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Societal and environmental impacts of seaweed farming in relation to rural development: The case of Kibuyuni village, south coast, Kenya

David O. Mirera *, Alex Kimathi, Morine M. Ngarari, Esther W. Magondu, Miriam Wainaina, Agwata Ototo

Kenya Marine and Fisheries Research Institute, P. O. Box 81651-80100, Mombasa, Kenya

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ABSTRACT

Seaweed cultivation has become a major alternative source of livelihood to a number of coastal inhabitants in developing countries. It has a high return on investment compared to activities like fishing. Farming was introduced to communities in the south coast of Kenya to improve the wellbeing and enhance development initially with one village (Kibuyuni) but has currently spread to five other villages and continue to interest more participants. The current study aimed to understand the societal and environmental impacts of seaweed farming at Kibuyuni village in the south coast of Kenya to inform management interventions in the coastal areas. A multidisciplinary research approach using different methods including observation, surveys, focus group discussion and field experiments were used to collect data. Secondary data was mined from grey literature on the project that included project reports, farm records and unpublished status reports. On growth of seaweeds, the study revealed that off bottom culture method provided better growth rates and was fully adopted by farmers. Seaweed farming is practised within specific times of the day and month thus offer flexibility in involvement of farmers and labourers to participate in other income generating activities for diversification and spreading of risks. Further, the farming has different production chains that create employment for casual labourers. The industry raised a total of $ 12,000 direct income to Kibuyuni village through sell of dry seaweeds in 2017 in addition to other indirect benefits accrued. Income gained from sell of dry seaweed revolutionised the village through construction of modern houses, paying of school fees, medical care, food security and nutrition among other investments. Women form the highest proportion of seaweed farmers (75.2%) while youth and men contribute 7.62% and 17.14% respectively. Income earned from the business has given women an opportunity to contribute in the family decision-making process. Prices for dry seaweeds have fluctuated over time though the local buyers have maintained the purchasing power. During the last years, farmers have been involved in fabrication of value added products from seaweeds like soaps, salad, shampoo and fish feed with an aim of increasing revenue from seaweed farming. Investments in seaweed farming enterprises at Kibuyuni have opened the village to development of road networks and electrical power supply. The study found out that seaweed farming has minimal environmental impacts to the marine (herbivores fish increased while carnivores fish decreased after establishment of farmers) and terrestrial ecosystem bordering the farms. Therefore seaweed-farming has a potential of impacting positively on the wellbeing of coastal communities if proper management interventions are put in place to mitigate the associated negative impacts that may arise in addition to broader effects of development like migrations that are currently minimal.

1. Introduction

Currently, commercial harvesting of seaweeds takes place in at least 35 countries from the Northern to Southern hemispheres, and in cold, temperate and tropical areas. However, production from natural sources has not been able to meet the global market demand. Farming of seaweed has expanded rapidly to close the global demand and supply gap. Globally, there are seven cultivated seaweed taxa and only three are used majorly for hydrocolloid extraction i.e. *Eucheuma denticulatum, Kappaphycus alvarezii* (carrageenans) and *Gracilaria* species-agar (FAO,

* Corresponding author.
E-mail addresses: dimirera@yahoo.com (D.O. Mirera), kimathi_alex@yahoo.com (A. Kimathi), morinemukamik@gmail.com (M.M. Ngarari), nimmss2003@yahoo.com (E.W. Magondu), miriam.wainaina63@gmail.com (M. Wainaina), agwatao@yahoo.com (A. Ototo).

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2014, 2016). Therefore, farming of seaweed is viewed as a major source of livelihood to many coastal villages in developing countries (Hurtado-Ponce et al., 2001; Ask et al., 2003; Msuya, 2006). The farming has low investment costs and yields are high with a return of 78%–100% annually (Padilla and Lampe, 1989; Luxton and Luxton, 1999; Slater et al., 2017).

Seaweeds are one of the highly farmed marine plants in east Africa because they require low-level technology and short grow-out periods (45 days to harvest). Generally, it is argued that farmed marine plants have low negative environmental impacts and more positive societal impacts. Consequently, farmed seaweeds do not require refrigeration or high-tech post-harvest processing other than sun drying or drying under shade that is compatible with traditional fishing, subsistence activities like shell collection in intertidal areas and subsistence agriculture (Bryceson, 2002; Pickering, 2006; Msuya et al., 2007). Previous studies in east Africa have established seaweed farming to be a potential source of income and employment especially for women and the youth in the coastal areas (Wakibia et al., 2011; Bryceson, 2002; Wakibia et al., 2006; Msuya, 2013b). In Zanzibar, Tanzania, seaweed aquaculture is a well-entrenched activity that generates foreign currency and gives women, an opportunity to earn an income for self and family development (Msuya, 2012; Murphy and Allen, 2002; Msuya et al., 2007; Valderrama et al., 2013).

Seaweed farming in Kenya was initiated together with Tanzania at experimental scale in the 1980s with good growth being attained though farming was halted citing market challenges (UNEP, 1998). Further experiments by McHugh (2003) concluded that seaweed farming in Kenya had low prospects of developing as an industry. However, later experiments by Wakibia et al. (2006) recorded significantly higher growth rates (3.5 and 5.6%/day) that are comparable to other studies globally and therefore gave a new dimension to the seaweed farming industry (Doty, 1986; Msuya, 2013a). Between 2009 and 2010, Kenya Marine and Fisheries Research Institute (KMFRI) through Government of Kenya (GoK) funding supported local farmers to develop small-scale seaweed farms in the south coast of Kenya (Kibuyuni). A number of actors have further supported the seaweed industry in the south coast of Kenya among them Regional Coastal Management Programme (ReCoMaP), Non-Governmental Organisations (PACT/Act-Kenya, Plan international), Community Based organisations (CBOs) and Beach Management Units (BMUs) all geared towards improved human wellbeing.

To date, there has been limited documentation of the societal and environmental impacts of seaweed farming enterprises as providers of livelihoods, environmental health and contribution to general community development. Therefore to adequately recommend seaweed farming as an alternative livelihood and contributor to environmental management among the communities living in east Africa, a study was undertaken to quantify and analyse the societal impacts of the investments using the case study of Kibuyuni village in the southern coast of Kenya. The results of this study will inform the scientific community and stakeholders in extension on efficient decision-making and policy development for seaweed farming.

2. Structure of the study

2.1. Target site

The study was conducted at Kibuyuni village that is located near the shores of the Indian Ocean (S 04° 38.377′, E 039° 20.352′) in the south coast of Kenya (Fig. 1). The village has two key infrastructure facilities that support seaweed farming and fishing (seaweed processing factory and fish landing/handling shade "fish banda" respectively). Seaweed farming in the village was initiated at experimental scale in the year 2008 and increased thereafter to the current commercial levels. Kibuyuni village is characterised by rocky grounds that negatively impact terrestrial agriculture development. The seaweed-farming group has 105 members comprising of 75.2% women, 7.62% youths and 17.14% men. The study site was characterised by tidal fluctuations and the sea bottom had patches of sea grass being dominated by *Thalassia hemprichii, Thalassodendron ciliatum, Cymodeocea rotundata, Halodule wrightii* respectively. Beyond the seaweed farms seawards, there is a coral strip (most common and abundant genera were: *Porites, Pavona, Acropora, Galaxea, Favia, Echinopora*).

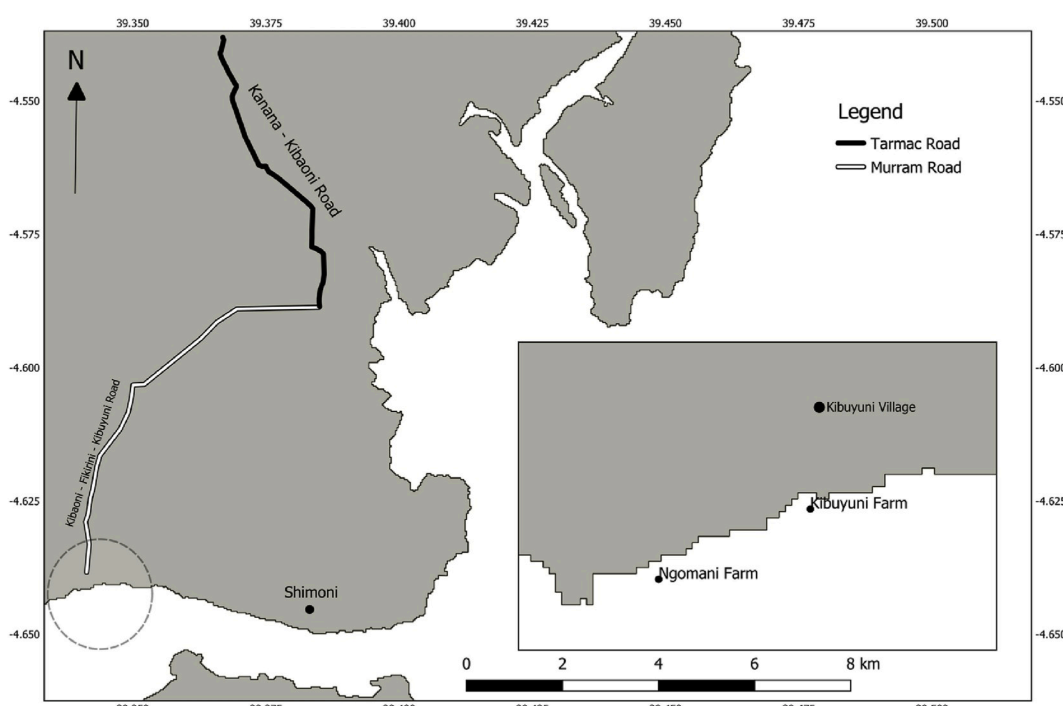

Fig. 1. Map of the South Coast of Kenya showing the seaweed farming village of Kibuyuni and the road network.

2.2. Methodology

A multidisciplinary approach was used to collect data during this study that included: observations, surveys and focus group discussions that were conducted with different families to assess impact of seaweed farming. Furthermore, data was obtained from grey literature sources, field reports in addition to status reports and sell records kept by farmers and the buyer. Semi-structured interviews using closed and open-ended questions were employed to complement the information from grey literature. Further, observations were made on the farmer's and village lifestyle and documentation made on the impact of seaweed farming. A proportion representing 30% of the seaweed farmers at Kibuyuni village was interviewed to assess the impact of seaweed farming on the livelihoods. Focus group discussions and observation methods were employed to assess the general impact of seaweed farming on the community. Also documentation was made on the observed contribution of seaweed farming to infrastructural development in the village.

To evaluate the potential for voluminous production, a comparative assessment of seaweed growth was made using three culture methods each having three replicates and the method with best results recommended for adoption by farmers. An environmental impact of seaweed farming on biodiversity was achieved through monitoring of three transects in the farming area that were established before the farms. Along each transect, three replicate blocks (50 m long, 4 m wide) were randomly selected and monitored using Under water Visual Census (UVC) and snorkelling (Hewitt and Martin, 1996, 2000). Observed fish was identified in-situ using identification sheets with individual fish photos and names (Anam and Mostarda, 2012).

Water quality parameters like temperature, salinity, dissolved oxygen and pH were measured in situ in the field using a multi-parameter (HANNA model). Water for nutrient analysis was collected using sample bottles and taken to the laboratory in Mombasa for analysis.

2.3. Data analysis

Data obtained was analysed using descriptive statistics through MS-excel spreadsheet and statistical package for social sciences (SPSS). The analysis was carried out in conformity with the protocols developed by Scoones (1998) and Scoones (2007).

3. Results

3.1. Production dynamics

The main seaweed species farmed commercially in Kibuyuni village, Kenya using off bottom method is *Eucheuma denticulatum* commonly known as "spinosum" while *Kappaphycus alvarezzi* commonly known as "cottonnii" is farmed at experimental scale using different methods (off bottom, net method and broadcasting) in the sub tidal areas. Average growth rates range between 3.0 and 6.6% per day depending on the farming method (Fig. 2). Currently, spinosum is commercialized through use of model farm designs with capacity of producing 1.5 tons dry seaweed (300 ropes, 10 m each i.e. 3 km of rope) in one harvest when fully seeded. The model farm production design was developed

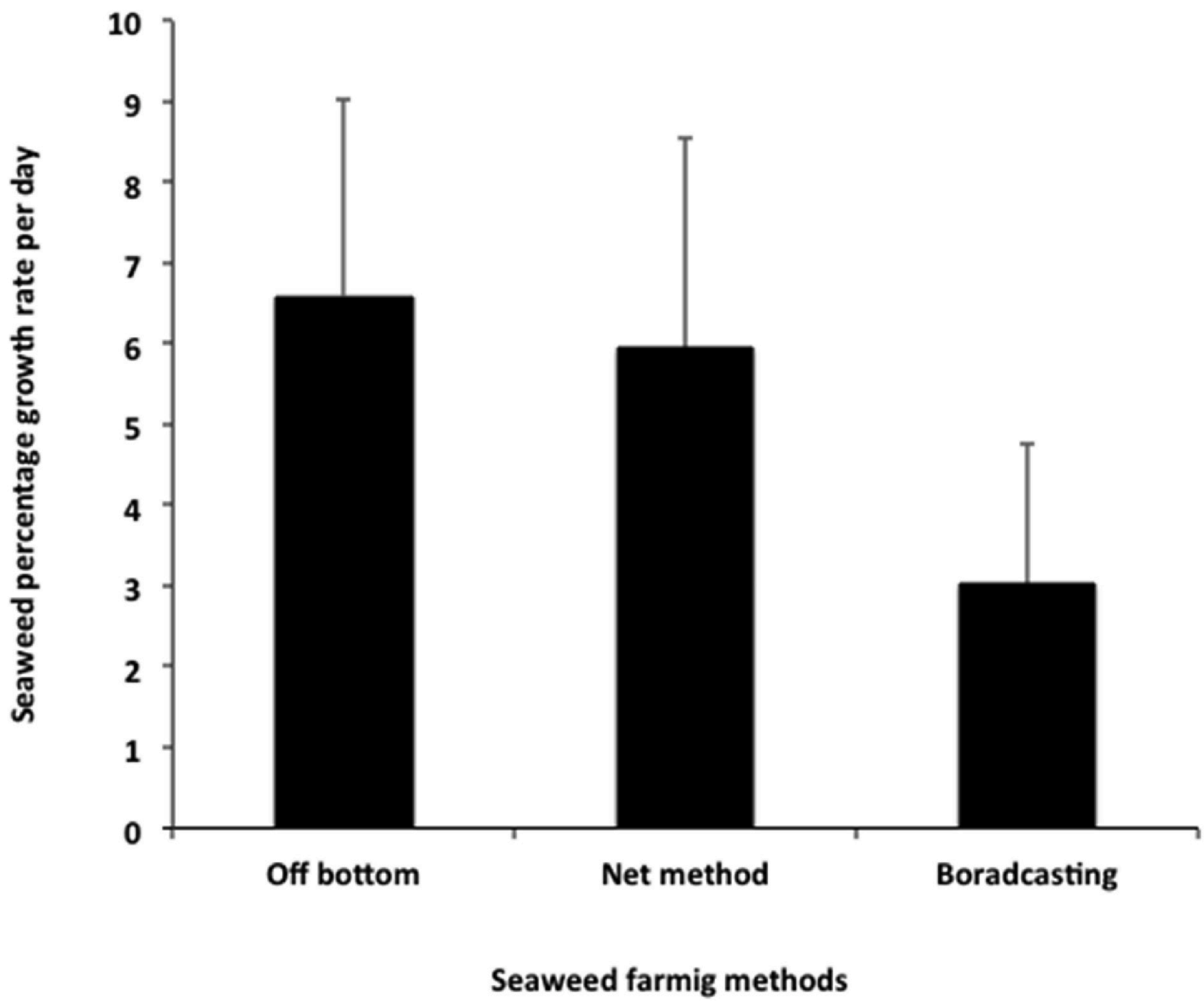

Fig. 2. Established percentage growth rate of seaweed (*Eucheuma denticulatum*) based on the different farming methods.

under the support of a World Bank project dubbed Kenya Coastal Development Project (KCDP).

The current study has shown increment in production of dry seaweed from less than one ton in 2008 to more that 45 tons (valued at $ 12,000) in 2017 (Fig. 3). Furthermore, the farming is attracting entry of new farmers from Kibuyuni and other coastal areas.

3.2. Dynamics of time involved in seaweed production chain

3.2.1. Preparation of lines (ropes) and tie-ties

Seaweed is farmed using monofilament polypropylene ropes that are 6 mm in diameter. Farmers cut ropes measuring 11 m (extra 1 m being for tying to the stakes) each either at the beach or at home in preparation for use in seeding seaweeds (1 m of rope costs $ 0.2 and thus $ 660 for one model farm and durability of ropes is 3–4 years). Short and thinner pieces of soft synthetic string often called a "tie-tie is cut (25–30 cm long) and attached to the rope at intervals of 20–25 cm along the rope with care to avoid sliding of seedlings (one model farm will require 3 rolls each costing $ 0.3 and a total of $ 0.9 for one model farm and durability of "tie-ties" is 3–4 years). To undertake this process one farmer will prepare 8 - 15 ropes/hour depending on the experience. This implies that one farmer could need 20–37.5 h to prepare 300 ropes that are required for one model farm. At the local labour cost of $ 4/day (day of 8 h), one model farm will cost $ 10–18.75 to prepare.

3.2.2. Seeding and deployment of lines (ropes)

After preparation of ropes farmers seed them and transfer to the farms. Farmers at Kibuyuni, seed/plant lines at different tidal cycles since its labour intensive and not achievable in one tidal cycle. The study revealed that on average one farmer can seed between 0.56 and 2.67 ropes/hour depending on experience. Observations at the field showed that farmers worked variedly during seeding ranging between 1.5 and 4.5 h/day based on the tidal cycle. Therefore, if farmers' worked for a maximum of 4.5 h/day, each will seed between 2.5 and 12 ropes/day. Hence, one farmer will require 90–540 h to seed a model farm depending on the tide and tying efficiency. At a local labour cost of $ 4/day (day of 8 h), cost of seeding a model farm will vary between $ 45–270. The study showed that currently farmers are only able to seed 40%–50% of a model farm. The current seeding capacity has enabled farmers to harvest 560 kg of dry seaweeds valued at $ 140, at a price of $ 0.25/kg. Also seaweed harvests are much lower during the southeast monsoon when the winds are strong due to high seaweed breakages leading to biomass loss and during the dry seasons when growth is much reduced.

Seaweeds are seeded by tying prepared ropes onto sharpened wooden stakes (1 m height and 5–10 cm diameter) drilled to the ground using hammers for stability to withstand wave effect. Stakes are sourced from nearby shrubs or purchased at $ 0.1/piece. A model farm will require 600 wooden stakes to hold 300 lines at both ends. Therefore stakes for a model farm will cost $ 60 and have a durability of two years in the farm.

3.2.3. Harvesting and drying of seaweeds

Seaweed harvesting involves taking the entire plant from the farm to the beach/drying racks for sorting and drying using farm owned motorize boats or sacks/polythene bags that are carried manually. At sorting a portion is cut and taken back for seeding the farms while the rest is dried. Seaweeds are spread thinly on the racks and dried for an estimated 2–3 days on hot and sunny days or 4–5 days on cloudy and rainy days. The labour required to dry seaweeds range between $ 0.25–0.375 (dry season) and $ 0.5–0.625 (wet season). Drying is done to attain the recommended moisture level of 35%. Approximately, 1 h is needed in the transparently roofed areas per day to manage the drying process through turning and spreading for enhanced quality. More time (2 h) is required encase drying is done in the open areas especially during the rain season because plastic/polythene sheets must be used to cover the seaweeds on the racks. Well-dried seaweeds are pressed and temporarily packed into polythene/sisal bags by the farmers awaiting

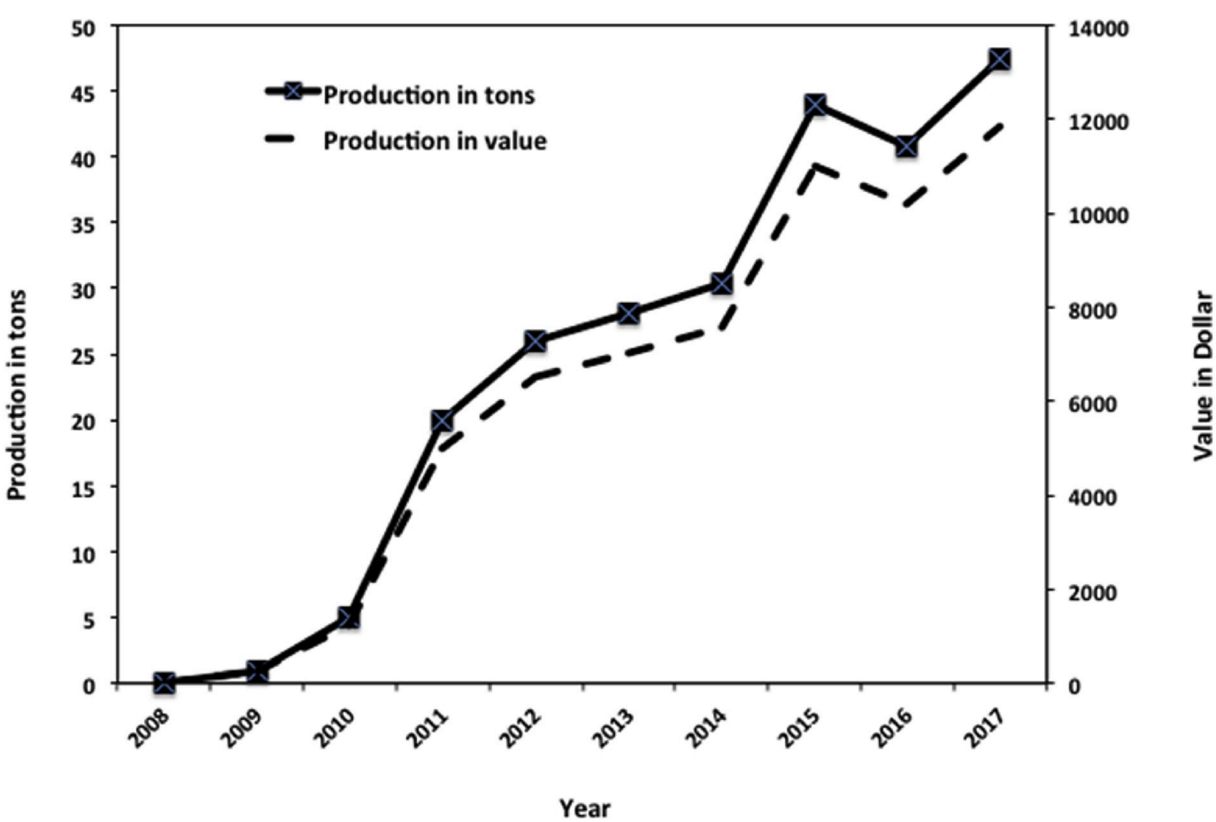

Fig. 3. Production (tons) and value ($) of dry seaweed harvested in Kenya over the years (Exchange rate at 1$ = Ksh 100).

purchase. Selling is made to a buyer with whom farmers have made agreements. After seaweed is bought, buyers use baling machines to package seaweeds into bales of 100 kg in preparation for export.

Based on the different levels in the seaweed production process, its evident that seaweed farming is a labour intensive activity and farmers have to either employ causal labourers or use family labour to achieve higher production. The study found that the household sizes and or number of employed casual labourers influenced the effective farmed area (Fig. 4).

3.3. Impact on infrastructure

Seaweed farming in Kenya is undertaken in extreme remote locations that lack infrastructural facilities like road network, electricity, communication network, and appropriate fish landing facilities "bandas", health care facilities and water. At Kibuyuni, seaweed farming has enhanced infrastructural development over the last decade. Seaweed farming has facilitated development of a good road network Kanana-Kibaoni (tarmac) and Kibaoni-Fikirini-Kibuyuni (gravel). Furthermore, electricity has been supplied to Kibuyuni village due to the influence of seaweed farming and the development of a fish "banda". Presence of electricity in the village has improved lighting system, communication system (mobile phones charging) and the general business environment. Consequently, electrical power has enhanced education in the village due to the ability to read and do homework after normal school hours. Also, expansion of seaweed farming has facilitated construction of a modern fish landing/handling shade "banda" to reduce post harvest loses of landed fish. Other infrastructural developments made as a result of seaweed farming include seaweed store to hold dry seaweeds, seaweed cottage factory for production of value added products like seaweed powder (used in making soap, fish feeds, shampoo), juice, cakes and salads.

3.4. Household income, livelihood and investment

For the last half a decade, farmers at Kibuyuni village gained income from sell of dry seaweeds that they used to meet the daily needs at the family level. In 2016, five highest producers harvested a total of 18 tonnes of dry seaweeds valued at $ 4500 while the least five producers harvested a total of 0.32 tonnes valued at $ 80. Through FAO support in the period 2015–2017, seaweed farmers at Kibuyuni were trained on fabrication of different value added products from seaweeds for enhanced income. The study revealed that 200 g seaweed bar soap with a market price of $ 3 locally would require 1.5 g of seaweed powder as an ingredient. Thus though the income from the value added products is still low, farmers have been able to start small enterprises to get extra income in addition to the dry seaweeds.

Most farmers have used earnings from seaweed farming to construct modern housing to shelter households. Some of the houses are finalised and currently occupied by the families while others are at different stages of completion. Modern houses are built using coral blocks/stone and roofed with iron sheets compared to the old ones that were mainly built with sticks and mud walled and roofed with "makuti" (palm leaves). Farmers have also used seaweed earnings to support education through paying school fees, boarding fees and buying uniforms for siblings. Furthermore, seaweed earnings are used to pay medical bills, purchase food and clothes and meet other household requirements (Fig. 5). In addition, earnings have enabled farmers to access credit facilities in the local businesses payable after selling seaweeds.

3.5. Impact on capacity development

Different stakeholders have provided trainings to farmers over the last two decades. The study showed that 98% of the farmers have attended an organised training in the last three years. Trainings were conducted using different approaches that included; organised class training programs, on-farm trainings, participatory research trainings and in situ technical trainings through demonstrations. The trainings

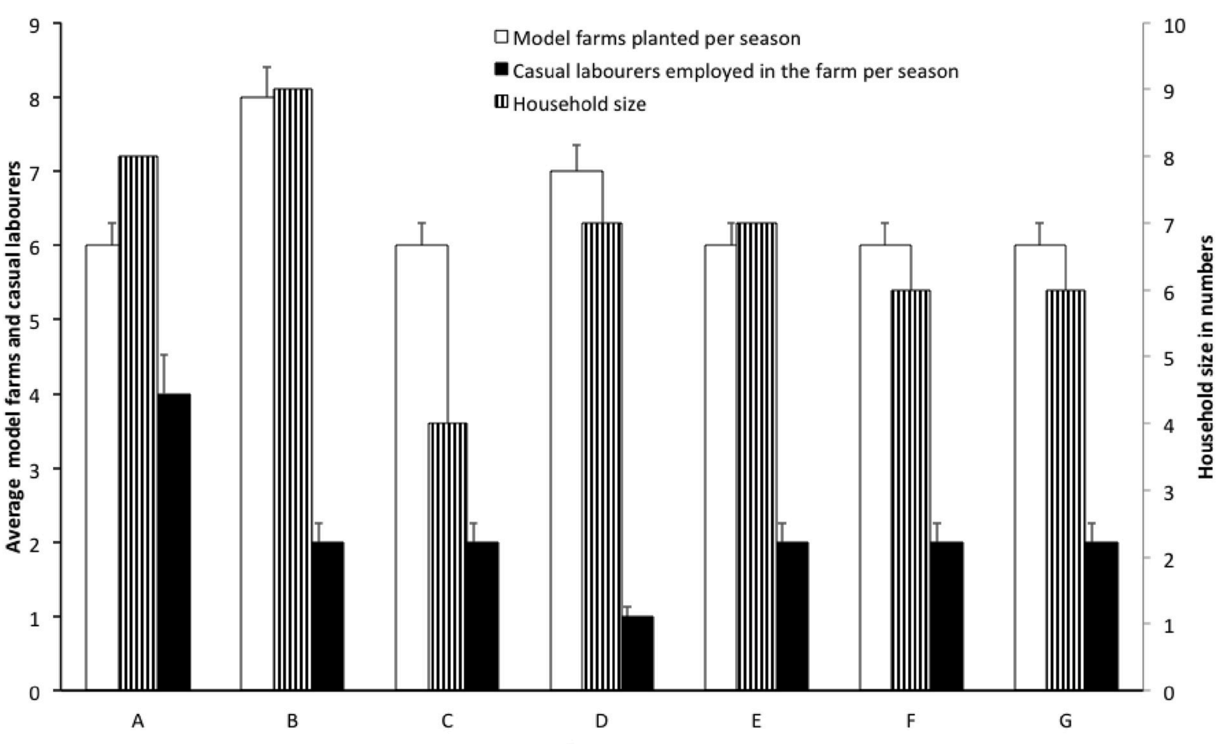

Fig. 4. Comparative assessment of the number of model farms planted, casual labourers employed and household size in the seaweed farming families in a production season.

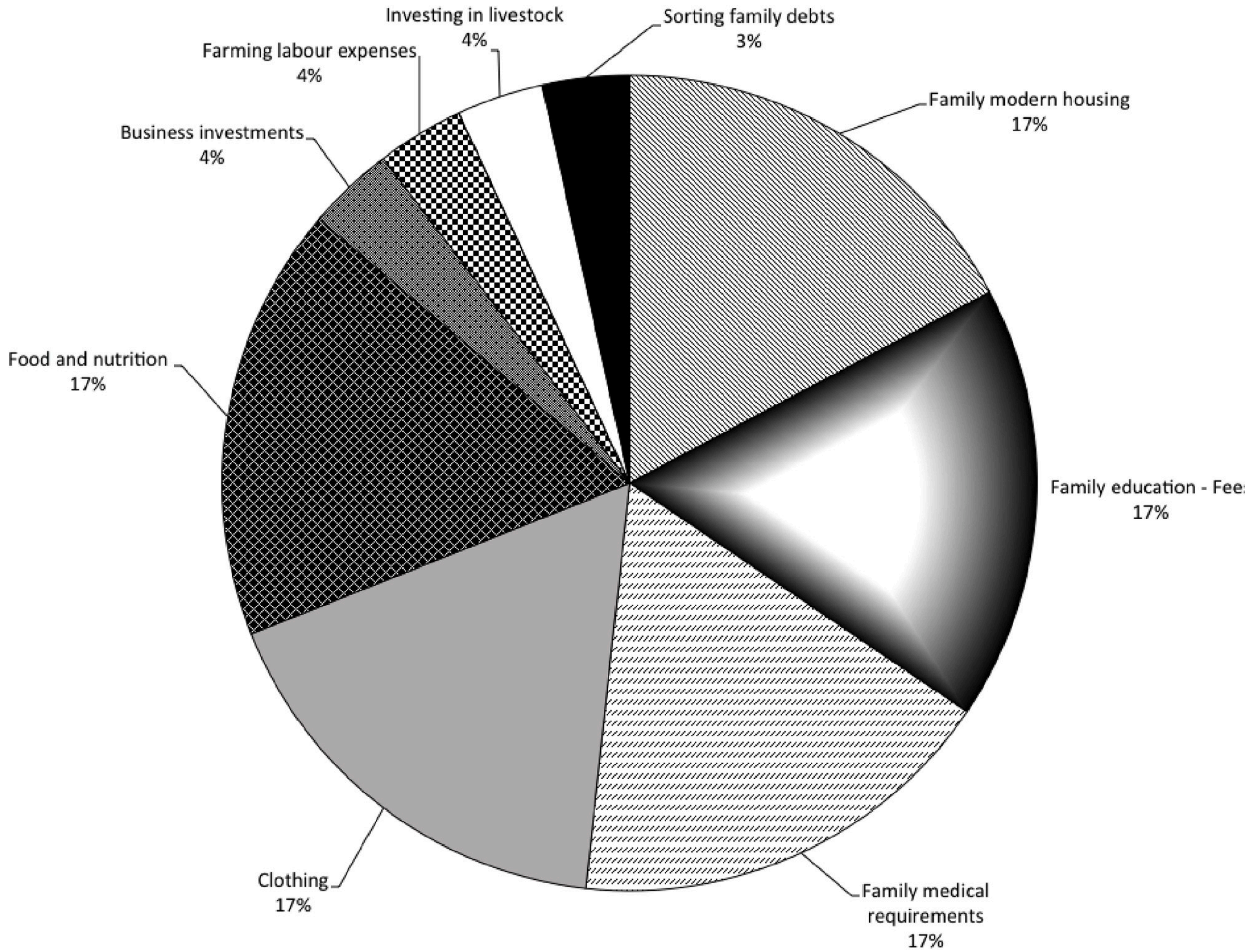

Fig. 5. Contribution of seaweed farming proceeds to the livelihood needs of the farmers at Kibuyuni village, southern coast of Kenya.

provided to farmers covered a range of topics like farming methods, growth and survival, innovations, identification or taxonomy, stocking densities, farm management, disease identification and management, drying techniques, value addition, marketing and business skills. According to the study 90% of the farmers have been given trainings on other lifestyle/management aspects like HIV/Aids prevention, conflict management and group dynamics.

3.6. Gender and social consequences of seaweed farming

The research found that women represented 75.2% of the farmers (Fig. 6). The number of farmers increased by 65.3% during the Kenya coastal development project (KCDP) when farmers were given material input support for model farm development. Comparatively, Kibuyuni village contributes 50% of all the seaweed farmers in the south coast of Kenya.

According to the study, 60% of the women strongly agreed that seaweed farming had improved cohesion among them and to the communities of the farming areas in general, 15% remained neutral and the rest strongly disagreed. The research found that the ability to negotiate around conflicts has helped to minimise theft and vandalism in seaweed farms. About 80% of the women agreed that seaweed farming has empowered them to participate in societal issues. Consequently, conflicts are well mitigated through constant meetings and awareness to the Beach Management Units (BMU) in addition to clearly demarcating seaweed farms.

According to the study, 70% of the households involved men in seaweed farming mainly during planting, line preparation, transportation of seeding materials to planting areas and harvesting either manually or using dugout canoes/boats. Children were also found to be of help to the households in providing labour when not going to school especially over the weekends and public holidays.

3.7. Seaweed marketing and market dynamics

Availability of reliable market has an impact on seaweed farming in Kenya. In the last decade, a seaweed buying company (C weed Company Kenya LTD) made an agreement with farmers to buy all quality dry seaweed produced. According to 75% of the farmers, the company has bestowed them greater confidence by investing in purchase of a baling machine and deployment of extension staff to support farmers.

Bought dry seaweeds are baled (packaged) into 100 kg bags and stockpiled at the farmers store at Kibuyuni while awaiting export through the port of Mombasa. According to the C weed Company Kenya LTD; Kenya seaweed exports are destined to different countries including China, France and the United States of America. However, farmers lack clear information on the precise destination for the Kenyan seaweed exports. Due to fluctuations in reliability of the local seaweed market, price/kg of dry seaweed has fluctuated variedly ($ 0.09 in 2010, $ 0.3 in 2015, $ 0.25 in 2017).

The research found that farmers are diversifying seaweed market outlets through sale of value added seaweed products (soap, shampoo, seaweed cakes, seaweed salad) among the community members and outside visitors. Farmers unanimously agreed that value added products

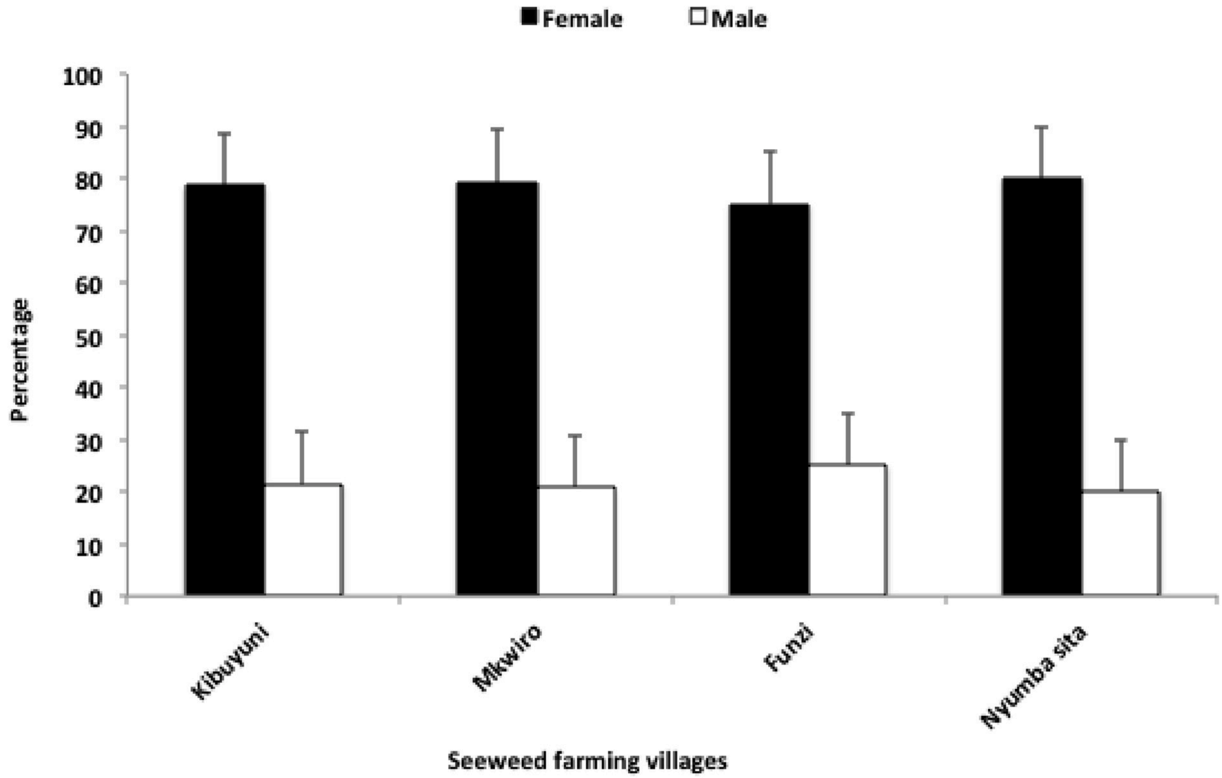

Fig. 6. Participation in seaweed farming in different farming villages in the south coast of Kenya.

could fetch better prices once the quality standardization marks are attained through the Kenya Bureau of Standards and other international standardization organisations.

3.8. Environmental dimension of seaweed farming

Seaweeds are grown in sub-tidal coastal areas that are submerged at high tides (spring and neap) and exposed for short periods at low spring tides throughout the year. Tidal forces principally drive water circulation in the farming areas. According to the study, seaweed farms did not abstract water circulation in the area.

The current findings showed that seaweed farming influenced food web interaction in the ecosystem. A dynamic drift in abundance of fish species according to trophic levels was observed in the seaweed farming areas. Herbivores contributed less than 20% before seaweed farming but contributed 76% after established of the farms. Carnivorous species decreased from 52% before the farming to 20% after start of farming (Fig. 7). The study showed variations in species occurrence where abundant and less abundant species observed before seaweed farms disappeared with the introduction of seaweed farms (Table 1). There were no major variations in water quality parameters before and after establishment of seaweed farms. Water temperature and salinity measured at midday showered an incremental trend over the years (Table 2). Seaweeds trapped a lot of sand sediments in some areas during the windy periods of the year.

According to the study, seaweed farming uses wooden stakes/sticks to tie ropes used for seeding. Stakes are young trees/shrubs that are harvested form the local forest around the farming areas and that may influence deforestation with the expansion of farms and number of farmers.

4. Discussion

The study revealed that a farmer will require less than $ 300 to fully plant, harvest and dry seaweeds from a model farm that is able to provide revenue of $ 375 in one harvest when the cost of farming ropes is not considered. Most of the seaweed farming materials like ropes, stakes and tie ties can be used for more than two years in the production process thus reducing the production costs. This makes seaweed farming a low capital investment with a high rate of return over short time periods (Smith, 1987; Hurtado-Ponce et al., 2001; Wakibia et al., 2011). Indeed, other aquaculture activities do not return the same economic benefit per unit effort and area as seaweed farming (Wakibia et al., 2011). Consequently, the faster growth of seaweeds (3.0–6.6% daily depending on the farming method) gives a faster production over the short culture period of 6 weeks or 42 days and is comparable to other studies (Padilla and Lampe, 1989; Luxton and Luxton, 1999; Wakibia et al., 2006, 2011; San, 2012; Kimathi et al., 2018).

Finfish (Milkfish) and shell fish (mud crab) mariculture in east Africa is undertaken through Organised Community Groups (OCGs) and thus limited income accrues to the individual farmers (Mirera, 2019, 2011; Mmochi, 2015; Mirera et al., 2014). Comparatively, seaweed farming provide huge sources of revenue to local village community members that enable investment interventions. Since the earnings are directly utilised in the village there is an observable livelihood impact on the wider coastal community within a short time period. Indeed according to Hurtado-Ponce et al. (2001) and Ask et al. (2003), seaweed farming is ranked as a major source of livelihood to thousands of coastal inhabitants in developing countries.

Based on the current study, to increase seaweed production and make more economic benefits, farmers are encouraged to farm in model farms (300 ropes of 10 m long) that have capacity to produce 1.5 tones ($ 375) in one harvest. San (2012) argues that a motivated family is able to make 3 km of rope (3000 m) that is able to produce 10 MT of dry seaweed per year (valued at a minimum of $ 2200). According to experiments by Wakibia et al. (2011), 0.1 ha farm (which is 70% of the model farm) produced an average net yield of between 0.88 and 1.21 tons dry weight for *E. denticulatum* with a rate of return on investment of 15–63% meaning that the industry is capable of supporting itself which is similar to studies by Samonte et al. (1993) and Firdausy and Tisdell

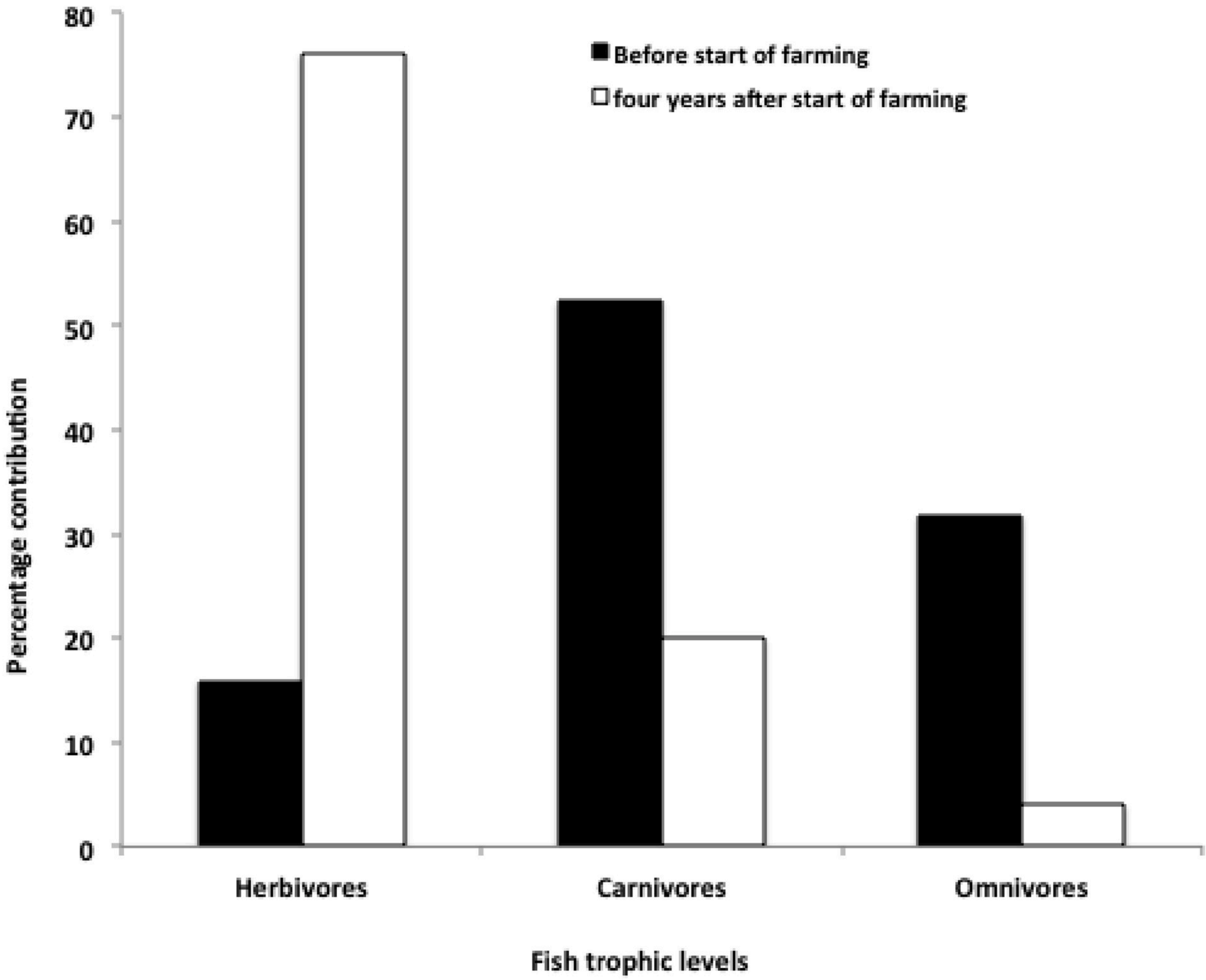

Fig. 7. Percentage fish trophic level dynamics at Kibuyuni sub tidal areas before and after initiation of seaweed farming.

Table 1
Dynamics in occurrence of the top five and least five fish species in abundance before and during the seaweed farming at the Kibuyuni farm site.

Top five abundance species in 2009	2014	2018
1. *Dascyllus aruanus*	Present	Absent
2. Siganus canaliculatus	Absent	Absent
3. *Thalassoma hebraicum*	Absent	Present
4. *Parupeneus barbericus*	Present	Absent
5.*Cheilodipterus quinquelineatus*	Present	Present
Least five abundant species in 2009	**2014**	**2018**
1. *Sphyraena jello*	Absent	Absent
2. *Aulostomus sp.*	Absent	Absent
3. *Dascyllus trimaculatus*	Absent	Present
4. *Labroides dimidiatus*	Present	Present
5. *Abudefduf sparoides*	Present	Present

Table 2
Trend in environmental parameters observed in the Kibuyuni seaweed farms between 2009 (start of seaweed farming) to 2018 (up scaling and expansion of the seaweed farms).

Activity/ parameter	2009	2014	2018
Status of seaweed farming	Initiation of seaweed farming at Kibuyuni village	Seaweed farming up scaled and model farms developed	Seaweed farming supported by private investor (extension and provision of market)
Temperature (°c)	28.7	28.9	29.7
Salinity (ppt)	31.2	30.3	29.8
Dissolved Oxygen (mg/l)	6.98	12.5	8.6
pH	8.3	8.2	8.4
Ammonium (mg/l)	0.9	1.26	1.25
Nitrate (mg/l)	0.35	0.25	0.26
Phosphate (mg/l)	2	2.15	2.14
Chlorophyll-a (μg/l)	0.8	0.9	0.85

(1991). The study displayed a high level of commitment by the farmers to seaweed farming which is a prove of concept that the willingness of individuals to engage in aquaculture or other alternative livelihoods is influenced directly and indirectly by a number of personal, social and economic factors (Slater et al., 2013).

Indeed seaweed farming has the potential of increasing income for the farmers and hence improving the wellbeing of coastal communities and national development based on the number of people supported by the seaweed farming industry (Shechambo et al., 1996; Semesi, 2002; Msuya, 2006; Smith and Renard, 2010). According to Slater et al. (2017), seaweed aquaculture could be an economic powerhouse that is able to provide livelihoods and can be a driver of positive social development in the rural coastal communities in facilitating provision of universally significant societal benefits in terms of access to food and infrastructure (roads, electricity, water, education, housing and healthcare). Thus similar to the Asian experience where introduction of seaweed farming enhanced infrastructural development in the local communities (Beveridge et al., 2010).

Through seaweed farming, members are able to own assets, which they couldn't attain in their lifetime through participation in either small-scale fishing or subsistence farming. Valderrama et al. (2013) argues that small-scale fishers and subsistence farmers have limited sources of income and therefore own limited assets. Furthermore, since seaweed farming is not migratory like other types of artisanal fishing, farmers are empowered to access credit from nearby businesses, which they are able to pay after getting the farming proceeds. Reliability of the seaweed income helps families to meet daily needs even without cash at hand as a result of the paying power that helps to improve the economic base of the village as alluded by Eklund and Pettersson (1992). None migratory means that seaweed farmers have certainty of location, which facilitates making choices about family, housing locations that improve household stability and investments as compared to capture fisheries which often involves long distant movements away from other family members which results to family separation, conflicts and poor investments (Fatunla, 1996).

Families that participated in seaweed farming had a number of dependants whose needs relied on earnings from seaweed farming. Similarly, on the global scale seaweed farming is ranked as a major source of livelihood to many coastal communities in low-income countries where dependency ratio is high (Hurtado-Ponce et al., 2001; Ask et al., 2003; Msuya et al., 2007). Comparatively, seaweed farming has a high lump some earning compared to other fisheries where earnings are on a daily basis and unable to support meaningful investment other than food (Smith and Renard, 2010; Mirera et al., 2013). In Tanzania and Philippines, a higher income from seaweed farming was found to contribute significantly to an increased standard of living for the families (Mshigeni, 1994; Hurtado-Ponce et al., 2001).

The study showed seaweed farming as a labour intensive activity with more labour required at seeding compared to other farming enterprises. Similar observations have been made by other studies elsewhere (San, 2012; Valderrama et al., 2013).

Seaweed farming could be a major source of employment like other kinds of aquaculture thus minimising levels of unemployment (FAO, 2016). According to the current study, seaweed employees are paid between $ 1.5–2.0/day (a day is equivalent to 2–4 h every low spring tide for a minimum of 10 days/month). The daily labour costs are similar to what normal casual labourers are paid in east Africa whose working time is 8 h (Msuya et al., 2007). With a potential of a farmer employing 5 people per five-day tidal cycle, more than 1000 community members are directly employed in the farms and many more get indirect employment in the seaweed buying company and in value addition.

Work in the seaweed farms is regulated by tidal fluctuations thus allowing more flexible and efficient labour participation compared to other wage worker systems with fixed 8 h working schedule. This makes decision-making decentralized to numerous independent seaweed farmers. In other areas, contract farming is used to coordinate the production of independent seaweed farmers in countries like India and Tanzania (Krishnan and Narayanakumar, 2013; Msuya, 2013b). This means that labourers and farmers can plan production schedules to be engaged with other activities during the off-season periods when farms are not accessible (Irz et al., 2007). Due to flexibility of working time in the seaweed farms, the study found that farmers are engaged in different activities like fishing (5.7% women and 8.6% men) and other businesses (20% women and 6.7% men) thus enhancing resilience to sudden changes that may have negative impacts on the seaweed crop as a livelihood (Slater et al., 2013).

Most of the earnings from seaweed farming in the current study came from direct sale of dry seaweeds to the local seaweed buying companies. Even though there is an increase in global seaweed markets, farmers have limited information of such market outlets (McHugh, 2003). Sale of dry seaweeds affect price stability due to monopoly of buyers although it is a common trend in most seaweed farming countries like Tanzania, Indonesia, Kenya, Philippines and Fiji (Firdausy and Tisdell, 1991; Lirasan and Twide, 1993; Mshigeni, 1994; Luxton and Luxton, 1999; Hurtado and Agbayani, 2002; Wakibia et al., 2011). To earn more income from seaweed farming, value addition has been recognised through making of soap, juice, salad and fish feeds (Novaczek et al., 2001; Msuya, 2006; Neish and Msuya, 2013). The current findings show effort in fabrication of value added products like soap and shampoo through development of a seaweed cottage industry. Value added products have increased the earnings from seaweed farming and forms a long-term strategy to reduce the negative social impacts of the export-oriented dry seaweed aquaculture that has been rampant in the shrimp industry in Asia (Béné, 2005).

In the study different stakeholders invested resources to provide diverse trainings to the seaweed farmers in recognition of the fact that scientists alone cannot generate site-specific technologies for the wide diversity of conditions of farmers in low income countries throughout the world, or even within one country (Reijntjes et al., 1992). Comparatively, in Indonesia different approaches that included training in different topics were used to improve education and communication among farmers for improved production (Neish, 2008b, 2013).

Msuya (2013b) found out that women and youth in Tanzania had limited alternative livelihoods since they only depended on collection of shells in the intertidal areas. Women form the majority of seaweed farmers in the current study and have been empowered financially and in education thus contribute significantly to family decisions and livelihoods. Elimination of the dependency syndrome by women has been observed to minimise conflicts in households (Msuya, 2006; Hurtado, 2013). Farming of seaweeds has also established a constructive competition among community members similar to observations by Kronen (2013).

Environmentally, the study observed seaweed farming to influence dynamic food web interactions where herbivorous fish species increased with the introduction of seaweed farms. This could be associated to the provision of shelter, feeding and nursery to fish and other associated organisms a fact that has been observed by other studies (Christie et al., 2009; Bryhn et al., 2015). Seaweeds were also observed to trap sand sediments in the current study. Therefore if farmed in large scale, seaweed farms could shelter fragile ecosystems like coral reefs from sand deposition (Bryhn et al., 2015). Furthermore, seaweed cultivation improves sediment retention by dampening wave energy thus helping protect shorelines subjected to erosion (Mork, 1996). On a global scale, seaweeds can serve as a sink for anthropogenic carbon emissions ("Blue Carbon") that could prevent extreme weather events (Nellemann et al., 2009; Isacs et al., 2016).

Water quality parameters in the study area remained similar over time a fact that could be associated to the sequestering effect (Conley et al., 2009; Holdt and Edwards, 2014; Kim et al., 2015). Therefore, seaweed farming has a potential to provide significant benefits to the ecosystem like increasing fish stocks, reproduction, habitat availability (shelter effect) through underwater vegetation like sea grass and water clarity that is important for photosynthesis (Kautsky et al., 1986; Svane and Gröndahl, 1988; Moy and Christie, 2012).

The study also revealed that seaweed farming has in some instances lead to conflicts between fishers and farmers due to encroachment of seaweed farms by navigating boats or putting farms in navigation routes. However, most of the conflicts were minor and were sorted through consultations between the village leadership and the Beach Management Unit (BMU) framework where all farmers and fishers are members. With the expansion of the industry, there is need for zoning and demarcation of farming areas and routes for enhanced management of coastal zones.

5. Conclusion

This study shows that seaweed farming could be an economic and development powerhouse in developing countries if farmed at large scale and by using appropriate methods. Field experiments showed that "spinosum" grows better when using off bottom method of farming leading to its adoption by all the farmers. The study observed a significant contribution of seaweed farming to the welfare of communities and farmers directly and indirectly. Therefore, there is an obvious uplifting of pro-poor inaccessible coastal villages involved in seaweed farming as an alternative livelihood. In terms of direct impacts on communities, and more specifically the farmers, this study points out a number of positive effects related to farming that include; provision of appropriate housing, medical care, education and access to credit. The most prominent contribution to the economy of the seaweed farming villages includes general infrastructural development like road network, electricity and other common facilities like fish "bandas", seaweed storage facilities and enhancement of indirect businesses in the community through increased flow of income. Further, seaweed farming was observed to be flexible in terms of working hours and days in addition to being a labour intensive activity thus providing opportunities for employment in the villages. Flexibility in working hours and days allows planning and enables farmers and labourers to engage in other income generating activities thus creating economic resilience in the communities. Engaging in seaweed farming was observed to have limited negative impacts to the environment like some aspect of deforestation in the long term and change in fish species diversity. Among the positive impacts of seaweed farming is the sequestering effect of seaweeds, trapping sand sediments that could impact coral reefs and environmental integrity. The study observed a monopolistic tendency in purchase of seaweeds that impacted negatively on prices of dry seaweeds. Therefore, for seaweed farming to become a way of live for the coastal villages there is need to develop policies to guide markets in addition to identification of new sites and suitable zonation of farming areas. Hence, the findings from this study are believed to be of great value for the development of the seaweed industry and for informed decisions on development in coastal areas.

Declaration of competing interest

All the authors submit a no conflict of interest in this submission.

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