponds and selling crabs at a smaller size improved profitability. However, the availability of seed-crabs and local feed sources limit the size of sustainable crab farms in a coastal community to approximately 500 commercial crabs per year. Before crab farming in ponds can become a profitable alternative income in East Africa, survival rates need to be improved, market conditions and profits to local crab farmers enhanced, and potential negative impacts on mangroves evaluated.

Keywords: Feasibility, livelihoods, cost-revenue, grow-out farming, crab-fattening, pond, cage culture

Introduction
The populations in coastal areas of East Africa have increased dramatically in the last decades, contributing to increased pressure and degradation of coastal resources. Examples include declining fish catches, deteriorating conditions of coral reefs, and reduction of mangroves (van der Elst *et al*., 2005). Various management responses are being undertaken to halt the deterioration of coastal resources, including restriction on fishing and extraction through MPAs, introduction of community-based management practices and regulation of harvest practices. However, these measures, in combination with decreasing coastal resources, increase the need for additional livelihoods for the large number of impoverished people that directly depend on coastal resources for their survival. Due to unproductive soils for agriculture, coastal residents usually have few alternative livelihood options, and intensified competition for coastal resources increases conflicts between stakeholders within the increasingly crowded coastal zone (Hecht, 2006). In the last decade, small-scale farming of mud crabs has been suggested as a viable alternative income for resource poor coastal communities in East Africa (ACDI/VOCA, 2005; Shipton and Hecht, 2007; Mirera, 2009; Mirera, 2014).

Mud crabs (*Scylla* spp.) are large portunid crabs that inhabit coastal mangrove habitats in the Indian Ocean. Four species of mud crabs are recognized (*S. serrata*, *S. paramamosain, S. tranquebarica* and *S. olivacea*), but only one species (*S. serrata*) is found in East Africa (Keenan *et al.*, 1998). All mud crab species have good taste and generate high prices on domestic and international markets, and are fished by artisanal and commercial fishers throughout the region. The unique ability of mud crabs to stay alive out of water for 4-5 days enables cost effective transport from remote coastal areas to national and international markets without the need for cooling (Keenan, 2003).

Mud crabs can survive and grow well in captivity and they have for the last 40 years been farmed throughout Southeast Asia and Southern China (FAO, 2015). In Southeast Asia, there are two basic forms of mud crab aquaculture: 'fattening' of adult crabs with a low meat content, and 'grow-out' of juveniles to market size. Fattening has been the dominating form, primarily conducted in ponds or small bamboo enclosures placed in the intertidal, where adult crabs with low meat content (and low market value) are fed for a short period (<1 month) to gain weight and higher market price. Generally, the fattening is completed prior to molting since mortality otherwise reduces production (Keenan, 2003). However, a growing part of the fattening industry now produce crabs that have recently molted, so called "soft shelled crabs", as these fetch a higher price and are in great demand in Southeast Asia. Grow-out farming of crabs is usually carried out in intertidal ponds or pens (net-fence systems) with or without mangroves, where juvenile crabs (10-100 g) are farmed through several molts until they reach market size. High growth rates have been reported from Asia for all systems, with production of commercial-sized crabs (200-400 g) 3-6 months after stocking with seed crabs (Keenan, 2003; Shelley and Lovatelli, 2011; Moksnes *et al.*, 2015).

Aquaculture of mud crabs in Asia consists of both small-scale farms and large industrial system of >100 hectares (Trino and Rodriguez, 2002; Keenan, 2003; Shelley and Lovatelli, 2011). Because of an increasing demand for mud crabs, the aquaculture industry has expanded very rapidly in the last 10 years and in 2014 global production reached 185 000 tons (valued at US$ 565 million), with most of the production taking place in China (FAO, 2016). For example, in Myanmar, the second largest crab producer, intensive farming is carried out with floating cages (up to a million cages in just one farm) where all seed crabs are collected from the wild.

The rapid expansion of cultured crabs has been possible due to an increasing market for soft-shell crabs in Asia, ready access to feed fish and vast areas of mangroves providing a steady supply of juvenile crabs, although seed supply now seems to be decreasing (Nicolini, 2013). Mud crab farming throughout Asia has historically been based on collection of wild seed crabs, but an unmet demand for mud crabs has led to over-exploitation of both adult and juvenile seed crabs, which has led to decreasing stocks in many countries (Keenan, 2003). Difficulties in obtaining juveniles from the wild for farming operations, plus concerns of further over-exploitation, has led to development of larval hatchery techniques, and today, for example, both Vietnam and China have industrial production of juvenile seed crabs for *S. serrata* and *S. paramamosain* (Shelley and Lovatelli, 2011) and development is under way also in other countries.

With the increasing industrial production of mud crabs based on seed crabs from hatcheries, feed is perceived as the next major bottleneck to mud crab aquaculture. Formulated diets to replace 'trash fish' are being developed, but the demand for low value fish resources is still high (Shelley and Lovatelli, 2011). Parallel to the development of industrial scale mud crab farming, the development of more extensive farming methods has also continued. In the Philippines and Malaysia such technologies have been transferred to resource-poor fishing villages for adoption as sustainable alternative livelihoods. These are low investment, small-scale grow-out farms in ponds or pens located within natural mangrove habitats and designed to maintain the integrity of the mangrove ecosystem. These farms show high survival and growth rates of crabs, with a high cost return (Wei Say and Ikhwanuddin, 1999; Trino and Rodriguez, 2002). These more extensive farming systems can also be found in Indonesia and Vietnam, for example, where mangroves forests are integrated with different species including mud crabs (Joffre and Bosma, 2009).

Mud crab farming in East Africa

East Africa has substantial populations of mud crabs (*S. serrata*) that are fished mainly by artisanal fishers using traditional capture methods such as hook, sticks, traps, and seine nets (Muthiga, 1986; Mirera *et al.*, 2013). This fishery is minor in comparison to Southeast Asia, but the local demand for mud crabs is increasing, as well as an increasing demand from the Asian market (ACDI-VOCA, 2005, Shipton and Hecht, 2007; Mirera, 2011); as indicated by the increasing number of Chinese traders becoming active in the region. The fishery is to a large extent unregulated and there are indications that some local crab populations in East Africa have decreased significantly as a result of increased fishing effort (Francis and Bryceson, 2001; Mahika *et al*., 2005; Mirera *et al.,* 2013).

In contrast to Southeast Asia, there is little tradition of aquaculture in East Africa, and especially marine farming is still in its infancy (Bryceson, 2002; Troell *et al.,* 2011). Research on mud crab farming was initiated in Kenya in the late 1990s assessing the use of mangrove pens, but with limited success (Mwaluma, 2002). Recent studies have assessed different methods for crab culture with the aim of involving local communities as a participatory management tool for mangrove forests (Mirera, 2009; Mirera and Mtile, 2009). These culture practices are based on collection of wild seed crabs as no larval hatcheries for mud crabs yet exist in East Africa.

In the last decades, developmental projects have been undertaken by various NGOs in East Africa to develop small-scale crab farming in local communities (e.g in Tanga, Rufiji, Kilwa, Mtwara and Mafia in Tanzania, and in the Mombasa, Kwale and Malindi areas in Kenya (Shipton and Hecht, 2007; Mirera, 2011). These projects have all focused on a method referred to as 'crab-fattening' that use small (0.30 x 0.30 m) individual cages with lids, built of local material (usually mangrove sticks or bamboo), that are placed in the intertidal zone within the mangroves, without cutting any trees. The cages are stocked with sub-adult crabs (one 150-300 g crab per cage) collected from the wild and farmed through several molts (many months) until they reach 500-1000 g. These 'extended' crab-fattening farms (referred to as 'cage culture' in this text) are presented as an alternative source of income for the local communities where the crabs are sold as a cash crop to local hotels or middlemen for export markets (ACDI-VOCA, 2005; Mahika *et al*., 2005; Shipton and Hecht, 2007).

These initiatives are all in a more or less developmental stage, and only negligible quantities of mud crabs are today produced in Tanzania and Kenya (Shipton and Hecht, 2007; UNEP-Nairobi Convention and WIOMSA, 2015). Still, as interest is growing for this activity the development of mud crab farming may now be at a critical cross-road. A demand-driven rapid expansion of cage culture could result in overexploitation of seed crabs with subsequent collapse of local mud crab stocks, and negative ecological and social impacts, similar to the situation in several Southeast Asian countries (Allan and Fielder, 2004). Lack of fishery data and basic information on reproductive biology and ecology of small juvenile mud crabs in East Africa make it difficult to assess sustainable limits for a seed crab fishery. It is possible that the pressure on crab populations may already be too high from fisheries that target the consumer market directly. Moreover, the present cage culture activities in East Africa rely to a large extent on mangrove snails (*Terebralia palustris*) as a feed resource, which are also consumed by the poorest segment of coastal communities, and there is a potential risk that further expansion of crab aquaculture may have negative effects on local food sources for humans (Hamad, 2012). There is therefore a need to assess alternative feed sources, not used for human consumption, which could be used to support an expansion of mud crab aquaculture.

Importantly, farming crabs in cages for extended periods may not be the best aquaculture method for the sustainable development of mud crab farming in East Africa. Recent studies suggest that growth in these culture systems is very slow compared to natural growth of *S. serrata* in East Africa (Moksnes *et al*., 2015), and that the mortality rates in captivity may be higher than in nature (Mirera, 2014). Moreover, it is also unclear if this farming system is sustainable from an economic perspective. A value-chain and profitability analysis of cage culture in the Tanga region, Tanzania, showed that farmers could not make a net profit due to low prices, and suggested that the farms need to increase in size to increase profitability (ACDI-VOCA, 2005). In contrast, profitability analyses of an experimental cage culture system in Kenya showed a high return on capital investment (Mirera, 2009). However, the cost of labour in maintaining cage culture farms were not included in these analyses, and it is therefore not clear if this activity is rational from an economic perspective.

Grow-out aquaculture of mud crabs using small juvenile crabs (<10 g) in pond or pen systems, compared to using sub-adult crabs, may constitute a more sustainable alternative for East Africa, both from an ecological and economic context. Small-scale pond and pen systems in Southeast Asia show high survival and growth rates with high profitability (Trino and Rodriguez, 2002). In the absence of hatcheries, recent field studies in East Africa demonstrated that small juvenile seed crabs can be efficiently collected along mangrove fringes (Mirera, 2014), and studies of grow-out culture methods in pond and pen systems in Kenya show high growth rates for such seed crabs (Mirera and Moksnes, 2015). However, it is not clear if this form of aquaculture could constitute a profitable activity since cost-revenue analyses are missing, and it is unclear how prices of mud crabs vary between different markets and countries in East Africa. It is also not clear if and how the profitability in cage and pond systems will increase with scale, and how seed crabs and feed limit the maximum scale of a sustainable farm in a coastal community setting, as such analyses are lacking.

Here we assess the profitability of small-scale aquaculture of mud crabs in cage and pond systems in Kenya and Tanzania using cost-revenue analyses based on realistic growth rates of crabs, and on realistic costs (including labour costs) and prices in the two countries, obtained through culture studies and market surveys in East Africa. Specific aims of the study were (1) to compare the profitability and identify the major costs in the two culture systems, (2) to assess how prices and profitability differ between markets and countries, (3) to assess how market size for crab affects profitability in pond culture, and (4) to assess the economy of scale in the two systems, and how seed and feed resources may limit the maximum size of a sustainable crab culture operation in a coastal community.

Material and Methods

The present study was part of a larger research project financed by MASMA-WIOMSA to assess if small-scale aquaculture of mud crabs could be developed into a sustainable alternative livelihood for coastal communities in East Africa. Using a multidisciplinary approach, parallel field studies and surveys were carried out in Kenya and Tanzania to assess opportunities and constraints of this activity from both an ecological and economic perspective.

Markets and prices for mud crabs

To assess markets and price ranges available to mud crab farmers in East Africa, informal interviews were carried out with crab fishers, crab farmers, middlemen, exporters, market salesmen and hotels in the Mombasa and Malindi areas in Kenya, in Dar es Salaam, Mafia and Zanzibar in Tanzania, and in Maputo in Mozambique. The prices were compared to earlier studies in East Africa and South East Asia obtained from the literature.

Cost-revenue analyses of cage and pond culture in East Africa

To compare the cost and profit margins of pond and cage culture of mud crabs in Kenya and Tanzania, cost-revenue analyses were carried out assessing the total cost to produce 450 commercially sized crabs (i.e. 500 g). For pond culture, the estimates were based on farming 0.5 and 2.0 g small juvenile seed crabs, stocked at approximately 5 crabs m^{-2} in 15x15 m earthen ponds, for 11.6 and 10.9 months, in Tanzania and Kenya, respectively (Table 2). The difference in culture periods was due to smaller seed crabs dominating in Tanzania (see below) requiring slightly longer time to reach commercial size. For cage culture, the estimates were based on 3 consecutive 3-month culture periods, growing 300 g seed crabs in cages with 200 individual compartments.

To estimate the growth period to commercial size for different sizes of seed crabs, a von Bertalanffy growth function of natural growth of *S. serrata* in East Africa was used:

$$L_t = 310*(1- e^{-0.57*(t-0.019)})$$

where L_t is the size (carapace width) at time (t) since settlement (Moksnes *et al.*, 2015). A growth model was used since existing studies of mud crab culture in East Africa have not raised crabs to commercial size. In pond culture, the growth rate was similar to the modeled growth (99%; Mirera and Moksnes, 2015), whereas in cage culture the growth rate was substantially lower (on average 39% of the modeled growth; Moksnes *et al.*, 2015). To partly adjust for this difference, a growth rate in cage culture that was approximately 75% of the modeled growth was used, simulating an improvement of the present growing conditions by approximately 50%. This was done to assess if cage culture could become profitable if growth rates improved. The same growth rates were used in both countries.

In both culture systems, the mortality rate was assumed to be 10% $month^{-1}$, which is similar to what is obtained in mud crab cultures in Southeast Asia (Baliao *et al.*, 1999, Trino *et al.,* 1999, Trino and Rodrigues, 2002). However, in East Africa, reported mortality rates have been substantially higher, ranging from on average 20-60% $month^{-1}$ in different culture systems (Mwaluma, 2002; Mirera, 2009; Mirera and Mtile, 2009; *see* Mirera and Moksnes, 2015 *for review*). Thus, it is important to note that the cost-revenue analyses assumed a substantial improvement of survival rates in the East African cultures, something that may be feasible under better management.

All cost estimates were based on data from experimental cage culture studies in Mtwapa Creek, north of Mombasa, Kenya, in 2005 (Mirera, 2009) and from experimental grow-out pond studies in Mtwapa Creek (Mirera and Moksnes, 2015) and on Mafia Island, Tanzania (H. Mahudi unpubl. data), in 2010-2011. Realistic estimates of all costs, including initial construction of the pond and all labour costs were made so that this activity could be compared to other established income generating activities. The labour (person-hours) for construction and maintenance were standardized between the two countries to make them comparable, while local costs for material and labour were included. Labour costs for construction and farm maintenance were based on estimated daily salaries in coastal communities in Tanzania (5000 Tsh day^{-1} = 2.9 \$US day^{-1}) and Kenya (350 Ksh day^{-1} = 3.8 \$US day^{-1}) and converted to monthly costs assuming a person working 6 h per day, 26 d per month. The costs of night guards were based on a monthly salary of 65 000 Tsh (37 \$US) and 4500 Ksh (49 \$US) in Tanzania, and Kenya respectively, working 8 h per day, 7 d per week. Conversions of currencies to US dollars were based on the exchange rate in Jan, 2015 (1 \$US = 1733 Tsh and 92 Ksh; www.oanda.com).

For pond culture, the initial costs of construction consisted of manual digging of the pond, building a mud levy around the pond and installing water pipes (10 persons working for 10 days). Yearly labour costs consisted of building a net fence around the pond (3 persons working 2 days), and yearly maintenance and repair of the pond (10 persons working for a total of 2 days). Life expectancy was assumed to be 10 years for the pond itself and 1 to 10 years for tools and material. Cost of seed crab collection for ponds were based on the average number of crabs collected per hour on Mafia Island, Tanzania (13 crabs h^{-1}), and in Mtwapa Creek, Kenya (7 crabs h^{-1}) during recruitment season (April to October in Mafia; Mirera, 2014). On Mafia Island, where collection can only be carried out at night (Moksnes *et al*., unpubl. data) the cost of flashlight and batteries was added (9 \$US per growth cycle). The daily labour costs for a pond consisted of collecting and preparing feed (*Terrebralia* snails, fish offal, etc.) and feeding the crabs (on average 2 person-hours per day). The labour cost of guards was based on 1 person working 7 nights (8 h/night) per week for the last 2.5 months of the growth cycle (when crabs had reached a market size of 300 g). Cost of harvesting crabs and selling them on the local market was based on one person fishing crabs with drop-traps once a week for a month, and two persons draining the pond and harvesting all remaining crabs at the end of the harvest cycle (in total 20 person-hours).

For cage culture, the initial costs consisted of building the 200 individual cages out of mangrove sticks (a total of 80 person-hours). Life expectancy was assumed to be 4-8 years for tools, and 4 growing cycles for the cage material. Cost of seed crabs were based on purchasing 250-300 g crabs from local fishermen for 0.12 \$US in Tanzania (ASDI/VOCA, 2005) and 0.20 \$US per individual in Kenya (Mirera, 2009). The average daily labour costs for a 200-compartment cage farm consisted of collecting and preparing feed, and feeding each crab individually, and repair of the cages (in total 8 person-hours per day). The cost of guards was assumed to be the same as for pond culture (1 person working 7 nights per week), but for the whole culture period (3 months). Cost of collecting commercially sized crabs from the cages and selling was estimated to 12 person-hours in total. The revenue from both forms of culture was estimated based on the prices of market sized mud crabs (>500 g) at tourist hotels on Mafia Island and Dar es Salaam, Tanzania (2.5 \$US per kg) and Mombasa, Kenya (5.4 \$US per kg; Table 1).

Effect of market size of crabs on costs in pond culture

A major difference between the Southeast Asian and East African markets, in particular Tanzania, is that smaller mud crabs (300 g) obtain good prices in the former market (Table 1). Because the inter-molt period increases exponentially with the size of a mud crab (Moksnes *et al.,* 2015), and larger crabs need more feed than smaller crabs, the cost and the need for feed increases exponentially for each additional molt that the crab must pass through. Because the risk of theft is high mainly for commercial size crabs, the cost of preventing theft at the culture site (e.g. night guard) makes up a larger proportion of the total culture cost the longer the commercial sized crabs are kept. Thus, it may be more profitable to harvest and sell crabs smaller than the present market size in Tanzania (>500 g).

To assess how the cost may change with size of the crabs at harvest in pond culture, the total number of seed crabs and amount of feed required (using a feeding rate of 10% of the biomass of crabs per day), and the total cost of seed crabs, feed and theft prevention (employing a night guard one month before the crabs reach 300 g and thereafter) to produce 100 kg of mud crabs harvested at either 300, 500, 700 or 1000 g body weight, using the same methods as in the cost-revenue analyses, were estimated. In these analyses, seed crabs of 15 mm Carapace Width (CW), an average mortality of 10% per month, and a 10x10 m pond for all size-classes were used, resulting in stocking densities between 4 and 7 crabs m^{-2} for the 4 size-classes (assuming no density-dependent mortality) to achieve the same total production of crabs.

Economy and sustainability of scale for grow-out pond farms

One possible way to increase the profitability of crab cultures would be to increase the size of the culture system since the cost per produced crab may decrease with the scale of the operation (i.e. economy of scale). For example, if the size of a pond increases from 10x10 m to 20x20 m, the area of the pond (and available space for crabs) increases 400%, whereas the circumference (and the cost of building a wall and fence) only increases by 200%, and the cost of transportation and distributing feed in the pond increase only a little. However, for crab culture based on collection of wild seed crabs and local feed sources there are issues of sustainability if the farms are too large due to limitations of the local ecosystem (i.e. mangrove forest for placing the farm and for extraction of feed and seed resources). To study these questions, we assessed the economy of scale of pond culture on Mafia Island in Tanzania, and how feed and seed resources limit the maximum size and the profitability of a sustainable farm. Mafia Island was chosen as an example because empiric data on seed and feed limitations are available (Nyqvist, 2010; Hamad, 2012).

The total cost of the required seed crabs and feed, and revenue was estimated for pond culture systems ranging from 50 to 500 m^2 in size, using the same methods as in the cost-revenue analyses (Table 2). The cost per crab was assumed to decrease in larger ponds due to: (1) no increase in cost for tools and pipes for pond construction, (2) little increase in labour costs for daily transportation of feed and feeding, and guarding the farm, (3) only a small increase in the cost of building the fence around the pond, and (4) the labour cost in collecting and preparing the feed (these costs were assumed to increase with area of the pond as the circumference increases with the area ($y = 4x^{0.5}$; where y is the circumference and x is the area). The labour cost of digging the pond and levies, and harvesting the crabs were assumed to increase proportionally with the area of the pond. Two price-scenarios of $US 2.5 and 5.0, representing the high end of prices offered by hotels on Mafia Island and in Dar es Salaam respectively, were assessed (Table 1).

Based on a field survey of alternative mud crab feed sources that were not used for human consumption on Mafia Island, it was estimated that approximately 20 kg of different feed sources (fish offal, maize bran and dried anchovy waste) should be available per day in an average village on Mafia Island. It was assumed that a total of 10 kg of maize bran and unwanted dried anchovies could be collected from 5 households and 5 kiosks in the village, and that 10 kg fish offal could be collected at the village landing site for fisherman every day (Hamad, 2012). These resources were assumed available for free, but competing alternative uses may exist. Based on an impact study of the collection of small juvenile mud crabs on Mafia Island, it was estimated that no more than 1200 small juvenile seed crabs could be fished from the same local area per recruitment season without negative effects on the local population (Nyqvist, 2010).

No attempt was made to analyze the economy of scale of cage culture because the cost-revenue analysis showed that the cost per crab decreased very little with the size of the culture system. This was due to the fact that the crabs were kept in individual cages that had to be constructed, repaired, and opened and closed at each feeding for each crab. Only the cost of guarding and tools decreased with the size of the cage culture.

Results

Markets and prices for mud crabs

In all markets, the best prices were obtained for live crabs, full of meat with both chelipeds (claws) intact. The market size and prices for mud crabs showed large variation both within and between countries and regions (Table 1). The commercial market size in Tanzania and Kenya (500-1000 g in most areas) is substantially higher than the general market size in Southeast Asia (150-400 g). Still, the price ranges per kg in Southeast Asia (US$ 3.0-13.6 kg^{-1}), most of which were based on information >10 years old, were similar to the highest prices presently found in East Africa (i.e. in Kenya; Table 1), indicating higher profit margins in Southeast Asia. In Kenya, there are indications that market sizes have decreased during the last decade, as good prices were also currently obtained for

Table 1. Market sizes and prices for mud crabs in Southeast Asia and East Africa. All prices are in $US based on exchange rates on 01-07-2012. References: (1) Cholik, 1999, (2) Wei Say and Ikhwanuddin, 1999, (3) Trino *et al.*, 1999; Trino and Rodrigues 2002 (4) Johnston and Keenan, 1999, (5) Cann and Shelley, 1999 (6) This study, (7) Mirera, 2011, (8) ACDI/VOCA, 2005, (9) Richmond *et al.*, 2006.

Country	Seed size (g)	Seed price US$ kg^{-1}	Market size (g)	Price/kg US$	Buyer	Ref
Southeast Asia						
Indonesia	350		>400	3.1[1]	-	1
Malaysia	100	1.2	150-300	3.0	Middlemen	2
Philippines	10		>300	8.9-9.5	Middlemen	3
Vietnam	25-100	2.0-4.0	>300	8.0-12.0	Middlemen	4
Australia		0.5-2.9	-	8.7-13.6	-	5
Kenya						
Mombasa			>500	4.7-6.5	Hotels	6
			250-500	2.9	Hotels	6
			>1000	15.0	Exporter	7
			>500	8.0	Exporter	6
Malindi			>500	4.1-5.2	Middlemen	6
			250-500	2.9-4.7	Middlemen	6
Tanzania						
Tanga	250	0.5	700-1000	0.8-1.4	Middlemen	8
Rufiji	-	-	500	1.0	Middlemen	9
Mafia Island	-	-	500	1.3-2.6	Hotels	6
Zanzibar	-	-	500	3.8[2]	Restaurant	6
Dar es Salaam	-	-	500	2.5-5.1	Hotels	6
Dar es Salaam	-	-	500	1.9-3.2	Exporter	9
Dar es Salaam	-	-	700-1000	2.6-7.0	Exporter	6, 8
Mozambique						
Maputo	-	-	200	2.0-3.7[3]	*Market*	6
			400	3.0-5.5[3]	*Market*	6

[1] *Price in 1994*
[2] *Market food-stands selling cooked seafood products to tourist.*
[3] *Prices paid by customers at fish market or to private vendors*

250-500 g crabs. In contrast, the market size in Tanzania is still large (>500 g), and the prices (US$ 0.8-7.0) are several times lower than in the other countries. A large variation was also found within the country. In northern Tanzania, in the Tanga region, the middlemen demanded large sizes (700-1000 g) and paid low prices (US$ 0.8-1.4, ACDI/VOCA, 2005) whereas middlemen in southern Tanzania (Rufiji) accepted smaller crabs (500 g) at similar prices (Richmond *et al.*, 2006). Hotels in Tanzania generally offered higher prices for crabs (US$ 1.3-5.2) than middlemen, and appeared to be more flexible in also accepting smaller crabs (300-500 g). In Kenya, the prices offered by middlemen and hotels were similar (US$ 2.9-6.5), and on average twice as high as in Tanzania. Highest prices in both Tanzania and Kenya were offered by exporters buying large, live crabs (700-1000 g) for the Asian market (Table 1). In Tanzania, there is also a small market for frozen crabs that are exported to the European market. This market accepts smaller crabs (350-700 g), but the prices are lower (US$ 3.0; Richmond *et al*., 2006).

In Maputo, Mozambique, mud crabs are an important ingredient in traditional dishes, and mainly sold on the local market, and the market size is smaller than in other East African countries (200-400 g). However, the prices on the local markets in Maputo are almost two times higher than in Tanzania (Table 2). In both Tanzania and Kenya, different sources gave very different information regarding size classes and prices for the same market section, indicating an unstructured and dynamic market.

Cost-revenue analyses of cage and pond culture in East Africa

From a cost perspective, the two culture methods differ strongly in the initial investment, and the amount of labour needed during the growth period (Table 2). For ponds, a large initial investment is needed for the construction of the pond, including tools and labour, and the material costs are high, in particular for the fencing around the pond to prevent crabs from escaping. In the first year, the total cost for the construction of a 15 x 15 m pond was estimated to be $US 998 in Tanzania and $US 1051 in Kenya (not including the costs of supervision). The larger costs in Kenya were due to the approximately 30% higher prices of material and labour in Kenya. Since the ponds with levees are expected to last for approximately 10 years (with minor yearly repairs), only the net fence needs to be replaced on a yearly basis over the following 9 years. To estimate the total cost per 11-month growth cycle and harvest, the investment cost in the pond was split with the number of years that the construction, tools and material were expected to last. This resulted in a yearly investment cost of $US 289 and $US 360, and a total cost per harvest of $US 773 and $US 989 in Tanzania and Kenya, respectively, to grow 450 small juvenile seed crabs to commercial size (Table 2). The construction costs represented 36-37% of the total cost per harvest, whereas the costs of daily labour maintaining the culture (on average 2.4 h per day) constituted approximately 41-42% in both countries. Since theft of crabs appears to constitute a major problem, the cost of a night watch for the last 2.5 months of the culture period was included, constituting about 12% of the total cost. Seed crab collection represented 12% and 8% of the total cost in Kenya and Tanzania, respectively.

In contrast, the cost in cage culture involves a smaller initial investment to construct the cages ($US 38 and $US 48 in material and tools, and $US 79 and $US 104 in labour in Tanzania and in Kenya, respectively), but a very high labour costs per growth cycle for maintenance. The total labour costs to maintain the crabs in 200 individual cages for three 3-month growth-cycles was $US 1464 and $US 1109 in Kenya and Tanzania, respectively, representing approximately 68% and 69% of the total cost per harvest. In addition to this, the need for guards during the whole production cycle to prevent theft of the easily accessible crabs constitute a major cost ($US 441 and $US 339 in Kenya and Tanzania) constituting approximately 21% of the total cost per harvest. In comparison, the total cost of crab seeds and cage construction was small (9-11% in total; Table 2). The high labour cost in cage culture is a result of the time consuming labour of opening and closing the lid of individual cages each day to feed, and the high amount of labour required to repair the cages (in total approximately 8 h per day).

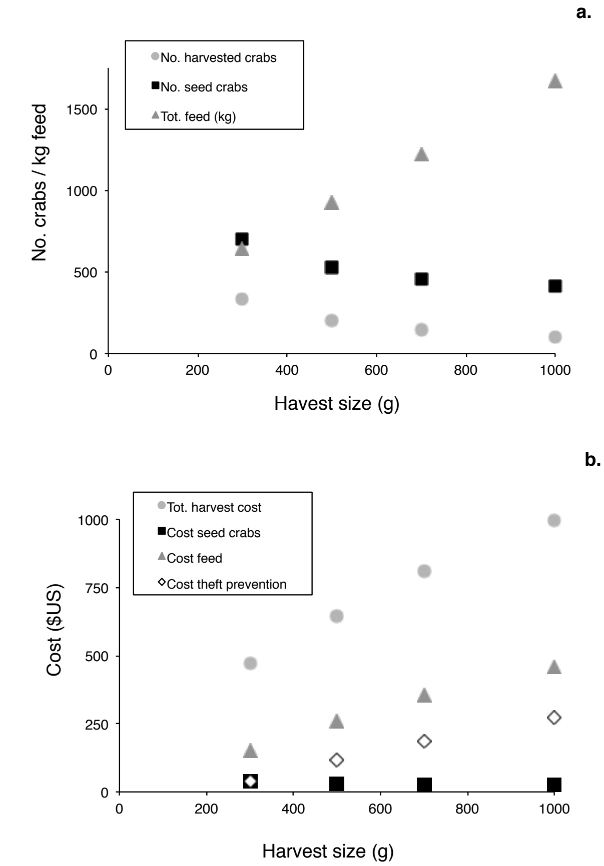
The cost-revenue analyses showed that profit margins were low in both systems, particularly in cage culture when using realistic costs of labour. Pond culture showed a $US 226 profit in Kenya in this scenario, but a net loss in Tanzania. The difference between the countries was explained by the more than 2x higher prices paid for market sized crabs in Kenya compared to Tanzania, on average, which more than compensated for the 30% higher labour and material costs in Kenya (Table 2). The break-even price to make a profit in Tanzania in this scenario was $US 3.5 kg^{-1}, which is presently only obtained when selling directly to some hotels and restaurants in Dar es Salaam and Zanzibar (Table 1), a market presently handled by middlemen. If the high initial investment cost of constructing the pond could be avoided, for example through support by an NGO or government, pond culture would be profitable also in Tanzania. However, the economic activity may then not be sustainable once the funding ends and the ponds need to be reconstructed. In contrast to pond culture, cage culture at this scale (450 crabs per year) showed large net losses in both Kenya and in Tanzania, mainly due to high labour cost of daily maintenance, which on its own was higher than the revenue obtained in both countries (Table 2).

Table 2. Cost-revenue of mud crab aquaculture in East Africa. Culture data and cost-revenue estimates assessing the total cost to produce 450 commercially sized crabs (i.e. 500 g) in ponds (15x15 m pond) and cages (200 compartment drive-in cages) in Tanzania and Kenya. To compare profit, 9-month growth-cycles in the pond systems were compared to 3 consecutive 3-month culture periods in cage fattening system. All cost estimates are per harvest cycle of 450 commercial crabs, and are in $US.

	Pond culture		Cage culture	
	Tanzania	Kenya	Tanzania	Kenya
A. Culture data				
Average seed-crab size (g)	0.5	2	300	300
No. seed-crabs	1170	1100	618	618
Stocking density	5.2	4.9	-	-
Culture duration (months)	9.2	8.6	3x3	3x3
Mortality per month	10%	10%	10%	10%
Mortality per harvest	62%	59%	27%	27%
Harvest density	2.0	2.0	-	-
Harvest (no. >500 g crabs)	450	450	450	450
B. Culture costs ($US)				
1. Culture construction	**289**	**360**	**84**	**111**
Labour costs/harvest	140	169	59	78
Material/harvest	149	191	25	33
2. Crab-seed costs	**65**	**102**	**71**	**121**
3. Daily maintenance	**325**	**405**	**1109**	**1464**
Labour costs	316	391	1107	1461
Material	9	14	2	3
4. Security against theft	**94**	**122**	**339**	**441**
TOTAL COSTS	773	989	1607	2141
C. Culture revenue ($US)				
Harvest (kg)	225	225	245	245
Price per kg	2.5	5.4	2.5	5.4
Revenue	**563**	**1215**	**638**	**1324**
D. Harvest profit ($US)	**-211**	**226**	**-970**	**-816**

Effect of market size of crabs on costs in pond culture

The results show that the culture time varied from 9.1 month to produce 300 g crabs to 11.6 and 16.4 months to produce a 500 g and 1000 g crab, respectively. The number of seed crabs needed to produce 100 kg of crabs decreased from around 700 seeds for crabs harvested at 300 g, to around 400 seeds to produce 100 kg of 1000 g crabs (Fig. 1a). Thus, although the total mortality was higher during the longer culture time needed to raise the larger crabs, their large final size still meant that fewer seed crabs were needed compared to raising smaller commercial crabs. In contrast, the total amount of feed needed for the whole culture period increased 2.6 times with the size of the harvested crabs, from 644 kg feed to produce 100 kg



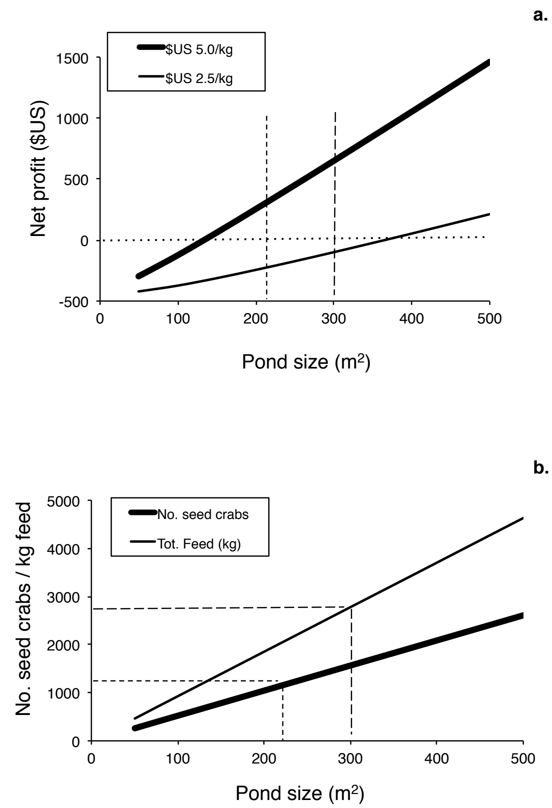


Figure 1. Pond culture of mud crabs. Relationship between the size of mud crabs at harvest (300, 500, 700 and 1000 g) and (a) the total number harvested crabs, total number seed-crabs, and total amount of feed needed to produce 100 kg of mud crabs, and (b) the cost of seed crabs, feed, theft protection (night guard) and the total cost to produce 100 kg of mud crabs at different harvest size.

Figure 2. Pond culture of mud crabs. Relationship between the size of aquaculture pond and (a) the profit of the aquaculture at two different price scenarios for 500 g crabs, and (b) the total number seed-crabs, and total amount of feed needed to produce two 500 g mud crabs m^{-2}. Dashed lines indicate the suggested maximum sustainable level of seed crabs and feed that can be collected at an average village on Mafia Island.

of 300 g crabs, to 1668 kg feed to produce the same biomass of 1000 g crabs. Because small seed crabs are relatively inexpensive to collect, feed is costly, and the cost of theft prevention is 3 times higher for the largest crabs, the total cost per harvest increased by over 100% with the size of the produced crabs, from $US 473 for 300 g crabs, to $US 996 to produce 100 kg of 1000 g crabs (Fig. 1b).

Economy and sustainability of scale for pond culture

The results show that as the size of the pond increases from 50 to 500 m^2, the profit in the $US 5 price-scenario increases rapidly from minus values at a pond size of 50 m^2, breaking even at a pond size of 133 m^2 (11.5 x 11.5 m), and making a profit of almost $US 1500 at a pond size of 500 m^2 (Fig. 2a). At the price-scenario of $US 2.5, the increase in profit is much slower, and the farm does not break-even until the pond is 365 m^2, making a profit of $US 213 at the 500 m^2 pond size (Fig. 2a). However, as the pond size increases, the total number of seed crabs needed increases from 260 to over 2600 crabs, and the total amount of required feed increases from 463 to over 4630 kg (Fig. 2b).

For crab feed, the limiting factor was assumed to be the amount of feed needed per day during the last inter-molt period (2.6 months) at the end of the growth period when the crabs are largest. Based on the maximum sustainable amount of feed that could be obtained per day from a village on Mafia (20 kg), a maximum of approximately 770 crabs with an average size around 270 g could be fed per village. This would result in a total amount of crab feed needed during the growth cycle of approximately 2800 kg and limit the maximum size of the pond to around 300 m^2 (Fig. 2b), which in turn limits the maximum profit at a price $US 5 per kg to approximately $US 650 per harvest. However, at a price of $US 2.5, a pond of this size is too small to yield any profit (Fig. 2a).

In addition, the availability of crab seed further limits the maximum pond size. The maximum sustainable number of seed crabs that could be collected per month (1200 crabs) limits the maximum size of a pond to approximately 230 m^2, in which a maximum of 460 market size crabs can be raised (assuming 10% mortality per month). This in turn limits the maximum profit of the $US 5 price-scenario to approximately $US 374 per harvest, and prevents the aquaculture operation realizing a profit if the price is $US 2.5 per kg. At this pond size, the break-even price is $US 3.4 per kg.

Discussion

Cage culture

In the last decades, various NGOs in East Africa have tried to develop small-scale aquaculture of mud crabs as an alternative livelihood for coastal communities. The method promoted is based on collection of subadult mud crabs (80-110 mm CW) from the wild that are farmed in individual cage-systems through several molts until they reach market size (Rice *et al*., 2006; Shipton and Hetch, 2007; Mirera, 2011). However, recent studies suggest that this culture method has several limitations, obtaining growth rates of <40% of those in the wild for *S. serrata* in East Africa (Moksnes *et al.,* 2015). In addition, the high mortality rates in these culture practices (on average 19% month^{-1}; Mirera, 2009, Mirera and Mtile, 2009) appear to be several times higher than natural mortality for this size-class of crabs (approximately 4% month^{-1}; Mirera, 2014) suggesting that this type aquaculture is in fact decreasing the overall local production of crabs. The present study adds to this critique by demonstrating that these culture activities also provide very low profits when taking into account the cost of labour.

Although we simulated much higher growth and survival rates than what is presently obtained in these forms of culture (75% of natural growth and 10% mortality month^{-1}, respectively) cage culture resulted in net losses (equivalent to $US 323 and 272 per 3-month growth cycle of 150 crabs, respectively in Tanzania and Kenya). The low profit was mainly due to the high cost of daily labour for maintenance, which is time consuming because each individual cage has to be opened and closed at feeding, and the need of almost daily repair. Excluding this labour cost in the cost-revenue analysis resulted in a profit equivalent to a salary of $US 0.28 and $US 0.03 per hour, approximately only 45% and 6% of the average salary in coastal communities in Kenya and Tanzania, respectively. Thus, the present form of cage culture does not appear to constitute an attractive source of income for coastal communities, at least not for persons that have other alternatives. If more realistic (lower) growth and survival rates had been used in the analyses the profitability of this culture method would have been even lower.

The results indicating low profit obtained by cage culture of crabs differs from analyses of an experimental cage culture system in Kenya, which showed a high return on capital investment (Mirera 2009). However, in that analysis the cost of labour for daily maintenance was not included. The present results are consistent with cost-revenue analyses from the Tanga region that also showed a net loss (ACDI/VOCA, 2005). In that study it was suggested that profit would increase for larger cage culture farms. However, in the present study we assessed farms that were many times larger than the farms presently in use in East Africa (10-100 crabs per farm; ACDI/VOCA, 2005; this study), and we found that profit increased very little with the size of the fattening operation.

In combination, the poor growth, survival, and profitability of mud crabs farmed through several molts in individual cages demonstrated that this culture method does not constitute a sustainable or profitable alternative livelihood in its present form. These issues must be solved before cage farming is promoted to coastal communities in East Africa. The poor survival rates in the cages, despite the fact the crabs are kept separately to prevent cannibalism, indicate that the intertidal cage environment where crabs only have access to water during high tides is a poor environment for completion of the molt processes. For aquaculture requiring molts, culture systems that allow crabs permanent access to water, such as pond or pen systems, appear to perform much better.

In Southeast Asia, mud crab fattening has been described as a profitable enterprise, but it differs in an important aspect from the fattening operation in East Africa, i.e. crabs are only fattened for a short period of time (<1 month), and are sold prior to molt, to decrease mortality (Keenan, 2003). Mud crab fattening in East Africa could possibly become profitable if farmers adopted the same strategy, and only fattened adult crabs with low meat content for a short period of time. Studies to investigate this possibility from practical, environmental and economic perspectives are encouraged.

Grow-out culture in ponds and pens

Grow-out aquaculture of small juvenile mud crabs in ponds or pens shows better potential to develop into a sustainable and profitable livelihood in East Africa compared to current cage farming practices. Recent studies demonstrated that small juvenile mud crabs can be efficiently collected at low tides with minimal negative environmental impact, and indicated high growth rates in both pond and pen cultures. However, high mortality rates and low market price and profitability are issues that need to be resolved for this farming to be profitable in East Africa.

Progress and challenges of pond and pen culture methods in East Africa

Recent studies have identified mangrove fringes and back-flats as important habitats for small juvenile mud crabs in East Africa where high numbers of small seed crabs (up to 40 crabs person^{-1} h^{-1}) can be collected at low tide by hand with no by-catch and minimal impact on the environment (Karlsson, 2009; Mirera, 2014). The studies also suggest that natural mortality of small juvenile mud crabs (<20 mm CW) in East Africa is very high (>50% month^{-1}), but decreases strongly with size indicating that small juvenile stages represent a bottleneck in the life-history of mud crabs where most crabs perish due to high predation mortality (Mirera, 2014; P-O Moksnes, unpubl. data). These results suggest that negative impacts of a seed crab fishery on local populations would be minimized if small juvenile stages were used as seeds, and that the aquaculture operation could increase the local production of crabs if survival in the culture were higher than in nature. In South East Asia, small-scale, grow-out farms for *S. serrata* using small juvenile seed crabs (12-50 mm CW) in pond or pens obtain mortality rates <10% month^{-1} (Baliao *et al*., 1999; Trino *et al*., 1999; Trino and Rodrigues, 2002), suggesting that grow-out culture based on collection on small juvenile crabs has the potential of increasing the local production of mud crabs and be more sustainable than culture based on collection of large crabs.

Experimental pond and pen studies in East Africa using small juvenile seed crabs show high growth rates (93-112% of natural growth rates) when shelter is provided in the culture systems (Mirera and Moksnes, 2015). However, mortality rates during the first 2-3 months of culture in these studies have been very high (on average 41-58% month^{-1}), likely due to high rates of cannibalism (Mirera and Moksnes, 2015), a problem that needs to be resolved before the culture could be profitable. Recent studies in East Africa demonstrate that juvenile cannibalism could be minimized by separating small and large juvenile seed crabs to keep the size-ratio below 50%, and by providing shelter to the juveniles in the culture system (Mirera and Moksnes, 2013; 2015). Studies in Southeast Asia also indicate that cannibalism is lower at lower stocking densities (Trino *et al*., 1999; Trino and Rodriguez, 2002). Further studies assessing how mortality can be decreased in East African grow-out culture in ponds and pens are needed.

Profitability and sustainability of grow-out culture in East Africa

In the Philippines, small-scale, grow-out culture of *S. serrata* in 200 m^2 pens integrated in mangrove forests was found to be profitable with a high return on capital investment (49-68%) even after including the cost of labour (Trino and Rodriguez, 2002). In the current cost-revenue analysis of similarly sized pond culture operations (225 m^2) in East Africa, simulating survival rates presently obtained in Southeast Asia (90% month^{-1}), but using growth rates, cost and market prices presently obtained in East Africa, showed a much smaller profit margin. At this size of operation, a positive return of the investment could only be obtained with prices above $US 3.4 per kg for market sized crabs, which is currently achievable in Kenya and Mozambique, but difficult in Tanzania. Market analyses showed that prices for mud crabs were over 50% lower in Tanzania than in other East African countries, and that most of the profit appears to go to middlemen and exporters (Table 1).

In Southeast Asia, the market size of mud crabs (>300 g) is smaller than the size in most markets in East Africa (>500-1000 g). Still, the prices for mud crabs available to farmers in South East Asia are much higher compared to East Africa (Table 1). Thus, there appear to be room to improve the prices obtained by crab farmers and fishers in East Africa, particularly in Tanzania. Studies investigating ways to develop new markets and market-chains for crab farmers to improve the prices and the profitability of the culture activity in East Africa are needed.

The present study showed that farming crabs to 300 g would require 25% and 75% less time, 48% and 159% less feed, resulting in 36% and 111% lower total costs compared to farming the same total biomass of crabs to 500 g and 1000 g, respectively. In addition to having lower costs, the shorter culture time of farming crabs to 300 g would allow more harvests in the same amount of time, and decrease the risk for unpredictable events (e.g. heat shocks, storms, theft, diseases, etc.) that may ruin the crop and subsequent profit. Thus, farming crabs to 300 g would be more sustainable from a feed perspective, less risky, and possibly also more profitable than farming larger crabs, if there was a market for this size class of crabs. In Kenya, a market for smaller crabs appears to be developing as both middlemen and hotels pay high prices (US$ 2.9-4.7) for crabs as small as 250 g, although larger crabs still obtain a higher price, particularly for the export market (Table 1). In Tanzania, most middlemen and hotels still want crabs of 500 g or larger, but some hotel are starting to accept smaller crabs because of increasing demand. There are also reports that middlemen in the Rufiji area, and exporters in Dar es Salaam are showing interest in 300 g crabs, particularly for the market of frozen mud crabs destined for Europe, which obtain a relatively high price (US$ 3.0; Richmond *et al.*, 2006). In Tanzania, the break-even price for farming crabs to 300 g in a 225 m^2 pond would be $US 2.2 per kg, and at a price of $US 3.0 per kg, the farm would make a net profit of $US 180 per 9-month cycle (assuming 10% mortality $month^{-1}$). Promoting a market for 300 g mud crabs in East Africa could thus be one way to assist the development of pond aquaculture in the region. However, since a larger number of seed crabs are needed to farm the same biomass of 300 g crabs compared to e.g., 500 g crabs (at 10% mortality $month^{-1}$), the availability of seed crabs may limit the size of a sustainable pond, and therefore its profitability. Since *S. serrata* in East Africa becomes sexually mature at around 300 g (Roberson and Kruger, 1994) care must also be taken not to promote a market for even smaller crabs. If fishers start to exploit immature crabs before they have a chance to reproduce it may have negative effect on wild populations.

Another way to increase profitability would be to increase the size of the mud crab farm. The present study showed that the profit of a pond culture operation increased rapidly with the size of the pond, making a profit of almost $US 1500 at a pond size of 500 m^2 in the $US 5 price-scenario, and breaking-even at a pond size 365 m^2 in the $US 2.5 price-scenario. However, both the availability of small juvenile seed crabs and sustainable crab feed limit the maximum size of pond culture systems in a coastal community to approximately 460 and 770 market size crabs per 11-month growth cycle, respectively. This in turn limits the maximum profit to approximately $US 374 per harvest at the $US 5 price-scenario, and prevents the aquaculture operation from realizing a profit if the price is $US 2.5 per kg.

The sustainable limit of 1200 seed crabs per village area (ca 5 km of mangrove shore line) is a rough estimate based on mark-recapture studies on Mafia Island. These studies showed limited dispersal of juveniles (Björkvik, 2010) and no detectable effects on local juvenile populations by removing ca 330 small juvenile mud crabs (5-15 mm CW) from a 50 m area of the shore in 2 weeks of intensive sampling (Nyqvist, 2011). However, this is only based on one studies from one location, and more studies are needed to assess the sustainable levels of seed crab fisheries in different areas of East Africa. Since the fishery of mud crabs is unregulated in Kenya and Tanzania, and there are indications of overfishing in several areas (Francis and Bryceson, 2001; Mirera, 2012), an unregulated fishery for juvenile seed crabs may enhance the overexploitation and result in declining stocks, as have been reported in Southeast Asia (Keenan, 2003). A fishery for juveniles may also lead to competition with local traditional fisheries for adult crabs. Even if juvenile seed crabs are fished in a sustainable way, the difficulty of collecting high numbers of juveniles may inhibit larger culture operations. The experience from intensive sampling of small juvenile crabs during a two year period at multiple sites in Tanzania, Kenya and in Mozambique suggest that it would be very difficult to obtain more than 1000 small juvenile mud crabs (<40 mm CW) within one month, from any mangrove area in East Africa due to the low densities of juveniles (Mirera, 2014; P-O Moksnes unpubld. data). Thus, natural availability of seed crabs put strong limitations on the scale of mud crab culture in East Africa.

In Southeast Asia, larval hatchery techniques have been developed for several species of mud crabs for production of juvenile seed crabs to industrial scale mud crab farms (Shelley and Lovatelli, 2011). Using seed crabs from hatcheries would clearly be more sustainable than collecting crabs from the wild, and could be a long-term solution to meet an increasing demand in East Africa. However, larval hatcheries require advanced laboratories and are sensitive operations. For example, in Australia, despite considerable efforts, larval hatchery methods for *S. serrata* have proved difficult to develop (Allan and Fielder, 2004). It is therefore not realistic to expect high-technology hatcheries to provide a dependent and low priced supply of seed crabs to local farmers in East Africa in near future.

Furthermore, cost and transportation issues may prevent the effectiveness of such hatcheries in remote resource-poor coastal communities.

Even if hatchery-produced seed crabs become available in East Africa, the availability of sustainable crab feed also limits the maximum size of pond and pen culture possible in coastal communities. To find acceptable and sustainable sources of feed for aquacultures is critical in many developing countries where low valued fish resources constitute important protein sources for human consumption (Funge-Smith *et al.*, 2005; Camber, 2008; Beveridge *et al.*, 2013). Most cage culture farms in East Africa use mangrove snails (*T. palustris*) as a feed. However, these snails are also consumed by humans, and recent field studies on Mafia Island indicate that intense collection to feed small cage culture farms can have negative effects on local snail populations (Hamad, 2012). Thus, mud crab farms using mangrove snails as feed can compete with food for humans if performed at a large scale. In the present study, we assessed how the availability of alternative crab feed resources, which were not used for human consumption, could affect the scaling-up of the farming operation. Hamad (2012) showed that alternative feed sources for mud crabs that were not used for human consumption (fish offal, maize bran and dried anchovy wastes), as well as mangrove snails, resulted in high growth rates in small juvenile mud crabs. On Mafia Island, it was estimated that approximately 20 kg of these feed sources should be available per day in an average sized village (Hamad, 2012), which would limit the maximum size of a pond culture to approximately 300 m^2 and 770 market size crabs (500 g) per village per year, and preventing a profit at the prices presently obtainable on the island. The size of the culture and the production could possibly increase by collecting mangrove snails as a complement. However, considering the large amount needed per day, it would be very time consuming and costly, affecting profitability, and importantly, will likely not be sustainable.

On Mafia Island there is a fish processing plant that produces over 100 kg of byproducts per day that could possibly be used as feed, if made available to crab farmers (Hamad, 2012). If the limitation of seed crabs was solved, villages with access to such or similar food sources could possibly increase the size of the total pond area and the production of mud crabs by approximately 6 times. It is important to note that even a 1800 m^2 pond is very small compared to the industrial grow-out farms for mud crabs in Southeast Asia and China that are often 10-100 times larger (Table 1). Even if all available byproducts on Mafia Island were used as feed there would not be enough feed resources on the island to support a commercial farm of that scale. A commercial-scale mud crab farm would therefore result in competition for food resources with humans and other cultured animals, unless commercial feeds or feed resources were imported. In addition, large-scale industrial mud crab farms would likely result in the clearing of mangroves and destruction of coastal environments, similar to what has occurred as a result of the development of penaeid shrimp farms (Naylor *et al.*, 2000).

In summary, grow-out pond culture of mud crabs could potentially be developed into a sustainable alternative source of income for coastal communities in East Africa. Methods to collect small juvenile seed crabs and farm them in ponds and pens are currently available in East Africa (Mirera and Moksnes, 2015; Mirera, 2014) and local sources of feed appear available in coastal villages. However, mud crab farming based on wild seed crabs and locally available feed can only be sustainable on a very small scale. Moreover, before this activity should be recommended there is a need to solve problems related to high mortality rates in the pond culture systems, and to improve markets and market-chains to increase profits for farmers. Decreasing the market size to 300 g crabs may be one way to improve profit margins. For expansion of these systems to larger scales, interactions with local ecosystems need to be carefully evaluated and hatcheries and formulated feeds need to be developed.

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