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Abundance, diversity and trophic status of wild fish around seaweed farms in Kibuyuni, South Coast Kenya

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Abstract
Seaweed farms attract fish aggregations by providing microhabitats and food sources to fish. This study investigated the influence of seaweed farming on abundance, species diversity and trophic status of wild fish species in seaweed farms at Kibuyuni. Fish were sampled from a farmed and an unfarmed sites using traps and underwater visual census from September 2013 to July 2014. Results from trap sampling showed higher fish species abundance at the unfarmed site, whereas underwater sampling indicated greater fish species abundance at the farmed site. Species diversity and trophic status were not significantly different between study sites ($p>0.05$). The farmed exotic seaweed *Kappaphycus alvarezii* occurred in stomachs of fish captured at the unfarmed site, indicating fish biomass transport between the study sites. There is need for creation of buffer zone around seaweed farms to limit possible overfishing of fish attracted to seaweed farms.

Keywords: Seaweeds, fish, abundance, diversity, diet, trophic

1. Introduction

Seaweed farming is increasingly becoming one of the popular alternative livelihood approaches used to fulfill Integrated Coastal Management (ICM) environmental and social objectives with a view to improve socioeconomic status of coastal communities and reduction of fishing pressure on over-exploited fisheries [24]. The major farmed seaweeds are two species of red algae: *Kappaphycus alvarezii* and *Eucheuma denticulatum*, commercially called “cottonii” and “spinosum” respectively [6]. Seaweed farming is a relatively recent development in the Kenya mariculture sector, with first trials conducted in south coast of Kenya in early 2000s using *E. denticulatum* and *K. alvarezii* [26]. Commercial farming of *E. denticulatum* was started in 2010 while controlled farming of the exotic *K. alvarezii* was started in 2011 at Kibuyuni. Seaweed farms were later established at Mkwiro, Funzi and Gazi fishing villages in the south coast of Kenya [15].

Coastal aquaculture installations such as seaweed farms are known to attract large numbers of wild fish species, sometimes in dense aggregations [2, 10, 25]. Some studies have attributed this to the microhabitat created by seaweed farming which might provide additional ecological benefits and thus influence the abundance and diversity of fishes [4, 9]. Consequently higher fish catches have been reported from fishing near seaweed farms [24]. The presence of seaweed farms also influences species composition of catches by providing important structural component in the habitat that can be used for refuge, shelter or food source by associated or diverse fish fauna [4, 9]. Consequently, fish catches from areas adjacent to seaweed farms may comprise varied fish species as has been reported in similar studies regarding fish farms [2, 7, 10].

Because preliminary monitoring revealed increased fishing activities by artisanal fishers near the seaweed farms in Kibuyuni, this study was designed to investigate and provide baseline scientific information on the influence of seaweed farming on abundance and diversity of inshore wild fish species. Information generated could be used in formulating management strategies for sustainable exploitation of fish aggregations around seaweed farms. For example, the capability of seaweed farms to aggregate fish without actually increasing fish production could have implications for ecological processes involving the fish that are being attracted to the farms [9]. Although the growth rates of the farmed seaweeds have been investigated [26], no study similar to the present has been carried out in Kenya.

2. Materials and Methods

2.1 Study Area

The study was undertaken at Kibuyuni fishing village in south coast of Kenya (Figure 1). The inshore area of Kibuyuni (4°38'0" S, 39°20'0" E) is a large intertidal reef flat covered by a belt of the sea grass *Thalassodendron ciliatum* and a substratum consisting of coral rubble and small pockets of sand [26]. The reef-flat is covered with about 10 cm of seawater at the lowest tide and 3.2 m at the highest tide, and is inhabited by soft corals, sponges, starfishes, sea urchins and fish such as rabbit fishes.

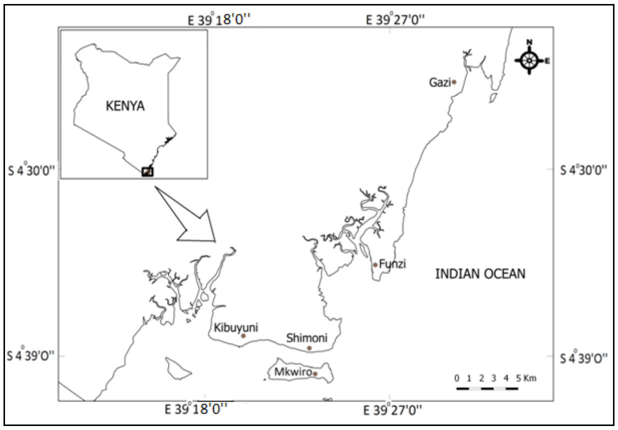

Fig 1: Map of Kenya coast showing study area in Kibuyuni south coast, Kenya.

During the present study, seaweed farm plots of varied sizes comprising two species of red algae; *E. denticulatum* and *K. alvarezii* were established in intertidal areas approximately 100 m from the highest shoreline and 10 m from lowest tide water, and stretching roughly 1.5 km along the coastline. Whereas most farm plots were under the *E. denticulatum* which also occurred naturally in patches outside the Kibuyuni seaweed farm area, the exotic *K. alvarezii* was only found in designated farm plots [15]. This study determined and compared the abundance, species diversity, diet and trophic status of fish species. Data were collected at a site near an established *K. alvarezii* farm plot and an unfarmed site outside the seaweed farm area. The unfarmed site had segments of local sea grasses, benthic microalgae and bare sand.

2.2 Study Design

The study used a quasi-experimental design since it was conducted using naturally occurring experimental units (fish) already exposed to treatment levels (sites) and lacked random assignment of experimental units to the treatment levels. Data collection was carried out at two (2) sites; a seaweed farm site within a farmed area where *K. alvarezii* was cultured and a control site within an unfarmed area at Kibuyuni where artisanal fishing activities took place about 500 m away from the farmed site. Both sites were located approximately 100 m from the highest shoreline and 10 m from the lowest tide water. At each site, sampling was done along transects each measuring 12 by 2 m.

2.3 Fish Sampling Procedures

Trap sampling using traditional basket valve traps, locally known as "Malema" [27] was carried out from September 2013 to July 2014. Three traps were deployed at approximately 1 m at the deep seaward edge of each site during onset of high tide. Each trap was anchored by a single stone attached to its lower side and was baited using a mixture of sea grass leaves, benthic algae, brittle stars and epiphytic sponge [9]. Trap positions were marked by buoys for easy retrieval and removal of the catch the following day during receding tide. Each trap was then re-baited and re-deployed in the same place. Trap sampling was done over a period of four (4) consecutive days each month.

Underwater visual census (UVC) was undertaken from February 2014 to June 2014 when preliminary analysis of data on trap catches indicated that, contrary to expectation; more fish were caught at the unfarmed site than at the farmed site**.** Using the UVC technique [5,16] each study site was sampled by one snorkeling diver who moved systematically along a 2 by 12 m transect for 20 minutes, recording fish species and approximate number of individuals on a slate.

2.4 Processing of Fish Samples

Fish catch from the traps was sorted and identified using standard taxonomic keys and guides [1, 11, 17]. The number of individuals of each species was determined and recorded. Fish were dissected to remove the stomachs which were then preserved in 5% formalin in labeled sample bottles for later analysis at the KMFRI laboratory. Food items in each stomach were identified to lowest possible taxonomic level using a dissecting microscope (Wild M3C Heerbrugg Switzerland), according to taxonomic field guides [18, 21]. The number of stomach specimens with food items, those without food items and the types of food categories contained in stomachs with food items were recorded. Trophic levels of fish were determined according to the types of food categories contained in their stomachs following the scheme adapted from Durville *et al.* [8], Fischer & Bianchi [11] and Froese & Pauly [12].

2.5 Data Analyses

2.5.1 Relative Abundance and Species diversity

Relative abundance (RA) of fish species per site was calculated as:

$$\text{RA (\%)} = \frac{\text{Number of individuals per species per site}}{\text{Total number of individuals of all species per site}} \times 100$$

Homogeneity of total fish species abundance between sites was determined using the Chi-square test [28]. Species diversity in each site was analyzed by Shannon-Wiener's H' [23] and Pielou's Evenness J' [19] indices:

$$\text{Shannon} - \text{Wiener index } H' = -\sum_{i=1}^{s} pi \ln\ (pi)$$

$$\text{Pielou's evenness index } J' = \frac{H'}{H\max} = \frac{H'}{\ln S}$$

where, pi is the proportion of total samples belonging to i^{th} species and S is the number of species in the samples. Differences in species diversity between sites was analyzed using diversity t-test [13]

2.5.2 Diet of Fish

Diet composition data was obtained from fish specimens caught by traps at sampling sites and used for the determination of the trophic levels of fish. The number of stomach specimens with food items was derived as:

Number of stomachs with food items=TS_e-TS_0, where TS_e = total number of examined stomachs specimens and TS_o = total number of stomachs that had no food items per site.

Relative Trophic Composition (RTC) of fish species per site was calculated as:

$$\text{RTC}(\%) = \frac{\text{Number of fish specimens belonging to one trophic level per site}}{\text{Total number of fish specimens belonging all trophic levels per site}} \times 100$$

Significant differences in proportions of trophic levels between sites were analyzed using Fisher's exact test [28].

The occurrence of *K. alvarezii* in the stomachs of fish specimens caught at the study sites was analyzed to determine whether there was fish biomass transport from the farmed area to the unfarmed area since *K. alvarezii* was only found at the farmed area. Frequency of occurrence of *K. alvarezii* in stomach contents of fish species between study sites was analyzed using frequency of occurrence method [14]. Significant differences in proportions of stomachs with *K. alvarezii* between sites were analyzed using Fisher's exact test [28]. All data obtained was processed and analyzed using Microsoft ® Excel, Minitab ® and PAST ® software. All statistical tests of significance were determined at $\alpha = 0.05$.

3. Results

3.1 Fish Abundance

Results in Table 1 indicate a total of 55 fish belonging to 22 species were caught at the farmed site, while 122 fish belonging to 25 species were caught at the unfarmed site. Chi square test showed that differences in fish species abundance between the unfarmed site and the farmed site were significant ($\chi^2 = 4.076$, df = 1, $p<0.05$). *Siganus sutor* Valenciennes, 1835 was the most abundant species at both the farmed and unfarmed sites (Table 1). Nine other species including *Acanthurus dussumieri* Valenciennes 1835, *Arothron hispidus* Linnaeus,1758, *Chaetodon auriga* Forsskål, 1775, *Chlorurus sordidus* Forsskål,1775, *Epinephelus coioides* Hamilton, 1822, *Lethrinus harak* Forsskål, 1775, *Lethrinus mahsena* Forsskål, 1775, *Plectorhinchus gaterinus* Forsskål, 1775 and *Scarus ghobban* Forsskål, 1775, were caught at both the farmed and unfarmed sites but in relatively lower numbers.

Table 1: Numerical and relative abundance of fish species caught by trap sampling.

Species	Farmed site	Unfarmed site	Farmed site (%)	Unfarmed site (%)
Acanthurus dussumieri	2	4	3.6	3.3
Apogon nigripinnis	1	-	1.8	0.0
Archamia fucata	2	-	3.6	0.0
Arothron hispidus	3	5	5.5	4.1
Balistapus undulatus	1	-	1.8	0.0
Caranx sexfasciatus	-	1	0.0	0.8
Chaetodon auriga	3	12	5.5	9.8
Chaetodon trifasciatus	-	1	0.0	0.8
Cheilinus chlorourus	1	-	1.8	0.0
Cheilopogon atrisiginis	-	1	0.0	0.8
Chlorurus sordidus	1	5	1.8	4.1
Epinephelus coioides	6	3	10.9	2.5
Epinephelus miliaris	-	1	0.0	0.8
Epinephelus polyphekadion	1	-	1.8	0.0
Gymnothorax undulates	-	2	0.0	1.6
Hipposcarus harid	-	2	0.0	1.6
Histrio histrio	-	1	0.0	0.8
Leptocarus vaigeinsis	-	2	0.0	1.6
Lethrinus harak	2	3	3.6	2.5
Lethrinus mahsena	1	1	1.8	0.8
Lutjanus bohar	1	-	1.8	0.0
Lutjanus fulviflamma	-	5	0.0	4.1
Muraenesox cinereus	-	1	0.0	0.8
Naso thynnoides	1	-	1.8	0.0
Ostracian cubicus	-	1	0.0	0.8
Parupeneus indicus	-	7	0.0	5.7
Parupeneus forsskali	-	4	0.0	3.3
Plectorhinchus gaterinus	2	1	3.6	0.8
Saurida gracilis	1	-	1.8	0.0
Scarus ghobban	3	19	5.5	15.6
Scarus niger	8	-	14.6	0.0
Scarus rubroviolaceus	1	-	1.8	0.0
Siganus stellatus	-	1	0.0	0.8
Siganus sutor	11	38	20.0	31.2
Sphaeramia orbicularis	2	-	3.6	0.0
Synanceia verrucosa	-	1	0.0	0.8
Zebrasoma velifer	1	-	1.8	0.0
Total	55	122	100.0	100.0

Underwater visual census indicated higher numbers of individual fish species at the farmed site (1740) than at the unfarmed site (220) (Table 2). Similarly more fish species were recorded at the farmed site (35) compared to 19 species recorded at the unfarmed site. Fish species abundance was significantly associated with the farmed site than the unfarmed site ($\chi^2 = 28.848$, df = 1, $p<0.05$).

Fish species recorded at both the farmed and the unfarmed sites included *Abudefduf sexfasciatus* Commerson & Lacepède, 1801, *Abudefduf vaigiensis* Quoy and Gaimard, 1825, *Centropyge multispinis* Playfair, 1867, *C. auriga, C. sordidus, Coris formosa* Bennett, 1830, *Dascyllus aruanus* Linnaeus, 1758, *L. harak, Lethrinus nebulosus* Forsskål, 1775, *Lutjanus fulviflamma* Forsskål, 1775, *Parupeneus macronema* Lacepède, 1801, *Plectorhinchus flavomaculatus* Cuvier, 1830, *Plectorhinchus gaterinus* Forsskål, 1775, *S. sutor* and *Thalassoma hebraicum* Lacepède, 1801. The shoaling *Sardine sp.* dominated the farmed site with a relative abundance of 63.2% while all other fish species had relative abundances ranging from 0.1% to 4.3%. The most abundant fish species at the unfarmed site included *L. fulviflamma* (48.2%), *L. harak* (14.1%), *A. sexfasciatus* (8.2%), *C. auriga* (5.0%), *A. vaigiensis* (4.5%) and *C. multispinis* (4.5%).

Table 2: Numerical and relative abundance of fish species from UVC.

Species	Farmed site	Unfarmed site	Farmed site (%)	Unfarmed site (%)
Abudefduf sexfasciatus	62	18	3.6	8.2
Abudefduf sparoides	1	-	0.1	0.0
Abudefduf vaigiensis	15	10	0.9	4.5
Anampses lineatus	15	-	0.9	0.0
Calotomus spinidens	8	-	0.5	0.0
Centropyge multispinis	17	10	1.0	4.5
Chaetodon auriga	36	11	2.1	5.0
Chaetodon lineolatus	14	-	0.8	0.0
Chlorurus sordidus	1	1	0.1	0.5
Coris formosa	36	5	2.1	2.3
Dascyllus aruanus	9	5	0.5	2.3
Dascyllus melanurus	-	6	0.0	2.7
Gamphosus caeroleus	5	-	0.3	0.0
Hemigymnus melapterus	7	-	0.4	0.0
Labroides dimidiatus	3	-	0.2	0.0
Lachnolaimus maximus	-	3	0.0	1.4
Leptoscurus vaigiensis	12	-	0.7	0.0
Lethrinus elongates	15	-	0.9	0.0
Lethrinus harak	66	31	3.8	14.1
Lethrinus nebulosus	10	3	0.6	1.4
Lutjanus fulviflamma	67	106	3.9	48.2
Monodactylus argenteus	10	-	0.6	0.0
Parupeneus forsskali	15	-	0.9	0.0
Parupeneus barberinus	3	-	0.2	0.0
Parupeneus macronema	26	2	1.5	0.9
Plectorhinchus flavomaculatus	4	2	0.2	0.9
Plectorhinchus gaterinus	11	2	0.6	0.9
Plectorhinchus orientalis	1	-	0.1	0.0
Plectorhinchus picus	15	-	0.9	0.0
Plectorhinchus vittatus	-	1	0.0	0.5
Sardine sp.	1100	-	63.2	0.0
Scarus ghobban	13	-	0.7	0.0
Scarus niger	20	-	1.1	0.0
Scarus rubroviolaceus	20	-	1.1	0.0
Siganus sutor	75	2	4.3	0.9
Sphyraena barracuda	2	-	0.1	0.0
Synodus variegates	-	1	0.0	0.5
Thalassoma hebraicum	22	1	1.3	0.5
Thalassoma lunare	4	-	0.2	0.0
Total	1740	220	100	100

3.2 Species Diversity

Fish caught by traps at the farmed site had a higher diversity index of 2.72 compared to 2.50 at the unfarmed site (Table 3). Similarly the evenness index was higher at the farmed site than at the unfarmed site However, the differences in diversity values between study sites for fish caught by traps were not significant (p = 0.082). Results from UVC data showed that both diversity and evenness indices were lower at the farmed site than at the unfarmed site (Table 3). Differences in diversity values from the UVC data between the two study sites were not significant (p = 0.191).

Table 3: Shannon Wiener's H' and Pielous J' evenness indices from Trap and UVC sampling at the two study sites.

Sampling Method	Site	H' index	J' index
Trap	Farmed	2.72	0.88
	Unfarmed	2.50	0.77
UVC	Farmed	1.79	0.50
	Unfarmed	1.92	0.65

3.3 Diet of Fish

Stomach contents of 39 fish trapped from farmed and 93 from the unfarmed study sites were analyzed of which 20 stomachs were empty (i.e. 6 and 14 were from the farmed and unfarmed sites respectively). Carnivorous fish species fed mostly on bivalves, invertebrates, crabs, crustaceans, detritus and fishes, while herbivorous species such as siganids mainly fed on sea grass, detritus and algae. Stomachs of omnivorous fish species had mixed contents of animal (except fish) and plant material. Stomachs of almost all herbivorous species analyzed were found to have remnants of the farmed algae species *E. denticulatum* and *K. alvarezii*.

The relative trophic composition of fish species caught at the farmed site showed that herbivores were the most dominant at both study sites, followed by carnivores and omnivores respectively (Figure 2). However Fisher's exact test showed no statistical significant differences in proportions of carnivores ($p = 1.000$), herbivores ($p = 0.651$), and omnivores ($p = 0.672$) between the two study sites.

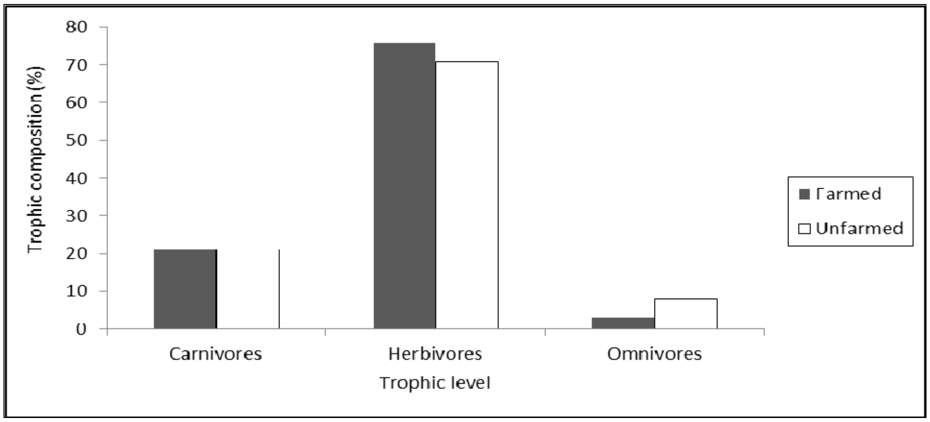

Fig 2: Relative trophic composition (%) of fish species caught at study sites.

The farmed exotic algae *K. alvarezii* was observed in stomach contents of fish from both study sites. Remnants of *K. alvarezii* occurred in 24 out of the 33 (73%) fish stomach specimens that had food items at the farmed site. At the unfarmed site *K. alvarezii* occurred in 60 out of the 79 (76%) fish stomach examined. Fisher's exact test showed no statistical significant differences in proportions of fish stomachs with *K. alvarezii* between the study sites ($p = 0.812$).

4. Discussion

Results from UVC sampling revealed higher fish abundance at the farmed site compared to the unfarmed site, consistent with earlier reports by Kenya Marine and Fisheries Research Institute which indicated large numbers of fish observed in the seaweed farms at Kibuyuni [15]. The higher fish abundance at the farmed site suggests that Kibuyuni seaweed farms attract different fish species from contiguous areas. The results of a similar study carried out by Bergman *et al* [4] also indicated higher fish abundance in algal farms than at the control areas without farms. Arechavala-Lopez *et al.* [2] and Bacher *et al*. [3] argued that fish farms continuously attract fish from surrounding waters. This would explain the preference of artisanal fishers to fish areas adjacent to the Kibuyuni seaweed farms [15]. The relatively lower numbers of fish caught by traps at the farmed site could be related to ready availability of food in farme sites, hence fish were less likely to enter traps seeking food.

The finding of similarity in fish species diversity between the study sites could be related to spillover effects following attraction of fish to seaweed farms for food and shelter. However, although Bergman *et al*. [4] found that algal farms in one lagoon had a more diversified fish fauna than the controls, farms in another lagoon exhibited similar species diversity compared to controls. Bergman *et al*. [4] attributed differences in findings to effects of farming intensity and character of the substratum of the different lagoons, which may as well explain the results in the present study.

Analysis of trophic composition of fish species indicated that herbivores were most dominant in the study areas suggesting that seaweed farms are preferred habitats for herbivores likely as a source of food. Farmed seaweeds increase habitat complexity [4] thereby increasing fish stocks either by increasing food supply for herbivores.

Being an exotic species restricted only to the seaweed farms where it was grown, the occurrence of *K. alvarezii* in stomachs of fish captured at the unfarmed site provided a possible indication of biomass transport between the two study sites. This further indicates that seaweed farms may continuously attract fish from surrounding waters and diminish their populations through fishing as observed in similar studies on fish farms [2, 7, 10]. Aquaculture installations, such as seaweed farms attract large numbers of wild fish owing to their varied attractive structural and dietary features [4]. Randall *et al.* [20] similarly demonstrated cross-boundary movements of fish and quantified the trophic connectivity between dominant habitat types by direct examination of their stomach contents as found in this study.

In Kibuyuni reports indicated increased artisanal fishing activities around Kibuyuni seaweed farm area [15]. Given the indication of biomass export from the farmed area to adjacent unfarmed areas, spill over fish movement may result in enhanced vulnerability if the species are targeted by local artisanal fishers. Heavy fishing pressure on such targeted fish species can remove a significant proportion of individuals attracted to fish farms with potentially serious implications for reproductive and economic outputs [22]. Thus, although the findings of the present study suggest that local artisanal fisheries appear to benefit from partial fish biomass export from seaweed farms; there is need for protection of aggregating fish populations by creating a no-fishing buffer zone around the farms as suggested by Arechavala-Lopez *et al.* [2].

Significant grazing on farmed seaweeds by herbivorous fish may cause reduction in seaweed growth and total yields. Sievanen *et al*. [24] reported that herbivorous fish, particularly the *Siganus* sp., caused reduction of seaweed growth in some seaweed farms in the Philippines and Indonesia, to extents that discouraged some farmers from seaweed farming. The findings of the present study found that herbivores dominated the study area and supports earlier assertions of herbivory effects on seaweeds in Kibuyuni farms [15]. There is therefore need for studies on the impact of herbivory on the growth and total yields of the farmed seaweeds.

5. Conclusions

The results of this study show that seaweed farms have the potential to attract and enhance abundance of wild fish species, mostly herbivores suggesting that farmed seaweeds provide readily available alternative food source. The occurrence of *K. alvarezii* in stomach contents of fish captured at the unfarmed site provided an indication of fish biomass transport between the study sites given that *K. alvarezii* was only found in the farmed area. This observance explains the increase in fishing activities by local artisanal fishers in areas adjacent to seaweed fish farms. There is a need for studies on the impact of herbivory effects on the growth and yield of farmed seaweeds. Putting in place conservation measures, such as creating fishing buffer zones around seaweed farms to curtail possible overfishing by local artisanal fishers of target species spilling-over from seaweed farms to adjacent areas is also important.

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