Eklöf J.S., Msuya F.E., Lyimo T.J. and Buriyo A.S. 2012. Seaweed Farming in Chwaka Bay: A Sustainable Alternative in Aquaculture? In: People, Nature and Research in Chwaka Bay, Zanzibar, Tanzania, de la Torre-Castro, M. and T.J. Lyimo (eds.). Pp. 213 – 233. ISBN: 978-9987-9559-1-6. Zanzibar Town: WIOMSA.

– CHAPTER 12 –

Seaweed Farming in Chwaka Bay:

A Sustainable Alternative in Aquaculture?

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INTRODUCTION

In Chwaka Bay, aquaculture (the farming of aquatic organisms) is represented by a small-scale but much debated activity; farming of marine macroalgae, or *seaweed farming*. Aquaculture as a whole dates back several millennia in areas like South-East Asia, but has during the last decades become heavily promoted as an alternative livelihood in developing countries to (i) reduce pressure on overharvested natural resources (e.g. fish stocks) and (ii) supply cheap food and income (Tacon 2001). Many promises of this "Blue Revolution" have, however, not been fulfilled, because technical know-how and experience is often lacking (Dadzie 1992; Machena and Moehl 2001), and because some of the hitherto dominating forms (for example farming of giant shrimp/prawns) have been riddled with huge sustainability problems of their own (Deb 1998; Bryceson 2002).

Seaweed farming is, in comparison to e.g. intensive shrimp farming, an alternative form of aquaculture, which has been described as "the most sustainable" form of aquaculture. This is primarily because (i) farming can be conducted in shallow coastal areas or the open ocean (instead of in dugout ponds), (ii) the seaweeds require no addition of fertilizers or pesticides, only enough light and water motion, (iii) the rapid growth rate (up to 15 percent per day) results in relatively short farming cycles (Mshigeni 1976; FAO 2002), and (iv) farming generates a cash income to farmers. Most open-water seaweed farming involves two genera of tropical red algae (Rhodophyta); *Eucheuma* and *Kappaphycus* (Zemke-White and Ohno 1999), farmed for the extraction of carrageenan; a valuable polysaccharide used as a stabilizing, emulsifying and thickening agent in food, cosmetics and pharmaceuticals.

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Figure 1. Photograph of "off-bottom" seaweed farm during a low tide in Chwaka Bay, Zanzibar East coast. Photo: J.S. Eklöf.

In this chapter, we review the knowledge on and status of seaweed farming in Chwaka Bay in particular and the rest of Zanzibar in general. After a short summary of the historical development of the activity, we focus our analysis on three crucial aspects of livelihood sustainability; (i) the socio-economic impacts of the activity on society, (ii) the ecological interactions between the farmed seaweeds and the ecosystems where they are farmed, and (iii) the interactions between these socio-economic and environmental aspects. Finally, we review the measures and efforts that are or have been suggested to increase the sustainability of this activity.

BRIEF HISTORY OF CHWAKA BAY SEAWEED FARMING

The history of East African seaweed farming actually started in Chwaka Bay (Table 1). Inhabitants here, as in most Tanzanian coastal areas, used seaweeds for treating wounds and as fish bait for centuries (Mshigeni 1983b; de la Torre-Castro and Rönnbäck 2004). In Chwaka, however, the collection developed in the 1930s to an organized export of two carrageenan-containing algae, *Eucheuma denticulatum* (Burman) Collins and Hervey and *Kappaphycus alvarezii* (Doty) Doty, to Europe (Andersson 1953; Mshigeni and Semesi 1977; Mshigeni 1983b). As many other seaweed enterprises after, this first Tanzanian seaweed business underwent a "boom-bust" pattern. First, the activity rapidly grew into a full-fledged export business, and supplied 500-800 tonnes dry weight per year (DW/year) by the mid-1950s. Twenty years later, however, the export had declined to 150 tonnes per year (due to overexploitation and international competition) and eventually collapsed (Mshigeni 1998, 389-97).

Table 1. Chronology of the start and spread of seaweed farming in Tanzania. Modified from Msuya (2010).

Area	Activity	Result/Year	Reference
Theoretical studies			
-	Theoretical studies	Publications, 1973, 1976	Mshigeni (1973, 1976)
-	Theoretical studies	Kiswahili booklet, 1983	Mshigeni (1983b)
First experiments			
Zanzibar, Tanga	First experiments	1985	Mshigeni (Unpublished report)
Commercial cultivation			
Paje and Jambiani, Zanzibar	Nursery farms/ expansion	1989	Pettersson-Löfquist (1995)
Chwaka Bay, Zanzibar	Introduction in Chwaka Bay	1990	Shechambo et al. (Unpublished), Eklöf et al. (2005)
Mainland-Tanga, Bagamoyo, Mafia	Feasibility studies & expansion	1992-1996	Zuberi et al. (unpublsihed report), (F. E. Msuya 2010), Bagamoyo seaweed farmers
Mainland-Mtwara/ Lindi	Feasibility studies & nursery farms	1995	Msuya (unpublished report)
Mainland-Mtwara/ Lindi	Expansion	1996	Msuya (unpublished report)
Mainland-Tanga	Deep water bamboo rafts	2000	Zuberi (Unpublished report)
Mainland-Bagamoyo, Zanzibar	Deep water floating systems	2005-2006	Msuya (2006b), Msuya et al. (unpublished report)
Zanzibar-Chwaka Bay	Deep water floating systems	2009	Personal observations

At this stage, Professor Keto Mshigeni of the University of Dar es Salaam introduced the notion of instead farming seaweeds (Mshigeni 1973; Mshigeni 1976) as a new form of income in the *Ujamaa* village system. Following theory development and practical small-scale testing in the early 1980s (Mshigeni 1983a), the ideas were in 1989 realized in large scale as a part of Tanzania's structural adjustment programme. In cooperation with a Danish seaweed export company, who at the time sought new production areas in East Africa (Lirasan and Twide 1993), the first experimental farms were established in shallow intertidal areas outside the villages of Paje and Jambiani (Lirasan and Twide 1993), and reached Chwaka Bay the year after (Mohammed 1999). Following failed initial trials with local strains of *E. denticulatum,* a more sturdier Philippine strain was introduced and is still used today. The seaweeds were initially, and are still, primarily farmed using the "peg-and-line" or "off-bottom" method (Fig. 1), where algal fronds are tied (using

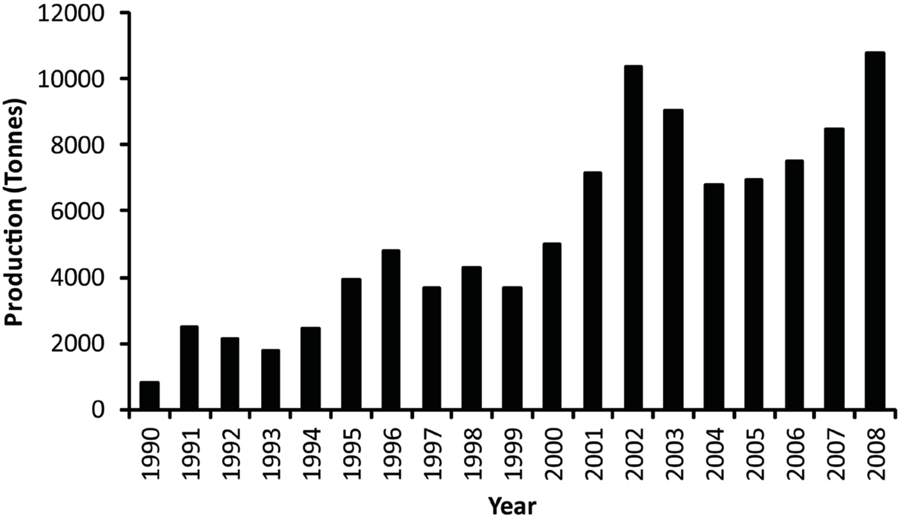

Figure 2. Annual seaweed production (dry weight) in Zanzibar, 1990-2008. Source: Department of Fisheries and Marine Resources (DFMR), Zanzibar.

ribbons called "tie-ties") to ropes stretched between wooden pegs driven into the sediment. Farms are placed in easily accessible and well-flushed sub-tidal areas, which in Chwaka Bay correspond to sub-tidal sand and seagrass banks outside the major villages (Chwaka, Marumbi, Michamvi, Uroa, Ukongoroni, etc.). Farming is conducted by local villagers (primarily women), who harvest and plant seeds during spring low tides every 4-10 weeks (depending on growth rates). The dried raw seaweeds are then sold to local export companies, who in turn sell to the international companies that ship the seaweeds to carrageenan factories in Europe, USA and Asia. Yearly production of seaweeds (tonnes DW per year) in Tanzania started at about 800 in 1990, and has today levelled off at. ca.10,000 (Fig. 2). Around 90 percent of those seaweeds are produced in Zanzibar.

SOCIO-ECONOMIC EFFECTS OF SEAWEED FARMING

In Chwaka Bay, seaweed farming was in 2003 the second most important income-generating activity, following artisanal fishing (de la Torre-Castro and Rönnbäck 2004). Some 482 farmers were in 2008 involved in the activity, selling dried seaweeds to one of the two companies C-Weed Company and Zanzibar Shell export (Msuya, unpublished). These figures mirrors the importance of the activity for the Zanzibar macro economy as a whole, where seaweed farming is the second-largest activity following tourism, and constitute the largest marine export product from Tanzania (>10 times higher export volumes than sea cucumber, unpublished data). The farming employs 15,000–20,000 people in all Zanzibar, of which 90 percent are women (Mshigeni 1998; Msuya 2006a; Fröcklin 2012), and six companies are responsible for the export; C-Weed Company, Birr Sea-Weed Company, Zanzibar Agro-Seaweed Company Ltd (ZASCOL), Zanzibar East Africa Seaweed Company (ZANEA), ZanQue, and Zanzibar Shell**.**

Seaweed farming has undoubtedly had major socio-economic effects on farmers and local communities in both Chwaka Bay and in the rest of coastal Tanzania, particularly during the first years after its introduction (Pettersson-Löfquist 1995). Most importantly, seaweed farming gave farmers – who were and are primarily women – a new form of cash income, e.g. ca. 1,800 TZS per day in Chwaka village in 2003 (ca. USD 1.80 at the time). This daily wage was slightly lower than that of the poorest-earning fishermen (de la Torre-Castro and Rönnbäck 2004). According to several studies from the early and mid-1990s, this new financial input facilitated an improvement in household economy; farmers could with money from seaweeds pay their children's school fees and buy school uniforms, repair and improve their houses, and buy better food (Msuya 1993; Pettersson-Löfquist 1995; Semesi 2002; Msuya 2006a). This contributed to a common view of seaweed farming as a "highly sustainable activity" (e.g. Msuya 1993, Saleh 1998), which unfortunately has changed.

Constraints for Socio-Economic Sustainability

Since the early "glory days" of seaweed farming in the 1990s, the current outlook of farming profitability has changed. In Chwaka village, as in many other areas, farmers are unsatisfied; many feel that even though they spend much of their time on a physically very demanding activity, they do not earn enough to sustain themselves or their families (Bryceson 2002; Rönnbäck et al. 2002; de la Torre Castro and Jiddawi 2005). Moreover, they contract a range of health problems (e.g. poor eye sight and skin infections) by spending much time in seawater (Fröcklin et al. 2012; Forss, unpublished data). Therefore, many farmers today spend less time farming than before, or have completely abandoned the activity to be able to earn a higher income from other activities (Bryceson 2002; de la Torre Castro and Jiddawi 2005). Moreover, it appears that the full potential effect of these low incomes on farming is not realized. Kinship relations have been identified in the community dynamics in the Bay. It affects total household income since most farmers are married to higher-earning fishermen (de la Torre-Castro and Ronnback 2004; de la Torre-Castro 2006; de la Torre-Castro and Lindstrom 2010).

Environmental Constraints

The low earnings from seaweed farming appear to depend on a combination of interacting environmental and economic factors (Fig. 3). A first problem is the near inability to farm the most valuable species; *Kappaphycus alvarezii*, which produces a much stronger structural form (isomer) of carrageenan than *Eucheuma* *denticulatum*, and therefore fetches a much higher market price; 260–400 TZS per kg dry weight, compared to 160–200 for *Eucheuma*, respectively (1USD = 1,485 TZS. in October 2010). However, *K. alvarezii* cannot be farmed in many areas (including Chwaka Bay) due to poor growth and die-offs driven by disease (Msuya 2007; Msuya 2011b). As a consequence, farmers forced to farm the cheaper *E. denticulatum,* who constitute the majority in East Africa, may at best lose up to 50 percent of their potential income, or in the worst case be completely unable to sell their product. These seaweed diseases and die-offs are not exclusive to Tanzanian seaweed farms (Uyenco et al. 1981, 625-30; Ask and Azanza 2002), and are stress responses to unsuitable conditions, e.g. too high stocking densities, rapid changes in salinity and/or temperature, overgrowth of fouling organisms, or by disturbances such as herbivory, excessive nutrient loads, and siltation (Uyenco et al. 1981, 625-30; Msuya 2007)**.** Environmental factors can constrain farming incomes also in other ways, e.g. in terms of farm location. Outside Chwaka village, for instance, most suitable farming areas are shallow sub-tidal banks, accessible only by boat. Farmers therefore have to pay for a small fee transport and subsequently loose part of their potential income (de la Torre-Castro and Rönnbäck 2004).

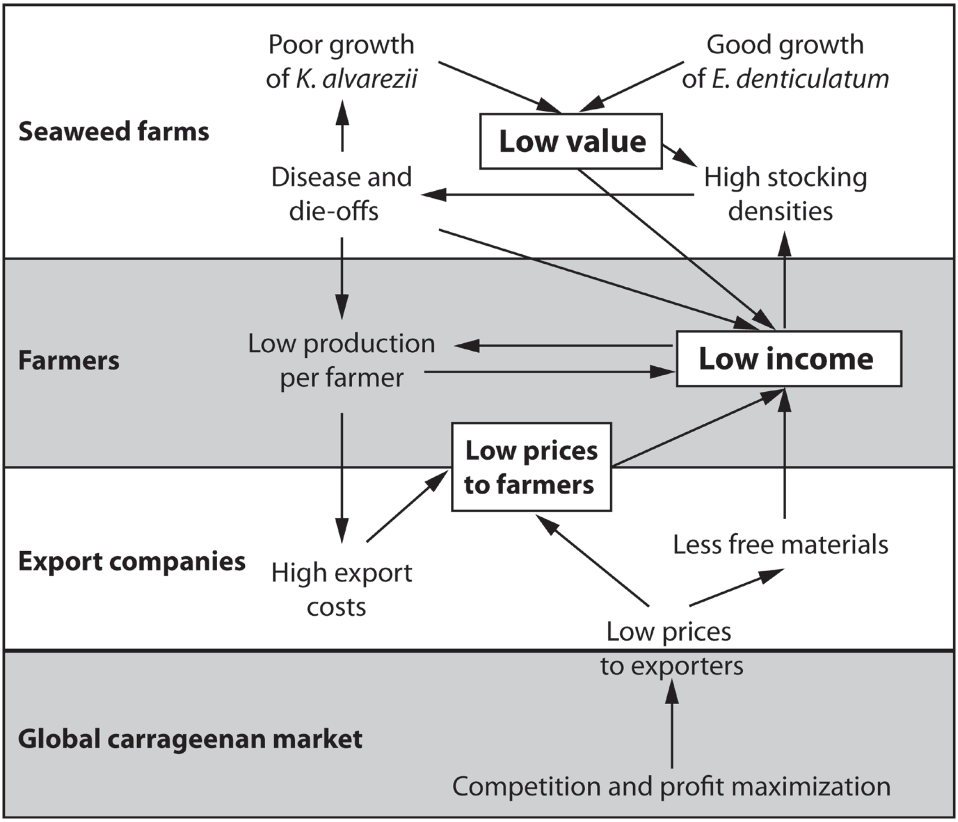

Figure 3. Conceptual figure of interactions between environmental and economic factors which appear to keep earnings from seaweed farming to farmers – and indirectly, farming intensity – at low levels.

Socio-Economic Constraints

In addition to environmental factors, a range of socio-economic factors constrain seaweed farming. First, prices on seaweeds have not kept up with the high inflation in Tanzania, and even though the Tanzanian government in 2006 raised minimum price levels and abandoned the old "monopsony" system (where certain export companies had the exclusive right to purchase seaweeds in every village), exporters still keep prices low as they are "squeezed" by competition on the global market (Lange and Jiddawi 2009). Second, the export companies are naturally interested in keeping prices low to maximize profits, which can result in a cynical approach to farming. One of the main companies were earlier exposed to deliberately promote farming in the poorest areas with few or no livelihood alternatives, because farming will there become a "*way of life*" where farmers "*don't think too much about price, they just farm because they have always farmed*" (see Bryceson 2002 and Rönnbäck et al. 2002 for more details). Even though a company representative later emphasized the importance of improving the farmer's situation for the benefit of the whole carrageenan industry (Ask 2001, 14-18), farmers on Zanzibar were apparently not satisfied (de la Torre-Castro and Jiddawi 2005; Lange and Jiddawi 2009). A third factor is that the average farmer today produces less than half of the biomass per year compared to those farming in the early 1990s, most likely because of the low income generated (Lange and Jiddawi 2009). Finally, there are indications that companies in some of the newer farming areas (e.g. Tanga on the Tanzanian mainland) have occasionally stopped buying seaweeds, due to low production volume of the high-price *Kappaphycus* and/or high export costs (caused by the export distance). Moreover, some companies have stopped supplying farmers with previously free farming materials (lines and tie-ties), without increasing prices (Msuya, personal observation).

Do Interacting Constraints "Lock" Farming in a Low-Income State?

By reviewing these factors together, it is obvious that they often interact and "boost" each other via positive feedback (Fig. 3). For instance, low prices can on the one hand result in overstocking to increase profits, resulting in increased risk for die-offs and potential loss of income. On the other hand, low prices can result in a reduction in farm intensity (to make time for other activities), which also reduces income to the farmer. If these feedbacks are strong enough, they could potentially "lock" the activity in a chronic low income-state, similar to poverty traps in economy (Azariadis and Stachurski 2005, 295-384).

INTERACTIONS BETWEEN SEAWEED FARMING AND THE ENVIRONMENT

Seaweed farming has often been referred to as one of the most environmentally sustainable forms of aquaculture (Msuya 1993; Saleh 1998; Santelices 1999; Zemke-

Figure 4. ***Eucheuma denticulatum*** **seaweeds farmed in a shallow** ***Enhalus acoroides*** **seagrass bed in Chwaka Bay. Photo: Johan S. Eklöf.**

White and Ohno 1999; Ask 2001). On the one hand, open-water seaweed farming is carried out in natural environments and requires no fertilizers or antibiotics, which makes the activity much more sustainable than e.g. intensive shrimp farming. On the other hand, seaweed farming constitutes the introduction and assisted growth of massive quantities of non-native strains (or even species) in densities and ecosystems that they normally do not occur in (see e.g. Fig. 4 for seaweed farm in seagrass bed in Chwaka Bay). The presence of these massive amounts of seaweeds could therefore affect native species and ecosystems, e.g. by (i) competing for limiting resources like light, space and nutrients, by (ii) altering trophic interactions (as they constitute a novel food source to herbivores), and by (iii) exuding potentially toxic substances like hydrogen peroxide and halogenated compounds (Mtolera et al. 1995; Mtolera et al. 1996). In addition, farming-associated disturbances like trampling and boat moorings can disturb habitat-forming sessile species like seagrasses and stone corals.

On-farm Effects on Biota

Concerns about the environmental sustainability of Tanzanian seaweed farming were early raised by local scientists (Mtolera et al. 1992). As a consequence, the introduction of farming triggered a series of studies in the major farming areas south of Chwaka Bay. The results indicated that farming impacted most of the

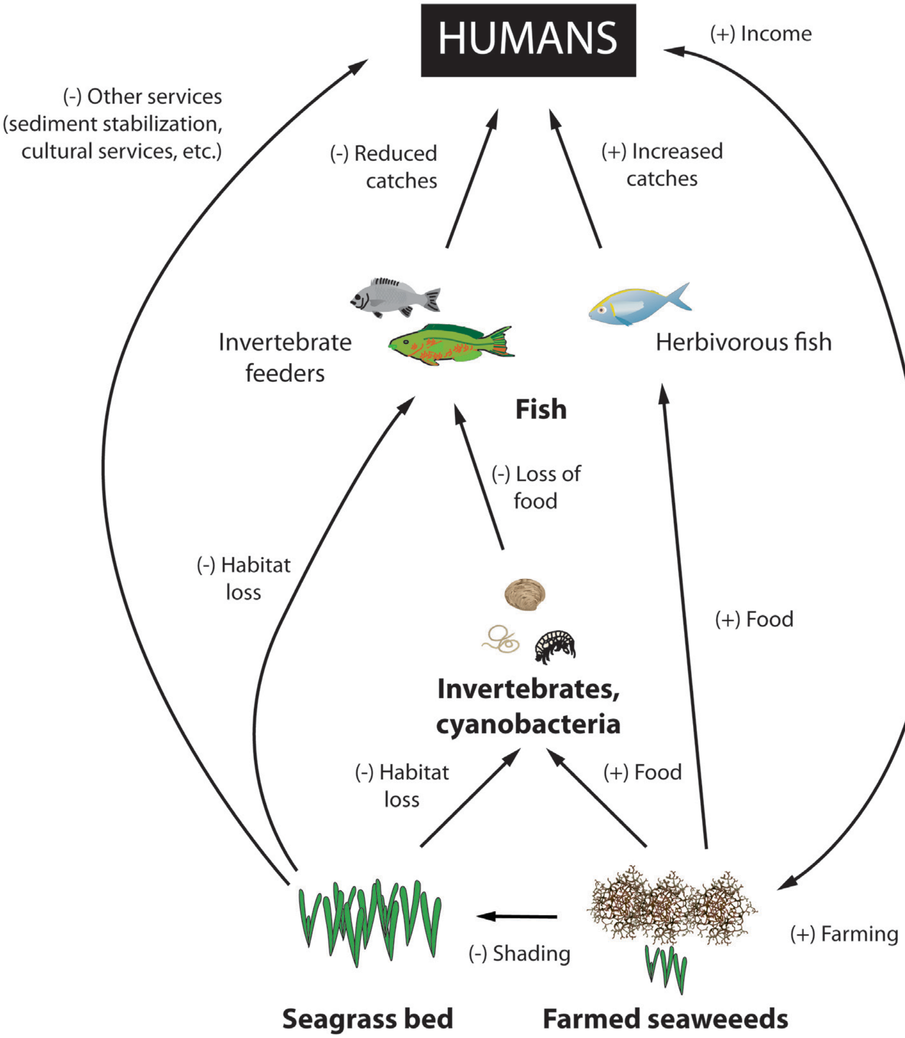

Figure 5. Conceptual diagram of environmental effects of seaweed farming on various levels of seagrass food webs. Symbols courtesy of IAN, University of Maryland.

studied organisms negatively; farming altered meiofauna community structure and reduced meiofauna diversity (Ólafsson et al. 1995), reduced bacterial production (Johnstone and Ólafsson 1995), and reduced macro-flora and -fauna diversity and abundance (Msuya et al. 1996; Semesi 2002).

Effects on Seagrasses

In Chwaka Bay, seaweed farms are – in contrast to many other areas – often placed in seagrass beds (Fig. 4; see chap. 5). The reasons for this practice vary, and include lack of available vegetation-free areas and the belief that some species of seagrasses fertilize seaweed growth (de la Torre-Castro and Rönnbäck 2004). More than two thirds of interviewed farmers in Chwaka village acknowledge that farming has negative effects on seagrasses, primarily because farmers "clean" their plots by deliberately uprooting seagrass plants (de la Torre-Castro and Rönnbäck 2004). However, seaweed farming could also impact seagrasses through e.g. (i) shading, (ii) competition for nutrients in the water (Collén et al. 1995), (iii) mechanical abrasions by algal fronds, (iv) trampling, and (v) excretion of toxic hydrogen peroxide and halogenated compounds (Mtolera et al. 1995; Mtolera et al. 1996). A series of field studies with comparative sampling in farm and non-farming areas (as controls) has, as expected, shown that seagrass cover, canopy height, shoot density and biomass was generally lower in seaweed farms (Eklöf et al. 2005; Lyimo et al. 2006). However, results on seagrass biomass and diversity changes over one year revealed insignificant differences with seasons (Lyimo and Hamisi 2008). In addition, a survey of growth characteristics of the two seagrass species *Thalassia hemprichii* and *Enhalus acoroides* showed that seaweed farming does not have direct impact on the growth characteristics of seagrasses (Lyimo et al. 2006). The inconsistency of these results highlight a major drawback of comparative surveys – that "control" and "farm" areas always will differ in more ways than the presence/absence of farms (even before farming was started), which makes it inherently difficult to separate farming effects from natural spatial and temporal variation. The only way to detect farming effects are to design experiments based on the Multiple Before-After Control-Impact experimental studies (MBACI) method, where replicated farm and control treatments are randomly allocated to similar areas, and then monitored over time. Only one study has so far tested environmental effects of seaweed farming in this way, and this study was conducted in Chwaka Bay (Eklöf et al. 2006a). By randomly allocating seaweed farm treatments to seagrass plots of 1.5m × 2.5m, the authors showed that over an 11-week farming cycle, the mere presence of the farmed seaweeds reduced the leaf length, biomass and growth of the dominating seagrass species (*Enhalus acoroides*) by ca. 40 percent. The most likely causes to the impact was (i) shading, as only a few percent of incoming light penetrated the algal thicket, and (ii) mechanical abrasion by the farmed seaweeds (which broke off the seagrass leaf tips). Meanwhile, another co-occurring seagrass species – *Thalassia hemprichii* – was not affected by the farming, which most likely was the consequence of reduced interspecific competition from the much larger and competitively superior *E. acoroides*; i.e. an indirect effect of the seaweed farming. Even though these negative effects are undisputable, actual farming areas outside Chwaka and Marumbi villages in Chwaka Bay have 15-20 percent seagrass cover (primarily found in narrow strips between farm plots) after more than 10 years of farming (Eklöf et al. 2005). In combination with the relatively limited size of the farming areas; 2.5km^2 or 5 percent of the total Bay surface area (de la Torre-Castro and Rönnbäck 2004), it appears that at the current intensity, seaweed farming has limited impacts on the Bay seagrasses as a whole (Eklöf et al. 2006a). This is supported by anecdotal information from farmers, claiming that seagrasses usually grow back into farms two-three months after farming is ceased (de la Torre Castro and Jiddawi 2005).

Effect on Cyanobacteria Diversity and Nitrogen Fixation

Epiphytic and epibenthic diazotroph cyanobacteria are among the sources of readily available nitrogen to the farmed seaweeds, which can replace the nitrogen removed through seaweed harvesting. Any effect that may result into reduction of this process would therefore cause long-term effects on seaweed yield. The results of a comparative study conducted in Chwaka Bay to assess farming effects on cyanobacterial diversity, abundance and nitrogen fixation rates in seagrass meadows showed insignificant effects on total microalgal biomass, dissolved inorganic nutrients as well as nitrogen fixation rates (Lyimo and Hamisi 2008). There was, however, a higher frequency of occurrence of cyanobacteria species in control than farmed areas, which could potentially be due to farming activities (Lyimo and Hamisi 2008).

Effects on Macrofauna and Food Webs

Seaweed farming in Chwaka Bay also affects the diversity, abundance, biomass and community structure of fauna, including infauna (small invertebrates like worms, molluscs and crustaceans in the sediment) and larger epifauna (sponges, sea urchins, etc. living on the sediment). These patterns have been demonstrated in both comparative field surveys (Eklöf et al. 2005) and experiments (Eklöf et al. 2006), and appear to be primarily caused by the loss of seagrasses. Eklöf et al. (2005) showed that 99 percent of the difference in macrofauna community composition between seaweed farms and non-seaweed farm areas could be explained by percent cover of benthic macrophytes (seagrasses and benthic macroalgae like *Halimeda* spp., not including farmed seaweeds) and percent sediment organic matter content; two variables in turn strongly affected by farming. Interestingly, farming had particularly strong impacts on lucunid bivalves, which at the one hand depend on seagrass presence and at the other hand benefit seagrass growth by harbouring sulfide-reducing bacteria (Barnes and Hickman 1990, 215-238).

Effects on invertebrate benthic organisms are likely to cascade up the food chain to fish, as they constitute a major food source for invertebrate feeders like snappers and emperors (de la Torre Castro et al. 2008). Visual fish surveys in areas just north of Chwaka (i.e. Kiwenga and Matemwe) showed that even though fish species diversity and density did not differ between seaweed farms and reference areas, herbivorous fish were much more common in farms than in control areas (Bergman et al. 2001). As such effects could affect fish catches; another study was conducted inside Chwaka Bay, to test if farming affected potential fish catches in *madema* basket traps (see Chap. 11). The results showed that herbivores like the seagrass rabbit fish (*Siganus sutor*) dominated catches in traps placed within seaweed farms, whereas invertebrate feeders dominated catches in traps placed in a reference seagrass site (Eklöf et al. 2006b). A follow-up survey within seaweed farms confirmed that the presence of the farmed seaweed themselves drove the dominance of herbivorous fish (Eklöf et al. 2006b). Not surprisingly, algal herbivores like *S. sutor* regularly feed on *Eucheuma denticulatum,* both according to farmers' own observations (Bryceson 2002), and fish stomach content analyses (de la Torre Castro et al. 2008). Viewed together, these results indicate that the farmed seaweeds attract fish; a notion early claimed by fishermen south of Chwaka Bay (Mtolera et al. 1992). At the one hand, it could therefore be argued that seaweed farming could aid in the flow of another ecosystem service, fisheries. On the other hand, high fish catches do not account for the fact that if seaweed farms attract fish without increasing actual fish production (which is possible), fishing on farm-associated fish could increase the risk for local depletion of stocks (because fish are concentrated to smaller areas). It could also reduce grazing pressure on other plants; in Hawaii, for instance, food preference of native herbivorous fish for the introduced *Kappaphycus* indirectly reduced grazing control over other invasive seaweeds on coral reefs (Stimson et al. 2001). It should also be noted that in Southeast Asia, where farming operations are much larger than in Chwaka Bay, resource user conflicts between farmers and fishermen over the right to use certain areas are very common (Sievanen et al. 2005). Even though kinship between farmers and fishermen in Chwaka appear to "buffer" such conflicts (de la Torre-Castro and Lindström 2010), they could become more common if farming is expanded.

Viewed together, these results show that seaweed farming indeed affects various components of the Chwaka Bay ecosystem, from seagrasses via invertebrates to fish catch composition (Fig. 5). This emphasizes that even though the current impacts on the ecosystem are minimized by the low farming intensity, much stronger impacts should be expected if seaweed farming is expanded.

Off-farm Effects: Spread of "Invasive Aliens"

In an international perspective, the major environmental concern about seaweed farming is the risk for spread of farmed "alien" seaweeds to adjacent ecosystems. Even though this issue has received little interest in Tanzania, the establishment and potential impact of farmed seaweeds in Chwaka Bay has been investigated in one field survey and one field experiment. By snorkelling surveys, Andersson (2005) found that the farmed seaweeds (*Eucheuma*) did occur also outside farms but in limited amounts, which could be due to limited spread but also intense gleaning (collection) by seaweed farmers and fishermen. A subsequent field experiment showed that *Eucheuma denticulatum*, which had been deliberately added to coral reef areas, were rapidly consumed by grazing fish (Andersson 2008). This could indicate a limited risk that farmed seaweeds could spread to and eventually overgrow coral reefs in the Bay. However, a very similar situation occurred three decades earlier in Kaneohe Bay (Hawaii), and developed into an ecological "catastrophe". In the late 1970s, an abandoned seaweed farming project was initially found to have little impact, because herbivorous fish appeared to control the growth of the escaped algae; *Kappaphycus alvarezii* (Russell 1983). However, nearly 20 years later, the algae were suddenly observed to not only have survived and remained, but to have spread to, overgrown and finally suffocated many of the coral reefs in the Bay (Conklin and Smith 2005). In Chwaka Bay, we are aware of no such effects, but following the Boxing day tsunami 2004, massive amounts of *E. denticulatum* were washed up on the shores, even though farmers reported minimal losses from farms (Eklöf et al. 2006a). According to many fishermen, these washed-up seaweeds originated from deep areas near the Bay mouth, where drift algae from farms apparently had accumulated over the 20 years of farming (Eklöf, personal observation). Undoubtedly, the limited knowledge on these issues in Tanzania, combined with the development in Hawaii, emphasizes the need for in-depth studies of the distribution and potential spread of farmed algae in Chwaka Bay and elsewhere. Such studies have recently started in a joint Swedish-Tanzanian research project funded by Sida.

Environmental Factors Affecting Seaweed Production

The growth of seaweeds is like all other organisms regulated by environmental factors. Besides light, which is crucial for all plants, one of the most important is temperature. The surface water temperature in Chwaka Bay varies over the year from ca. 22 to 35°C (Eklöf et al. 2005; Andersson 2008), whereas seaweed growth optimum is 25-30°C (Mshigeni 1983b). As expected, *E. denticulatum* growth declines when temperate exceeded 32°C (Buriyo et al. 2001).

Another factor is salinity, which during most time is about 33-35 ‰ in the Bay (Buriyo and Kivaisi 2003; Eklöf et al. 2005); i.e. optimal for *E. denticulatum* and *K. alvarezii* growth. But during periods with heavy rains, salinity in the intertidal farming areas may drop to 26 ‰ (Buriyo et al. 2001). The subsequent negative effects on growth are confirmed by farmers, who cannot farm during monsoons due to poor growth (de la Torre Castro and Jiddawi 2005).

A third factor is supply of essential macro-nutrients like nitrate, ammonium and phosphate. Even though concentrations in Chwaka Bay (Mohammed and Johnstone 2002) matches those required for macroalgal growth (Lobban and Harrison 2000), experimental nitrogen and phosphorus addition more than doubled *E. denticulatum* growth (Andersson 2008). On the one hand, this suggests that seaweed farming – and farming profits – could benefit from higher nutrient loads, and potentially mediate eutrophication (Msuya and Neori 2002; Rodrigueza and Montano 2007). On the other hand, *E. denticulatum* and *K. alvarezii* are sensitive to high nutrient loads, and farming of enough algae to remediate eutrophication will most likely affect other aspects of the ecosystem (see above).

A fourth and somewhat surprising factor, which potentially could benefit seweed growth, is seagrass presence. Based results of a field survey, Mtolera (2003) suggested that seaweeds farmed in areas with seagrasses (near Uroa village) grow faster than those in seagrass-free areas (outside Paje village), because seagrasses extract and excrete sediment-bound nutrients (Mn, Fe and Zn) that when taken up by the seaweeds enhance their resistance to infections. This intriguing hypothesis requires thorough field and lab testing, but could provide an incentive to keep seagrasses intact close to farms.

Finally, seaweed growth can be severely hampered by herbivory. Grazing pressure within farms has not been measured in the Bay, but is probably substantial because algal-feeding rabbit fish dominate the farm fish community (Eklöf et al. 2006b). Moreover, Sea urchins (*Echinometra mathaei*), the most abundant benthic grazers, appear to be particularly attracted to the seaweeds (Eklöf et al. 2006a).

COUNTER-MEASURES TO INCREASE FARMING SUSTAINABILITY

Seaweed farming spread rapidly on Zanzibar during the 1990s, and clearly contributed to the economy at local and the national level. However, the development of farming in Chwaka Bay, as well as in other areas in East Africa, has been slow (Rice et al. 2006; Rönnbäck et al. 2002). The major constraints are the poor growth of Kappaphycus spp. and the low and fluctuating prices on seaweeds, which constrains socio-economic sustainability (see above). To reduce the risk that seaweed farming becomes locked in a "low income" state (Fig. 3), there is need for innovation, intensification and expansion of the activity (Rice et al. 2006). This has been suggested to be aided by (i) moving *K. alvarezii* farms to deeper waters (Rice et al. 2006), (ii) improving *E. denticulatum* farming and develop alternative uses and markets (looking for more markets to sell the less preferred *E. denticulatum*), (ii) promote value addition on the seaweeds, and (iii) farming other species. Meanwhile, a potential expansion must take all aspects of sustainability – environmental, social, economic, etc. – into account (Eklöf et al. 2006a). In this final section we briefly review the feasibility of these strategies, emphasizing the necessity of increasing the overall sustainability of the activity.

Farming in Deeper Waters

One of the main approaches suggested to increase production and combat die-offs in *Kappaphycus alvarezii,* and thereby increase profits, is to establish farms in deeper and cooler water (Msuya 2007; Rice et al. 2006). Such farming techniques have been put into practice in some areas in Tanzania using a floating lines system (Msuya 2006b; 2007; 2010). In Chwaka Bay, however, field trials have so far been unsuccessful due to strong winds (Msuya, unpublished data), and the particular setting with shallow areas, strong currents, and major fluctuations in water depths could make deep-water farming within the Bay very challenging. Moreover, moving farms to deeper areas outside the Bay would require that farmers have access to large boats with powerful engines, and the finances to use them and still make enough profit. Currently, most farmers lack the finances to make such investments, and the potential environmental impacts of farming at the scales and/or intensi-

Figure 6. Possible value addition products from seaweed farming; soap produced partly from seaweed extracts on Zanzibar. Photo: Flower E. Msuya.

ties necessary to achieve high enough profits from deep-water farming, should be thoroughly investigated before large-scale initiation of such enterprises.

Improving Existing Eucheuma and Kappaphycus Production

To improve seaweed growth rates also in off-bottom farming, the export companies have themselves imported new strains and species of *Kappaphycus*; *K. striatum* (or *kikarafuu*) and two new varieties of *K. alvarezii* (*kikorosho* and *bulabula*). These have either performed poorly or are still under trial farming. When new strains are introduced, it is crucial that all seeds are carefully controlled for non-native epiphytes or disease, to reduce the risk for additional negative effects on the farmed seaweeds as well as the environment where they are farmed. According to an anonymous key person within one of the seaweed export companies, companies have conducted field trials with new strains without notifying authorities or any quarantine procedures (Eklöf, personal observation).

The government of Zanzibar (SMZ) has with funding from Regional Program for the Sustainable Management of the Coastal Zones of Indian Ocean Countries (ReCoMaP) also experimented with the "cast method"; a farming method where seaweeds are tied to stones instead of line, and therefore can be farmed in hard-bottom areas as well. Such small-scale methods could with proper planning and site selection expand seaweed farming into rocky bottoms areas. However, lessons from SE Asia indicate that implementation of such methods could – if management is not strict – encourage farming in coral reef areas, which negatively impacts coral growth (Primavera J., personal communication).

The export companies are also trying to boost seaweed production in new ways. Birr Sea Weed Company has, for instance, designed a system of giving gifts (e.g. clothes and money) to the best producers of seaweed (Msuya, personal observation). Such systems should, however, not replace increases in prices, because they create a patron-client relationship situation where farmers may feel pressured to continue farming and/or accept the low prices.

Improving Seaweed Markets

Since the seaweed export companies only sell to certain buyers abroad, seaweed farmers in Chwaka village have themselves started to search for other buyers, i.e. to become exporters themselves. This is being conducted under The Seaweed Cluster Initiative in Zanzibar (ZaSCI), and one group has applied to the government for license to export seaweed from Chwaka and other villages to China and Singapore (Msuya, personal observation). If granted, such efforts could encourage farmers to produce more, because they have control over a larger part of the supply chain. It should, however, be noted that without government subsidies, the high costs involved in export and the fierce price competition on the global market, could make it difficult for small export companies to survive.

Innovation and Value Addition

In 2006, the Seaweed Cluster Initiative in Zanzibar (ZaSCI) was started to increase innovation of the seaweed industry through modification of the farming techniques and adding value on the seaweed. With the vision "*to be the best producers and sellers of quality seaweed and seaweed value-added products by 2015*", ZaSCI has adopted and tried to spread the deep-water floating lines technique, and prepared to construct drying racks in Chwaka to improve seaweed quality. ZaSCI as well as United Nations Industrial Development Organization (UNIDO) have also pushed value-addition to promote farming. Chwaka village is one of the villages where training and production of e.g. soap (see Fig. 6), body cream and food out of seaweeds has been done (Msuya 2006b, 2011a). Large volume production and marketing of such products, coupled with product diversification, are among the strategies of sustaining the industry. It is, however, unknown whether markets exists and are large enough to sustain such production.

Farming of Other Species

Local scientists have also started looking into the possibilities of farming species from other genera of macroalga such as *Gracilaria* for production of agar; another highly valuable phycocolloid with a small but existing local market (Buriyo and Kivaisi 2003).

THE NEED FOR A HOLISTIC VIEW: HOW RELATIVELY SUSTAINABLE IS OPEN-WATER SEAWEED FARMING?

This chapter shows that in Chwaka Bay, and probably on Zanzibar as a whole, the socio-economic sustainability of seaweed farming has for some time been quite low. This is clearly demonstrated by the fact that many farmers farm less or have completely ceased farming, and that various forms of "subsidies" (via governments, NGOs or other social factors) are in place to sustain the activity. Ironically, this low socio-economic sustainability appears to at the same time keep the environmental sustainability relatively high, simply because farming is conducted at a relatively small scale. If seaweed farming is to become more sustainable for farmers, the factors constraining the activity, primarily the low income (see Fig. 3), must be weakened. One major problem with this is that the opposing stakeholders have very different means to "push" their respective agenda. The seaweed farmers, for instance, want higher prices but are poor and often relatively unorganized, whereas the export companies – who want to keep costs (including prices) at a minimum – have huge financial means and are highly organized. There have been efforts to organize farmer "walkouts" to try to force higher prices, but the companies have simply bought seaweeds from other areas (de la Torre-Castro and Jiddawi 2005). In such situations, it is not surprising that many farmers resort to their only available mean of negotiation; i.e. to completely stop farming. Moreover, even though the suggestion to move farming to deeper waters may increase production, it is currently too costly in terms of equipment and transport costs to ensure high enough production, and the activity could there interfere with fisheries (Sievanen et al. 2005) and have currently unknown environmental effects (Eklöf et al. 2006b). Finally, as deep-water farming is already implemented at large scales in Southeast Asia (Sievanen et al. 2005), it is unknown whether the smaller Tanzanian and East African production could be competitive on the global market.

Seaweed farming has been a first step in the right direction towards aquaculture sustainability. However, we - as others - emphasize that the current form of seaweed farming constitutes a prime example of a "corporate-intensive monoculture" of a "cash crop", which are inherently prone to problems like disease, poor health among farmers, and prices dictated by global market forces (Bryceson 2002; Rönnbäck et al. 2002; Fröcklin et al. 2012). From this angle, seaweed farming has become worryingly similar to those forms of aquaculture (e.g. intensive shrimp farming) that it was originally intended as an alternative to. Combined with the need for sustainable alternative livelihoods in areas like Chwaka Bay (de la Torre Castro and Jiddawi 2005; chap. 1), there is a pertinent need for a thorough evaluation by independent experts of the relative sustainability of seaweed farming in relation to existing and potential livelihood activities. Most likely, small-scale integrated polyculture of seaweeds, fish and bivalves constitutes the natural next step towards even higher sustainability (see also chap. 13).

ACKNOWLEDGEMENTS

We thank the seaweed farmers and fishermen of Chwaka Bay and Tanzania for their support and assistance over the years. We also thank the many researchers, companies and government representatives who contributed with the information cited herein. The work of JSE was supported by Formas and Sida.

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