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Effect of the Presence of Seagrass and Nutrients on Growth Rates of Farmed *Kappaphycus alvarezii* and *Eucheuma denticulatum* (Rhodophyta)

Flower E. Msuya and Dotto Salum

Institute of Marine Sciences, University of Dar es Salaam, PO Box 668, Zanzibar, Tanzania.

Abstract—The effects of seagrass cover and nutrients on seaweed cultivation were examined in tidal pools in Tanzania. The seaweeds *Eucheuma denticulatum* and *Kappaphycus alvarezii* were cultivated from August 2006 - August 2007 in pools with and without seagrasses, and with and without added nutrients. Growth rates of fertilised *E. denticulatum* were significantly lower in the presence of seagrasses ($P < 0.05$) but there were no significant differences ($P > 0.05$) in the rest of the treatments. Monthly growth was lowest during the hotter months (December-February) and heavy rains (March-May), and highest during the cooler months (June-August).

Keywords: *Eucheuma denticulatum, Kappaphycus alvarezii*, seaweed culture, growth, seagrass, nutrients.

INTRODUCTION

Commercial seaweed cultivation in Tanzania started in 1989 following initial experiments in the early 1980s. Three species are currently farmed: *Eucheuma denticulatum*, *Kappaphycus alvarezii* and *K. striatum*. Primarily *E. denticulatum* and *K. alvarezii* are grown and contribute significantly to the economy of the country, especially in Zanzibar, being amongst its major marine exports and improving the economic status of coastal farmers. The annual production has increased from about 800 MT in early 1990 to the current 6 000 MT. The production varies from 4 000–10 000 MT annually, averaging 6 000 MT (Department of Fisheries and Marine Resources, Zanzibar).

Since the start of seaweed farming, there have been debates as to whether seaweed farmers uproot the seagrass when starting seaweed farms. Whereas other stakeholders think that this is the case, farmers deny this and some of them maintain that seagrasses die during the farming process. This shows the importance of studying the relationship between seagrass beds and seaweed farming to see if seagrass cover adversely effects seaweed growth. Coupled with this is the fact that, despite the importance of the industry, research has so far concentrated on the effects of seaweed farming on other organisms and the intertidal ecology of seagrass beds (e.g. see Olafsson *et al*., 1995; Msuya *et al*., 1996), but not on the seaweeds themselves. In addition, the substratum in which seaweeds

Corresponding author: FEM
Email: msuya@ims.udsm.ac.tz; flowereze@yahoo.com

grow is one of the major factors that determine their growth. It is known, for example, that a muddy substratum is unsuitable for culture of the two seaweeds (Msuya, 1995). Cultivating seaweeds on a substratum covered by seagrass may result in reduced growth due to competition between the farmed seaweed and the seagrasses for nutrients and space. Only one study has examined the effects of seagrasses on the growth of the seaweeds (Mtolera, 2003). However, this was a short-term study and did not include nutrients and environmental parameters.

Nutrients are known to enhance the growth of many seaweed species but their importance in seaweed culture has been given little attention in Tanzania. Elsewhere, it has been shown that the addition of nutrients to cultivated eucheumoids, whether in monoculture or integrated systems, results in higher growth rates (Qian *et al*., 1996; Lombardi *et al*., 2006; Rodrigueza & Montano, 2007). Two studies have documented *E. denticulatum* and *K. alvarezii* culture in Tanzania: Msuya and Kyewalyanga (2006) undertook experiments at the stocking density used by farmers in Tanzania, a density double that used in the current study, and Msuya and Salum (2006) investigated the effects of nutrients at a lower stocking density. Both studies yielded slightly higher growth rates of *E. denticulatum* and lower growths for *K. alvarezii*. The current study investigated the year-round effects of seagrass cover and nutrient addition on the growth of *E. denticulatum* and *K. alvarezii* at a low stocking density

MATERIALS and METHODS

Study site

The study was conducted in Uroa on the East Coast of Unguja Island, Zanzibar, Tanzania (6°5'60" S; 39°25'0" E), where both *Eucheuma denticulatum* and *Kappaphycus alvarezii* are farmed commercially. Uroa was selected as the study site as it has small pools of water at low tide ideal for the addition of the nutrients.

Experimental set-up

Four tidal pools ~ 4x2 m and 30 cm deep were used for the study. The pools contained small *Thalassia*, *Cymodocea* and *Halodule* seagrasses. Seaweeds purchased from farmers were cultivated using the off-bottom method which is employed by seaweed farmers in Tanzania. In this method, seaweed cuttings of about 100 g are tied on nylon ropes and each rope is stretched between wooden anchoring pegs. The stocking density of seaweeds was half that used by farmers i.e. 50 g. The seaweeds were tied on 2 m long, 4 mm diameter ropes using short nylon cords known as tie-tie at 20 cm intervals. The initial weight of each line containing seaweed was 500 g. Four treatments were used, comprising: 1) seagrasses with nutrients added at low tides on each sampling date, i.e. once per month, 2) seagrasses with no additional nutrients, 3) no seagrasses but with additional nutrients, and 4) neither seagrasses nor additional nutrients. In the "without seagrass" treatment, the seagrasses in the pools were removed two weeks prior to commencement of the experiments. Nitrogen and phosphorus were added where applicable by applying 16 ml of a commercial liquid fertiliser (12N:10P:8K+TE; Mukpar Booster, Mukpar Tanzania Ltd), giving initial concentrations of 42.7±1.3 μM for total ammonia nitrogen (TAN) and 36.1±0.4 μM for soluble reactive phosphate (SRP). The fertiliser was diluted to 1 litre and sprayed once per month on the seaweeds at low tide, allowing 2-3 h for the seaweeds to take up the nutrients. Fertilised pools were 100 m from the unfertilised treatments. Seaweed growth was monitored every second month and all other parameters (see below) were measured monthly. This routine was repeated from August 2006 to August 2007.

Sample collection and analysis

Specific growth rates

The seaweed strings were removed for monitoring by untying the lines from their anchoring pegs, shaking to remove excess water, and weighing on a mechanical scale. Specific growth rates were calculated from the fresh weights as follows:

$$SGR = 100 X [\ln (w_t/w_0)]/t$$

where w_o was the initial weight and w_t the weight at *t* culture days. Where some cuttings were missing because seaweed was broken off by strong winds or grazing, a formula was used in the calculation as follows:

(w*13)/n where w was the recorded weight, 13 the initial number of seaweed cuttings on a rope, and n the number of cuttings at the time of sampling.

Nutrients

Three replicate 500 ml water samples were collected in the pools at low tide and filtered through 47µm Whatman filter paper in the laboratory. Total ammonia nitrogen (TAN) and soluble reactive phosphate (SRP) were determined spectrophotometrically according to Parsons *et al*. (1984). Oxidised nitrogen could not be measured due to problems with nitrate column.

Data analysis

Analysis of variance and t-tests were conducted to test for variation in growth rates between the four treatments and the two seaweed species. Pearson's correlation analysis was used to establish the relationship between growth rates and nutrients.

RESULTS

Nutrient concentrations and uptake

Before addition of the fertiliser, the total ammonia nitrogen (TAN) averaged 6.6±1.6 µM and the soluble reactive phosphate (SRP) 1.9±0.1 µM, with no significant difference between both the seagrass and non-seagrass pools that were to be fertilised or left unfertilised (ANOVA, P>0.05). After the addition of nutrients, the TAN concentration averaged 42.7±1.3 µM and the SRP 36.1±0.4 µM. In the 2–3 hours allowed for nutrient uptake before the tide came in, the nutrient concentrations in the enriched treatment were reduced to before-fertilisation levels (TAN 5.8±1.6 µM; SRP 2.0±0.0 µM). TAN uptake was 81% efficient and that of SRP, 95% efficient, presumably by the seaweeds and also seagrasses, microflora and the sediment.

Effect of seagrass cover

The overall data revealed significant differences (paired t-test, P<0.05) between growth rates of strings of *Eucheuma denticulatum* in the fertilised pools with and without seagrasses, lower growth rates being recorded in the presence of seagrass. No significant differences (P>0.05) were found in the rest of the treatments. Individual data nevertheless revealed relatively lower growth in *E. denticulatum* in the seagrass pools than in the non-seagrass pools, whether fertilised or not (Figs 1 and 2). Additionally, lowest growth rates were recorded in the pools with seagrass (3.37% d^{-1} for the fertilised and 2.5% d^{-1} for the unfertilised pool), while the highest growth rates (>10% d^{-1}) were recorded in those without seagrass.

Kappaphycus alvarezii, on the other hand, tended to have higher growth rates in the nutrient-enriched pool with seagrass than without seagrass (Fig. 3) although these results were not statistically significant; the highest value (9.5% d^{-1}) was recorded in the former. The effect was less pronounced in the unfertilised treatments (Fig. 4) which showed no difference with or without seagrass.

Effect of nutrients on growth

A comparison of fertilised and unfertilised treatments revealed no significant differences in growth rates (t-test, P>0.05) between those with and without additional nutrients and between the two seaweed species. However, although not statistically significant, *E. denticulatum* tended to grow faster in the unfertilised than the fertilised pools without seagrass (Fig. 5), as did *K. alvarezii* (Fig. 6). In the seagrass pools, no marked increase in the growth rates of *E. denticulatum* (Fig. 7) and *K. alvarezii* (Fig. 8) were observed with nutrient-enrichment. Correlation analysis

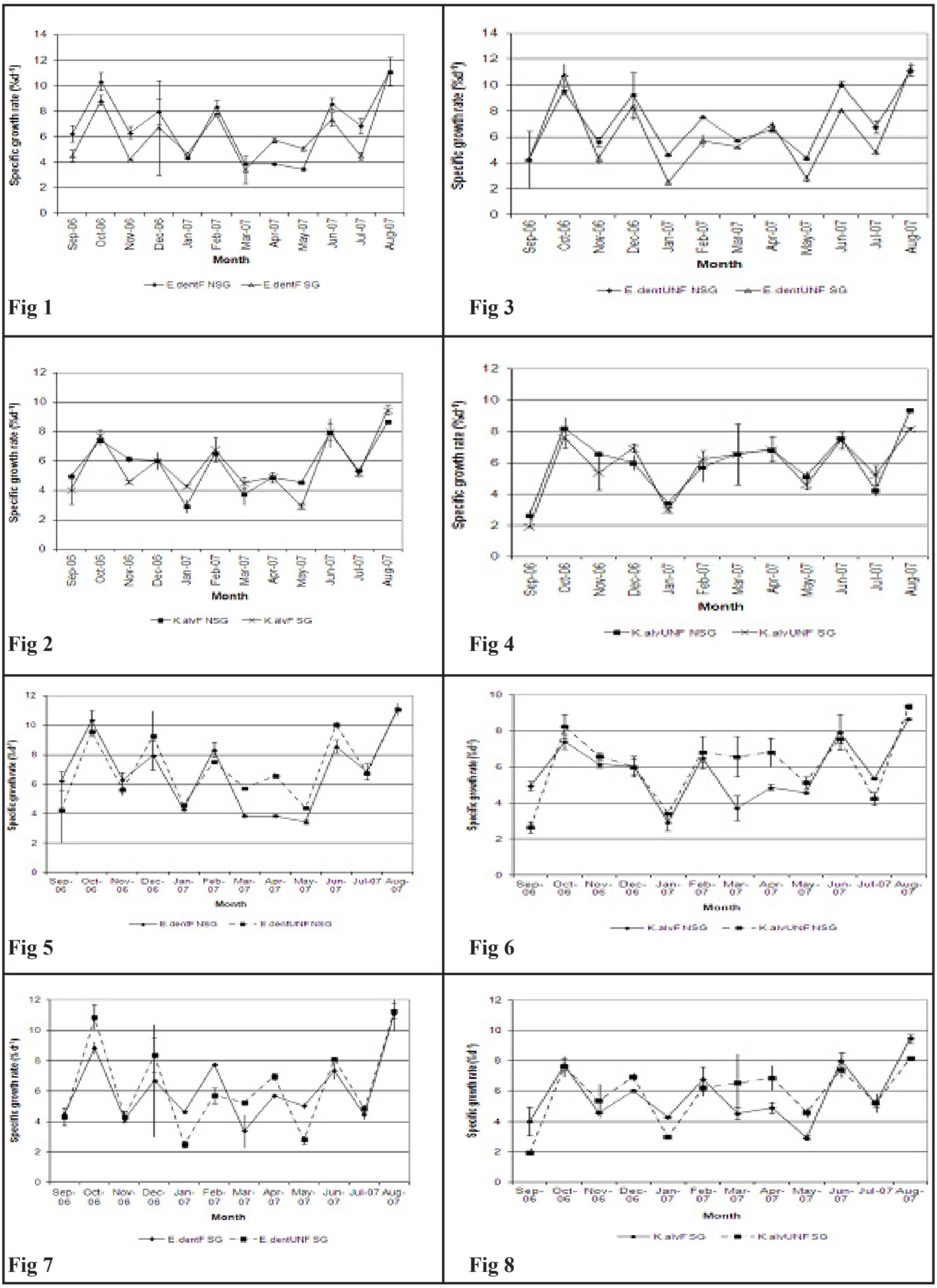

Figure 1. Monthly mean growth rates (%d^{-1}±SD) of a) fertilised *Eucheuma denticulatum* and b) *Kappaphycus alvarezii* in tidal pools with and without seagrass; c) unfertilised *Eucheuma denticulatum* and d) *Kappaphycus alvarezii* in tidal pools with and without seagrass; fertilised and unfertilised e) *Eucheuma denticulatum* and f) *Kappaphycus alvarezii* in tidal pools without seagrass; and fertilised and unfertilised g) *Eucheuma denticulatum* and h) *Kappaphycus alvarezii* in tidal pools with seagrass.

revealed significant correlation between TAN and growth rates in both *K. alvarezii* (Pearson test, r=0.546, $P<0.05$) and *E. denticulatum* (r=0.553, $P<0.05$) in pools without seagrass but not between pools with seagrass ($P>0.05$). There was no significant correlation between SRP and the seaweeds' growth ($P>0.05$).

Comparison of species

On comparing the two seaweed species, significant differences in growth rates were found between the two species only in the fertilised treatments with seagrass (t-test, $P<0.01$) and without seagrass ($P<0.05$), but not the unfertilised treatments ($P>0.05$). The overall results combining all the treatments showed that *E. denticulatum* yielded relatively higher but non-significant growth rates than *K. alvarezii* (6.4±2.4 and 5.7±1.8% d^{-1} respectively).

Monthly variations in growth

Lowest seaweed growth rates (3-4% d^{-1}) were recorded during the hottest months of December–February (associated with NE monsoons having temperatures of 30-32°C), with the lowest growth in the hottest month of January. Similarly, low growth rates were recorded during the heavy rains (March-May). Highest growth rates of 9-11% d^{-1} were recorded during seasons with cooler air temperatures (June-August with temperatures of~26.6°C) within the SE monsoon. Surprisingly, November, which is known to be cooler in the short rain season which should favour seaweed growth, yielded lower growth rates than the hot month of December. Fertilised treatments of both species were more affected during heavy rains, yielding lower growth rates than the unfertilised treatments. This suggests that the seaweeds were stressed by the rains that lowered the salinity, especially at low tides, and the short-term fertilisation may have aggravated the situation since it was applied during low tides.

DISCUSSION

The results of this study show that, overall, seagrass cover affected the growth rate of *E. denticulatum* when additional nutrients were supplied to the seaweed. This was not the case for *K. alvarezii*. Additional nutrients had no significant effect on the growth of the two seaweeds in the absence of seagrass. The lowest growth rates for *E. denticulatum* were recorded with seagrass and the highest without seagrass, suggesting that the effect of seagrass merits further study. These results contrast with those of Mtolera (2003) who found that *E. denticulatum* grows better without seagrass. The current study nevertheless yielded insufficient evidence of adverse effects of seagrass that would necessitate their clearance when establishing seaweed farms. However, there are areas where seagrasses are very dense and, with larger seagrass species such as *Syringodium* and *Enhalus* (as opposed to the *Thallasia* and *Cymodocea* found at Uroa), it would be hard to farm seaweed in such seagrass beds. A similar study to this in areas with large seagrass species would be needed to elaborate this point.

The lack of differences in growth between fertilised and unfertilised treatments is surprising as pre- and post-dosing determinations indicated that the residence time was sufficient for complete uptake of the nutrients in the treated pools before the tide came in. Competitive uptake by other biota in the tidal pools may account for this anomaly in the results, or the monthly dose may have been too little to have an effect. However, it has been shown in other studies that the two species grow faster in land-based systems that allow for a longer residence time of the additional nutrients (Qian *et al*., 1996; Lombardi *et al*., 2006; Rodrigueza & Montano, 2007). In contrast to this, Wakibia *et al*. (2006) recorded lower seaweed growth in areas where excretions from "numerous vertebrates" introduce substantially higher nutrient levels at Kenyan sites. The results of the current study may thus have been affected by other environmental parameters that interacted with nutrients, e.g. rainfall, temperature and salinity as demonstrated by Msuya and Kyewalyanga (2006) and Davis and Fourqurean (2001).

The hot season and heavy rains negatively affected the growth of the two seaweed species. Similar results were obtained by Wakibia *et al.* (2006) who found growth in these two seaweeds was lowest during the hot season (January-associated with NE monsoons) and highest during the cold season (August-associated with SE monsoons) in Kenya. Heavy downpours of rain are common in Zanzibar (pers. obs.) and would lower the salinity in tidal pools, especially at low tides. Low salinities are known to be one of the factors that reduce seaweed growth (Martins *et al*., 1999). Continuous rain for three to four days also occurs in Zanzibar and would reduce growth due to reduced light intensity (hence photosynthesis). Salinities are known to drop by up to 20% following such downpours e.g. from 40 to 32 in land-based culture facilities (Msuya *et al*., 2006).

Growth rates obtained in this study (6.4±2.4 and 5.7±1.8% d^{-1} for *E. denticulatum* and *K. alvarezii* respectively) were nevertheless similar to, and sometimes higher than, those reported in other studies such as those of Glenn and Doty (1990), Hurtado-Ponce (1992), Msuya and Neori (2002), Hayashi *et al*. (2007) and Wakibia *et al*. (2006). They are also above the commercial value of 3.5% considered good for commercial cultivation of the two species (Adnan & Porse, 1987; Doty, 1987; Luxton *et al*., 1987).

It is thus concluded that, in the present experimental set-up, seagrass lowered the growth of *E. denticulatum* but had no effect on *K. alvarezii*. Additional nutrients had no significant effect on the growth of the two seaweeds but the monthly dose may have been too little to have an effect. The hot season and heavy rain resulted in lowered growths in both seaweed species, while short rains and milder temperatures favoured their growth. Insufficient adverse effects of seagrass were found that would necessitate their clearance to establish seaweed farms in the study area. However, the effects of more dense seagrass beds on seaweed farming, e.g. *Enhalus* or *Syringodium*, would require more study.

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