

Experimental farming of *Kappaphycus alvarezii* (Doty) Doty with income estimates at different sites in the Mandapam region, Palk Bay, southeast coast of India

C. Periyasamy · P. Anantharaman · P. V. Subba Rao

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Abstract The cultivation of *Kappaphycus alvarezii*, a kappa carrageenan producing red seaweed, was done for 1 year from April 2012 to March 2013 in subtropical waters of Indian Peninsula at three different sites (Mangadu in Rameswaram Island, Munaikadu and Vedalai—on main land coast) on Palk Bay side of Bay of Bengal of Rameswaram–Mandapam region of southeast coast of India. These experiments were carried out to confirm the results obtained in an earlier study (April 2011 to March 2012) at more or less the same sites—one is different (Mangadu) and two are the same (Munaikadu and Vedalai). The maximum crop yields of 326.55 ± 10.23 and 316.65 ± 15.13 kg FW raft⁻¹ were obtained in October 2012 at Mangadu and Munaikadu, respectively, and 308.40 ± 8.89 kg FW raft⁻¹ in March 2013 at Vedalai. Similarly the maximum daily growth rates (DGRs) of 3.76 ± 0.07 and 3.69 ± 0.11 % were found in October 2012 at Mangadu and Munaikadu, and 3.64 ± 0.06 % was obtained in March 2013 at Vedalai. A significant negative correlation between DGR and seawater temperature at Mangadu ($r = -0.604$) and Munaikadu ($r = -0.700$) was found (at 0.05 level). Further, a significant positive correlation was seen (at 0.05 level) between nitrite and phosphate at Mangadu ($r = +0.613$) and Vedalai ($r = +0.599$). However, salinity and seawater temperature were significantly positively correlated ($r = +0.693$) at Munaikadu (at 0.05 level). ANOVA showed that the growth rates among these three sites were found to be statistically insignificant. Tip grazing by *Siganus javus* and *Diodon holocanthus* during the monsoon period (October 2012 to January 2013) was observed. Seasonal epiphytes *Lyngbya majuscula* and *Cladophora*

fascicularis were the main problematic epiphytes from April to June. Net income would be Rs15,000 to Rs16,000 (US\$250–US\$265) per month, and if the cultivation is taken up in earnest perspective, the farmers would improve their living standards.

Keywords Seaweed farming · Daily growth rate · *Kappaphycus* · Red seaweed · Carrageenan

Introduction

Seaweeds have been used for food, feed, and fodder from time immemorial and they also form a source of phycocolloids like agar, algin, and carrageenan (Chapman and Chapman 1980; Tseng 1981). Agar is obtained from *Gelidium*, *Gelidiella*, and *Pterocladia*, algin from *Macrocystis*, *Laminaria*, and *Sargassum*, and carrageenan from *Chondrus*, *Gigrtina*, *Eucheuma*, and *Kappaphycus* (Levring et al. 1969; Bixler and Porse 2011). The natural production of these species can not sustain the industries; hence, cultivation of some of these economically important seaweeds had been initiated and success has been achieved for the species of *Laminaria*, *Undaria*, *Porphyra/Pyropia*, and *Gracilaria* (Tseng 1981). Among these phytochemicals, carrageenan especially kappa carrageenan, has an important role for its use either in food industries or in pharmaceuticals (Bixler and Porse 2011). *Kappaphycus alvarezii* is the main for this chemical. Its natural resources can not meet the increasing demand of carrageenan, and hence, the cultivation of this seaweed has become imperative to supply raw material for the industries for production of kappa carrageenan. The entire global harvest of *Kappaphycus* production is 183,000 t (dry) and comes from cultivation alone (Bixler and Porse 2011).

C. Periyasamy (✉) · P. Anantharaman
CAS in Marine Biology, Annamalai University, Parangipettai, Tamil Nadu, India
e-mail: periyasamy.c@live.com

P. V. S. Rao
Aquaculture Foundation of India, Madurai, Tamil Nadu, India

Doty and Alvarez (1975) introduced *Kappaphycus* in Philippine waters where farming techniques have been improved and utilized for many years (Trono et al. 2000; Ask and Azanza 2002). Subsequently, the *Kappaphycus* cultivation has been expanded worldwide. Commercial *Kappaphycus* cultivation is going on in the following countries: China (Qian et al. 1996), Indonesia (Adnan and Porse 1987; Luxton 1993), Madagascar (Mollion and Braud 1993), Malaysia (Neish 2003), Philippines (Doty 1973; Parker 1974; Doty and Alvarez 1975), and Tanzania (Lirasan and Twide 1993). In some countries like Antigua, Barbados, Jamaica, St. Lucia, Belize, Brazil (Goes and Ries 2012), Cambodia, Cuba, Djibouti, Fiji, French Antilles, French Polynesia, Guam, Hawaii, Honduras, Japan, Kenya, Karibati, Maldives, Mexico, Micronesia, Mozambique, Myanmar, Samoa, Solomon Islands, Tonga, Tuvalu, USA (Hawaii), Venezuela, and Vietnam the cultivation was either not successful or occurs only on a very small level (Neish 2003).

The introduction of *K. alvarezii* in Indian waters has been described by Subba Rao et al. (2008) and Periyasamy et al. (2014a, b), and subsequently, several workers have attempted its cultivation in Indian waters at different locations along the Indian coast (Bindu 2011; Periyasamy et al. 2014a). A comprehensive report on the origin and development of *K. alvarezii* farming in India has been published by Krishnan and Narayanakumar (2010). Periyasamy et al. (2014a), in an earlier study, have reported the growth of cultivated *K. alvarezii* at three different sites (Vedalai, Munaikadu, and Thonithurai) along the coastal waters of Palk Bay side of Bay of Bengal, Ramanathapuram District, Tamilnadu, and the present study (April 2012 to March 2013) is the continuation of the earlier one (April 2011 to March 2012) at more or less the same sites (two sites are same and one site is different) to confirm the results during the successive years of study in order to decide whether to proceed to commercial farming with the hope of earning a monthly fixed amount by self-help groups (SHGs), either with or without obtaining loans from nationalized banks or any other funding agencies and with an assurance of buyback agreement from various buyers/promoting companies.

Material and methods

Study site The *Kappaphycus* seedlings were drawn from the previous experimental locations or nearby sites. Young and healthy fragments were selected for seeding. The experimental farming was done at three different sites, viz., Mangadu (9° 17' 05.54° N, 79° 10' 54.78° E), Munaikadu (9° 17' 22.39° N, 79° 07' 56.84° E), and Vedalai (9° 17' 20.01° N, 79° 07' 57.90° E) on the Palk Bay side of Bay of Bengal in Ramanathapuram district, Tamil Nadu. Mangadu is a new site in Rameswaram Island. Munaikadu and Vedalai are earlier

studied sites during April 2011 to March 2012 located on the mainland coastal waters.

1. Mangadu: The habitat was characterized by sand bottom with intermittent rocks. Water depth varied from 0.5 to 1.0 m.
2. Munaikadu: The habitat was clay interspaced with pebbles. Water depth varied from 1.0 to 1.5 m.
3. Vedalai: The habitat was mostly rocks with intermittent tide poles. Water depth varied from 1.5 to 2.0 m.

During Northeast Monsoon (middle of November to middle January), the water motion was very heavy and rest of the time it was relatively calm at all the sites. Water was clear most of the times at the experimental sites except during Northeast Monsoon period. Tidal fluctuations varied from +0.06 to +0.7 m relatively to the chart datum. The rainfall varied from 15 to 25 cm from October to February. The vegetation included seagrasses and seaweeds at all the sites.

Farming and monitoring of growth and yield The cultivation was done at all three sites by the raft method adopted by Trono and Ohno (1989) and Subba Rao et al. (2008). The raft size was 3×3 m. The seeding was done as per the procedure described earlier by Periyasamy et al. (2014a, b). Initially, the seed material used was 60 kg per raft, and 45 rafts were floated at each site and placed at the sites in the sea in such a way that they were not exposed even at low tides. Periodical weeding and maintenance were attended to ensure good growth. The harvesting was done after 45 days and reseeded of the harvested raft was done as described earlier (Periyasamy et al. 2014a). The harvesting and seeding were done in such a way that the growth data (crop yields and growth rates) were achieved in every month. The biomass of harvested plants from 15 rafts was obtained every month, and mean and standard deviation were calculated. Further, the daily growth rate (DGR) was calculated using the formula of Dawes et al. (1994):

$$\text{DGR}(\%) = \ln(W_f/W_o)/t \times 100,$$

where W_f is the final fresh weight (g) at t day, W_o is the initial fresh weight (g), and t is the number of culture days. The crop yield was the final harvested yield after 45 days of growth. Mean and standard deviation were also obtained for DGR.

Environmental parameters During the experimental period, surface seawater temperature was recorded from the vicinity of experimental sites at fortnightly intervals using a thermometer. Seawater samples were collected at fortnightly intervals

and analyzed in triplicate for salinity, nitrate, nitrite, and phosphate. Salinity was measured by a refractometer (Atago, accuracy = ± 1). Nitrate, nitrite, and phosphate were determined following the methods described by Strickland and Parsons (1972). Triplicate samples were analyzed. From the recorded data, mean value with standard deviation for each month was finally calculated for seawater temperature, salinity, nitrate, nitrite, and phosphate.

Pearson's correlation coefficient (r) was computed for growth rates and environmental parameters. One-way ANOVA was used to determine significant differences among the growth rates of the three locations.

Grazing and epiphytes Type and level of grazing were recorded at the cultivation sites at fortnightly intervals. Epiphytes were also collected fortnightly from inside the rafts as well as from the frames of the rafts and were identified taxonomically.

Estimate of income The overall annual crop yield in all three locations was taken for economic calculation. Net income per member at each site was calculated.

Results

Crop yield and growth rate The crop yields varied from 255.05 ± 11.73 to 326.55 ± 10.23 kg FW raft⁻¹ during the study period at the three locations. At Mangadu, the minimum crop yield (232.00 ± 16.58 kg FW raft⁻¹) in May 2012 was recorded with the maximum (326.55 ± 10.23 kg FW raft⁻¹) in October 2012. The overall annual crop yield was 278.49 ± 26.38 kg FW raft⁻¹. At Munaikadu, the minimum crop yield (255.05 ± 11.73 kg FW raft⁻¹) in July 2012 was recorded with the maximum (316.65 ± 15.13 kg FW raft⁻¹) in October 2012. The overall annual crop yield was 288.65 ± 19.63 kg FW raft⁻¹. At Vedalai, the minimum crop yield (261.15 ± 11.24 kg FW raft⁻¹) in June 2012 was noticed with a maximum (308.40 ± 8.89 kg FW raft⁻¹) in March 2013. The overall annual crop yield was 282.57 ± 14.71 kg FW raft⁻¹ (Fig. 1). Among these three locations, the maximum crop yield was recorded in Mangadu (326.55 ± 10.23 kg FW raft⁻¹) followed by Munaikadu (316.65 ± 15.13 kg FW raft⁻¹) and Vedalai (308.40 ± 8.89 kg FW raft⁻¹), while the minimum was at Mangadu (232.00 ± 16.58 kg FW raft⁻¹) followed by Munaikadu (255.05 ± 11.73 kg FW raft⁻¹) and Vedalai (261.15 ± 11.24 kg FW raft⁻¹).

The daily growth rates (DGRs) of this seaweed at all the three locations were also found to vary from 3.00 ± 0.16 to 3.76 ± 0.07 %. At Mangadu, the minimum growth rate ($3.00 \pm$

0.16 %) in May 2012 was recorded with a maximum (3.76 ± 0.07 %) in October 2012. The overall annual growth rate was 3.40 ± 0.21 %. At Munaikadu, the minimum growth rate (3.21 ± 0.10 %) was found in July 2012 with a maximum (3.69 ± 0.11 %) in October 2012. The overall annual growth rate was 3.48 ± 0.15 %. At Vedalai, the minimum growth rate (3.27 ± 0.10 %) was obtained in June 2012 with a maximum (3.64 ± 0.06 %) in March 2013. The overall annual growth rate was 3.44 ± 0.12 % (Fig. 2). Among these three locations, the maximum growth rate was at Mangadu followed by Munaikadu and Vedalai with the minimum also at Mangadu followed by Munaikadu and Vedalai.

Maximum crop yields and DGRs were recorded in October 2012, October 2012, and March 2013 at Mangadu, Munaikadu, and Vedalai, respectively, with respective minimum values in May 2012, July 2012, and June 2012.

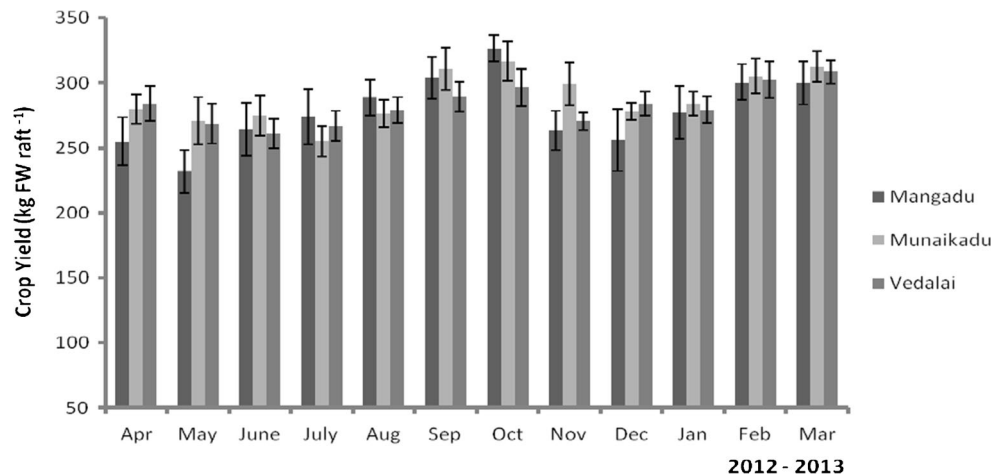
Environmental parameters The surface seawater temperature varied from 28.33 ± 0.58 to 33.33 ± 0.58 °C. However, 35 °C was recorded only for 2 months (May 2012 and June 2012) in Mangadu. The lowest temperature was recorded (28.33 ± 0.58 °C) at Mangadu in March 2013, at Munaikadu (28.67 ± 0.58 °C) in October 2012 and February 2013, and at Vedalai (28.33 ± 0.58 °C) in October 2012 and November 2012. The maximum temperature was recorded at Mangadu (35.00 ± 1.00 °C), and at Munaikadu (33.33 ± 0.58 °C) and Vedalai (33.33 ± 0.58 °C), the same temperatures were found. The mean annual temperatures recorded were 31.44 ± 2.32 , 30.64 ± 1.61 , and 30.22 ± 1.62 °C at Mangadu, Munaikadu, and Vedalai, respectively (Fig. 3).

Seawater salinity varied from 28.0 ± 0.71 to 32.5 ± 0.71 ‰. The highest salinity was recorded at Mangadu (32.5 ± 0.71 ‰) followed by Vedalai (32.0 ± 1.41 ‰) and Munaikadu (31.5 ± 1.71 ‰) while the lowest salinity was observed in Munaikadu (28.0 ± 0.71 ‰) and similar minimum values (28.50 ± 0.71 ‰) were obtained both at Mangadu and Vedalai. The mean annual salinities were 30.79 ± 1.32 , 30.04 ± 1.03 , and 30.04 ± 1.05 ‰ at Mangadu, Munaikadu, and Vedalai, respectively (Fig. 4).

The nitrate content varied from 0.72 ± 0.05 to 2.36 ± 0.20 $\mu\text{mol L}^{-1}$. The maximum nitrate content was recorded at Mangadu (2.36 ± 0.20 $\mu\text{mol L}^{-1}$) followed by Munaikadu (2.14 ± 0.06 $\mu\text{mol L}^{-1}$) and Vedalai (1.77 ± 0.08 $\mu\text{mol L}^{-1}$) while the minimum was at Munaikadu (0.72 ± 0.05 $\mu\text{mol L}^{-1}$) followed by Vedalai (0.83 ± 0.06 $\mu\text{mol L}^{-1}$) and Mangadu (0.94 ± 0.60 $\mu\text{mol L}^{-1}$). The mean annual nitrate contents were found to be 1.37 ± 0.44 , 1.17 ± 0.49 , and 1.15 ± 0.29 $\mu\text{mol L}^{-1}$ at Mangadu, Munaikadu, and Vedalai, respectively (Fig. 5).

The nitrite content recorded varied from 0.39 ± 0.10 to 1.22 ± 0.03 $\mu\text{mol L}^{-1}$. The maximum nitrite content was found at Mangadu (1.22 ± 0.03 $\mu\text{mol L}^{-1}$) followed by Vedalai ($1.08 \pm$

Fig. 1 Seasonal variation in crop yield (kg FW raft⁻¹) at three different locations (April 2012 to March 2013)



0.07 $\mu\text{mol L}^{-1}$) and Munaikadu ($0.95 \pm 0.50 \mu\text{mol L}^{-1}$) while the minimum was observed at Munaikadu ($0.39 \pm 0.10 \mu\text{mol L}^{-1}$) followed by Vedalai ($0.42 \pm 0.02 \mu\text{mol L}^{-1}$) and Mangadu ($0.54 \pm 0.04 \mu\text{mol L}^{-1}$). The mean annual nitrite contents observed were found to be 0.77 ± 0.27 , 0.62 ± 0.20 , and $0.67 \pm 0.23 \mu\text{mol L}^{-1}$ at Mangadu, Munaikadu, and Vedalai, respectively (Fig. 6).

The phosphate content varied from 0.37 ± 0.09 to $3.22 \pm 0.34 \mu\text{mol L}^{-1}$. The maximum phosphate content was recorded at Munaikadu ($3.22 \pm 0.34 \mu\text{mol L}^{-1}$) followed by Mangadu ($3.15 \pm 0.04 \mu\text{mol L}^{-1}$) and Vedalai ($2.98 \pm 0.18 \mu\text{mol L}^{-1}$) while the minimum was observed at Mangadu ($0.37 \pm 0.09 \mu\text{mol L}^{-1}$) followed by Munaikadu ($0.41 \pm 0.04 \mu\text{mol L}^{-1}$) and Vedalai ($0.51 \pm 0.03 \mu\text{mol L}^{-1}$). The mean annual phosphate contents observed were 1.41 ± 0.05 , 1.33 ± 1.00 , and $1.40 \pm 0.93 \mu\text{mol L}^{-1}$ at Mangadu, Munaikadu, and Vedalai, respectively (Fig. 7).

Grazing and epiphytes At Mangadu and Munaikadu, grazing of the tips was noticed from October 2012 to December 2012,

while at Vedalai, the same was observed from August 2012 to December 2012. The grazing of tips was 10 to 15 % higher at Mangadu when compared to that at Vedalai and Munaikadu. Tip grazing was mainly due to *Siganus javus* and *Diodon holocanthus*.

At Mangadu, nine epiphytic seaweeds were recorded during the study period and they were growing in different months, whereas at Munaikadu, six epiphytic algae were recorded growing seasonally in abundance. However, at Vedalai, four epiphytic algae were recorded and showed comparatively less growth. Epiphytes were not observed during June 2012 and July 2012 at Vedalai. Epiphytes included *Lyngbya majuscula*, *Gracilaria corticata*, *Padina tetrastromatica*, *Jania adherens*, *Sargassum wightii*, *Turbinaria ornata*, *Ulva reticulata*, *Gelidiella acerosa*, *Cladophora fascicularis*, and *Ceramium cruciatum*. Among these seaweeds, *L. majuscula* and *Cladophora fascicularis* were the main problematic epiphytes. *L. majuscula* was growing like a mat on the surface of the bamboos (raft) as well as on

Fig. 2 Seasonal variation in daily growth rate (DGR) (%) at three different locations (April 2012 to March 2013)

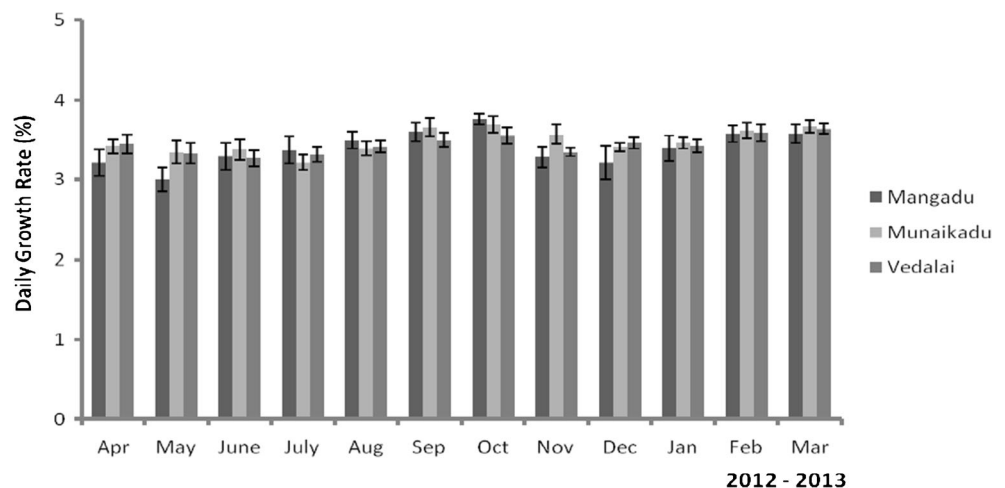
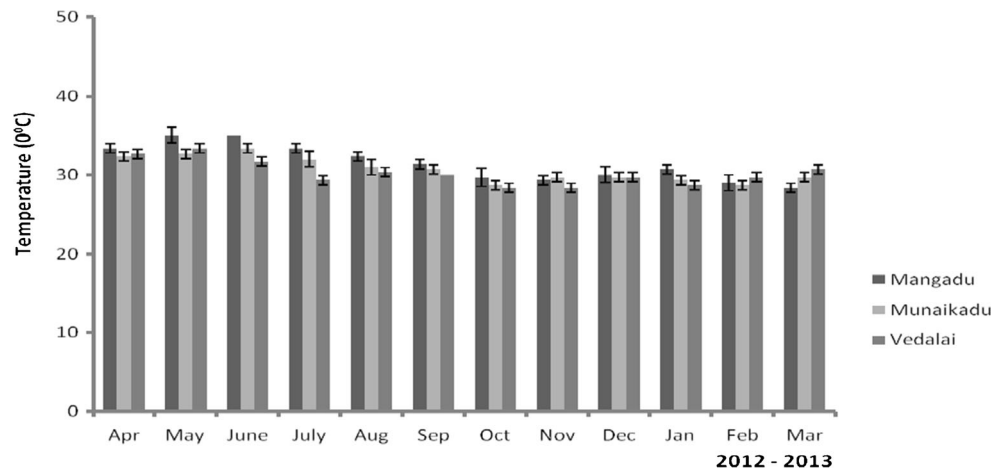


Fig. 3 Seasonal variation in seawater temperature (°C) at three different locations (April 2012 to March 2013)



the bottom of the sea resulting in the uplifting of the crop (ropes as a whole) even at the slightest movement of the seawater, and this caused the direct exposure of the crop to the sunlight which reduce the growth. *Cladophora fascicularis* entangled with the crop during the monsoon period from November 2012 to January 2013 at Munaikadu and during February 2013 and March 2013 at Mangadu.

Estimate of income Net income for one seaweed farmer was calculated (Table 1) with the respective location’s annual crop yield. The annual crop yield was 278.49, 288.65, and 282.57 kg FW raft⁻¹ at Mangadu, Munaikadu, and Vedalai, respectively. Seed required for reseedling per raft was 60 kg. Net dry weed (10:1 ratio) after deducting seed (60 kg FW raft⁻¹) was arrived at, monthly dry weed output was calculated (26-day operation), and, at last, yearly dry weed output was arrived (12 months) and subsequently yearly income (Rs27.50 kg⁻¹ of dry weed or US\$0.42 kg⁻¹ of dry weed) was calculated for all three locations. Monthly income was calculated per member from the calculated yearly income. Monthly income was maximum (Rs16,348.48 or

US\$272.47) at Munaikadu and minimum (Rs15,622.04 or US\$260.37) at Mangadu whereas it was intermediate (Rs15,913.76 or US\$265.23) at Vedalai. The income may increase if the growers maintained the raft well and per kilogram cost is increased by the buyer. With the current per kilogram dry selling cost, each member can earn from Rs15,000 to Rs16,000 (US\$250–US\$265) per month.

Discussion

K. alvarezii cultivation was carried out in the subtropical waters of Mandapam region, Palk Bay, southeast coast of India. The sites included Mangadu, a new site (in Rameswaram Island of Indian peninsula), Munaikadu, and Vedalai (these two are earlier sites) to confirm the growth rates obtained in an earlier study (April 2011 to March 2012) with the present one (April 2012 to March 2013).

During the present study, the DGRs obtained were 3.64± 0.06 to 3.76±0.07 %. The variations seen in the present

Fig. 4 Seasonal variation in salinity (‰) at three different locations (April 2012 to March 2013)

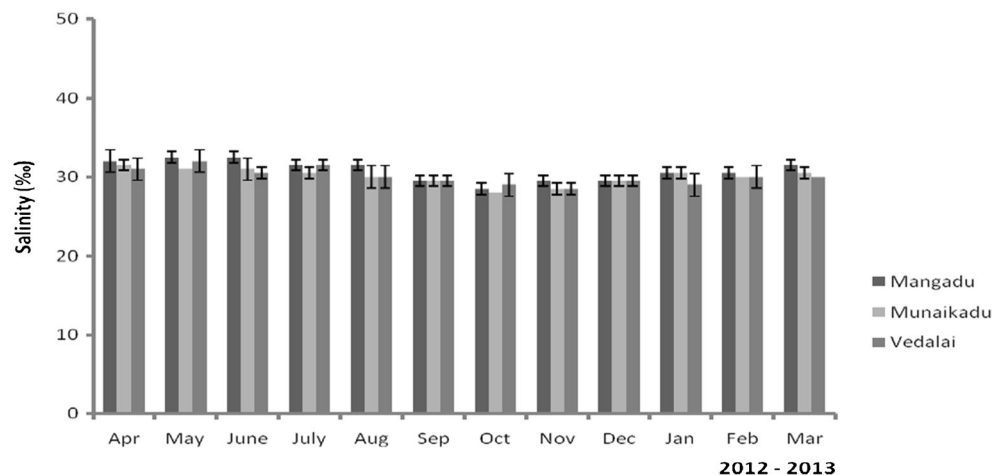
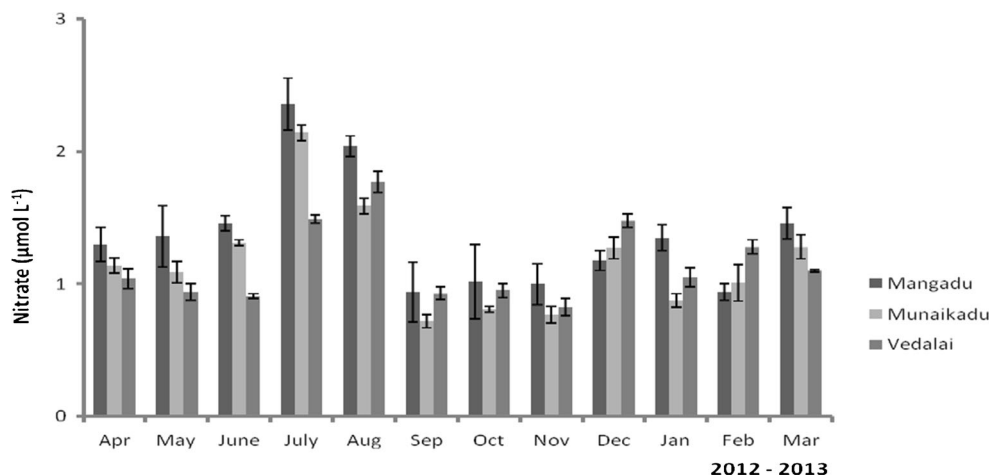


Fig. 5 Seasonal variation in nitrate content ($\mu\text{mol L}^{-1}$) at three different locations (April 2012 to March 2013)



growth rates might be mainly due to the locations and prevailing environmental parameters at the sites. These growth rates are comparable with the ones obtained elsewhere for the same alga in the world. The following DGRs have been recorded in different countries: in China, from 1.9 to 4.6 % (Li et al 1990); in India, Gujarat, northwest coast, from 3.64 to 13.98 % (Subba Rao et al. 2008); in Indonesia, from 3.0 to 4.0 % (Adnan and Porse 1987; Luxton 1993); in Philippines, from 3.7 to 7.2 % (Hurtado-Ponce 1992) and from 5.9 to 8.9 % (Dawes et al. 1994); in Tanzania, from 3.4 to 6.8 % (Lirasan and Twide 1993); in Hawaii (USA), from 1.9 to 6.2 % (Glenn and Doty 1990); in Fiji, from 2.3 to 5.3 % (Luxton et al. 1987); in Maldives, from 2.0 to 7.0 % (De Reviers 1989); in Dazilam, from 2.0 to 3.3 % (Glenn and Doty 1990); in Zanzibar, from 5.0 to 7.0 % (Lirasan and Twide 1993); in Japan, from 0.13 to 8.12 % (Ohno et al. 1994); in Vietnam, from 3.16 to 10.80 % (Ohno et al. 1996); in Cuba, from 1.0 to 10.0 % (Areces 1995); in Brazil, from 4.5 to 8.2 % (Paula et al. 2002); in Venezuela, from 4.4 to 7.7 % (Rincones and Rubio 1999); and in Mexico, from 2.0 to 7.1 % (Munoz et al. 2004). In an earlier

preliminary study, the growth rates recorded for this seaweed in Indian subtropical waters at Okha (northwest coast of India) were in the range of 2.45 to 7.64 % (Mairh et al. 1995).

The highest growth rates and crop yields were recorded in October/March at all the three sites in the present study as well as in the earlier study (April 2011 to March 2012) while the same was reported during April to December in Fiji (Prakash 1990), September to February in Philippines (Hurtado-Ponce et al. 2001), and October/ March at Okha, Gujarat, India (Subba Rao et al. 2008). The reported period (October/March) for the highest DGRs and crop yields in the present investigation coincided with those observed at Okha, Gujarat, by Subba Rao et al. (2008). The results indicated that the growth rates are site and season specific.

The highest growth rates and crop yields were obtained at slightly higher seawater temperature (28.7 to 30.7 °C) which is in agreement with the results obtained by Trono and Ohno (1989) as well as Subba Rao et al. (2008). The minimum growth rates and minimum crop yields in the present

Fig. 6 Seasonal variation in nitrite content ($\mu\text{mol L}^{-1}$) at three different locations (April 2012 to March 2013)

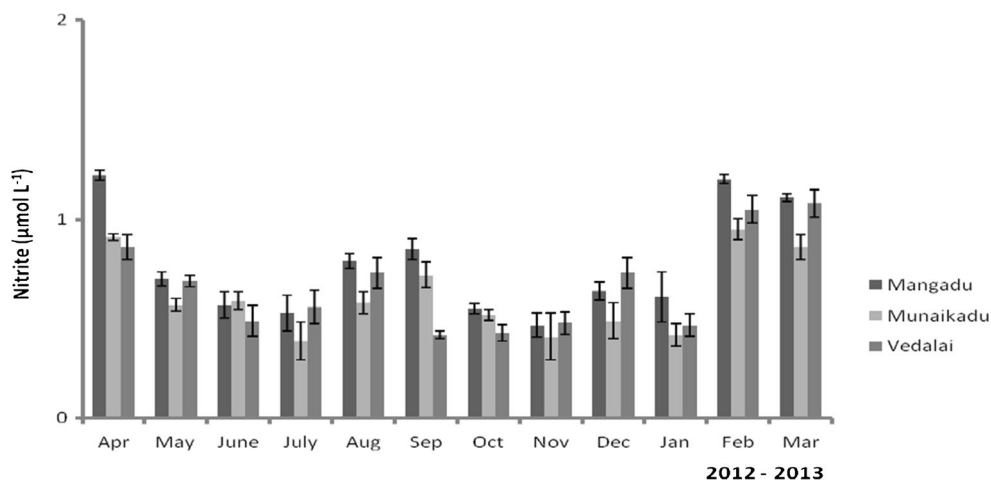
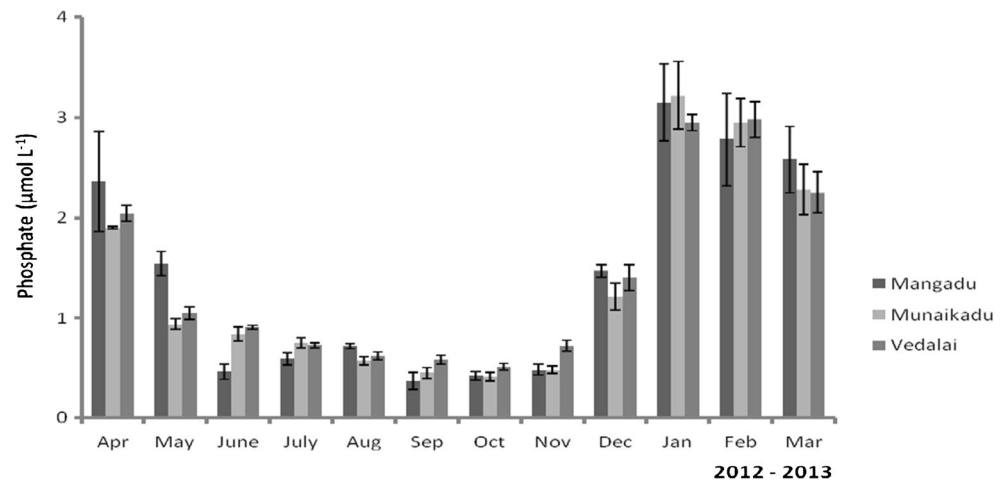


Fig. 7 Seasonal variation in phosphate content ($\mu\text{mol L}^{-1}$) at three different locations (April 2012 to March 2013)



experimental locations were reported at 31.7 to 35.0 °C, and so temperature appeared to be the main environmental factor affecting the growth rates as well as crop yields of this seaweed as noticed in this study, and the same was also reported by Ohno et al. (1994) and Munoz et al. (2004) in Mexico. In Japan, Mairh et al. (1986) cultivated *Kappaphycus striatum* in the field over a temperature range of 14.3 to 31.2 °C with the highest growth rates recorded at 21 to 31 °C, and they also recorded optimum temperature between 24 to 31 °C for the growth in the laboratory and the plants could not survive at 17 °C or lower temperatures. In India, Mairh et al. (1995) reported that in outdoor chambers, *K. striatum* showed higher growth rates between 23 to 30 °C with declining DGR above 30 °C and below 20 °C. And, this coincided with the present study; i.e., beyond 32 °C, the growth (DGR and Crop yield) of the alga decreased.

Ohno et al. (1994) showed that *K. alvarezii* grew well only during the warm weather season (20 to 30 °C) in the subtropical waters of Tosa Bay, Japan. Similar results were found for the subtropical waters of Brazil, where the positive correlation with temperature was observed in the growth of brown strain of *K. alvarezii* (Paula and Pereira 2003). Glenn and Doty (1992) demonstrated the variations in growth rate, although they also found an inverse significant relationship between maximum temperature and growth. Further, they reported that photosynthetic temperature response increased up to 32 °C for *K. alvarezii*, and then sharply declined the growth beyond this temperature.

Pearson's correlation coefficient (r) at 0.05 level showed a significant negative correlation between DGR and seawater temperature at Mangadu ($r=-0.604$) and Munaikadu ($r=-0.700$). Further, a significant positive correlation was seen between nitrite and phosphate at Mangadu ($r=+0.613$) and Vedalai ($r=+0.599$). However, salinity and seawater temperature were significantly positively correlated ($r=+0.693$) at Munaikadu. This indicated that the growth was dependent on seawater temperature, salinity, and nutrients (nitrate, nitrite,

and phosphate) as reported by Glenn and Doty (1990). The maximum growth (crop yield and DGR) was recorded at lower salinity of 28 ± 0.71 to 30 ± 0.41 ‰ and at relatively higher temperature (28.67 ± 1.16 to 30.67 ± 0.58 °C), and the lowest growth (crop yield and DGR) was observed from May 2012 to July 2012 in all three locations due to high temperature (33.3 to 35.0 °C) and high salinity (31.5 to 32.5 ‰). Single ANOVA test showed that the growth rates among these three sites were found to be statistically insignificant, although commercially viable growth rates were recorded.

Generally, *Eucheuma* species appeared to grow in moving water. Water motion helps to clean the plants, bring fresh nutrients, remove metabolites, and apply hydraulic forces that stimulate plant growth. Water motion is also an important factor to take into account during the selection of farm sites and during crop logging (Neish 2003). Azanza-Corrales et al. (1996) showed the importance of water motion in the “seeding” or natural sporulation experiments done in *Eucheuma* and *Kappaphycus* farms in the Philippines. In the present study, at all the three sites, the water motion was moderately high during the monsoon period (October 2012 to January 2013) during which optimum growth was found. During April 2012 to June 2012, the water motion was very less with relatively high temperature resulting in lesser growth. The maximum growth (crop yield and DGR) at all the sites during October/March was found when the nitrate, nitrite, and phosphate were rich in nutrients.

According to the site fertility concept, seaweed growth rate would be regulated by a complex interaction of irradiation, temperature, nutrients, and water movement (Santelices 1999). Some of these factors might interact regulating the growth target species, and the major decline of one factor (for example, nutrients) could be compensated by some other factor (water movement). Thus, in environments with low or erratic nutrient supply, surge ammonium uptake was described for *K. alvarezii* as a strategy to avoid nitrogen limitation of growth (Dy and Yap 2001).

Table 1 Expected income of one member in commercial cultivation

Site	Annual crop yield (fresh weight kg raft ⁻¹)	Net fresh weight after deducting seed (60 kg)	Net dry weed for sale (if we take 10:1)	Expected monthly output (26 days)	Expected yearly dry produce (kg) (10-month operation)	Yearly income (Rs27.50 kg ⁻¹ or US\$0.42 kg ⁻¹)	Monthly income (Rs)
Mangadu	278.49	218.49	21.85	568.07	6,816.89	187,464.42 (US\$3,124.41)	15,622.04 (US\$260.37)
Munaikadu	288.65	228.65	22.87	594.49	7,133.88	196,181.70 (US\$3,269.70)	16,348.48 (US\$272.47)
Vedalai	282.57	222.57	22.26	578.68	6,944.18	190,965.06 (US\$3,182.75)	15,913.76 (US\$265.23)

Grazing by herbivorous marine animals was a major problem for *Eucheuma* sea plant farmers since the beginning of the agronomic development (Doty 1973; Parker 1974; Doty and Alvarez 1981). Russell (1983) and Uy et al. (1998) lent formal confirmation to common observations of farmers when they observed that fish selectively grazed smaller branches of *Eucheuma*. Juvenile parrot fish (scarids) and surgeon fish (acanthurids) were observed to consume as much as 50 to 80 % of *Eucheuma* populations at 0.5- to 2.0-m depth (Russell 1983). Rabbitfish (siganids), puffer fish, and invertebrates including holothurians, crustaceans, starfishes, and sea cucumbers were commonly seen in the vicinity of *Eucheuma* farms (Neish 2003). Several farms were affected due to heavy grazing all around the world in a particular season. In the present investigation, at all the three sites, the level of grazing was only tip grazing by *S. javus* and *D. holocanthus* during the monsoon period (October 2012 to January 2013), and no grazing was found during the rest of the period.

Seasonal weeds posed a serious problem from the beginning of *Eucheuma* cultivation (Parker 1974). Fletcher (1995) provided a review on the impacts of pest weeds on *Gracilaria* cultivation farms that was very relevant to the situation with *Eucheuma*. There were three types of pest weeds and they were macroalgae (seasonal and attach to habitat structures or to crop), true epiphytes (filamentous algae and attach to cortical layer and damage the plant), and microalgae (diatoms). In the present study, sites with only seasonal epiphytes were observed. Among these seaweeds, *L. majuscula* and *Cladophora fascicularis* were the main problematic epiphytes. Proper maintenance from April to June would solve the *Lyngbya* problem. Collecting *Cladophora* species and drying the same on the shore would solve the issue from further propagation through reproduction. No diseases were encountered during the study period.

At all the three sites, the mean annual DGR was found from 3.40±0.24 to 3.48±0.15 % which almost coincided with that of the earlier study conducted from April 2011 to March 2012 (DGR of 3.02±0.39 to 4.04±0.41 %) by using 3 m×3 m bamboo raft. This DGR may be considered to be adequate for commercial seaweed farming as the economical commercial farming needed DGR of 3.5 and more (Parker 1974; Adnan and Porse 1987; Luxton et al. 1987; Ask and Azanza 2002; Subba Rao et al. 2008). The income per member might increase if the incumbent follows the cultivation practices like (1) seeding the rafts in seawater column to avoid direct sunlight, (2) initial seeding is 60 kg FW raft⁻¹ (3 m×3 m size), (3) reseeded the lost seeds in the rafts with new ones wherever necessary, and (4) proper weeding and maintenance of rafts. The average expected monthly income recorded was Rs15,622.04 (US\$260.37), Rs16,348.48

(US\$272.47), and Rs15,913.76 (US\$265.23) at Mangadu, Munaikadu, and Vedalai, respectively, and in brief, the income per member would be Rs15,000/– to 16,000/– (US\$250–US\$265) per month which is better as compared to the earlier reported (Rs7,000/– or US\$116 to 10,000/– or US\$265) obtained during 2010–2011 (Periyasamy et al. 2014a, b). In view of this, *Kappaphycus* cultivation may be proposed as an important alternative livelihood option to the coastal fisher folk especially women. This seaweed farming could also reduce the fishing pressure as well as minimize global warming. Before implementing commercial farming, the growers (farmers) have to be well educated on cultivation protocol involving farm maintenance, harvesting, drying, quality, packing, and selling. When followed scrupulously, this protocol, the SHGs/growers will get good income through seaweed farming. The earnings of one village people could motivate the other adjoining village people and thus result in commercial expansion which would fulfill the problem of unemployment in rural India and also pave the way for starting *Kappaphycus*-based industries, the product of which would be utilized for internal consumption as well as export.

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