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Comparison of Seaweed Growth, Fish Abundance and Diversity in Deep Water Floating Raft with Tubular Nets and Shallow Water Off-bottom lines Seaweed Farms

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Abstract

This study compared the growth performance of *Eucheuma denticulatum*, fish abundance and diversity between deep water (using tubular nets) versus shallow water (off-bottom) seaweed farming methods. For each farming method, three plots were set and fish abundance, diversity and seaweed growth rates were measured at intervals of 15 days. Belt transects measuring 10 m x 4 m each, were established on seaweed farms for fish observations. Fish were identified to the lowest possible taxonomic level by underwater census. The results showed that the growth rate of *E. denticulatum* in deep water farms was slightly higher at an average daily growth rate (DGR) of 3.42 ± 0.18% day^{-1} compared with 3.01 ± 0.27% day^{-1} for shallow water farms but with no significant differences (p = 0.079) likely due to higher herbivory in the deep water farms. Fish abundance and diversity were higher in deep water farms but insignificant ($t_{(34)}$ = 0.69, p = 0.49 and $t_{(34)}$ = 0.424, p = 0.67, respectively). Habitat complexity and seaweed growth rate were almost similar for both farming methods hence attracting comparable numbers of fish. Further studies are recommended on fish community structures, differences between the two farming methods and effects of herbivory.

Keywords: *E. denticulatum*; seaweed farming methods; growth; fish diversity and abundance.

Introduction

Zanzibar began exporting seaweeds as early as the 1930s when red seaweed, under the genus *Eucheuma*, was harvested from naturally occurring wild stocks and exported to Europe (Mshigeni 1973, Msuya et al. 2012). Following the collapse of export trade in the late 1970s due to overharvesting of wild stock, the red algae *Eucheuma denticulatum* and *Kappaphycus alvarezii* from Philippines were introduced to Zanzibar in 1989 (Mshigeni 1992, Bergman et al. 2001) and the farming started in the same year (Mtolera 2003). Rising demands for seaweed products and the need for local communities to develop alternative livelihoods are driving the seaweed farms to expand into new areas (Sievanen et al. 2005, Graham et al. 2006, Hehre and Meeuwig 2016). Seaweed has been proposed as a form of sustainable aquaculture (Feidi 2005, Eklöf et al. 2006a) and alternative occupation to coastal communities worldwide, as a tool for economic empowerment of coastal women especially in developing countries (Bryceson 2002). Furthermore, it is advocated to be a way to improve reef health through poverty alleviation and reduced fisheries exploitation (Sievanen et al. 2005).

The culture of eucheumatoids has spread from Asian countries to the Western Indian Ocean (Cai et al. 2013). The major seaweed producers in the world include Indonesia, the Philippines, the United Republic of Tanzania, Malaysia and China (Valderrama et al. 2015, Buschmann et al. 2017). Farmers in Zanzibar use the off-bottom farming method in the shallow intertidal areas (Mtolera 2003), where farms are suspended over seagrass or sandy areas (Bergman et al. 2001, Eklöf et al. 2006a). The farming of seaweed was okay in the first decade and the production increased from 260 tons in 1990 to about 15,000 tons in 2012 (Msuya et al. 2012); then dropped to about 9,000 to 11,000 tons during succeeding years (Department of Fisheries Zanzibar per. comm) due to die-off, 'ice-ice' syndrome, epiphytes and fouling. The die-offs that started in the early 2000s were attributed to the variability of environmental (water quality) parameters in space and time (Mmochi et al. 2005). Deep water cultivation techniques have been ventured in developed and developing countries to reduce die-offs and fouling and increase the farming areas to maximize seaweed production (Msuya et al. 2007, Kimathi et al. 2018). Seaweed farmers in Zanzibar are being advised to move to deep water using the floating raft method (with tubular nets) which has proved to minimize the problem of die offs (Góes and Reis 2011, Msuya 2015) caused by higher water temperatures at the intertidal and subtidal zones (Mmochi et al. 2005). Use of tubular nets is among the new farming techniques and has been successfully used in Brazil and India (Góes and Reis 2011).

Seaweed farming is reported to have both positive and negative effects on the environment. The positive effects include oxygen exchange which improves the quality of polluted waters as well as the attraction and protection of fish (Bergman et al. 2001, Eklöf et al. 2006b, de Carvalho et al. 2015). Negative impacts include formation of anaerobic spots on the substrate, change of substrate structure and interference with tourism activities (Bryceson 2002, Eklöf et al. 2005). In spite of these, the contribution of seaweed farming to the economies of the coastal communities may be substantial. Seaweed farming is an important industry bringing foreign revenue into Zanzibar's economy and raising farmers' and communities' living standards, especially women (Msuya et al. 2012). Also, these macroalgal beds offer refugia to young fishes (Dahlgren and Eggleston 2000) before they move to adult habitats supporting rapid growth (Grol et al. 2011).

The presence of structurally complex seaweed farms can improve fish aggregation and fisheries (Bergman et al. 2001, Eklöf et al. 2006a). In Zanzibar, where seaweed farming is a widespread activity, the potential effects of seaweed on fish abundance and diversity could be significant. However, to date, this postulation has never been ascertained. Deep water seaweed farming using floating rafts is among the new techniques introduced in a number of tropical regions including Zanzibar. However, the information regarding the seaweed growth in this new method is limited. There have been a few studies in Brazil on *K. alvarezii* cultivated using tubular nets. The studies reported faster growth rate in tubular nets than off-bottom methods but the difference was insignificant (Góes and Reis 2011, Pellizzari and Reis 2011, Reis et al. 2015). Studies in Zanzibar compared the growth performance of *K. alvarezii* in the off-bottom versus floating farming methods (Msuya et al. 2007) and tubular nets farming for *K. alvarezii* and reported insignificant differences in daily growth rates between the two methods (Msuya 2015). Therefore, the goal of this study was to determine the growth performance of *E. denticulatum* in deep water using tubular nets (TN) versus its farming in shallow water using the off-bottom (OB) farming method and to compare fish abundance, diversity and how they relate to seaweed growth.

Materials and Methods

Study area

Unguja Island (one of the two main islands of the Zanzibar Archipelago) is situated at 6° 8′ 0″ S and 39° 19′ 0″ E (Jonson 1990), 40 km off the coast of mainland Tanzania (Figure 1). The study was conducted off Pongwe Village, located on the mid-eastern coast of Unguja Island, from April 2018 to April 2019. Pongwe beach is protected by an offshore reef which keeps the inner waters calm and safe. It has a large intertidal area covered by seagrass, coral rubble substratum and sand which made it suitable for this study. Agriculture, fisheries and seaweed farming form the basic occupations for livelihood sustenance and food security in the area.

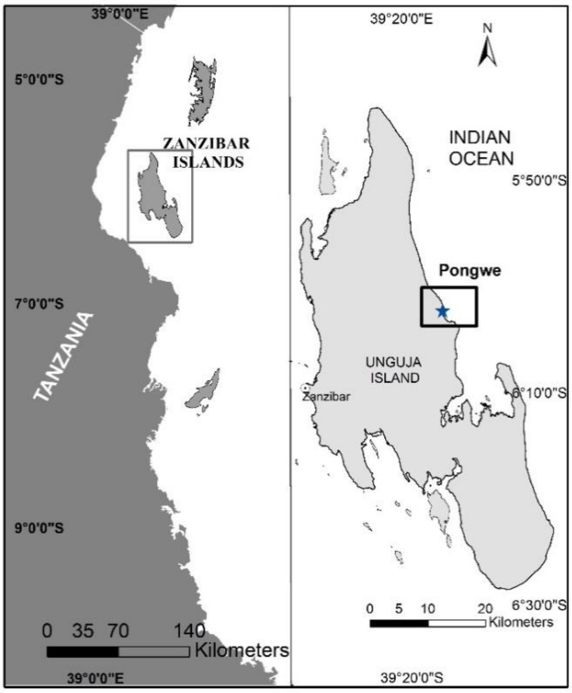

Figure 1: A map of Unguja Island (Zanzibar) showing the study site.

Experimental setup and data collection

Two different approaches were used to set up the seaweed farms, namely shallow water farms using off-bottom method (OB) and deep water farms by using floating raft method with tubular nets (TN). The study was done for a period of thirteen months in six production cycles, the size of the farms was 40 m^2 each. Sampling was done at intervals of 15 days (during the neap tides) from the two seaweed farm sites in each production cycle. Off-bottom farms were closer to shore, while floating farms were 30 m farther offshore. Generally, fishers in the area avoid seaweed farms so as to minimize conflicts and potential damage to gears and farms. The dominant habitat in both types of farms was sand with minimal seagrass cover.

Three farms were set in sub-tidal (shallow water) using the traditional off-bottom method (OB) of farming seaweed also called "*tie tie*" technique; where seaweed fronds were tied to ropes stretched between wooden pegs driven into the sea bed. The distance between one line and another was 30 cm. Seaweed cuttings weighing approximately 100 g each were tied to the line using *tie tie* at intervals of 30 cm. The farms were set at a depth of 2 m during high tide and were almost exposed during the low spring tide.

Another three farms were set in deep water using the floating raft with tubular net method (TN). A PVC tube (1 m long) was used as an auxiliary tool to fill the seedlings onto the tubular nets. Seaweed cuttings were inserted inside the nets such that they were spaced 30 cm apart (Góes and Reis 2011). The nets were then tied to the floating rafts by using nylon ropes. The distances between one net to another was 50 cm. The rafts were anchored by using two 50 kg sand bags at each of the four corners of the raft and each raft held 15 nets. The rafts were anchored at a depth of 4-5 m during high tide and 1-2 m during low spring tides with anchor lines of about 5 m (Figure 2A-B).

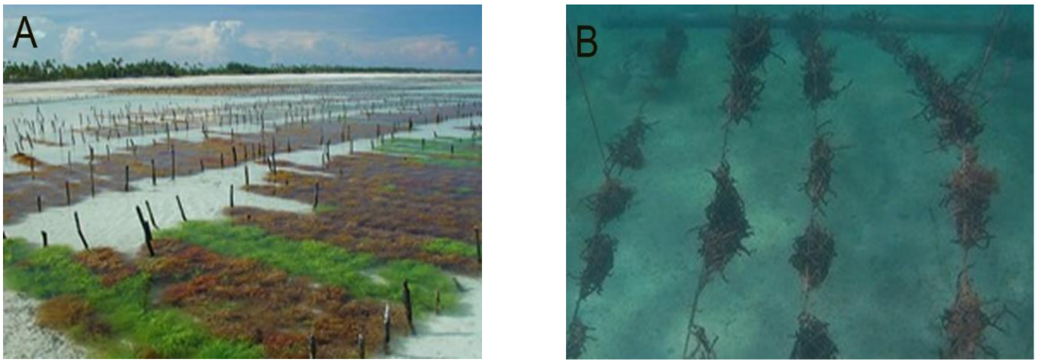

Figure 2: (A) Shallow water farm using off-bottom method; (B) deep water farm using tubular nets.

Seaweed daily growth rate and total biomass yield

The seaweeds were harvested after 45 days, the period recommended for harvesting fully grown seaweeds. After harvesting, the seaweeds were shaken to remove excess water and weighed using a commercial weighing scale to obtain fresh weights. From the fresh weights, growth rates (DGR, %) of the seaweeds, were calculated as:

$DGR = 100 \times [\ln (W_t/W_0)]/t$

where; W_o is the initial biomass and W_t is the biomass at t culture days.

Abiotic factors

Salinity, temperature and dissolved oxygen were monitored and measured *in situ* at each sampling day. Salinity was measured using a refractometer Model STX-3, while temperature (°C) and dissolved oxygen (DO) were measured using DO meter EXTECH 407510.

Fish sampling

Abundance and diversity of juvenile fish was assessed by Underwater Visual Census (UVC). The sites were surveyed by snorkeling at shallower sites and SCUBA diving at deeper sites. Eighteen (18) belt transects (each replicated three times) measuring 10 m x 4 m each, were established at each seaweed farm. All fish within each transect were identified to the lowest possible taxonomical level, counted and their total length estimated (after Edgar et al. 2004). Prior to fish size estimation, training and calibration exercises were undertaken. Each transect was sampled for 15 minutes. All fish counts and length estimations were done by one observer (B.M. Yahya) in order to eliminate among-observer variations. Juveniles were defined as individuals of less than one third of the species' maximum length (after Nagelkerken and van der Velde 2002). Maximum lengths of species were obtained from Bianchi (1985), Richmond (2011) and Froese and Pauly (2019).

For adult fishes, Diver Operated Video (DOV) method with the GoPro HERO5 camera, adopted from Pelletier et al. (2011) was used for fish census in the habitats, where a diver swam through the same transect in a straight line at a constant speed and elevation (1.5 meters above the bottom). There were at least 5 minutes between UVC and DOV observations. The videos were downloaded to a computer for subsequent identification of fish, estimation of fish size and analysis of fish abundance. To facilitate the statistical analysis, sub-adults and adults were pooled together (after Berkström et al. 2013).

Data analysis

Fish species diversity was obtained by using PRIMER (Clark and Warwick 1994) to calculate the Shannon-Wiener diversity index (H). An independent t-test and post-hoc Tukey's tests were used to test for significant differences among the mean abundance and diversity of fish in the farmed areas, seaweed growth rate and temperature. Before analysis, data were tested for homogeneity of variance using Levene's test and transformed in case of non-conformity. Mann–Whitney U test was used to test for significant differences in salinity and dissolved oxygen, since even after being transformed; the data did not match the assumptions of normality (Shapiro-Wilks test) and homogeneity of variances (Levene‟s).

Results

Seaweed growth rate and abiotic factors

Seaweed biomass increased from 215 kg to 537 kg after 45 days in deep water farms (TN) and from 200 kg to 508 kg in shallow water farms (OB). However, the biomass increase between the two sites was not significant ($t_{(34)} = 0.59$, $p = 0.067$). The growth rate of the seaweeds was measured as specific growth rate (DGR, % d^{-1}). Results showed that the mean daily growth in percentage was slightly higher in deep water farms compared to shallow water farms, although the t-test showed no significant difference in daily growth rates of seaweed in two farming methods (p= 0.079). Mean water temperature was significantly higher in shallow water farms compared to the deep water farms (p = 0.013). No significant difference in salinity was observed between deeper and shallow water farms (p = 0.496). Dissolved oxygen was significantly higher in deep water than shallow water farms (p = 0.004) (Table 1).

Table 1. Mean and standard deviation values of the daily growth rate, abiotic factors and statistical test between deep and shallow water

	Farming methods	Mean ± SD	t-test	Mann-Whitney U test	p
Daily growth rate (% day^{-1})	Deep (TN)	3.42 ± 0.18	1.839		0.079
	Shallow (OB)	3.01 ± 0.27			
<u>Abiotic factor</u>					
Temperature (°C)	Deep (TN)	27 ± 0.18	2.57		0.013
	Shallow (OB)	28.7 ± 0.18			
Salinity	Deep (TN)	34.15 ± 0.15		320.5	0.496
	Shallow (OB)	34.27 ± 0.08			
Dissolved oxygen (mg/L)	Deep (TN)	8.01 ± 0.12		148.5	0.004
	Shallow (OB)	7.51 ± 0.08			

Fish abundance and diversity

A total of 7938 fish belonging to 41 species were observed during the survey. Of these, 4721 (59.47%) belonging to 36 species were observed in deep water farms (TN) of which 4208 (89.13%) were categorized as juveniles and 513 (10.86%) were adults. 3217 (40.52%) individual fish belonging to 20 species were observed in shallow water farms (OB) of which 3063 (95.21%) were juveniles and 154 (4.78%) were adults. The mean fish abundance was higher in deep water farms 262.27 ± 107.40 than shallow water farms 178.72 ± 54.77. The two farming sites had higher number of juveniles than adult fish (Figure 3). However, the independent t-test revealed that there was no significant difference in total fish abundance between deep and shallow water farms $t_{(34)} = 0.69$, $p = 0.49$), or abundance of juveniles ($t_{(34)} = 0.52$, $p = 0.06$) or adults ($t_{(34)} = 1.36$, $p = 0.18$).

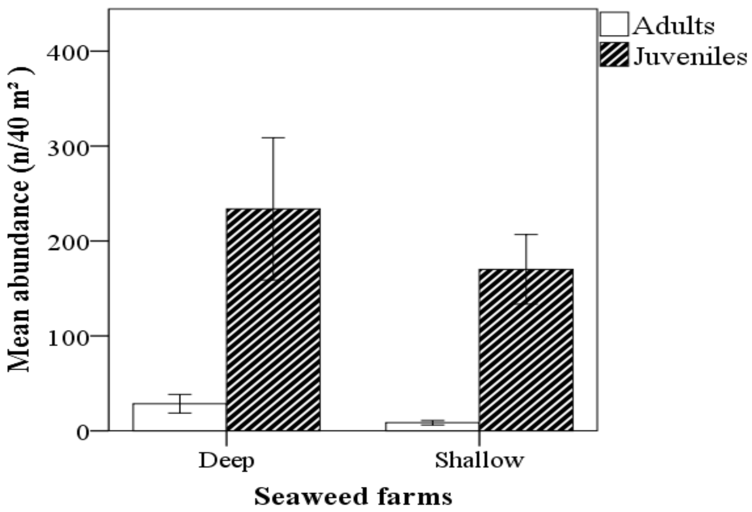

Figure 3: Mean fish abundance in deep and shallow water seaweed farms.

There was an increase in overall fish abundance with growth of seaweed both in shallow and deep water farms. In deep water farms, the mean fish abundance increased from 86.83 ± 65.97 at day 15 to 529 ± 290.33 at day 45, while in shallow water farms it increased from 92.66 ± 49.83 at day 15 to 373.5 ± 177.20 at day 45. The increase was observed in both juveniles and adults (Figure 4).

Fish diversity was higher in deep water farms (1.18 ± 1.08) compared to shallow water farms (0.97 ± 0.85). However, the difference was not significant ($t_{(34)} = 0.42$, $p = 0.67$). No significant difference in juvenile fish diversity was observed between deep and shallow water farms ($t_{(20)} = 0.45$, $p = 0.65$) or adult fish ($t_{(34)} = 0.45$, $p = 0.13$). Fish species with high individual density that appeared in both farms were mostly from the families Siganidae, Lethrinidae, Mullidae, Lutjanidae, Scaridae, Labridae and Plotosidae (Table 2).

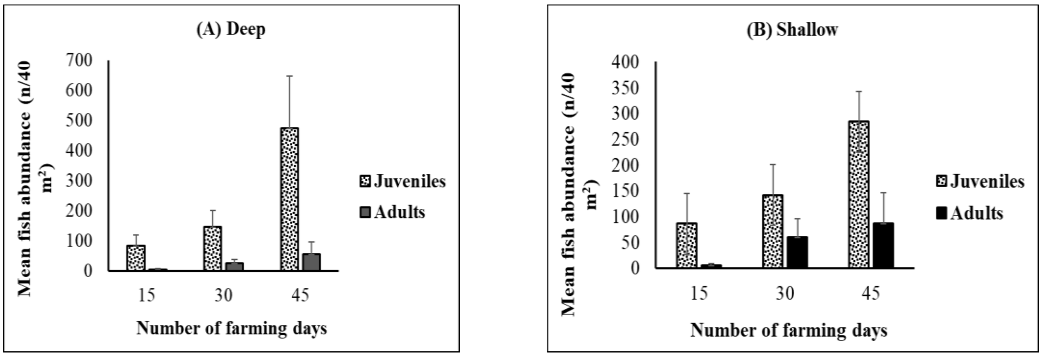

Figure 4: Mean fish abundance of (A) deep and (B) shallow in relation to number of seaweed farming days.

Table 2: List of the eight fish species most frequent and their densities (n/40 m²) in deep and shallow water farms

Family	Species	Deep	Shallow	Deep		Shallow	
		Mean ± SD	Mean ± SD	Adult	Juveniles	Adult	Juveniles
Labridae	*Cheilio inermis*	0.55 ± 0.55	1.22 ± 0.70		x	x	x
Scaridae	*Leptoscarus vaigiensis*	0.22 ± 0.12	1.22 ± 2.42	x		x	x
Lethrinidae	*Lethrinus harak*	31.38 ± 1.62	8.27 ± 0.22	x	x	x	x
	Lethrinus variegatus	4.44 ± 0.55	1.27 ± 1.27	x	x		x
Lutjanidae	*Lutjanus fulviflamma*	40.0 ± 25.47	49.8 ± 1.55		x	x	x
Mullidae	*Parupeneus barberinus*	7.27 ± 5.55	22.05 ± 0.12	x	x	x	x
Plotosidae	*Plotosus lineatus*	1.55 ± 0.67	0.44 ± 0.04	x	x	x	
Siganidae	*Siganus sutor*	45.00 ± 25.02	80.88 ± 43.80	x	x		x

Note: x = present

Discussion

The slightly higher final seaweed biomass and daily growth rate in deep water farms suggests that farming seaweed in deep water will increase seaweed production by increasing the farming area. The results support other finding that innovative methods of farming in deep water can improve seaweed farming and production (Msuya 2015). In spite of no significant differences obtained in DGR when these two methods were compared, the daily growth rate obtained in deep water farms (3.42 ± 0.18% day^{-1}) was closer to the recommended DGR (day^{-1}) value for commercial cultivation which is 3.5% day^{-1} (Doty 1987, Glenn and Doty 1990). However, in East Africa, the DGR (% day^{-1}) of *E. denticulatum* is reported to be up to 6.7% day^{-1}, but it depends on seasons (Kimathi et al. 2018). The lack of significant difference in daily growth rates in the present study could be contributed to the effects of herbivory. During sampling, we observed higher fish bites on seaweed in floating farms than off-bottom farms, which implies that in deep water there may be higher growth rate but seaweed biomass was reduced by herbivory (B. Yahya pers. obsv). Thus, the herbivory effects should be taken into consideration when farming in deep water, however, their impacts would likely be minimal on large scale and/or unfragmented farms. Nevertheless, the study set-up did not anticipate the potential differences in effects of herbivory on the farms.

With exception to salinity, in this study temperature and dissolved oxygen varied significantly between the two farming sites. Since the growth of *E. denticulatum* was relatively stable throughout the cultivation periods, no correlation could be tested with productivity parameters. Those parameters were within the range considered for cultivation of Eucheumatoids, which is recommended between 25 °C and 28 °C, and salinity of 30 to 40% (Ask and Azanza 2002). The same findings were also reported from other studies (see for example Góes and Reis 2011, Kimathi et al. 2018). Our results were contrary to those of the earlier study by Msuya (2015), who reported that water temperature in Muungoni (southern part of Zanzibar island) varied from a minimum of 29 °C to a maximum of 33 °C in the deep water and 29–34 °C in shallow water, and hence affected seaweed productivity. It is however, noteworthy that the shallow water farming can be affected when exposed to high temperature leading to die-offs during the highest spring tide events of March, April, May, September and October (Mmochi et al. 2005).

Slightly higher fish abundance and diversity were found in deep water floating farms than shallow water farms with higher percentages of juveniles, even though the difference was insignificant. This indicates that both seaweed farm types act as fish-aggregating devices (FADs) and attract a number of juvenile and adult fish species. The findings in the present study are in agreement with previous studies (Msuya et al. 2007, Tewari et al. 2006) which reported that farming structures attract fish and can be considered as a positive influence. Fishes use floating materials to protect themselves, eggs, larvae and juvenile stages from predators (Castro et al. 2002). The lack of significant difference in fish abundance between the two farming sites indicates that seaweed farming provides a novel ecosystem through the addition of new structurally complex habitat. Fish were attracted to the macroalgae whether in shallow or deep water settings. Habitat type proved to have significant effects on fish assemblage, density and composition (Dorenbosch et al. 2009) and is suggested to be a major determinant of the distribution and abundance of fish (Bergman et al. 2001). Since the biomass in the two sites was similar (mostly due to greater herbivory in the deep water site), the effects on fish abundance and diversity did not differ. However, the fish community structures between the two sites were probably different. Investigation into the fish community structure of fish assemblages would have provided valuable information, however, it was beyond the scope of this study. These macroalgal habitats seem to provide a key middle step in the life cycle of some tropical fishes (de Carvalho et al. 2015). Furthermore, there was an increase in number of fish with number of farming days which suggests that, since the *E. denticulatum* is coarsely branched, and as it grows becomes more structurally complex vegetation in terms of the arrangement of biomass in space, it provides better shelter and refugia for various species (Eklöf et al. 2006a).

The most common fish species observed in seaweed farms were *S. sutor* and *L. vaigiensis* (herbivores), both of which graze on seaweed farms (Eklöf et al. 2006a, Hehre and Meeuwig 2016). Seaweed farmers have reported that rabbitfish forages heavily on farmed seaweeds. Lugendo et al. (2005) found that habitats with high macroalgal cover had the highest frequency of *L. vaigiensis* juveniles. The presence of high number of species like *L. fulviflamma*, *L. harak*, and *C. inermis* (invertivore-piscivores), *P. barberinus* and *L. variegatus* (invertivores) and *P. lineatus* (omnivores) indicates that seaweeds act as important feeding grounds to several fish species. Castro et al. (2002) reported that fish associated with floating structures probably feed on invertebrates associated with the structures. Moreover, seaweed beds around Zanzibar have been shown to harbour more than 2.5-fold of mobile invertebrates than seagrass meadows (Tano et al. 2016), providing the chances for those fishes to choose their food items.

Conclusion and Recommendations

In Tanzania deep water farming has been introduced after concerns about reduced productivity and environmental effects of shallow water seaweed farming activities. Conversely, the present study was unable to establish significant differences in productivity between the two methods. The average daily growth rate of *E. denticulatum* cultivated in deep water using floating raft with tubular nets was only slightly higher compared to shallow water off-bottom method. Deep water farming will provide new grounds for farming seaweeds but for increasing productivity further studies are required. Studies using herbivore exclusion set-up could provide further insight into the anticipated higher growth of seaweed grown in deeper water farms. Fish abundance and diversity was found to be only slightly higher in deep water farms, however the fish community structure was probably different. This warrants further investigation.

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