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Research Article

Effects of stocking density and additional nutrients on growth of the commercially farmed seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* in Zanzibar Tanzania

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ABSTRACT
Since commercial seaweed cultivation in Tanzania started in 1989, only limited research has been done on impact of stocking density and nutrients, which are factors that may limit seaweed growth. In this study, *Eucheuma denticulatum* and *Kappaphycus alvarezii* were cultivated at low (50 g cuttings of seaweed (half of what farmers use) in 4m long nylon ropes) and high (100 g cuttings of seaweed (the stocking density of farmers) in 4m long nylon ropes) stocking densities under in situ growth conditions and the seaweeds were fertilised by nitrogen and phosphorous enrichments. Specific growth rates (SGRs) of both species were significantly higher at the lower stocking density ($P<0.05$), whether the seaweeds had been fertilised or not. The addition of nutrients had no significant effect ($P>0.05$) on the seaweeds as the SGRs were similar for both species and densities except for *K. alvarezii* at high density ($P=0.04$). Thus, lower stocking density enhances the growth rates of these two seaweeds while additional higher nutrients have little effect.

KEYWORDS: *Stocking density, nutrients, seaweed growth, Eucheuma denticulatum, Kappaphycus alvarezii, Zanzibar*

INTRODUCTION

Seaweed farming in Tanzania started in the early 1980's when the first experiments were conducted in three locations on the Mainland Coast and Zanzibar Islands (Mshigeni 1985- University of Dar es Salaam, unpublished report). In 1989 commercial farming started when private entrepreneurs established commercial farms in Zanzibar using imported strains of *Eucheuma* from the Philippines. Currently, three species *Kappaphycus alvarezii*, *K. striatum*, and *Eucheuma denticulatum* are farmed in Zanzibar and Mainland Tanzania.

In spite of the growing industry in Tanzania, only a limited research work has been done on the impact of important parameters on the farmed seaweeds themselves especially nutrients and stocking density. Most works have studied the impact of the seaweeds on other parameters such as the intertidal ecology (Johnstone and Olafsson, 1995; Olafsson *et al.* , 1995; Msuya *et al.* , 1996-Institute of Marine Sciences,

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unpublished report) and socioeconomics of the people (Pettersson-Löfquist, 1995; Msuya, 2006). The effect of stocking density on the growth rate of these seaweeds has not been studied. Equally important is the effect of nutrients on seaweed growth which has been minimally studied in Tanzania. It has been shown in other areas that higher nutrients increase the growths of the seaweeds (Qian *et al.* , 1996; Lombardi *et al.* 2006; Rodrigueza and Montano 2007). In Tanzania, only one study by Msuya and Kyewalyanga (2006- Institute of Marine Sciences, unpublished report) is reported that looked at the effects of nutrients on the growth of the two species. The authors found no difference between fertilised and unfertilised seaweeds. No other study on those parameters could be found in the literature.

Farmers usually plant about 100 g cuttings of the seaweed at 20 cm intervals. It was thus, hypothesized that a lower stocking density would result in higher growth rates of the seaweeds. It was further hypothesized that addition of nutrients will increase further the growth rate of the seaweeds at least under the low stocking density.

Research on how the farmed seaweeds are impacted by the factors found in the cultivation areas is important for the improvement of the seaweed farming industry e.g. increased production for the benefit of the farmers and the country at large. The current study looked at the effects of stocking density and nutrients on the growth of the seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* in Zanzibar, Tanzania.

MATERIALS AND METHODS

Study site

The study was conducted in Uroa on the East Coast of Unguja Island, Zanzibar, Tanzania. Unguja Island is located between latitudes 5° 40' & 6° 30' South and longitude 39° East. In this site, both *Eucheuma denticulatum* and *Kappaphycus alvarezii* are farmed commercially.

Experimental set up

Five rafts (6 x 2 m^2) were constructed using bamboo poles. The poles were fixed by tying with 6mm thick nylon ropes. Anchors (80 kg on each of the four sides of the rafts) were made of concrete blocks that were made especially for marine environment, i.e., with extra cement and rock pebbles. The anchors were fitted to the rafts using 8 mm thick nylon ropes which are strong against ocean waves. Due to strong winds experienced in Uroa most of the time, the rafts were placed at 0.5 m from the bottom, positions that allowed half a meter of up and down movement following flooding and ebbing of the tide.

Two rafts were used for *Eucheuma denticulatum* (fertilised and unfertilised) and two for *Kappaphycus alvarezii*, also fertilised and unfertilised. Seaweed cuttings/seedlings were planted using the 4mm thick ropes that are used by farmers in Zanzibar. The ropes were cut into 2 m long pieces. Ten such ropes or lines (in two replicates) were planted for each treatment and species with extra lines to cover for possible losses during the running of the experiment. For the low stocking density, about 50 g of the seaweed cuttings (purchased from farmers) that gave an initial weight of 500 g per line were tied to the lines while at the high density about 100 g (as used by the farmers) that gave an initial weight of 1000 g per line were tied. The distance between the seaweed cuttings was 20 cm as is used by farmers. For the fertilisation treatment, 16 ml of liquid 12N:10P:8K were added to the planted seaweeds at each treatment. This was done by mixing the 16ml with the seawater to make 1 litre and spraying the mixture on the seaweeds at each sampling date (twice per month) during low tides. At the time of adding nutrients, water levels in the rafts were about 40 cm. Enough time was allowed (2-3 h) for the seaweeds to take up the nutrients before the tide came in. The treatment with additional nutrients was placed at a distance of 100 m from the treatment without additional nutrients. The study was conducted for one year from July 2005 to June 2006.

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Sample collection and analysis

Nutrients

Water samples (500 ml) in three replicates for analysis of nutrients were collected twice a month in the rafts for each treatment during low tides. The samples were then transported to the laboratory and filtered through 4.7µm Whatman filter papers. Measurements of absorbencies of the respective nutrients were done using a spectrophotometer with methods of Parsons *et al.* (1984), and concentrations of growth limiting nutrients, i.e. total ammonia nitrogen (TAN) and soluble reactive phosphate (SRP) were determined. Total nitrate (nitrite/nitrate) could not be analysed because of problems with nitrate column.

Seaweed growth rates

Sampling was done bimonthly. Four lines were harvested during the first half of the month and the remaining six were harvested during the second half of the month. This was done to ensure availability of samples in case of loss of the seaweed materials due to e.g. strong winds and grazing. After harvesting, the seaweeds were shaken (Fujita 1985) to remove excess water and weighed using a commercial weighing scale to obtain fresh weights. Whole lines were weighed. Specific growth rates (SGR, %) were calculated as:

$SGR = 100 \times [\ln (w_t/w_0)]/t$ where w_0 is the initial weight ($t=0$) and w_t is the weight at t cultivation days. Where some cuttings were missing (because of seaweed breaking-off caused by strong winds or grazing), a formula was used in the calculation as follows:
(w*13)/n where w is the recorded weight, 13 the initial number of seaweed cuttings on a rope, and n is the number of cuttings at the time of sampling.

Environmental parameters of salinity and water temperature that are directly related to seaweed growth were monitored by using a hand refractometer (VEE GEE USA, STX-3), and a hand pH-Temperature meter (HANNA Instruments pHep HI 98128) respectively.

RESULTS

Growth conditions

The seaweeds were growing at salinities 32 – 35% and temperatures of 28 – 31^{o}C. Water column nutrients varied from 6 – 15 µM total ammonia nitrogen and 2 – 3 µM soluble reactive phosphate. In some cases *K. alvarezii* was overgrazed by seaurchins of the species *Echinometra mathaei* and *Tripneustes grattila*. The seaweeds broke off from the lines due to strong winds and were carried away by ocean currents (after six weeks of growth many parts of the fully grown seaweed cuttings in the high stocking density broke off owing to heavy fronds). Both grazers and strong winds caused loss of data which explains the missing data points on figs. 1- 4. This result was not observed in the low density.

Effect of stocking density

The seaweeds cultivated under the low stocking density grew at higher rates (specific growth rates, SGRs) than those cultivated under the high stocking density for both species whether fertilised or not (Figs. 1&2). The SGR of *Eucheuma denticulatum* varied from an average of 2.2 – 7.4% d^{-1} under the low density and from 1.7 – 5.1% d^{-1} under the high density, while that of *K. alvarezii* was 1.7 – 6.8 and 1.5 – 5.3% d^{-1} respectively. Statistical analysis (ANOVA) for the low and high stocking densities showed significant differences between SGRs of fertilised and unfertilised *E. denticulatum* ($F=9.06$, $DF=34$, $P=0.005$ & $F=7.59$, $DF=37$, $P=0.009$ for unfertilised and fertilised treatments respectively). For *K. alvarezii* the fertilised treatment showed significant differences in SGRs between low and high stocking densities ($F=10.84$, $DF=36$, $P=0.002$) but not the unfertilised treatment ($F=2.96$, $DF=32$, $P=0.095$). This shows that low stocking density enhances the growth of the seaweeds.

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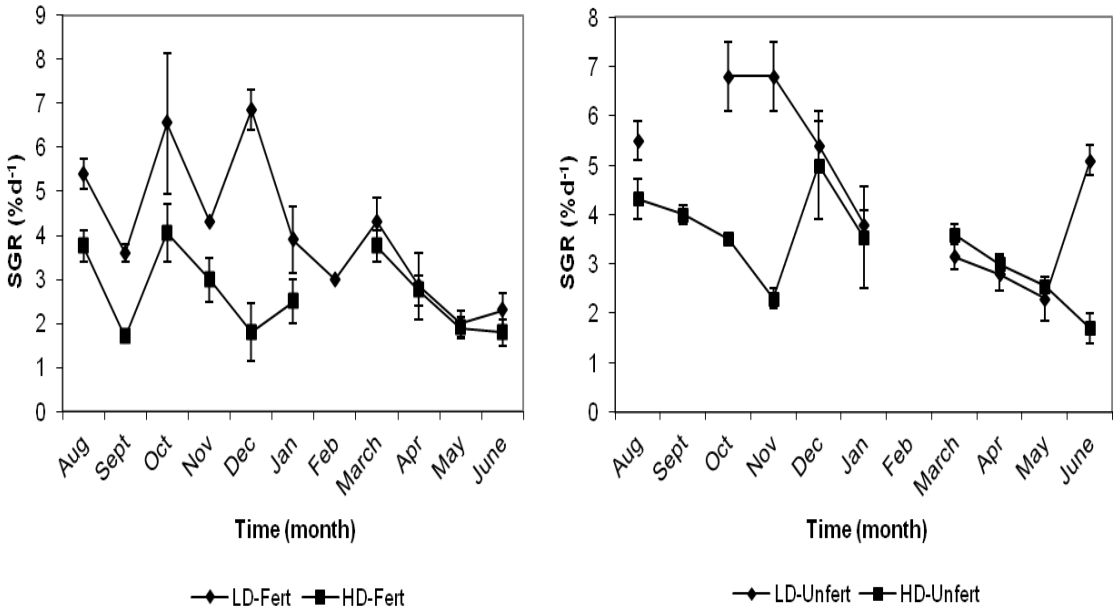


FIGURE 1: *Variation in specific growth rates (%±STD) of the seaweed K. alvarezii cultivated under low (LD) and high (HD) stocking densities, Uroa, Zanzibar.*

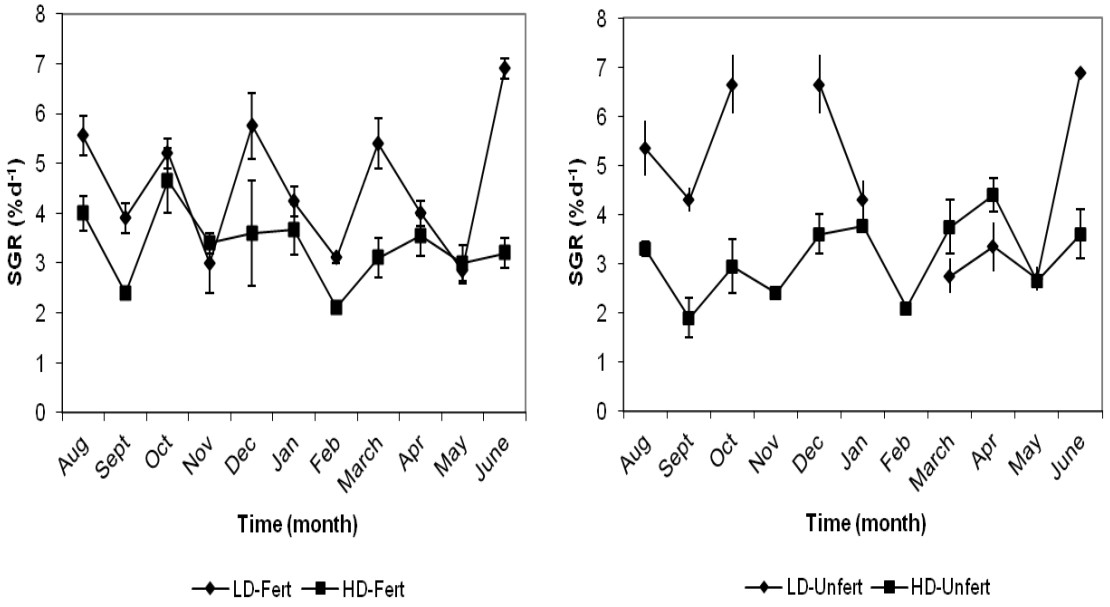


FIGURE 2: *Variation in specific growth rates (%±STD) of the seaweed E. denticulatum cultivated under low (LD) and high (HD) stocking densities, Uroa, Zanzibar.*

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Effect of nutrients

The treatment with nutrients showed no significant differences in SGRs (P>0.05) of both species and stocking densities except for *K. alvarezii* cultivated under high density which showed significant differences between fertilised and unfertilised treatments (F=4.39, DF=34, P=0.044). This treatment showed lower growth rates in the fertilised than the unfertilised treatment (Figs. 3&4). These results show that while the addition of nutrients has minimum effect on the seaweeds, the *K. alvarezii* did show significant differences in SGR under high density probably due to stress related to the seaweed being more sensitive to changes e.g. crowding, high temperatures, and other environmental changes. Some of these issues will be discussed later in this paper.

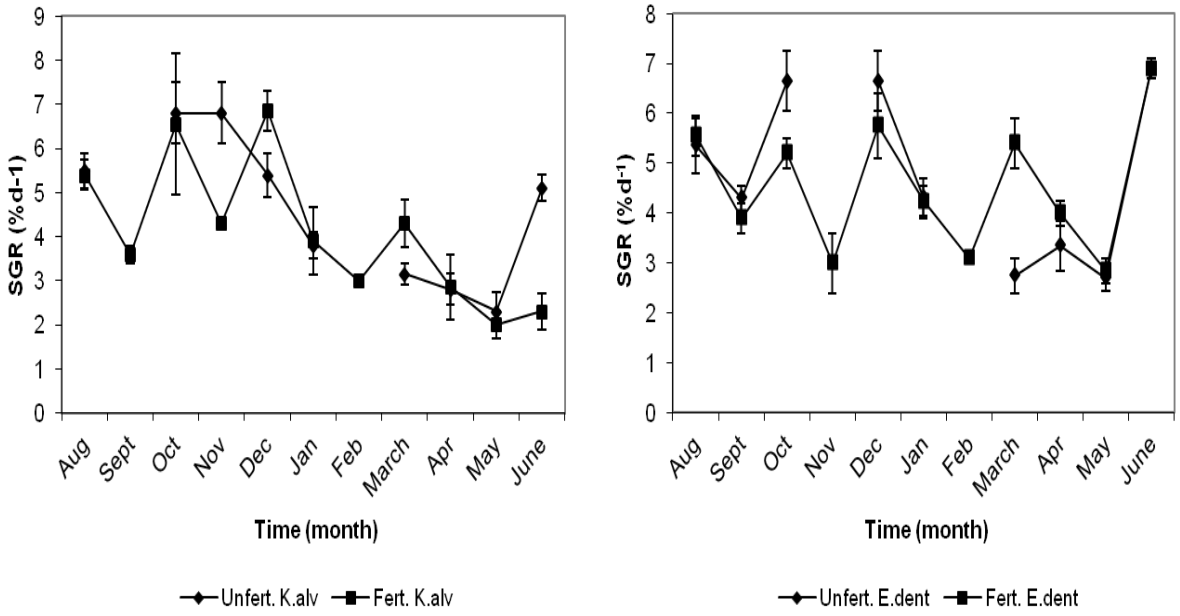


FIGURE. 3: *Variation in specific growth rates (%±STD) of the unfertilised and fertilised K. alvarezii and E. denticulatum cultivated under low stocking density, Uroa, Zanzibar.*

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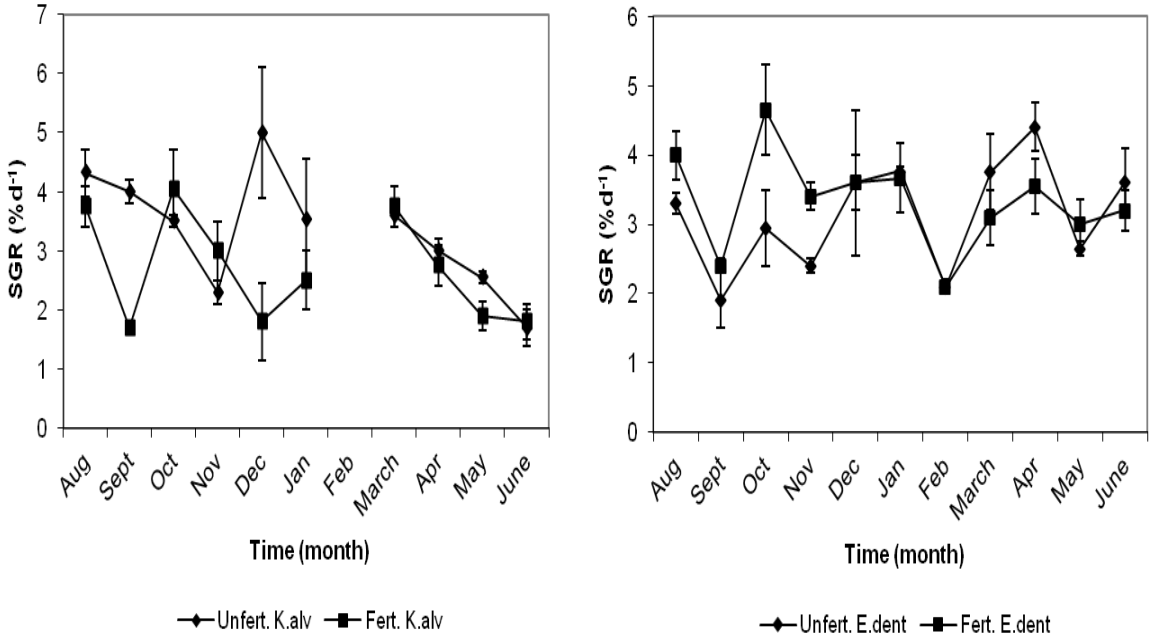


FIGURE 4: *Variation in specific growth rates (%±STD) of the unfertilised and fertilised K. alvarezii and E. denticulatum cultivated under high stocking density, Uroa, Zanzibar.*

Seasonal variations

During the months of heavy rainfall (March – May) and hot season (January – February), the seaweeds grew at lower rates due to possible stress from too much rainfall and too high temperatures (≥30 ^{0}C). During the months of low rainfall (September-November) and temperatures (June-August), the seaweeds grew at higher rates (see Figs. 1- 4).

DISCUSSION

Stocking density is one of the factors that are known to significantly affect seaweed growth and this study has shown similar results where a lower density has increased seaweed growth. A number of studies have shown this effect although in different seaweed species than the one used in this study. These include the review by Neori *et al.* 2004 (and references therein). High stocking density like the one used in this study, which is used by many farmers in Tanzania, leads to low growth most probably due to stress on the seaweed when competing for space and resources. The breaking of the seaweeds after six weeks of cultivation at the high stocking density shows that the farmers loose further more seaweed through the use of the high density.

Nutrients had little effect on the seaweeds under both stocking densities, results that are similar to those of Msuya and Kyewalyanga (2006- Institute of Marine Sciences, unpublished report) who cultivated the seaweeds in the same area under the high stocking density. The significant differences found between fertilised and unfertilised *K. alvarezii* under the high density is most probably related to the fact that the species is less resistant to environmental changes than *E. denticulatum.* The less resistant aspect of *K. alvarezii* has been documented in studies of seaweed die-offs in Tanzania and other areas (Mmochi *et al.* 2005- Institute of Marine Sciences, unpublished report, Hayashi *et al.* 2010, Msuya 2007, Vairappan *et al.* 2008, Hayashi *et al.* 2010,). Its cultivation under the high density may have stressed the seaweed leading to it being more affected by nutrients. These results are, however, experimental-set-up-specific.

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The setting of the experiment in the sea weakens the effects of nutrients as the nutrients get diluted by high tides. Other experimental set-ups like those of Qian *et al.* (1996) and Rodrigueza and Montano (2007) who used the seaweeds as biofilters in integrated systems resulted in higher growth rates in the fertilised treatments. Unlike the objectives of the other works, the current study was aimed at looking for ways of improving the seaweed cultivation for the benefits of the farmers and countries by using the cultivation conditions of the farmers.

Growth rates obtained here are higher than those of other works except for the bad growing seasons (during months of heavy rains and high temperatures) when the rates were lower. During bad seasons, growth rates were similar to those reported in other works and sometimes lower, e.g. Msuya and Neori (2002) who obtained growth rate of 3% in unfertilised *E. denticulatum* cultivated in a land-based integrated system in Zanzibar. Glenn & Doty (1990) and Hurtado-Ponce (1992) obtained average growth rates of *Eucheuma denticulatum*, *Kappaphycus alvarezii*, and *Kappaphycus striatum* of about 3.5%. Higher growth rates similar to those of the good growth seasons of the current study were reported by Hayashi *et al.* (2007) on *K. alvarezii*. A growth rate of 3.5% per day is considered significant in commercial cultivation of *Eucheuma* spp. (Adnan and Porse 1987, Luxton *et al.* 1987).

In conclusion, lower stocking density (half of what farmers use) results in higher growth rates than the high stocking density used by seaweed farmers in Tanzania. Higher nutrient levels have little effect on growth rates of both *E. denticulatum* and *K. alvarezii*, in this experimental setup, and, thus, do not add much to the seaweed farming industry. However, additional of nutrients would be necessary and beneficial in other set-ups such as land-based systems.

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