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Daily Growth Rate of Field Farming Seaweed *Kappaphycus alvarezii* (Doty) Doty ex P. Silva in Vellar Estuary

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Abstract: The present study of seaweed culture exhibit the results of seasonal variation of daily growth rate with five different initial seedling densities such as 75, 100, 125, 150 and 175g during the entire culture period. During postmonsoon season, the maximum daily growth rate (6.11 ± 0.04%) was recorded with initial seedling density of 125g at 30th day. The minimum growth rate (2.28 ± 0.01%) was observed in 175g inserted seedling density at 15th day of culture period. In summer season the highest growth rate (5.69 ± 0.05%) was observed in 125g of initial inserted seedling density at 30th day culture period. The minimum growth rate (2.0 ± 0.16) obtained from 150g of initial seedling density at 15th day of the culture period. In premonsoon season the growth rate peak value (6.03 ± 0.04%) was observed from 125g of initial seed density at 30th day of culture period and the lowest growth rate was recorded (2.16 ± 0.27%) from 175g of inserted seedlings at 15th day.

Key words: Seaweed Culture % *Kappaphycus alvarezii* % Vellar estuary % Daily Growth Rate and Different Seedling Density

INTRODUCTION

The culture of seaweed *Porphyra* has been successfully adopted in Japan [1, 2] cultivation methods are reviewed by various authors [3-11]. The culture of the red algal genus *Eucheuma* is described by [12-15]. The culture method of *Undaria* by [16-17].

Prior to 1973, all seaweeds in the Philippines were harvested from natural stocks. The Philippines is the major source of carragenophytes in the world market [18]. Doty [14, 19, 20] seaweed forming in the Philippines. Farming techniques have undergone several innovations since it was first introduced. Today seaweed farming is a viable alternative source of income for small scale fishermen [21, 22]. In Tawi-Tawi, Mindanao seaweed farming is a major source of livelihood among seaweed farmers [23].

The seaweed cultivation has been adopted in Japan for a number of seaweeds [24] in China for *Laminaria* [25], in Taiwan for *Gracilaria* [26, 27] and in the Philippines for *Eucheuma* [14, 19, 28]. Open ocean upwelling system has been used to establish cultivation of *Macrocystis* in Atlantic ocean [29, 30]. The available data revealed that about 99% of *Eucheuma* is commercially cultivated in four countries, Philippines, Indonesia, Malaysia and Tanzania. Experimental farming had been carried out in several countries including China, Venezuela, Japan, Fiji, USA (Hawai), Maldives, Cuba and India. Due to increased demand for carrageenan, cultivation of these species has been promoted in Indonesia [31]. The first culture from nature areas such as estuaries, bays and ponds for growing the seaweeds on nets and ropes. These techniques are practiced commercially in Japan with several seaweeds including *Porphyra* [6, 32] in China with *Laminairia* [29] and in the southwest Pacific with *Eucheuma* [14, 19, 20, 28 33].

In the last 30 years, commercial production of eucheumatoid species has increased from less than 1000 dry weight mt to over 100,000 mt that are produced annually by about 40,000-50,000 families worldwide [34]. Therefore, numerous tropical countries with coastlines are searching for seaweed cultivation as a sustainable alternative livelihood for coastal villagers, particularly as part of coastal management. Thus, countries including Cuba [35] and Brazil [36] have introduced *K. alvarezii* in the warm waters of the Caribbean and the Western Atlantic in order to evaluate the feasibility of producing biomass for the carrageenan industry. Today, seaweed

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farming is a viable alternative source of income for small-scale fishermen [21, 22]. In Tawi-Tawi, Mindanao, seaweed farming is a major source of livelihood among seaweed farmers [23].

Marine red alga *Kappaphycus striatum* (= *Ecucheuma striatum* = *Kappaphycus alvarezii*) is one of the best sources of kappa carrageenan as compared to other seaweeds. *Eucheuma striatum* and *E. denticulatum* (= *E. spinosum*) and *E. gelatinae* are cultivated commercially in the Philippines and in China respectively. Attempts have also been made to culture *E. spinosum* on pilot plant scale in Djibouti, East Africa. *Kappaphycus* is a better source of carrageenan as compared to *Hypnea*, which is a poor biomass yielder as compared to *Kappaphycus* and *Eucheuma*.

K. alvarezii (Doty) Doty ex Silva is economically important tropical red seaweed and highly demanded for its cell wall polysaccharide, being the most important source of ê-carrageenan in the world [37]. The market of carrageenan continues to grow and current sources of cultivated eucheumatoids seem incapable of meeting demand, at least in quality, price and volumes for requirements of the processing industry [38]. Commercial cultivation of *K.alvarezii* was developed in the Philippines during the later 1960s using local varieties selected from the wild [14]. *Kappaphycus* farms 80% of the Philippine seaweed export and is one of the three marine-based export winners of the country. In the raw material for the manufacture of Kappa Carrageenan which is an important ingredient for food (Jellies, ice cream, juice, jam, sausage, chocolate drinks etc.) and non-food (Personal care, cosmetics and pharmaceuticals) additive.

The successful experimental cultivation of *Kappaphycus*, previously called *Eucheuma* were done in Japan Island. Doty [28], established simultaneously demonstration farms in Mindanao, Visayas and Southern Luzon, Sacol Island and Zamboanga city. It was one of the demonstration farms in 1970 that originally used the fixed off-bottom method in shallow waters [14]. Test plantings of eucheumatiods have been successful in Hawaii [39-41], Indonesia [31, 42].

K. alvarezii (Doty) Doty ex P. Silva farmed in the Philippines and Indonesia is the main source of *k*-carrageenan in the world market [31, 43]. Over the last 30 years, strains of *K. alvarezii* and *K. striatum* (Schmitz) Doty from the Philippines have been introduced into more than 20 tropical countries for the purposes of mariculture [35, 41, 44-46]. Transplantation of *K. striatum* and *K. alvarezii* was also attempted in the subtropical waters of Shikoku, Japan [47, 48]. These authors demonstrated that cultivation is possible in subtropical waters during the warm season, when temperature rises above 20°C. Based on that result, Ohno *et al*., [48] predicted the spread of *K. alvarezii* cultivation to other subtropical regions.

In India, cultivation methods are reviewed by various authors [49, 50]. Raju and Thomas [26] cultured *G. edulis* by using a long line rope method in a sandy lagoon in Krusadai Island. The Central Marine Fisheries Research Institute (CMFRI) developed a technology using for the cultivation of *Gracilaria edulis* by vegetative method [51]. Variations on the method were tried by using rope nets in place of long lines [51, 52]. Using coral stones as substrates on open shore cultivation [53]. Experimental cultivation of *Gelidiella acerosa* was attempted by bottom culture by [54]. The cultivation method has been adopted in India for *Gracilaria edulis* [26, 55-57]. Rama Rao and Subbaramaiah [58] culture of *Hypnea musciformis* in the lagoon of Krusadai Island. In India, CMFRI has developed a viable technology in 1983 for commercial cultivation of agar yielding seaweed using coir rope nets [59, 60]. Paramasivam and Devados [61] reported field cultivation in Pamban area. *H. valentiae* at Krusadi Island on rope culture has been attended [62]. Pilot scale cultivation of some economically important seaweeds adopted in Vellar estuary by [63].

The first attempt at cultivation of a *K. striatum* was reported by Mairh *et al.* [64]. A detailed report on the experimental cultivation of *K. alvarezii* was given by Eswaran *et al*. [65]. Recently large scale *K. alvarezii* cultivation has begun in Tamil Nadu coast [65, 66]. Open sea farming of *Kappaphycus* in India was performed by Reeta Jayasankar [67]; Bindu [68] successfully carried out pilot scale cultivation of *K. alvarezii* in Vizhinjam bay.

In India, the demand from phycocolloid industry is great but the present production from natural habitat is very low and insufficient to cater the needs for local industry. This gap between the demand and supply can be bridged through mariculture practices of seaweeds by cultivating the useful species on commercial scale. There are several reports on the experimental field cultivation of economically important seaweeds in different maritime states of India [63-65, 69-71]. Vegetative propagation method at different environments using various culture techniques [26, 55, 70, 71]. Shoreline cultivation of *Kappaphycus* has been successfully established along the Gulf of Mannar and Palk Bay coast of Tamil Nadu [65] and similar cultivation is being organized along the Saurashtra coast in Gujarat in recent times. The aim of our present investigation is to adapt the known techniques of horizontal rope floating raft culture to suit the local condition of the Vellar estuary, Tamil Nadu, Southeast coast of India and to study the Daily Growth Rate of different initial seed density.

MATERIALS AND METHODS

Collection of Seed Material: The *K. alvarezii* seed materials were collected from (Pepsico Holding private Limited) Mandapam, Gulf of Mannar, Southeast coast of India. The seed materials were transferred to culture site. The live material has generally been shipped in plastic bags or jute sacks wet enough to prevent desiccation.

Preparation of Bamboo Raft: The good floating nature of 4 numbers of 12 feet bamboo poles for mainframes and 4 numbers of 6 feet bamboo poles for additional frames were selected for construction of bamboo raft with the help of ropes. The interior part of the main frame was 3 x 3m in size. Fish nets were tied under the raft to avoid the grazing.

Seed and Inserted Seed Rope Preparation: Well branched with good quality seed materials weighed approximately (75, 100, 125, 150 and 175g) was inserted in single braid knot (20 braid knots/single rope); thus 400 seed materials were prepared out of 20 ropes in a single raft. Approximately 30, 40, 50, 60 and 70kg of seed materials were inserted in a single raft; the distance between each tied rope was 15cm; finally the raft was tied at both corners of another raft. Stones were used for anchoring the raft. Usually 10mm breadth and 10m length ropes were used.

Seasonality: The experiment was conducted for three different seasons viz., postmonsoon, summer and premonsoon from January to September 2006. During monsoon season culture experiment was washout within 5 days due to heavy rain fall and fresh water flow. Daily growth rate was calculated every 15 days interval.

Experimental Design: Five different initial seedling densities viz. 75, 100, 125, 150 and 175 g were tried for the present study. Five rafts of 60 m were used for each seedling density. Three harvests were made during the study period January to September 2006. Excess materials were harvested leaving the initial density on the rope for further growth. In order to understand whether the duration of the cultivation period influenced the daily growth rate (%). In 75 days culture period, fresh seedling was done once after the harvest of 75 days.

Daily Growth Rate (DGR): Daily Growth Rate % was calculated using a formula Dawes *et al.,* [72]

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

W_f is the final fresh weight (g) at t day.
W_o is the initial fresh weight (g),
t is the number of culture days.

Statistical Analysis: Data were analyzed statistically using Analysis of Variance (ANOVA) to determine the differences in seasonal Daily Growth Rate with different initial seed density along with various seasons of culture period.

RESULTS

The present investigation, there were 5 different seedling densities such as 75, 100, 125, 150 and 175g were tried to analysis for daily growth rate at 15 days interval of total 75 days culture period in each season (Postmonsoon, Summer and Premonsoon) and during monsoon season culture was washout within 5 days due to fresh water influence in the culture. During postmonsoon season, the maximum growth rate (6.11 ± 0.04%) was recorded in initial seedling density of 125g at 30th day followed by (5.66 ± 0.05%) at 30th day of 150g inserted seedlings. The minimum growth rate (2.28 ± 0.01%) was observed in 175g inserted seedling density at 15th day and the significant differences were observed within and between the seasons and sampling days at (*p=0.05*) (Table 1).

During summer season, the highest growth rate (5.69 ± 0.05%) was observed in 125g of initial inserted seedling density at 30th day culture period followed by 150g of initial seedling density (5.15 ± 0.05) at the same 30th day. Significant differences within and between the samples observed at (*p=0.05*) and the minimum growth

Table 1: Seasonal variation of mean Growth Rate of different seed density of cultured seaweed *Kappaphycus alvarezii* in Vellar estuary

	Daily Growth Rate (%)		
Days Interval	Postmonsoon	Summer	Premonsoon
15th day	2.59±0.18	2.33±0.29	2.51±0.21
30th day	5.43±0.47***	4.93±0.52***	5.22±0.57*
45th day	4.22±0.45*	3.84±0.20***	3.95±0.21
60th day	3.78±0.49*	3.008±0.14***	3.10±0.15*
75th day	3.36±0.47**	2.50±0.11	2.72±0.33**

± Standard deviation

Note * indicates the level of significance (*= *p=0.05*, ** = *p=0.01*, *** = *p= 0.001*)

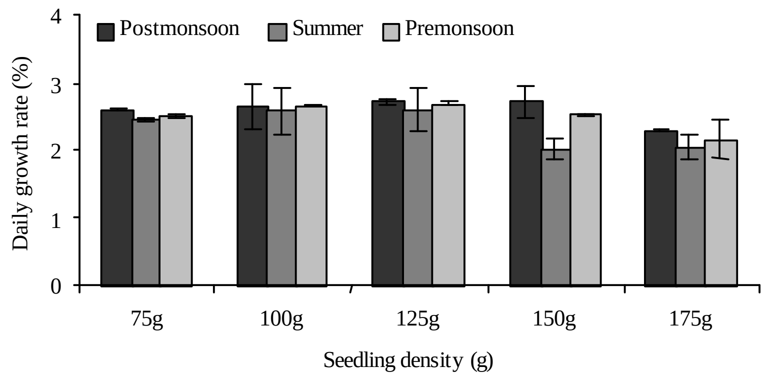

Fig. 1: Shows the Daily growth rate (%) of *K. alvarezii* on 15th day of culture period under different seed densities

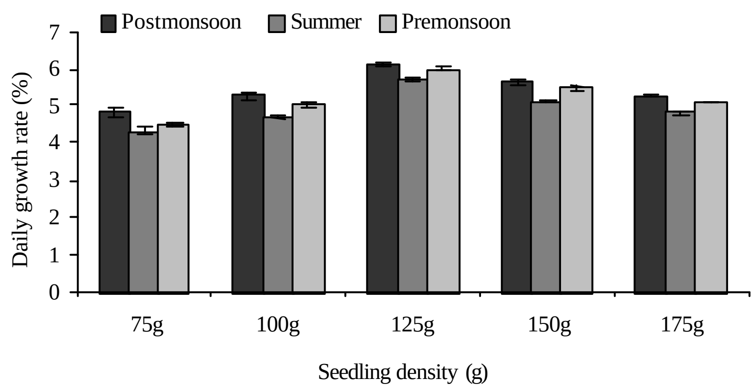

Fig. 2: Shows the Daily growth rate (%) of *K. alvarezii* on 30th day of culture period under different seed densities.

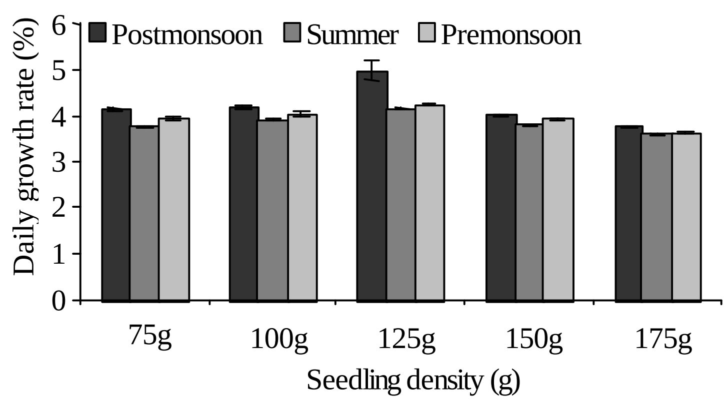

Fig. 3: Shows the Daily growth rate (%) of *K. alvarezii* on 45th day of culture period under different seed densities.

rate (2.0 ± 0.16) obtained from 150g of initial seedling density at 15th day of the culture period. During premonsoon season, the growth rate peak value (6.03 ± 0.04%) was observed from 125g of initial seed density at 30th day followed by (5.49 ± 0.04%) 150g of initial seedling density at the same 30th day of the culture period. The lowest growth rate was recorded (2.16 ± 0.27%) from 175g of inserted seedlings at 15th day and significant differences were observed at (*p=0.05*).

In 15th day of the culture period, the maximum daily growth rate (2.73 ± 0.40%) was observed in 125g of initial seed density at postmonsoon season and the minimum (2.0 ± 0.16%) attained from 150g of initial seed insertion during summer season (Fig 1). 30th day of the culture period showed the highest value (6.11 ± 0.04) in 125g of seed density during postmonsoon season and the lowest value (4.30 ± 0.11%) in 75g of initial seed density (Fig. 2).

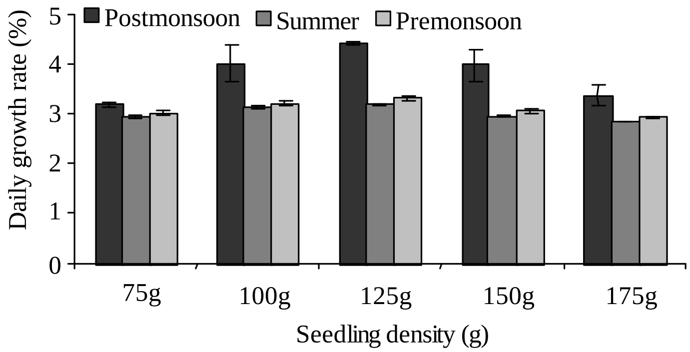

Fig. 4: Shows the Daily growth rate (%) of *K. alvarezii* on 60th day of culture period under different seed densities.

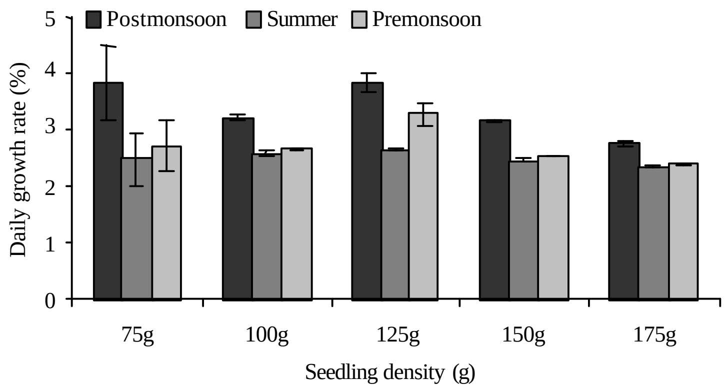

Fig. 5: Shows the Daily growth rate (%) of *K. alvarezii* on 75th day of culture period under different seed densities.

During 45th day of the culture period, the peak growth rate (4.98 ± 0.22%) was recorded at 125g of initial seed density in postmonsoon season and the low growth rate (3.57 ± 0.02%) observed in 150g seed density during summer season (Fig 3). The culture period of 60th proved the highest value (4.39 ± 0.04) from 125g of seed density during postmonsoon season and the lowest value (2.86 ± 0.01%) recorded at 175g of initial seed density (Fig 4). During 75th day of the culture period maximum (3.85 ± 0.65%) was observed at 75g seed density in postmonsoon season and minimum (2.34 ± 0.01%) was recorded at 175g seed density in summer season (Fig 5).

During 15th day of the culture period the mean growth rate of all different seed density observed the peak level (2.59 ± 0.18%) in postmonsoon season and low value (2.33 ± 0.29%) in summer and the significance was not observed at any level. In 30th day, mean growth was maximum (5.43 ± 0.47%) during postmonsoon season and the probability level of significant was attained at (*p=0.001*); the minimum (4.93 ± 0.52%) was recorded in summer and the significant was observed at (*p=0.001*). 45th day culture period shows the highest mean growth rate (4.22 ± 0.45%) in postmonsoon season and the significant was attained at (*p=0.05*); the lowest value (3.84 ± 0.2) during summer season and the significant (*p=0.001*). During the 60th day culture period the growth rate observed maximum at (3.78 ± 0.49) in postmonsoon season and the significant level of probability observed at (*p=0.05*); the minimum (3.0 ± 0.14%) was observed during summer and the significant was attained at (*p=0.05*). In 75th day culture period the growth rate recorded minimum (2.50 ± 0.11%) in summer and maximum (3.36 ± 0.47) in postmonsoon season and the significant level of probability was attained at (*p=0.01*) (Table 1). During the culture period, growth rate was in a decreasing trend with increasing seed density with days increases above 45 days.

DISCUSSION

Vegetative regeneration is an effective means of propagation of *K. alvarezii*. However, fragments do not form holdfasts and do not readily attach to other substrata [73, 74]. These characteristics should prevent its dispersal to new areas. Russell [74] supported this assertion because *K. alvarezii* does not survive in deep water in Hawaii. However, the lack of a sexual reproductive cycle commonly reported for this species

[75] must be reviewed. Reproductive structures have been described for cultivated strains [76] and the occurrence of tetrasporic and gametophytic phases has been observed in farmed populations in the Philippines [77]. The plants introduced and grown in the sea in Brazil produced tetraspores in the summer and autumn months, although with very low viability under laboratory conditions [79].

Over the last 30 years, the species has been transplanted to more than 20 countries, both inside and outside its native range. No plants have been found attached to rocks or other substrata at Ubatuba Bay, from its introduction since 1995 to present day. However, a knowledge of the factors that affects dispersal of vegetative branches must be considered before commercial cultivation. Growth rates observed for the transplanted branches during the first and second months in the sea were higher than the subsequent cuttings produced in the sea. The morphology and the size of these branches may explain the differences. Hence the earlier workers statements support to our present investigation here the vegetative plant cuttings through raft culture which did not produce any spores during the study period and not attached to the substratum.

During the culture period the growth rate was increasing with increasing seed density and days up to 125g and 45th day respectively, thereafter it shows decreasing trends. 125g initial seed density showed maximum growth rate than that of the above seedling densities. The effect of the size of branches on the growth rate of *K. alvarezii* was demonstrated by [35] observed the growth rates decrease with increasing size of cuttings.

Durko and Dawes [80] reported high salinity as being responsible for reduction in biomass of *Hypnea musciformis* during summer in Florida. Rama Rao [81] speculated that the high water temperature in summer inhibited the rapid growth of *H. musciformis*, while high light intensity was also important for diminishing this species in summer in Hawaii. The above study was coincide with the present investigation, here the *K. alvarezii* showed minimum (3684.89 ± 658.28%) in summer and highest value (4099 ± 622.28g fw m^{-1}) in postmonsoon season and shows significant difference at (*p=0.05*).

Much higher productivities have been extrapolated based on growth rate data not only for eucheumatoids [14] but *Gracilaria* and other red seaweeds [82-84] but yields as high as the present ones have rarely been achieved on farms or in large scale culture. On the other hand, the breakage ratio has been related to the size of the thallai and roughness of the sea reaching above 10% during windy weather [85]. In the present study, the initial seedlings weighing more than 125 g growth ranged between 2.5-3.36% day^{-1}, here the increased seedlings with increased days may reach declined growth.

The *K. alvarezii* showed maximum growth rates (4.3-6.1% day^{-1}) similar to the results obtained in subtropical waters of Brazil [86]. In Brazil, the brown strain of *K. alvarezii* grew between 3.6% and 8.9% day^{-1}. Nevertheless, the present results were slightly higher than those obtained in Panagatan Cays, Philippines, for the brown and green strains ranged from 2.3% to 4.3% day^{-1} [86] from April to June and the highest growth rates (above 5.5% day^{-1}) were obtained. The present investigation obtained highest growth rates (6.1% day^{-1}) during postmonsoon season (January to March). Glenn and Doty [46] reported average growth rates for *K. alvarezii* at 5.06% day^{-1} in Hawaii, present results showed 5.43% day^{-1} at 30th culture period in postmonsoon season. A detailed report on experimental cultivation of *K. alvarezii* was given by Eswaran *et al*., [65] and the maximum growth rate 5.4% noticed the first 30 days and thereafter the growth rate becoming less. The present results coincide with the above statement; here the maximum mean 5.43% during 30th day culture period subsequently the growth rate decreased until it was barely 2.5% during summer at 75th day.

According to the site fertility concept, seaweed growth rate is regulated by a complex interaction of irradiance, temperature, nutrients and water movement [88]. Some of these factors may interact regulating the growth of target species and the major decline of one factor (e.g. nutrients) could be compensated by another factor (water movement). Thus, in environments with low or erratic nutrient supply, surge ammonium uptake has been described for *K. alvarezii* as a strategy to avoid nitrogen limitation of growth [89]. The introduction of *K. alvarezii* has been the subject of much discussion and many countries have adopted a very cautious attitude to the introduction of this species. Nevertheless, all experimental evidence available today indicates the introduction of this species has deleterious effect on the natural biota of the countries involved [90]. However, it is important that quarantine protocols must be adopted and monitor procedures established in order to minimize the risks of such introduction as proposed by Zemke-White [91]. In the Vellar estuary and adjacent coast, the feasibility of cultivating *K. alvarezii* had been demonstrated in this study. As reported by Ask and Azana [34] growth rates above 3.5% day^{-1} are considered adequate for commercial farming. During January to March the best growing conditions were observed, with growth rates above 6.1% day^{-1}. Therefore, *Kappaphycus* cultivation could be proposed as an alternative livelihood for fishermen, self-help groups and coastal poor people and same time it reduces the fishing pressure. However, experimental testing of potentially useful farming areas, cultivation technologies and routines are needed before farms are expanded to large scale.

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