Seaweed resources in Sri Lanka: culture of *Gracilaria* and intertidal surveys

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by

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Dedicated to my Dad & Mum

W. D. Julian Ratnasekera & Irine M. M. Perera

For their Extreme Love, Encouragement and Prayers

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P.M.Annesty Jayasuriya

ABSTRACT

Gracilaria edulis showed high mean relative growth rates in the Puttalam Lagoon during June to August and November to February coinciding with the south-west and the north-east monsoons. The mean relative growth rate showed significant correlations with the total nitrogen content and the % surface irradiance of the lagoon which are probably the limiting factors for the growth of *Gracilaria* plants. Pulse feeding experiments (24 h per week) showed that the nitrogen concentration of 1 mmol/l was about the optimum for the growth of *Gracilaria* plants even though there was no significant difference on the effect of nitrate and ammonium fertilizers.

Plastic net was found to be the most effective substratum amongst those tested for the vegetative culture of *Gracilaria* in the Puttalam Lagoon. An optimum depth of 20 cm with an optimum density of 100 fragments/m^2 was also suggested for use in vegetative culture practices.

Spore settlement techniques gave significantly higher biomass on synthetic raffia than on rope. The final biomass was also greater after spore release in a normal daylength than after an extended day. However it is suggested that this method would be more suitable for small scale culture practices other than commercial culture due to the lack of spore bearing plants in the lagoon during parts of the year.

More work should be done on the aspect of turbidity in relation to light attenuation and finding suitable sites in the lagoon for the culture of *Gracilaria edulis*. It was suggested that the development of small scale culture practices with the help of the present technology would generate more employment opportunities to the fishing communities living around the Puttalam Lagoon.

Mapping work on the distribution of seaweeds in four different reef areas showed a distinct seasonal variation of algae in different quarters of the year. The highest dry standing crop of 98 t was observed by the *Sargassum* species along the west and the south-west coast of Sri Lanka. *Ulva* and *Caulerpa* species also achieved a relatively high biomass compared to other species. A dry standing crop of 1.5 t was observed for *Gelidium* which exists only around Beruwala reef areas.

Regeneration studies showed that cut or scraped *Sargassum wightii* plants with the holdfasts may gain the original biomass in about 5 months during the early months of the year whereas *Gracilaria corticata* may take only four months. *Gelidium* showed the slowest regrowth among the plants tested, needing 10 months recovery.

It is suggested that the culture experiments on *Gracilaria* sp. and the resources survey would be extremely beneficial to Sri Lanka for the commercial utilization of seaweeds in future.

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GENERAL INTRODUCTION

The role played by marine algae in human welfare is now coming to the fore more than ever. Although they have acquired considerable importance as a potential source of food, colloids, vitamins and certain minerals, very little work has been done on their taxonomy and ecology in Sri Lanka.

The first studies on seaweeds in Sri Lanka were on the general distribution and taxonomy. These were carried out by foreign phycologists during short visits to the island. Many of these phycologists have experienced difficulties in collecting adequate specimens from different parts of the island for detailed systematic studies.

Harvey (1853) was the pioneer in the study of marine algae in Sri Lanka. He visited Sri Lanka in 1853 and collected marine algae from Trincomalee, Weligama and Galle. His collections are preserved in Trinity College, Dublin and the duplicates at the Royal Riks Museum in Stockholm and in the herbarium of J.G. Agardh in Lund. Collections of marine algae were also made by W. Ferguson and are preserved in the British Museum. Duplicates of his collections are also kept in the herbarium of J. G. Agardh in Lund. Professor Nils Svedelius stayed in Sri Lanka for about ten months and studied the algal vegetation at Galle (Svedelius, 1906). Another important survey was carried out by Boergeson (1936) who visited India and who made a short trip to Sri Lanka. He examined the coral reefs at Galle and collected algae from the southern coast of Sri Lanka.

In 1952 the Ceylon Fisheries Research Station initiated the first systematic survey of the island's coastal waters to determine the seaweed resource potential of these waters. Initially attention was focused on red seaweeds from which agar was to be extracted. Durairatnam & Medcof (1954) showed the presence of large quantities of *Gracilaria* species in Koddiyar Bay near Trincomalee. Further studies of marine algal resources of Sri Lanka were carried out by Durairatnam (1961). He recorded 47 species of Chlorophyceae, 42 species of Phaeophyceae and 85 species of Rhodophyceae. He stated that most of the Sri Lankan red algae were found growing in the southern and western parts of Sri Lanka, where the coast is rocky and fringed with coral reef. No seaweeds are found in the east coast of Sri Lanka where there are only sandy beaches except the Trincomalee area. According to Durairatnam (1961) large amounts of *Gracilaria* and *Hypnea* sp. were cast ashore during the north-east monsoon period in the Trincomalee area.

Durairatnam (1961) pointed out that the reef areas of Sri Lanka show a marked difference in vegetation during south-west and north-east monsoon seasons. The monsoon reversal of winds cause a characteristic circulation of near surface waters and has important repercussions on the plants inhabiting its waters. It brings about regions of upwelling and high productivity which have a vast effect on the changes of the distribution and the abundance of marine algae.

However, no suggestion was made by the above author for commercial harvesting of any of these seaweeds. Extensive studies of these seaweeds are however needed before commencing any commercial exploitation. These studies should include the estimation of algal biomass and their seasonal variations within the year and the effects of harvesting. Marine algal production through harvesting natural areas or through culture can be suitable for small-scale operations, and development along these lines can offer useful social benefits to poor coastal communities in the region.

PART 1

CULTURE STUDIES OF *GRACILARIA EDULIS* IN PUTTALAM LAGOON

1 INTRODUCTION

Gracilaria, a cosmopolitan seaweed genus, is fast gaining worldwide importance as a cheap source of dietary protein and minerals as a natural food for the cultivation of sea abalone (Chiang, 1981) and siganids (Westernhagen, 1973; 1974) and mainly as a raw material for the manufacture of agar (Armisen & Galatas, 1987).

Close to 5000 tonnes (t) of agar are processed annually from 25,000 to 30,000 t of dry *Gracilaria*, mainly from the wild in Chile, Argentina, Brazil and South Africa and from fish pond culture in Taiwan, Hainan Island and mainland China (Santelices & Doty, 1989). Steady increases in market demand, together with a lack of crop management, have led to overharvesting of the natural stock and to shortages of *Gracilaria* (Santelices & Doty, 1989). However, the production through culture is more predictable and stable where targeted outputs are easily attained. Cultivation involves a wide range of techniques as simple as the management of natural stocks or as complex as the propagation of selected clones and genetically bred hatchery seedstocks in capital intensive situations (Neisch, 1978). Therefore, the outcome has been great interest in *Gracilaria* farming and a diversity of farming methods have been developed all over the world (Santelices & Doty, 1989).

Field culture of *Gracilaria* is an established practice in Taiwan (Shang, 1976) and experimental culture has been carried out in several countries (Raju & Thomas, 1971; Kim, 1970; Chennubhotla *et al.*,1978;

Saunders & Lindsay, 1979; Li Ren *et al.*,1984; Pizarro & Barrales, 1986; Anon, 1987; Camara-Neto, 1987; Smith *et al.*, 1984; Smith, 1986; Santelices & Ugarte, 1990).

Although several studies on *Gracilaria* have been carried out in Sri Lanka (Balasubramanium, 1979; Durairatnam, 1956, 1965; Durairatnam & Medcof, 1954, 1955; Durairatnam *et al.*, 1972; Gunasekara, 1963; Jayasuriya, 1992) very little work has been done on its culture (Sivapalan, 1975; Sivapalan & Theivendirarajah, 1978). However, Sri Lanka has a long history (since 1800) of utilizing *Gracilaria* as a traditional industry. It has two main species of *Gracilaria* known as "Ceylon moss" which have been used commercially. These are *G. verrucosa* (Huds.) Papenfuss (synonym *G.confervoides*) and *G.edulis* (Gmel.) Silva (synonym *G.lichenoides*) which are known to Sinhalese fisherman as "Kanda parsi" and "Chan-Chaw parsi". The latter name appears to be of Chinese origin and it is very likely that edible algae were once exported to China as were other marine products of Ceylon (Deraniyagala, 1933).

Gracilaria edulis grows submerged in shallow areas of the lagoons in the north-west and northern part of Sri Lanka, mostly attached to seagrasses and dead coral. The mature plant grows up to a length of 40 cm and is freely branched, the branches being cylindrical and generally tapering into a point. The plants are light green to purplish red in colour and have a cartilaginous consistency. The other *Gracilaria* species, *G. verrucosa,* grows only in the north-eastern part of Sri Lanka. However the correct name of this species is uncertain according to the taxonomic classification by Bird & McLachlan (1982). Since early 1800's the fisherman living in these areas used to gather these plants by means of hooks attached to lines (Deraniyagala, 1933). Material was dried in the sun and left overnight in the dew, which is said to bleach it more effectively than the sun. It was reported by Deraniyagala (1933) that this dried seaweed was sold to the Moors of the northern parts of Sri Lanka who exported in to India or retailed it in Colombo.

Exports to England of dried bleached "Ceylon moss" approximated to 2,500 kg in 1831 and to 6800 kg in 1840 (Durairatnam & Medcof, 1954). "Ceylon moss" was described by Sigmond (1841) in Deraniyagala (1933) as a cure for constipation, asthma, catarrh, infections of the trachea, diseases of mucous membranes and disorders of the stomach. During 1941 to 1944 an estimated 10,000 kg of seaweed was exported to India annually (Durairatnam & Medcof, 1954). After the war this export trade ceased but a few fisherman living in the northern part of Sri Lanka continued to collect, bleach and supply small quantities to Colombo markets where it was sold locally. In the 1950's the trade of exporting seaweeds picked up again because of the strong demand from Japanese buyers. In the late 1960's, due to a drop in quality standards of Sri Lankan *Gracilaria* exports, mostly due to the deliberate adulteration of the product, the trade suffered heavily, the exports virtually coming to a halt. In the 1970's the trade picked up again with small quantities. In 1986 according to customs' statistics, around 150 t of dried "Ceylon moss" was exported, mainly to Japan.

At present seaweeds are mainly collected by hand picking. Two fisherman can collect a boat load of seaweed per day. The boats are unloaded on the beach and the crop is allowed to sun-dry for 4 to 5 days. The dried weed contains impurities and extraneous matter such as seagrass, other aquatic organisms, sand, shells etc. It is tightly packed in gunny bags and transported by cart to the purchasing centres. Even though some cleaning is done by the collectors during sun drying, further cleaning is carried out at the purchasing centres. Here the weeds are sifted on a table model wire mesh sieve to remove particulate matter such as sand and sea shells. The weed is stacked at the purchasing centre whilst awaiting transportation to Colombo. The middleman gets around Rs.10-12 (1 Rs. = 0.025 $ U.S.) for one kilo of dried seaweed. The dried weed is further cleaned by the exporters prior to bailing for shipment. A bail of dried weed weighs approximately 150 kg.

A very small percentage of the dried weed is sold locally. Retail packs, weighing 50 or 100 g are sold at most supermarkets, pharmacies and groceries in Colombo and suburbs. Packeting of seaweed is carried out by traders who get their supplies from their agents. These agents visit the producer areas periodically and purchase the dried weed direct from the collectors. A retail pack of 100 g is sold at Rs. 20-30 (50-75 cents U.S.), with the retailer getting a 15-20% commission. According to most Colombo traders packeted seaweed is a "slow moving" item except during the Islamic festive season, when there is good demand for the weed. However according to these traders, over the last few years there has been a growth in seaweed sales because it is used increasingly in local cuisine. They also believe that local "moss" is superior to imported "China moss" as evidenced by consumer preference for the former.

This "Ceylon moss" is a popular item of food in producer areas. A crude or hot extraction or complete hydrolysis of the seaweed yields a gel or viscous polysaccharide. By adding coconut milk and sugar this preparation can be served as a porridge or a drink. These preparations are very popular among the Muslim communities in the northern part of Sri Lanka. These villagers believe this porridge to be highly nutritious and it is considered essential during the fasting season.

Over the last few years no harvesting of *Gracilaria* has been done in the north-eastern part of Sri Lanka due to the civil unrest which has prevailed in the area during this period. At the moment all the exports come from the north-western part (Kalpitiya) of Sri Lanka. Only one species of *Gracilaria* (*G.edulis*) is reported from Kalpitiya area (Durairatnam & Medcof, 1954).

According to customs' reports in 1989 only 25 t of dried *Gracilaria* were exported from Sri Lanka. However, it was revealed that there is a very high demand for local *Gracilaria* from the importer countries. Often the exporters have experienced difficulties in getting adequate supplies of dried seaweed to fulfil these export orders. The unsettled conditions prevailing in the north and the east, have also deprived the exporters access to the resources of the Trincomalee area, an area which used to provide about 50-70 t of dried weed annually. This has created a vacuum which could be filled if the stocks were increased. The only alternative to increasing the stocks is artificial cultivation. The development of small scale farming would be essential in promoting the economic progress of the fishing communities living around the Puttalam Lagoon.

2 ENVIRONMENTAL ASPECTS AND CONTINUOUS GROWTH EXPERIMENTS

2.1 INTRODUCTION

2.1.1 Study area

Puttalam Lagoon, located in the Puttalam District in the north-western province of Sri Lanka, is a water body bounded on the east and south by the mainland, and on the west by Kalpitiya peninsula and the Karaitivu Islands. This lagoon is connected to the Gulf of Mannar via Dutch Bay and Portugal Bay in the north. It is approximately 35 km in length and the width varies from 2.5 km to 13 km. Including Dutch Bay it covers a surface area of about 236 km^2 (Fig. 2.1). The Puttalam Lagoon is surrounded by a rich mangrove vegetation, seagrasses and seaweeds which provide a favourable environment for the fish resources. The finfish and the shellfish are the major resources in the estuary as they provide the livelihood for a population of around 50,000 people around the lagoon.

2.1.2 Tide levels and current

The tide levels in Puttalam Lagoon do not rise and fall in rhythm with the tide level of the sea outside. The highest tides can be observed during the north-east monsoon as the water pushed into the lagoon from Dutch Bay can find no way out; and tides are lowest during the south-west monsoons as the water is pushed out from Puttalam Lagoon into Dutch Bay (Perera & Siriwardena, 1982). The highest tidal amplitudes were recorded at

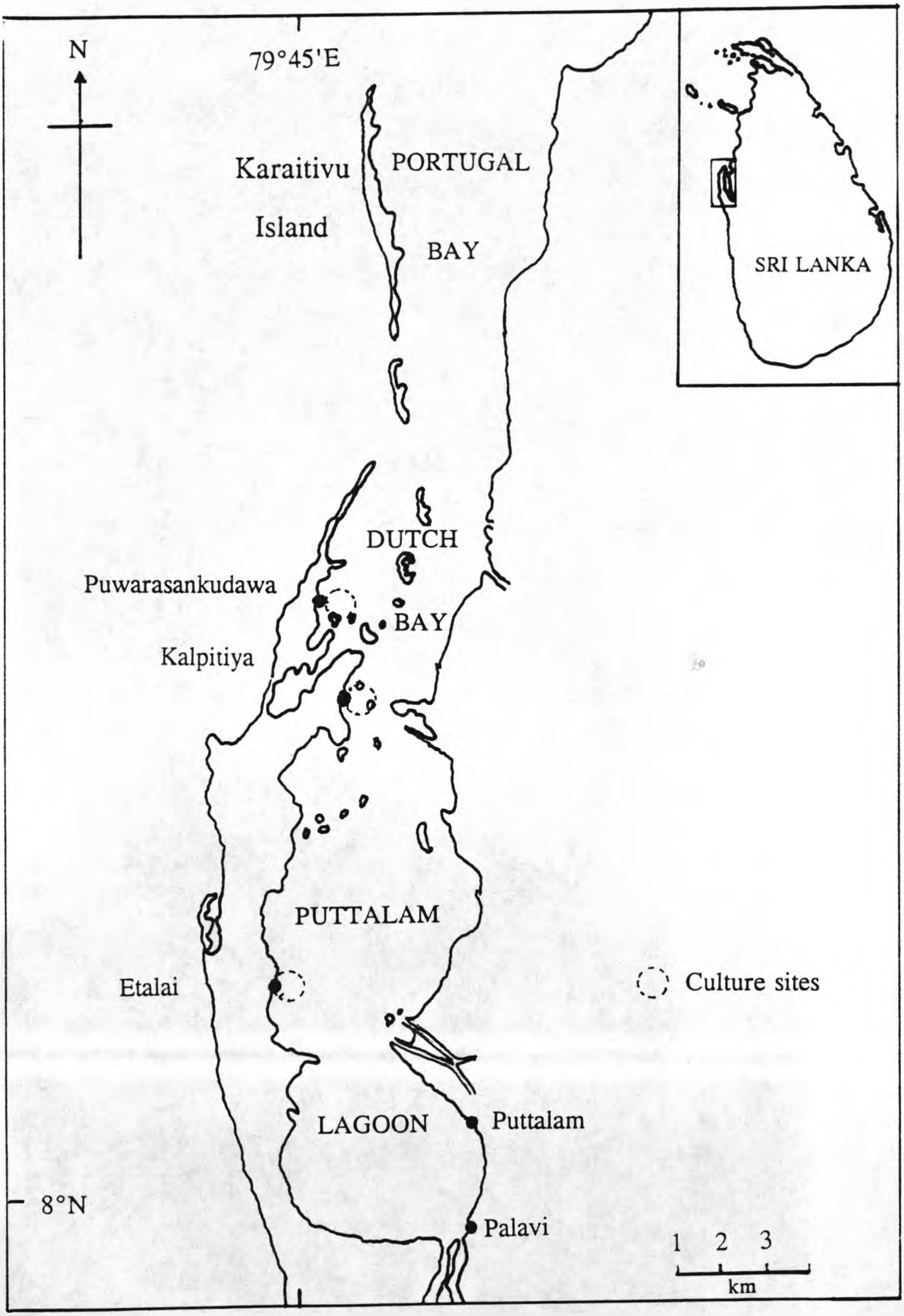

Fig. 2.1 Location of Puttalam Lagoon.

Kalpitiya whereas the lowest amplitudes occurred in the middle part of the lagoon (Table 2.1). However it was observed that the tidal wave characteristics such as wave length and amplitude change with the depth and the width of the lagoon. It was shown by Wijeratne (1992) that the maximum sea level change was less than 0.6 m, within an average time of a tide cycle which was approximately 13 hrs. The phase lag between Kalpitiya and Etalai was observed as 2 h 15 min, and Kalpitiya to Puttalam as 2 h 45 min. The studies done on current measurements in Puttalam Lagoon (Arulananthan, 1992) showed that the current speed changes with depth and time. He also showed that the changes in current speed with time were smaller than the changes with depth. Therefore, he suggested that this would indicate stratification in the lagoon.

2.1.3 Topography and substratum

Puttalam Lagoon is formed of two basins separated by a ridge of islets to the east of Kalmunai Point (Perera & Siriwardena, 1982) (Fig.2.2). Both basins have a more or less uniform bottom with a very gentle gradient. Deeper parts generally consists of a layer of soft black mud, but the narrow channels between Kalpitiya and Karaitivu (Serakkuli), where the tidal currents are very strong, are free of mud though they are the deepest areas (Fig. 2.2). These channels and shallower parts have a bottom of coarse particles of shell mixed with sand and mud. A sand bottom is found close to the shore line of high tide in a few places.

2.1.4 Vegetation

Eight species of seagrasses were recorded in the Puttalam Lagoon

Station	Lowest reading: (cm below mean sea level)	Highest reading (cm above mean sea level)	Tidal amplitude (cm)
Palavi Bridge	5	71	76
Puttalam town	5	71	76
Etalai	26	43	69
Kalpitiya	23	60	83

Table 2.1 Tide levels observed from January to December 1976 on one random day per month at Puttalam and Kalpitiya at ½ hour intervals (source: Perera & Siriwardena, 1982).

Fig.2.2 The type of bottom sediments in Puttalam Lagoon (redrawn from Perera & Siriwardena, 1982).

(Jayasuriya, 1991). Shallow areas up to approximately one meter depth was covered mainly by *Halodule* sp and *Thalassia* sp. *Enhalus* sp was the most abundant down to 1.5 m depth except in the south-western region of the lagoon. These seagrasses play a major role as substrata for many important epiphytic forms of macro- and micro-algae. The natural beds of *Gracilaria edulis* were found to be distributed along the shallow areas of the lagoon (Fig. 2.3). Most of these natural beds apparently coincided with the coarse muddy sand bottom areas of the lagoon.

2.1.5 Physicochemical parameters of the lagoon

The work carried out by the National Aquatic Resources Agency/Swedish Agency for Research Co-operation with Developing Countries Coastal Ecosystem Study Programme (NARA /SAREC) showed that the pH value of the Puttalam Lagoon fluctuated between 7.5 and 8.8 (De Alwis and Abeysirigunawardana, 1992). It was also noted that the temperature of the water immediately below the surface fluctuated from 28°C to 30.5°C. It was stated that no temperature stratification was observed due to the fact that the temperature of the water at the bottom of the lagoon did not indicate significant variations. The fluctuation of the water temperature from October 1990 to April 1993 is given in figure 2.4. The highest salinity recorded for the Puttalam lagoon was 46 ppt (Arulananthan, 1992). The salinity values recorded from October 1990 to April 1992 at Kalpitiya are given in Fig. 2.5). The average values determined for dissolved oxygen in the surface water samples as well as bottom water samples fluctuated between 5 and 7 mg/l (De Alwis & Abeysirigunawardana, 1992).

According to the Coastal Study Programme, traces of phosphates

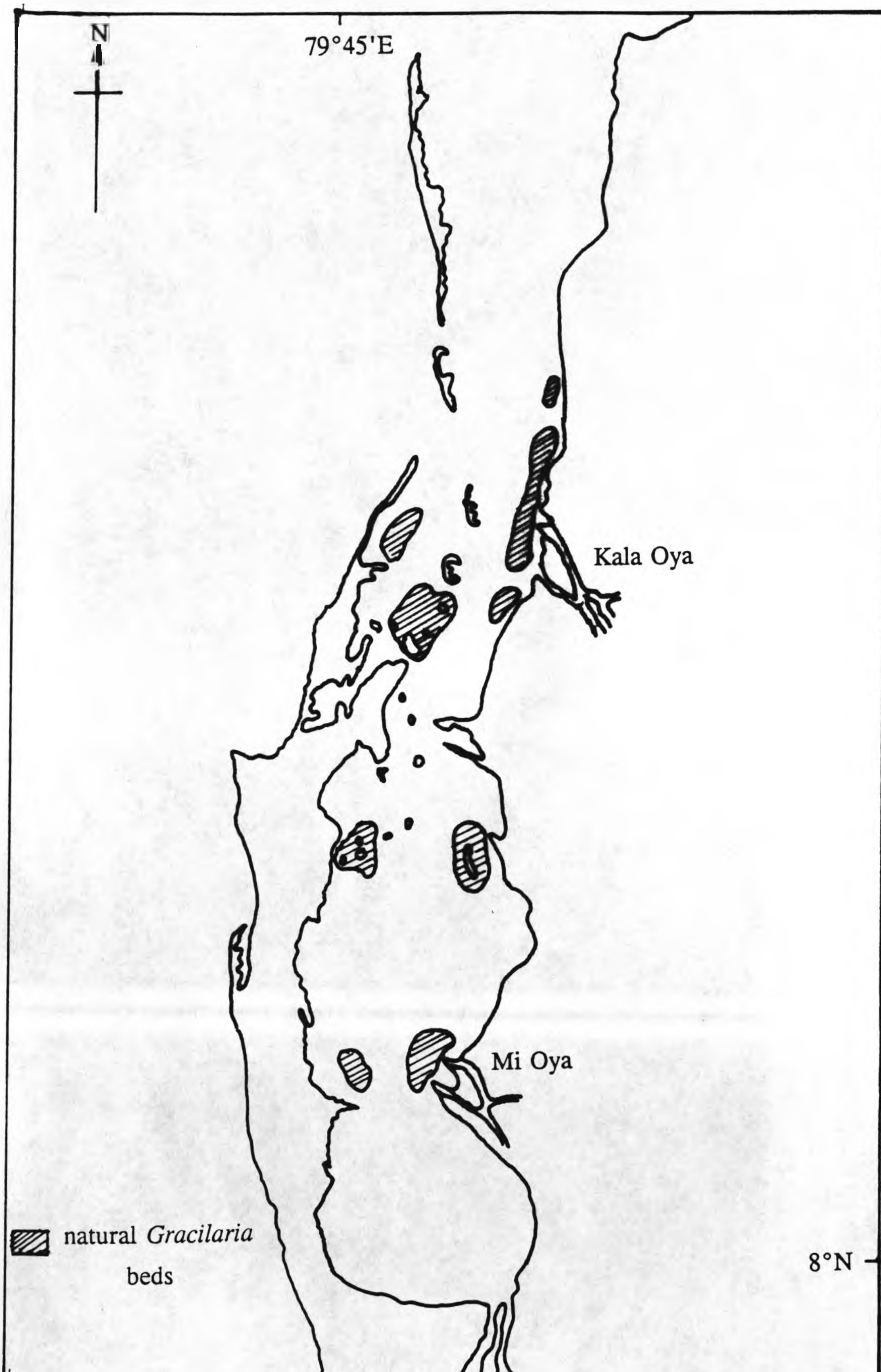

Fig. 2.3 Distribution of natural *Gracilaria* beds in the Puttalam Lagoon.

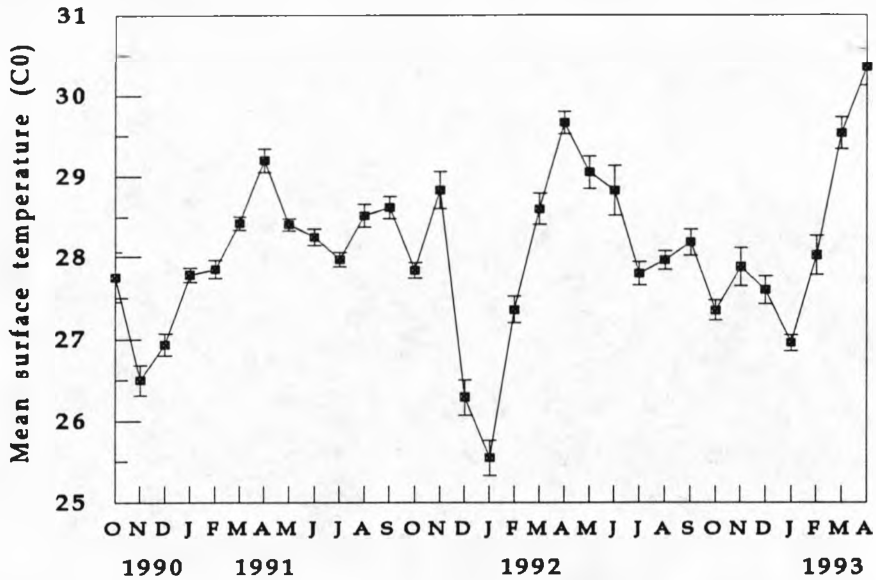

Fig.2.4 The mean monthly variation of the surface water temperature of the Puttalam Lagoon at Kalpitiya from Oct 1990 to April 1993. (Bars = ± S.E.)

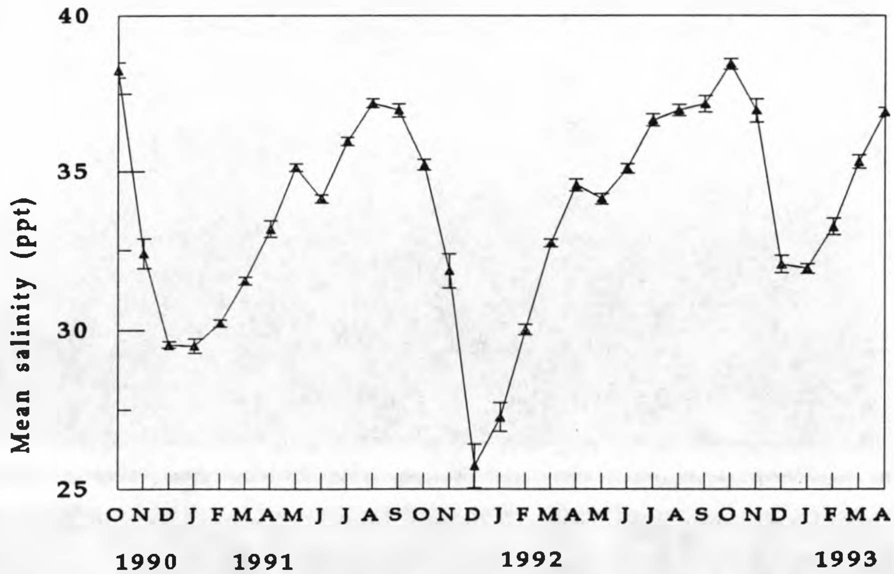

Fig. 2.5 The mean monthly variation of salinity of the Puttalam Lagoon at Kalpitiya from Oct 1990 to April 1993 (Bars= ± S.E.)

were found in most of the areas. No phosphate was found at a number of stations. Low nitrates and wide variations of the ammoniacal nitrogen were also noted in their observations.

The Puttalam Lagoon has two major fresh water inlets carrying water from the catchment areas (Kala Oya and Mi Oya, Fig.2.3). The lagoon also receives storm water from run-offs from the town of Puttalam. The Coastal Ecosystem Study Programme found that the upper reaches of the lagoon, ie. in close proximity to the town, contained high levels of nutrients when compared with the rest. The middle part of the lagoon showed the lowest levels of the nutrients. High productivity, dispersion and dilution would have been the contributory factors for the reduction of nutrients (De Alwis & Abeysirigunawardana, 1992). However, it also stated that the nutrient levels at the stations towards the open sea were also found to be slightly higher than the middle part but lower than those of upper reaches.

2.1.6 Experimental culture sites of *Gracilaria edulis*

The experimental culture sites of this study are situated mainly in the northern lower part of the lagoon. These sites are at Kalpitiya, Etalai and at Puwarasankudawa (Fig.2.1). Kalpitiya is the main town on the west coast of the lagoon. One of the Regional Research Centres of the NARA of the Ministry of Fisheries of Sri Lanka is also situated at Kalpitiya. Etalai is situated in the middle of the west coast of the lagoon. All three sites are coarse mud with sandy bottom sediments. The bottom sediments of Puwarasankudawa are less sandy compared to the other two sites. However, natural beds of *Gracilaria* exist only at Puwarasankudawa. Drag net fishing is being carried out in the other two places more often and that may be the reason for the absence of the natural stocks.

2.2 MATERIALS AND METHODS

2.2.1 Preparation of pilot farms

Pilot farms (10 m x 5 m) were prepared in the lagoon in front of the hatchery at Kalpitiya and at Puwarasankudawa to carry out culture experiments (Plates 2.1 & 2.2). About 60 mangrove stakes were driven into the mud as the boundary of each farm on all four sides. An 8.0 m high plastic mesh (1 cm mesh size) fence was also driven into the mud and fixed to the stakes around the farm. A door was fixed at one side to enable anybody to enter the farm. These farms were used for almost all the experiments conducted at Kalpitiya and at Puwarasankudawa sites.

2.2.2 Monitoring of physico-chemical parameters

Salinity, surface and bottom water temperatures, pH and turbidity were monitored daily at both sites. A handheld refractometer and a Hanna pH meter were used to measure the salinity and the pH respectively. Light attenuation was measured using depth in centimetres (D_s) of disappearance of a Secchi disk. Although the Secchi disk is widely used because of its simplicity, such estimates of light attenuation have large standard errors of estimate (Tyler, 1968; Holmes, 1970). Larger values of the attenuation coefficient (k) indicate more inhibition of light transmission.
k was estimated by the following formula (Walker,1980):
$k \times D_s = 1.45$

Plate 2.1. Pilot culture farm for *Gracilaria* at the Kalpitiya site.

Plate 2.2. Pilot culture farm for *Gracilaria* culture at Puwarasankudawa.

where $k = \frac{\ln I_1 - \ln I_2}{D_2 - D_1}$

and I_1 = incident light at depth 1 (D_1) ;

I_2 = incident light at depth 2 (D_2).

The proportion of light at experimental depths was estimated from the Secchi disc depth and the calculated value of k.

The NO_3 and NH_4 concentration of lagoon water were also monitored once per fortnight. The NO_3 concentration was measured by using the reduction column method for determination of nitrate by Parsons *et al.* (1984). The concentration of ammonia was measured by using the alternative method (Parsons *et al.*,1984). Nitrate measurements from January to June 1992 were obtained from the work done by the environmental study unit of NARA for the SAREC project.

2.2.3 Continuous growth experiment

Two sites (Kalpitiya & Puwarasankudawa) were selected from the lagoon for comparison of the growth rate of *Gracilaria edulis* throughout one year cycle. Six plastic mesh (2 cm) cylinders, each 40 cm long and with a diameter of 15 cm. were made. Each cylinder contained 50 g of seaweed and three of them were placed horizontally at 20 cm depth at each site inside the pilot farm (Plate 2.3). The plant biomass was measured after a fortnight and the plants removed from each of the cylinders leaving 50 g of seaweed biomass. Once a month 50 g of new material from the same places was introduced as seed material to each of these cages. Plants were selected for the Puwarasankudawa site from a adjoining seaweed bed and every month new plants were selected from the same place for those cages at the same site. Plants were selected for

Plate 2.3. Plastic mesh cages used for continuous growth experiment. (initially 50 g of plants after two week period.)

the Kalpitiya site from the north eastern part of the lagoon and the new plants were brought for those cages from the same place. This was done in order to maintain a similar genetic material within each cylinder.

Mean relative growth rate in weight (R^W) or length (R^L) of the plants was calculated according to the modified formula of Patwary & van der Meer (1984):

$$R^W \text{ or } R^L = (\%\ day^{-1}) = \frac{\ln N_t - \ln N_0 \ x100}{t}$$

where N_t = final fresh weight (g) or length (cm) on day t, N_0 =initial fresh weight or length, and t = time interval.

2.2.4 Continuous growth experiment with different concentrations of ammonium and nitrate fertilizers

This experiment was done in the same type of plastic mesh cylinder which were used for the above continuous growth experiment. Media of three different NH_4Cl concentrations (2 mmol, 1 mmol, 0.5 mmol) in lagoon water were prepared in duplicate in six tanks of 50 x 70 cm each. All six tanks also contained 0.15 mmol/l NaH_2PO_4, as a phosphate supplement. Another set of two tanks with the same volume was filled with lagoon water as a control. Sixteen plastic mesh cages were prepared and each was filled with 50 g of seaweed and immersed at 20 cm depth in the lagoon. Once a week two of these cylinders were transferred to each of the above tanks for 24 hours and then return to the lagoon.

A similar experiment was carried out at the same period and at the same site using three concentrations (2 mmol, 1 mmol, 0.5 mmol) of KNO_3 instead of NH_4Cl as in the former experiment. 0.15 mmol

NaH_2PO_4 was again used as the phosphate supplement. These experiments were conducted from 15th January to 30th April 1993 at the Kalpitiya site.

The seaweeds were not removed from the cages throughout the experiment. However, the observations of the weight of the seaweed in all the cages were recorded fortnightly. Mean relative growth rate by weight (R^w % day^{-1}) was calculated according the above formula of Patwary & van der Meer (1984).

2.3 RESULTS

2.3.1 Continuous growth experiment

The mean relative growth rates in weight of *Gracilaria edulis* at both sites showed two distinct peaks of high growth rates within a year (Fig. 2.6a and 2.6b). However, the maximum growth rates were higher at Kalpitiya than at Puwarasankudawa. During the months showing peak growth the plants inside the mesh cylinders looked thick and fleshy with a reddish brown colour. In April and October the plants started showing a pale yellowish colour and they started deteriorating gradually.

2.3.1.1 Variation in total nitrogen content of lagoon water

The mean relative growth rates showed a highly significant correlation ($p < 0.001$, Table 2.2 and 2.3) with the total nitrogen content of the lagoon (Fig. 2.7a and 2.7b). The correlation coefficient obtained for Kalpitiya ($r^2 = 0.576$) was higher than that obtained ($r^2 = 0.357$) for Puwarasankudawa. However, the correlation coefficients obtained for

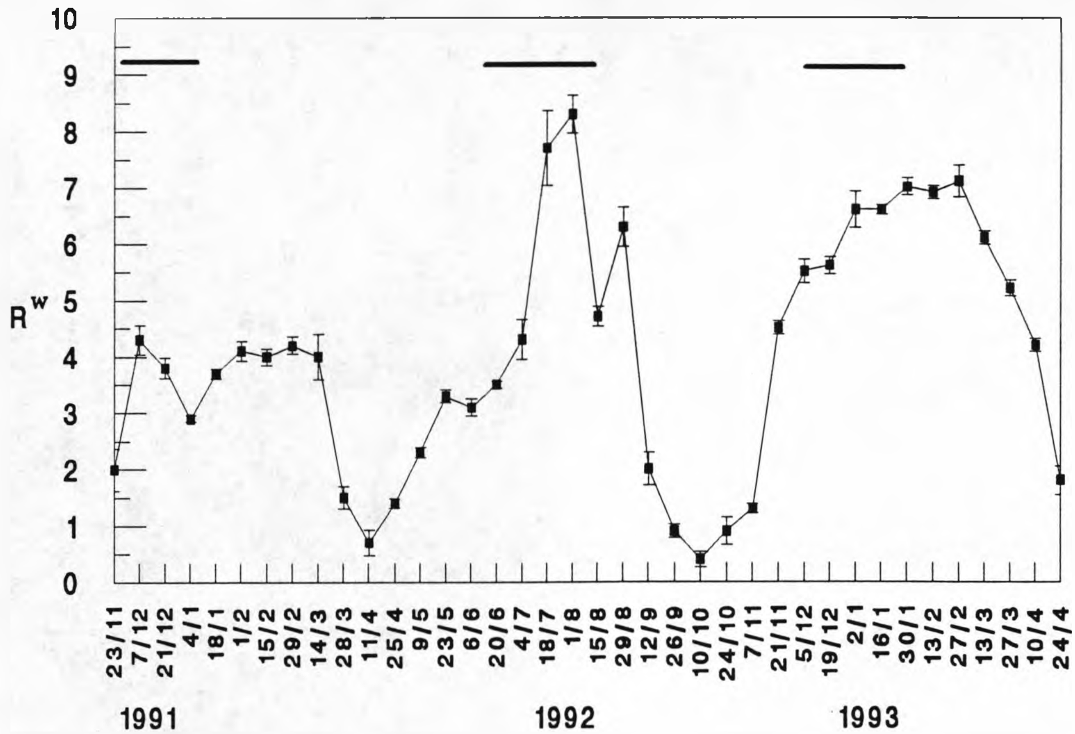

Fig. 2.6a Biweekly measurements of mean relative growth rates in fresh weight (R^w %/day) at Kalpitiya from Nov.1991 to April 1993. (Bars = $\pm$ S.E. and the thick lines indicates the monsoon periods).

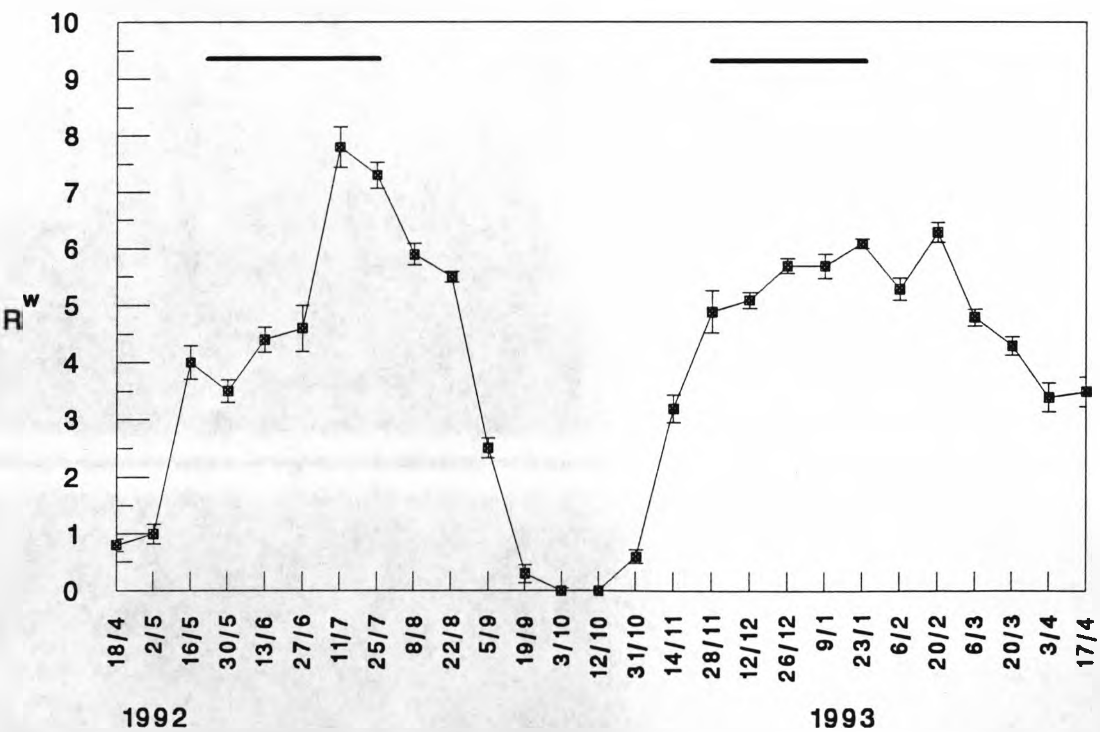

Fig. 2.6b Biweekly measurements of mean relative growth rates (R^w %/day) in fresh weight at Puwarasankudawa from April 1992 to April 1993 (bars = $\pm$ S.E. and the thick lines indicate monsoonal periods).

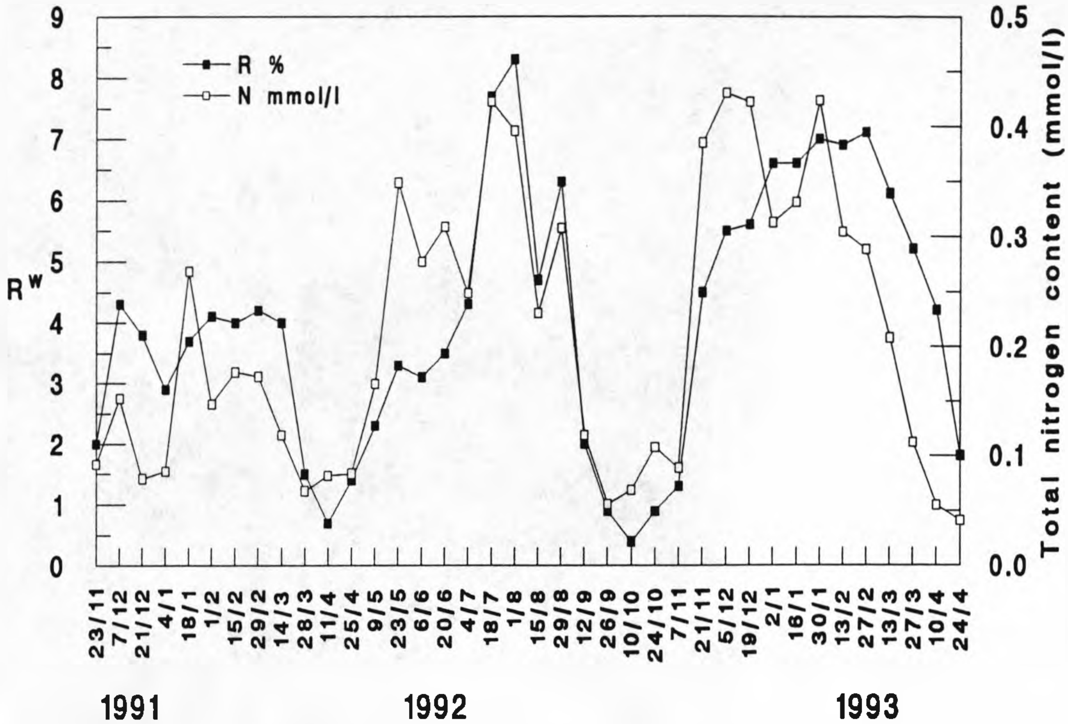

Fig. 2.7a Biweekly measurements of mean relative growth rate in fresh weight(R^W %/day) with the total nitrogen content (mmol/l) at Kalpitiya from Nov.1991 to April 1993.

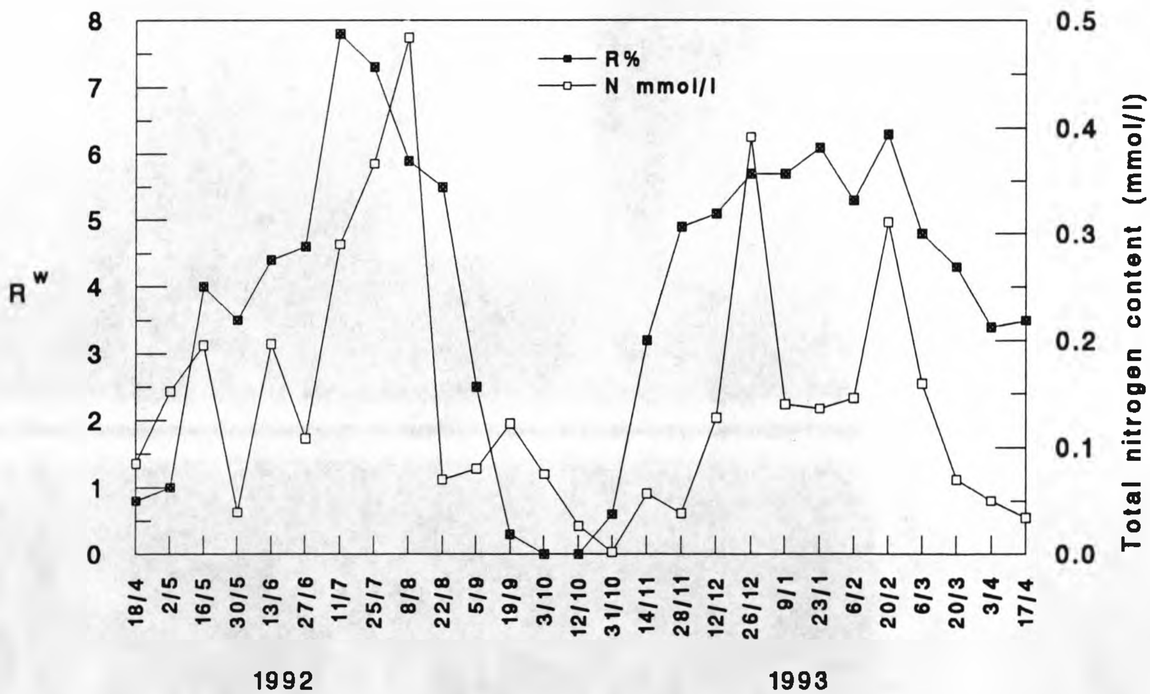

Fig 2.7b Biweekly measurements of mean relative growth rates in fresh weight (R^W%/day) with total nitrogen content at Puwarasankudawa from April 1992 to April 1993.

total nitrogen content at both sites were very much higher than those obtained for other environmental parameters.

2.3.1.2 Variation in salinity

The mean salinity fluctuation during the culture period at both sites was 24 to 38 ppt (Fig. 2.8a and 2.8b). At Kalpitiya there was no significant correlation of the mean relative growth rate and the mean salinity ($r = 0.122$; Table 2.2). However a significant correlation ($0.02 < p < 0.01$; Table 2.3) was shown with the mean relative growth rate and the mean salinity at Puwarasankudawa.

2.3.1.3 Variation in surface temperature

The surface temperature of the water did not show any drastic changes during this period at either site; it fluctuated from 25°C to 30.5°C (Fig. 2.9a and 2.9b). Moreover, the mean relative growth rate did not show any significant correlation with the surface temperature at either site.

2.3.1.4 Variation in pH value

The pH value also did not show any major variations and it fluctuated only from 8.2 - 8.7 (Fig. 2.10a and 2.10b) at both sites. There was no significant correlation with the mean relative growth rates and the pH values at either site.

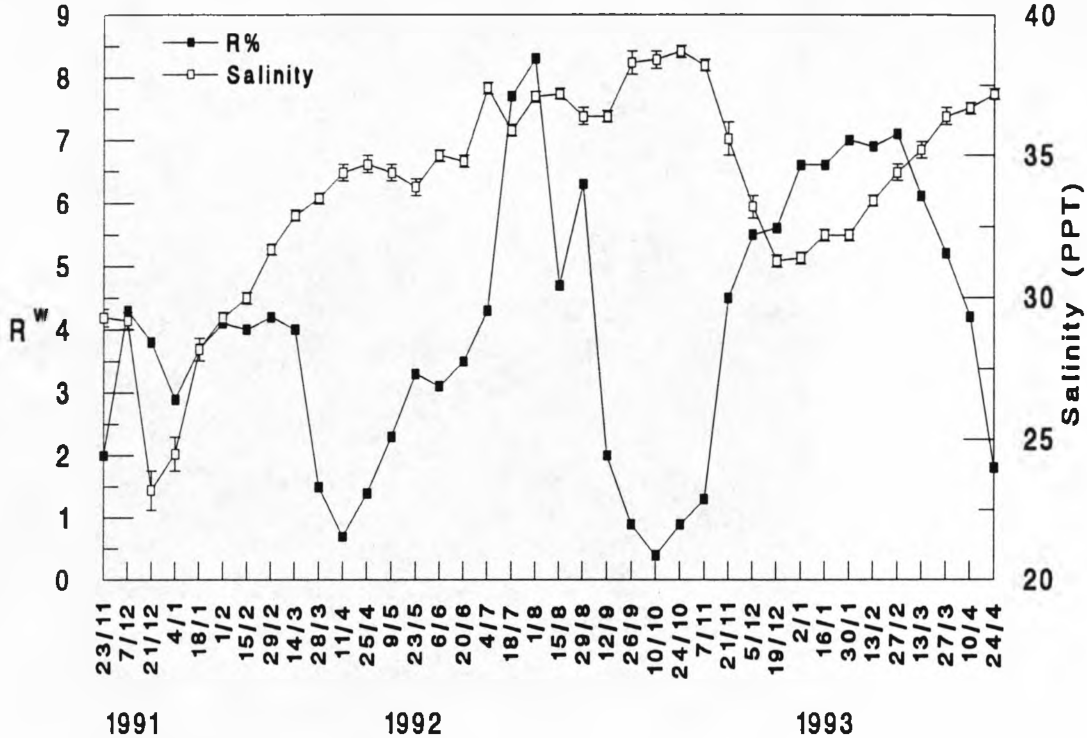

Fig.2.8a Biweekly measurements of mean relative growth rate in fresh weight (R^w %/day) with salinity at Kalpitiya from Nov.1991 to April 1993 (bars= $\pm$ S.E.).

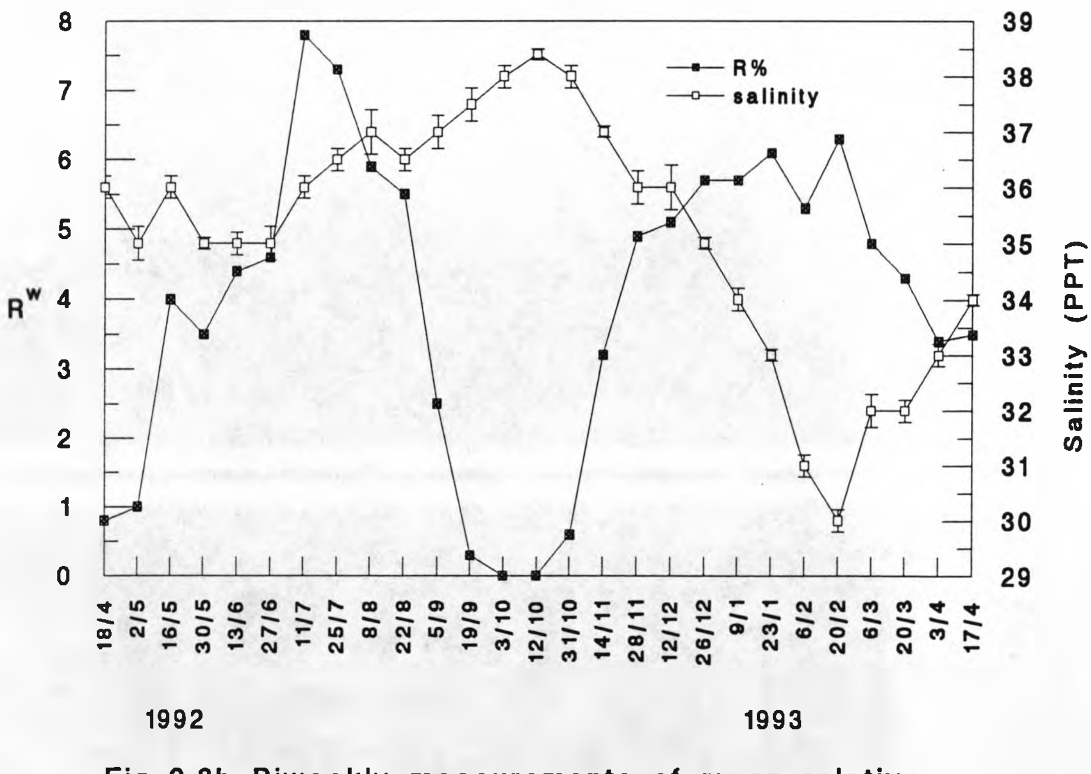

Fig 2.8b Biweekly measurements of mean relative growth rates in fresh weight (R^w %/day) with salinity at Puwarasankudawa from April 1992 to April 1993 (bars= $\pm$ S.E.).

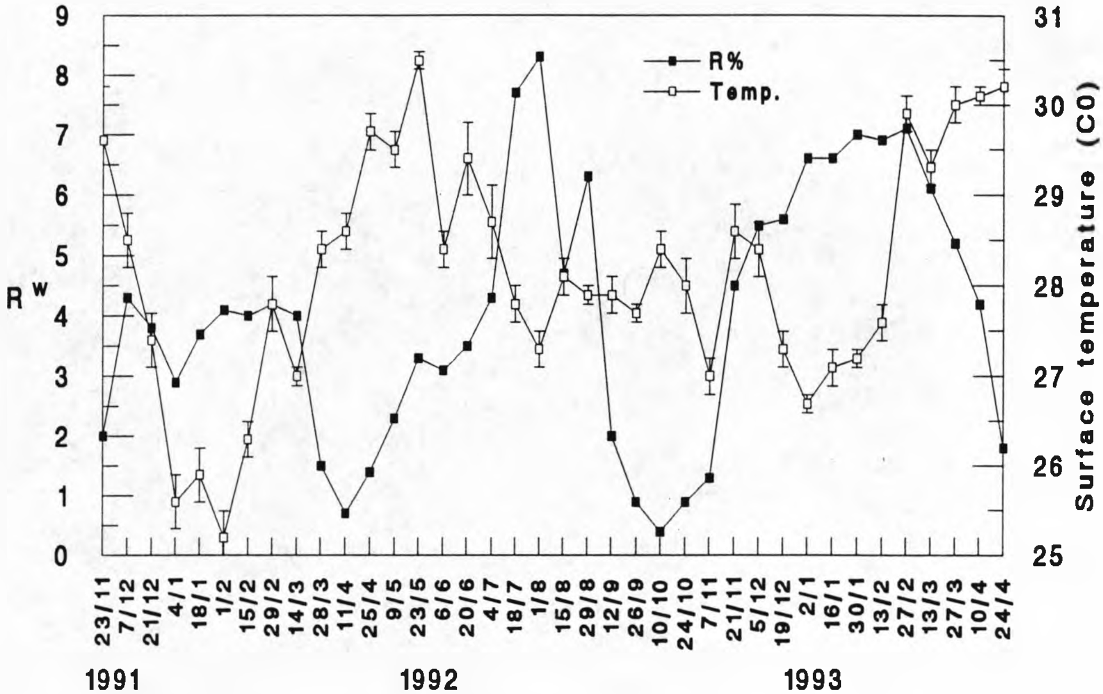

Fig.2.9a Biweekly measurements of mean relative growth rate (R^W %/day) with surface temperature at Kalpitiya from Nov. 1991 to April 1993 (bars = ± 1S.E.).

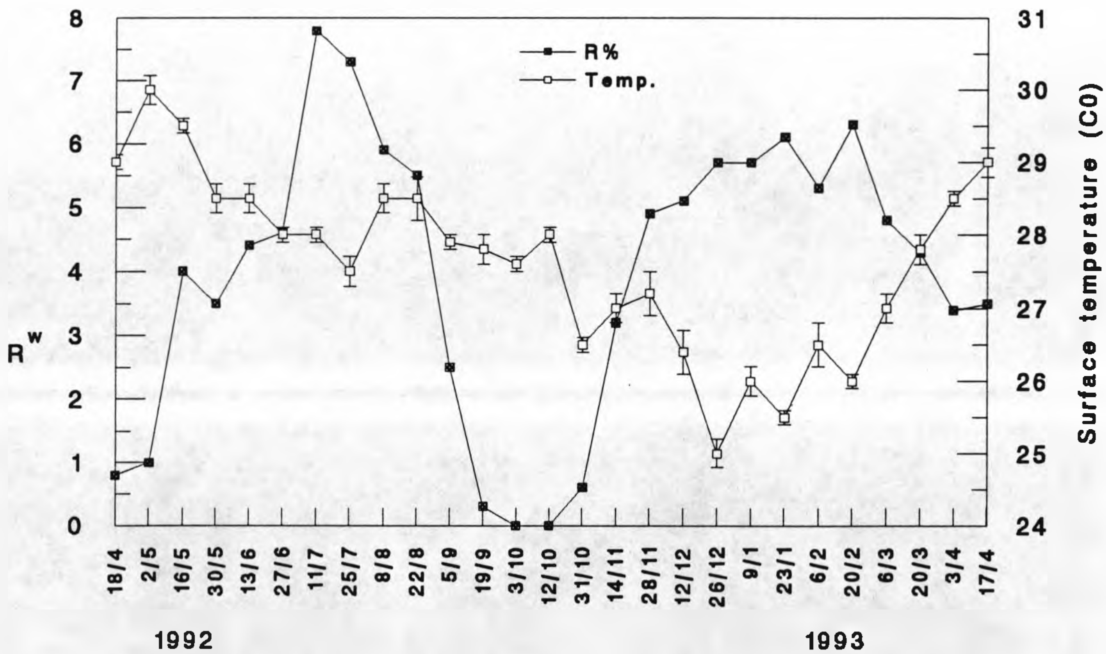

Fig. 2.9b Biweekly measurements of mean relative growth rates in weight(R^W %/day) with suface temperature at Puwarasankudawa from April 1992 to April 1993 (bars= ± S.E.).

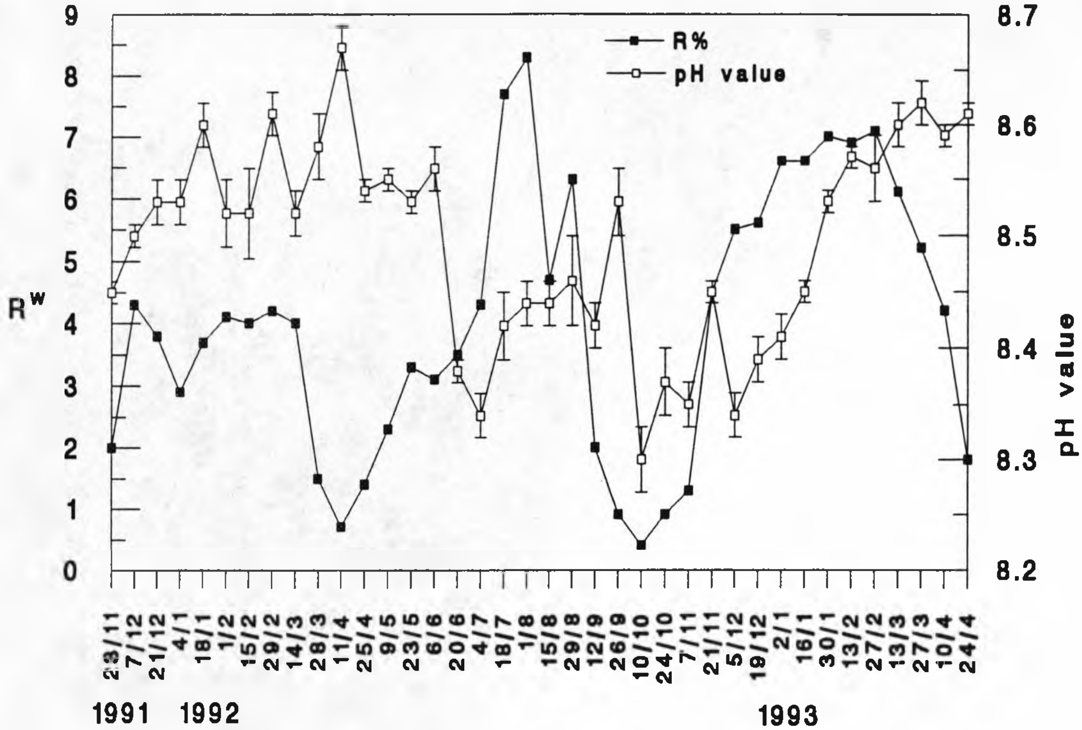

Fig.2.10a Biweekly measurements of mean relative growth rate in fresh weight (R^w %/ day) with pH measurements at Kalpitiya from Nov. 1991 to April 1993 (bars= ± S.E.).

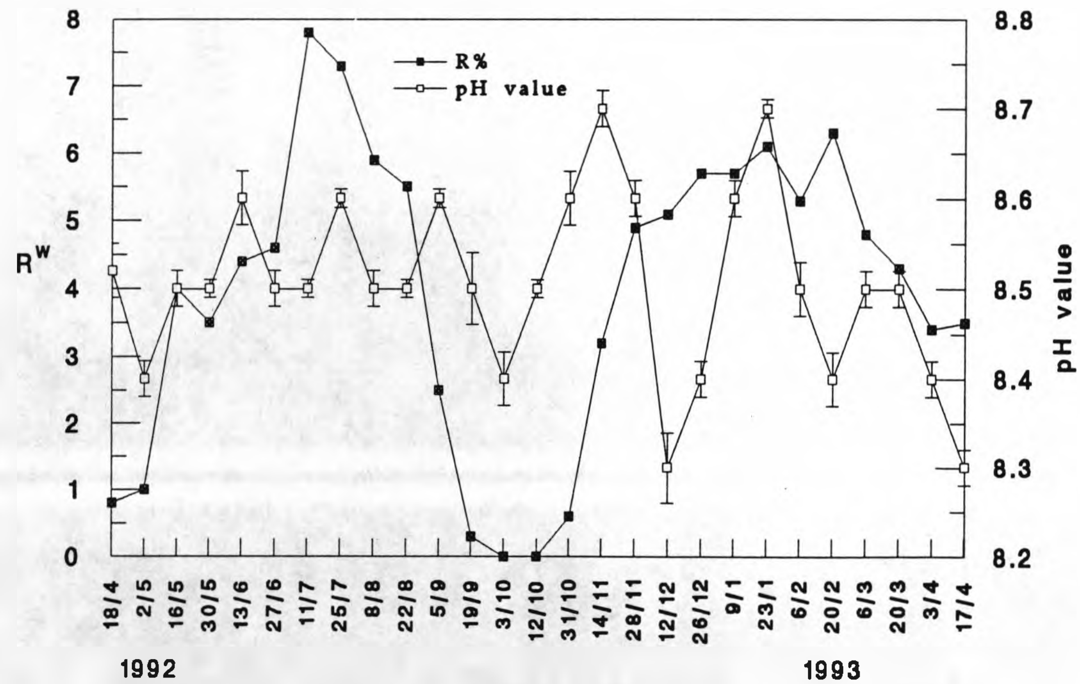

Fig.2.10b Biweekly measurements of mean relative growth rate in fresh weight (R^w %/day) with the pH measurements at Puwarasankudawa from April 1992 to April 1993 (bars= ± S.E.).

2.3.1.5 Variation in the % surface irradiance

Even though the work site is only approximately 0.8 - 1 m deep the % of the surface irradiance showed some interesting fluctuations during this period (Figure 2.11a and 2.11b). It was observed that there was a significant correlation ($p < 0.001$ at both sites) between the mean relative growth rates and the % surface irradiance at 20 cm at both sites. However, the correlation coefficient observed for Kalpitiya ($r^2 = 0.131$; Table 2.2) was lower than that observed for Puwarasankudawa ($r^2 = 0.186$; Table 2.3). A paired t-test shown that the % surface irradiance at both sites were significantly different ($p \leq 0.0001$).

2.3.2 Continuous growth experiment with fertilizers

It was clear that the *Gracilaria* plants in fertilized lagoon water showed higher mean relative growth rates than the plants in controls (Figs.2.12 & 2.13). It was observed that the growth rates in all the treatments were declining through out the culture period. However, the plants in 1 and 2 mmol/l concentrations of both fertilizers did not show significantly different in growth rates (Table 2.4). Plants in 1 mmol/l concentration of both fertilizers showed significantly higher growth rates than the plants in 0.5 mmol/l. However, the plants in concentrations of all fertilizers showed higher growth rates than the controls (Table 2.4). After the first two weeks the plants in all the cages showed high density throughout the period.

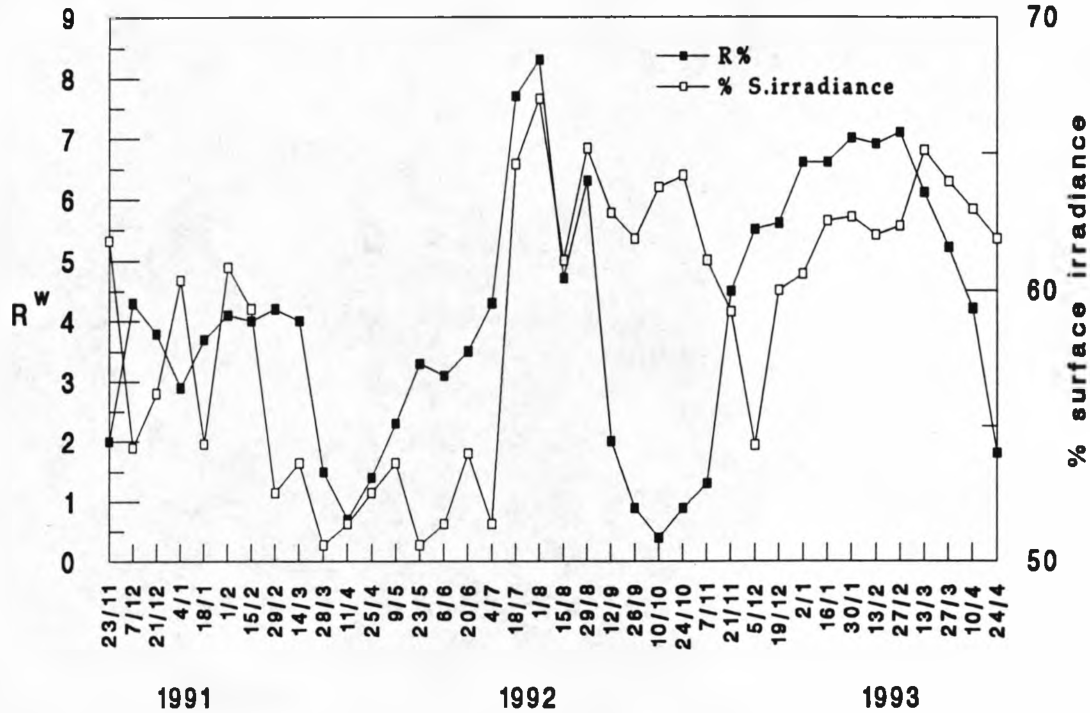

Fig. 2.11a Biweekly measurements of mean relative growth rates in fresh weight (R^W % /day) with the % irradiance at Kalpitiya from Nov. 1991 to April 1993.

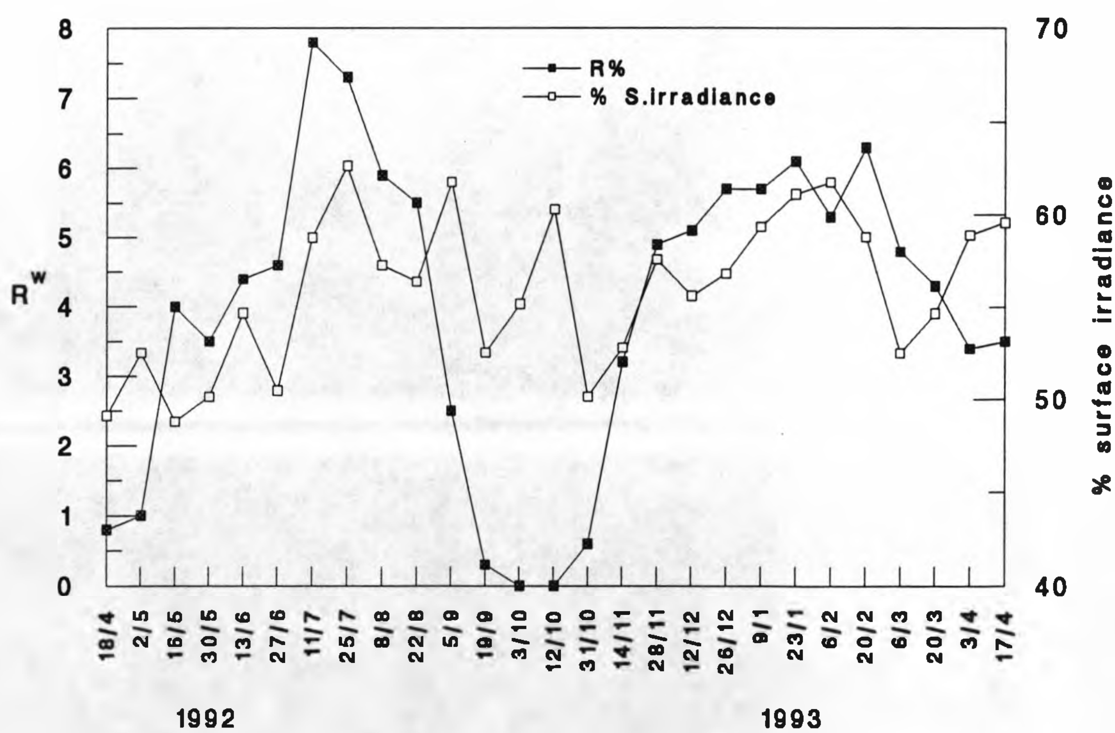

Fig.2.11b Biweekly measurements of mean relative growth rates in fresh weight (R^W %/day) with % surface irradiance at Puwarasankudawa from April 1992 to April 1993.

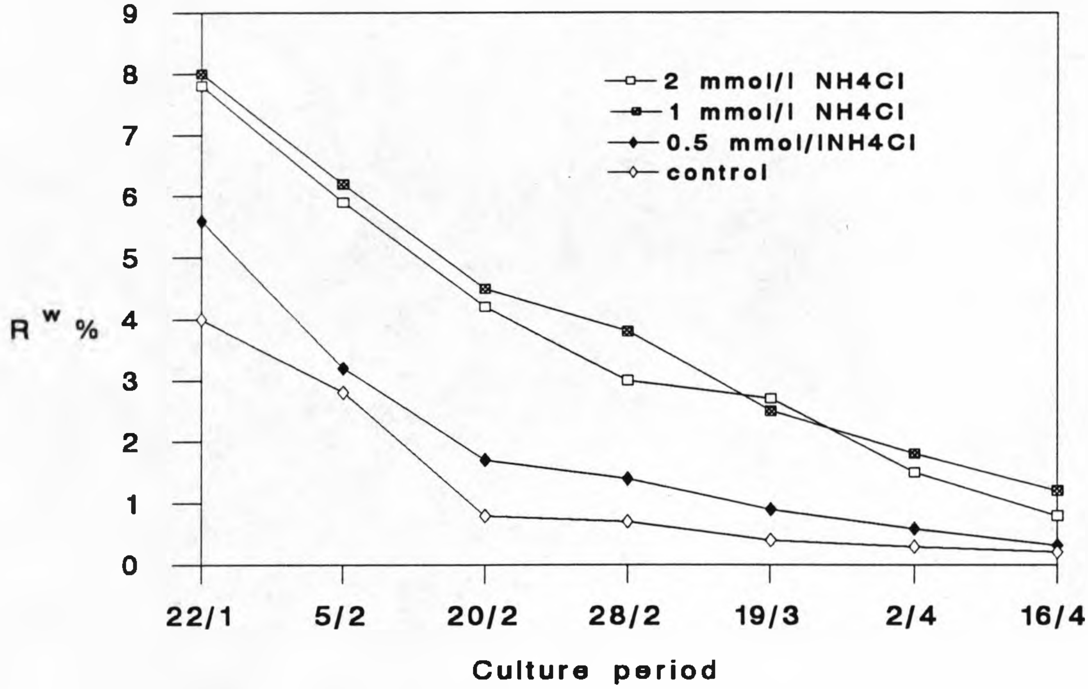

Fig. 2.12 Biweekly mean relative growth rates by weight (RW%) of *Gracilaria* plants cultured with different concentrations of NH4Cl fertilizers at Kalpitiya

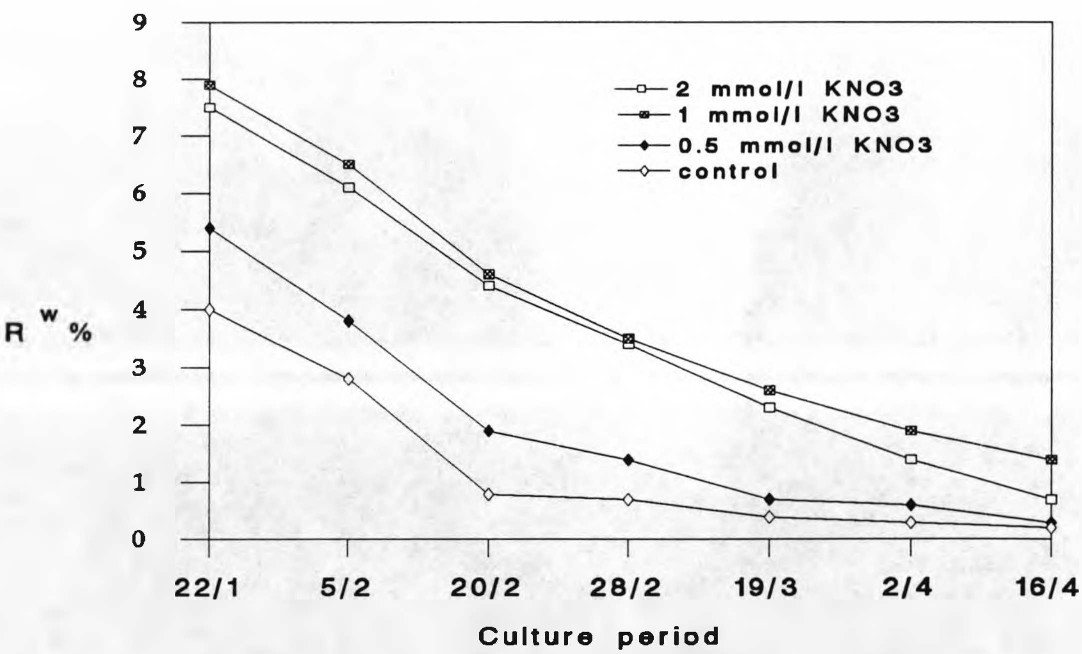

Fig. 2.13 Biweekly mean relative growth rates by weight (Rw%) of *Gracilaria* plants cultured with different concentrations of KNO3 fertilizers at Kalpitiya

FACTORS	R^2	R	DF	p VALUE	SIGNIFICANCE
TOTAL N_2	0.576	0.758	37	p<0.001	*
SALINITY	0.015	0.122	37	0.5>p>0.2	N.S.
TEMP.(S)	0.027	0.164	37	0.5>p<0.2	N.S.
pH	0.001	0.031	37	0.5<p	N.S.
% IRRADIANCE	0.131	0.361	37	.05>p>.02	*

TABLE 2.2 The correlation of the mean environmental factors and the mean relative growth rate of *Gracilaria edulis* at Kalpitiya (R^2 = correlation coefficient; * =significant correlation).

FACTORS	R^2	R	DF	p VALUE	SIGNIFICANCE
TOTAL N_2	0.357	0.597	26	p<0.001	*
SALINITY	0.218	0.466	26	.02>p>.01	*
TEMP. (S)	0.130	0.360	26	.10>p>.05	N.S.
pH	0.010	0.10	26	0.5<p	N.S.
% IRRADIANCE	0.186	0.431	26	.05>p>.02	*

TABLE 2.3 The correlation of the mean environmental factors and the mean relative growth rates of *Gracilaria edulis* at Puwarasankudawa (R^2 = correlation coefficient ; * = significant correlation; N.S. = not significant).

	NH_4Cl 2mmol/l	NH_4Cl 1mmol/l	NH_4Cl 0.5 mmol/l	KNO_3 2mmol/l	KNO_3 1mmol/l	KNO_3 0.5 mmol/l
NH4Cl 1mmol/l	N.S.					
NH4Cl.5 mmol/l	N.S.	*				
KNO3 2mmol/l	N.S.	N.S.	N.S.			
KNO3 1mmol/l	N.S.	N.S.	*	N.S.		
KNO3 0.5mmol/l	N.S.	*	N.S.	N.S.	*	
Control	*	*	N.S.	*	*	N.S.

Table 2.4 Twosample analysis on mean relative growth rates of *Gracilaria edulis* with three concentrations of NH_4Cl and KNO_3 solutions (significance: * = $p \leq 0.05$, N.S = not significant).

2.4 DISCUSSION

2.4.1 Continuous growth experiment

The variation in the mean relative growth rates of *Gracilaria edulis* throughout the year at the two different sites may be due to the change of one or more environmental factors prevailing in the lagoon. The peaks of growth rates occurred during June to August and November to February which coincided with south-west and north-east monsoons respectively (Fig.2.6a & 2.6b). Even though the south-west monsoon does not directly affect this area it may have some indirect impacts which affects the lagoon environment such as fresh water inlets which provide fresh water to the lagoon from the catchment areas. The north-east monsoon directly affects the lagoon area bringing rains from November to February.

The maximum mean relative growth rates in weight of 8.3 % day^{-1} and 7.8 % day^{-1} were obtained in July at Kalpitiya and at Puwarasankudawa respectively. This was higher than the average growth rates achieved for several *Gracilaria* species in the field or outdoor cultivation by different scientists: up to 4.6% day^{-1} for *G. secundata in* New Zealand by Luxton (1981); 5.2% day^{-1} for *G. folifera* near Beaufort, North Carolina by Rosenberg & Ramus (1981); 4.7% day^{-1} for *G. verrucosa* on the west coast of Vancouver, British Columbia by Saunders & Lindsay (1979); 7% day^{-1} for *Gracilaria* sp. in Israel by Friedlander & Zelikovitch, (1984). The maximum relative growth rates obtained for this study were also higher than the growth rates achieved for *G. edulis* (2.2% day^{-1}) by Raju & Thomas in 1971. However, these growth rates were almost equal or a little lower than the growth rate (8-9% day^{-1}) achieved in an outdoor raceway for *G. sjoestedtii* by Hansen

(1984).

The reason for *Gracilaria* plants showing pale yellowish colours inside the cylinders during slow growth periods may be due to a deficiency of nitrates in the lagoon. The growth rates at both sites showed highly significant correlations ($p \leq 0.001$) with the availability of total nitrogen content of the lagoon (Fig.2.7a & 2.7b). During the peak growth rates, the plants showed a reddish brown colour which may be due to the nitrogen storage function of the pigments as suggested by Lapointe (1981). Growth rates are correlated with the two monsoons which directly or indirectly bring nitrates to the lagoon. During the south-west monsoon nutrition can be brought to the lagoon by the two main fresh water inlets (Kala Oya and Mi Oya) which carry water from the catchment areas. Therefore, this would promote the growth rate of the *Gracilaria* in the lagoon during this particular period. The north-east monsoons directly bring rains to this area and subsequently it will increase the levels of the total inorganic nitrogen which would promote the growth rates of *Gracilaria* plants. This coincides well with the high growth rates achieved from three *Gracilaria* species in Manila Bay during the north-east monsoons (Trono and Corrales, 1981). However the growth rates were very low during the south-west monsoons in Manila Bay (Trono and Corrales ,1978) due to the very low salinities.

The total nitrogen content at Kalpitiya showed very low values (less than 0.1 mmol/l) during the months which showed low mean relative growth rates of *Gracilaria* plants. At Puwarasankudawa no growth was shown in September and this is probably due to the unavailability of nitrogen during this month.

A positive relationship between growth and light was shown in field studies of *G. verrucosa* (Whyte *et al.*,1981) and in tank cultures of *G.*

tikvahiae (Lapointe, 1981). The correlation coefficient obtained for the % surface irradiance at Kalpitiya was higher than that obtained for the site at Puwarasankudawa (Table 2.2 & 2.3). A high % surface irradiance was shown during the peak growth rates at both sites (Fig.2.11a Fig.2.11b).

The mean relative growth rates at both sites did not show any correlation with pH values (Fig.2.10a & Fig.2.10b). This may be due to the very low variability of pH in the Puttalam Lagoon. The work done by Trono and Corrales (1981) also shown that the *Gracilaria* biomass in Manila Bay had no relationship with the pH value.

The correlation with the surface temperature at both sites was very low and negative. Even though there was not much fluctuation in the surface temperature within the period, the peak growth rates were not observed during high temperatures such as 30°C-31°C. The highest temperatures (over 30°C) were in the month of April in both sites and the mean relative growth rates were lowest during this month. McLachlan and Bird (1986) pointed out that the *Gracilaria* species from warm water areas show maximum growth, and presumably production, between 25°C and 30°C. They also pointed out that they were unaware of any species with maximum growth at temperatures exceeding 30°C. However the increasing temperatures might be associated with a reduction in the nitrogen content of the water and it would affect the growth rates of the plants. Mann (1982) pointed out that the nitrogen become virtually undetectable during summer months in the North Atlantic waters.

Although a significant negative correlation was shown with the salinity ($0.02 > p < 0.05$) at Puwarasankudawa no significant correlation was shown with salinity at Kalpitiya ($0.5 > p > 0.2$). However *Gracilaria edulis* can be considered as a euryhaline species since it can thrive the salinity levels of 20   to 45 . However high salinities may be associated with low nitrogen in the water. Any correlation of growth with salinity could be indirect.

2.4.2 Continuous growth experiment with fertilizers

The increasing density of plants inside the cages would have affected the mean relative growth rates of the plants. This crowding effect of the plants would have decreased of growth rates in all the cages. However it was shown that all the levels of NH_4Cl and KNO_3 fertilizers had a positive effect on the growth rates of *Gracilaria* plants. The control plants showed a mean relative growth rate of 4% day^{-1} at the beginning which is almost equal to the growth rates of the continuous growth experiment in January (see Fig. 2.6a). The mean relative growth rates of the plants in higher fertilizer levels were two times higher than the control plants (Fig. 2.12 & 2.13). The same phenomenon was illustrated in the pulse feeding experiments on *Gracilaria tikvahiae* plants on the west coast of Florida by Friedlander and Dawes (1985).

If the excess plants were removed from the cages as they were in the continuous growth experiment, the growth rates would have increased in all the plants. However, it was clear from this experiment that the two fertilizers (two nitrogen sources, ammonium and nitrate) did not show any significant differences on growth rates (Table 2.4). This is in agreement with the results obtained by Friedlander and Ben-Amotz (1991) on culturing *Gracilaria conferta*, *Chondrus crispus* (Neish *et al.*, 1977; Bidwell *et al.*, 1985) and *Gracilaria tikvahiae* (Lapointe and Ryther, 1978).

It was also indicated in this study that plants immersed in 1mmol/l concentration of both fertilizers showed higher growth rates than those immersed in the 2 mmol/l (Fig. 2.12 & 2.13). However since there was no significant difference on growth rates between the 1mmol/l and 2mmol/l fertilizers it is likely that, under these conditions, the plants were saturated at 1 mmol/l.

3 CULTURE EXPERIMENTS WITH DIFFERENT FERTILIZERS

3.1 INTRODUCTION

The natural *Gracilaria* population in Puttalam Lagoon distinctly showed a colour change from pale green to dark reddish brown in different seasons of the year and in different places. This was thought likely to be due to the changes of the availability of nitrogen. These colour changes are due to the presence and absence of phycobiliprotein pigments formed by the absorption of nitrogen (Chapman & Craigie, 1977; Hanisak, 1979; Lapointe & Ryther, 1979; Lapointe, 1981). It was also suggested by Parsons *et al.*(1977) that low levels of dissolved inorganic nitrogen are especially common in tropical marine waters.

Nitrogen is the nutrient most frequently reported to limit the growth of seaweeds in natural ecosystems (Hanisak, 1983; Chapman & Craigie, 1977; Lapointe & Ryther, 1979). Since the seaweeds have the capacity (Chapman & Craigie, 1977; Hanisak, 1979) to store mineral nutrients when external supplies are available and then draw upon these reserves when external concentrations are low, nutrient supply to cultures has been successfully provided by the pulse feeding of various concentrations at suitable frequencies (Lapointe, 1985).

Pulse feeding by Friedlander & Dawes (1985) to *Gracilaria tikvahiae* plants resulted in a significant increases in the percent of ash free dry weight, demonstrating a rise in organic matter. The pulse fed plants showed an increase in protein, a decrease in carbohydrate, and a decrease in carbon nitrogen ratio (Friedlander & Dawes, 1985). The higher pigment levels in the nutrient treated plants, suggested the nitrogen storage function of the pigment (Lapointe, 1981).

Therefore the aim of these experiments was to find out the effect on growth patterns of *Gracilaria* cultures by pulse feeding them with ammonium and nitrate fertilizers. This would be important to promote the large scale and small scale *Gracilaria* cultures in the Puttalam Lagoon.

3.2 MATERIALS AND METHODS

3.2.1 Effect of different concentrations of ammonium and the comparison of ammonium and nitrate fertilizers on the growth of *Gracilaria edulis*.

Frames of 40 x 60 cm with a plastic mesh (2 cm) substratum were used for both of these experiments. Three concentrations (2 mmol/l, 1 mmol/l, 0.5 mmol/l) of NH_4Cl in duplicate with 0.15 mmol/l NaH_2PO_4 in each were prepared with lagoon water. These media were prepared separately in the same type of six glass tanks as in the experiments in section 2. Two glass tanks were prepared with lagoon water as a control. This experiment was conducted from 15th August to 30th November 1992.

The comparison of ammonium and nitrate fertilizers on the growth of *Gracilaria edulis* were also monitored by a same type of method from 24th August to 5th December 1992. Three concentrations of KNO_3 (2 mmol/l, 1 mmol/l and 0.5 mmol/l) and 0.15 mmol/l NaH_2PO_4 were used as nitrate and phosphate sources respectively. Three concentrations of NH_4Cl (2 mmol/l, 1 mmol/l, 0.5 mmol/l) and NaH_2PO_4 (0.15 mmol/l) were taken as ammonium and phosphate sources respectively. The seeding material for both experiments was selected from the healthy natural *Gracilaria* stocks. The thalli with fleshy and elastic texture were used to get seeding fragments. Eight and sixteen frames were prepared for the experiment with ammonium fertilizers and the ammonium and nitrate fertilizers respectively. Both experiments were conducted at Kalpitiya and Puwarasankudawa sites during the same period. Sixteen fragments of 5 cm length were tied to each of the frames separately and submerged horizontally in the lagoon at 20 cm depth. Frames were submerged in the above two solutions in duplicate for 24 hours once a week. Weekly length measurements were observed from five plants of each frame for 7 weeks.

The dry biomass of all the plants in different cages were taken at the end of the experiment by drying them in the sun for three days. The sundried weight of *Gracilaria* plants were taken as dry weight, during all the other experiments conducted at Kalpitiya. Table 3.1 gives the weights of the sundried and ovendried samples of *Gracilaria edulis*. Growth rates were calculated by plotting the log lengths of individual plants with weekly intervals (for the first 7 weeks and the latter 7 weeks of the culture period seperately) and fitting the regression lines for each graph (e.g. Fig. 3.1 & 3.2).

3.3 RESULTS

3.3.1 Experiment with different NH_4Cl concentrations

The plants which were in 2 and 1 mmol/l concentrations of NH_4Cl solutions appeared healthier than the plants which were in 0.5 mmol/l NH_4Cl solution and in natural lagoon water. After about one month the plants in the higher concentrations were a dark reddish brown colour (Plates 3.1 & 3.2) while the plants in the lower concentration and the control solution remained the pale greenish colour.

The mean relative growth rate of *Gracilaria* during the first 7

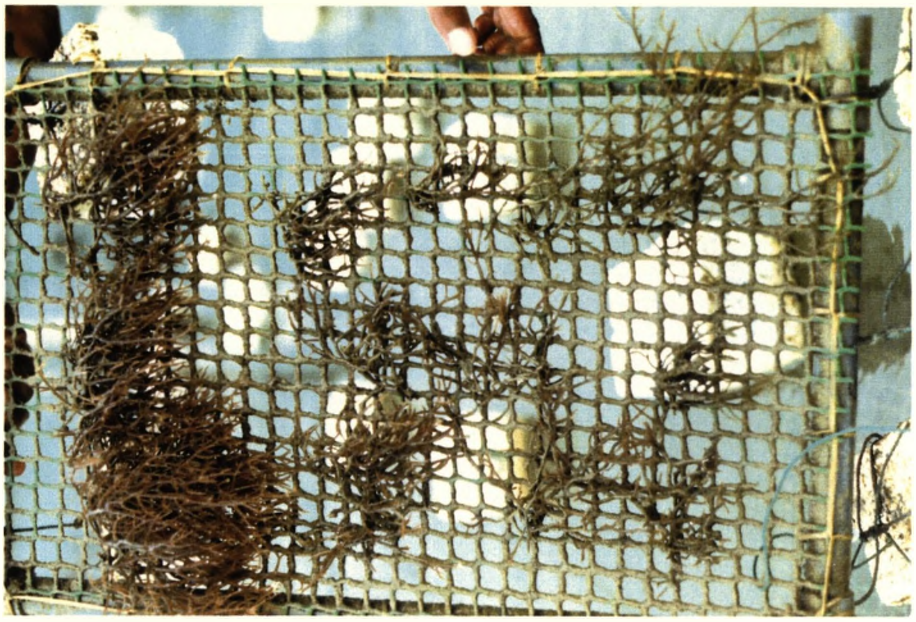

Plate 3.1. Frames in 1 mmol/l KNO_3 solution after one month. (Plants becoming reddish in colour.)

Plate 3.2. Frames in 1 mmol/ KNO_3 solution after two and half months. (Plants appeared reddish brown in colour.)

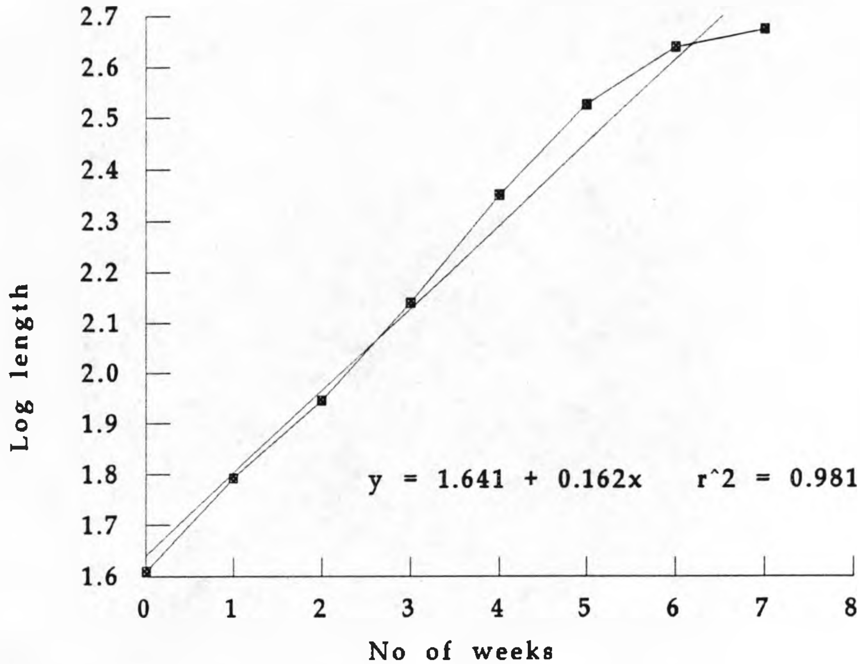

Fig.3.1 Weeky log lengths of the *Gracilaria* plants which were treated with 1 mmol KnO3 solution. The regression equation gives the growth rate and the regression coefficient (r2).

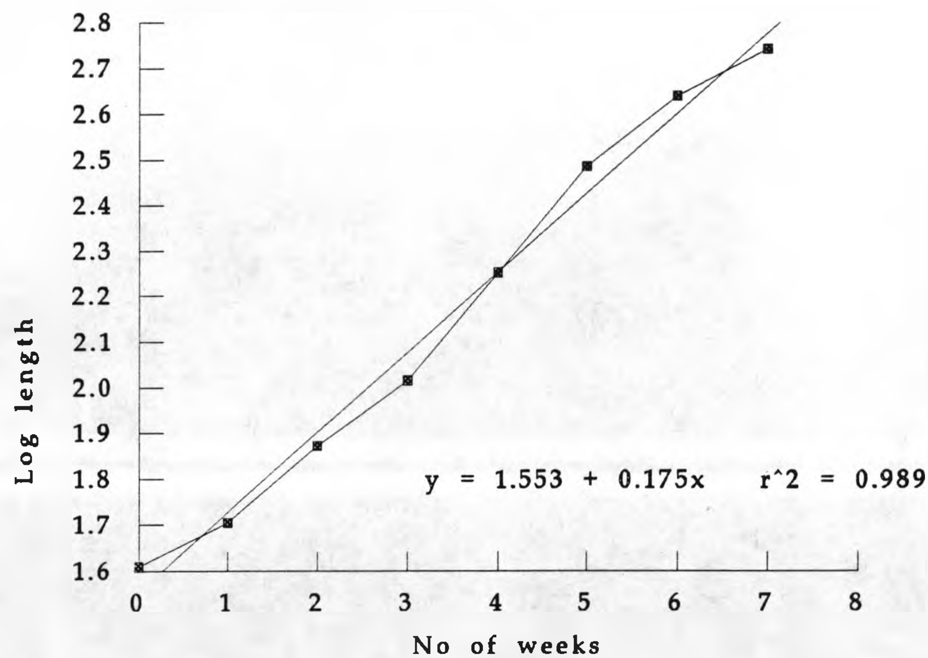

Fig.3.2 Weekly log lengths of *Gracilaria* plants which were treated with 1 mmol NH4Cl solution. Regression equation gives the growth rate and the regression coefficient (r2).

weeks increased with concentrations of NH_4Cl (Fig. 3.3). The effect of NH_4Cl addition was significant ($p < 0.0005$, Table 3.2a) though there was no significant difference between growth rates at individual concentrations. However, according to the Tukey's test there was a significant difference between each added concentration and controls (Table 3.2b).

During the second 7 weeks the mean relative growth rate was considerably lower (Fig. 3.3) but again significantly affected by NH_4Cl addition (Table 3.3a). In this case there was a significant difference between the growth rate at 2 mmol/l and those at 0.5 mmol/l NH_4Cl and in the control (Table 3.3b).

The highest mean wet biomass of 4.96 kg m^{-2} was observed on the frames at 2.0 mmol/l NH_4Cl concentration. It also showed the highest mean dry biomass of 518.7 g m^{-2} (Figure 3.4). The effect of NH_4Cl on dry biomass was highly significant ($p < 0.004$; Table 3.4a). But the highest mean dry biomass achieved at 2 mmol/l was not significantly different from the biomass obtained at 1 mmol/l (Table 3. 4b).

3.3.2 Comparison of ammonium and nitrate fertilizers.

The *Gracilaria* plants in fertilizer tanks showed a healthier growth and appeared a dark reddish colour throughout the culture period compared to the plants in controls. The effect of fertilizer solutions on the growth rate of *Gracilaria* plants during the first 7 weeks was significant ($F = 10.13$; $p < 0.0005$, Table 3.5a). The highest mean relative growth rate was observed with 1 mmol/l KNO_3 (Fig. 3.5). Tukey's pairwise comparisons test showed that this growth rate was significantly different from all the growth rates observed in other concentrations and the

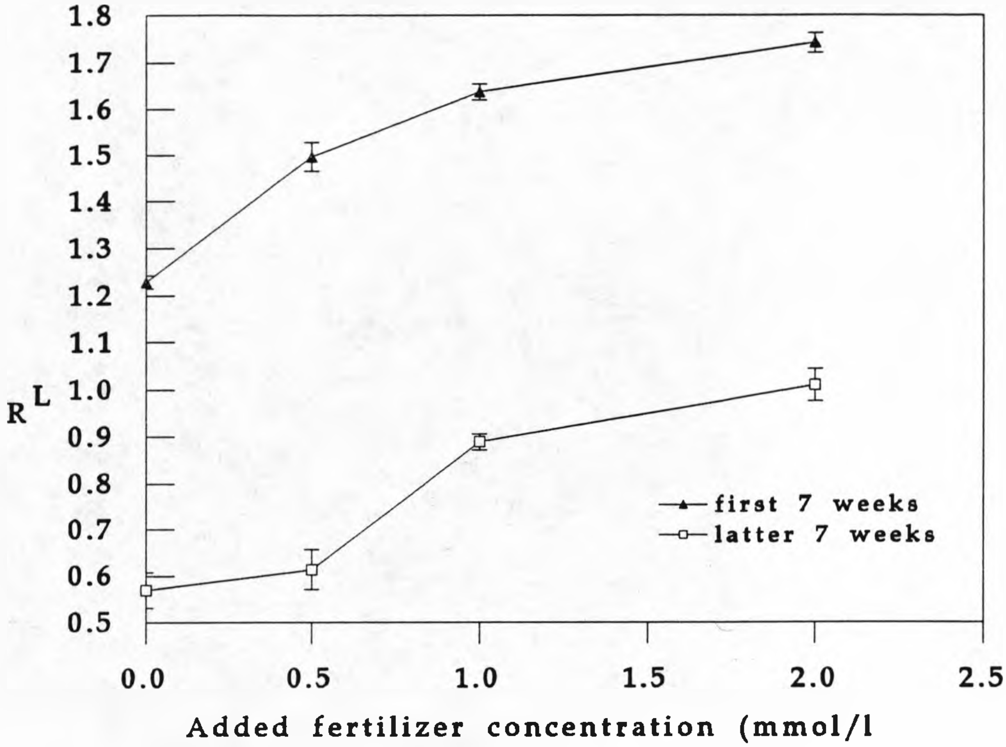

Fig.3.3 Mean relative growth rates in lenghts (R^L % /day) with different NH4Cl concentrations (culture period = 15th Aug. to 30th Nov. 1992, bars= $\pm$ 1S.E.).

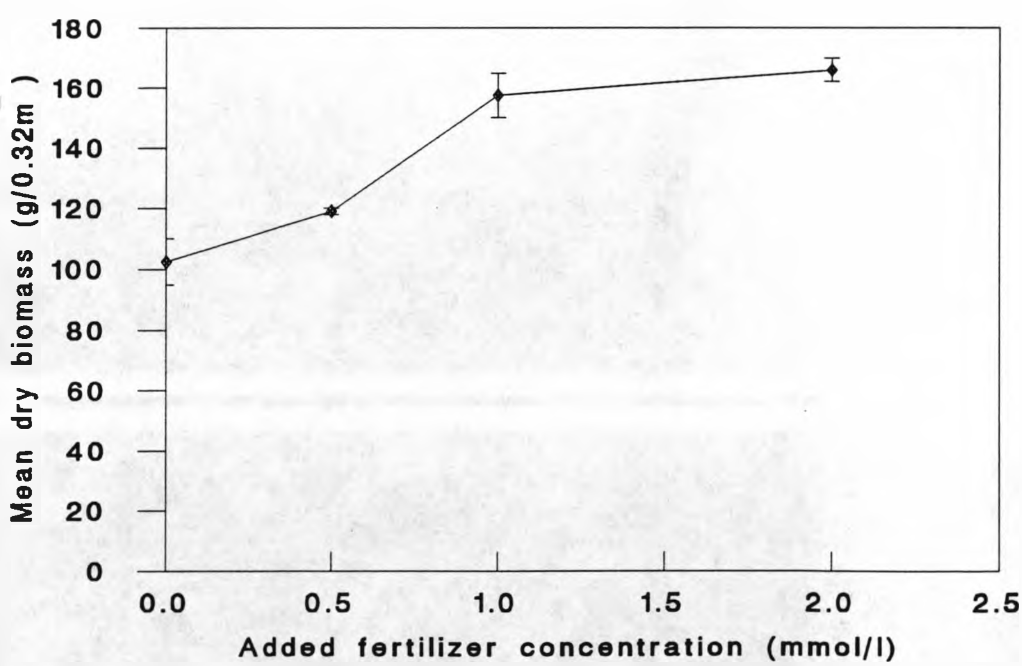

Fig.3.4 Mean dry biomass/frame with different concentrations of NH4Cl from 15th Aug.-30th Nov. 1992 (concentration 0= control, bars= $\pm$1S.E.).

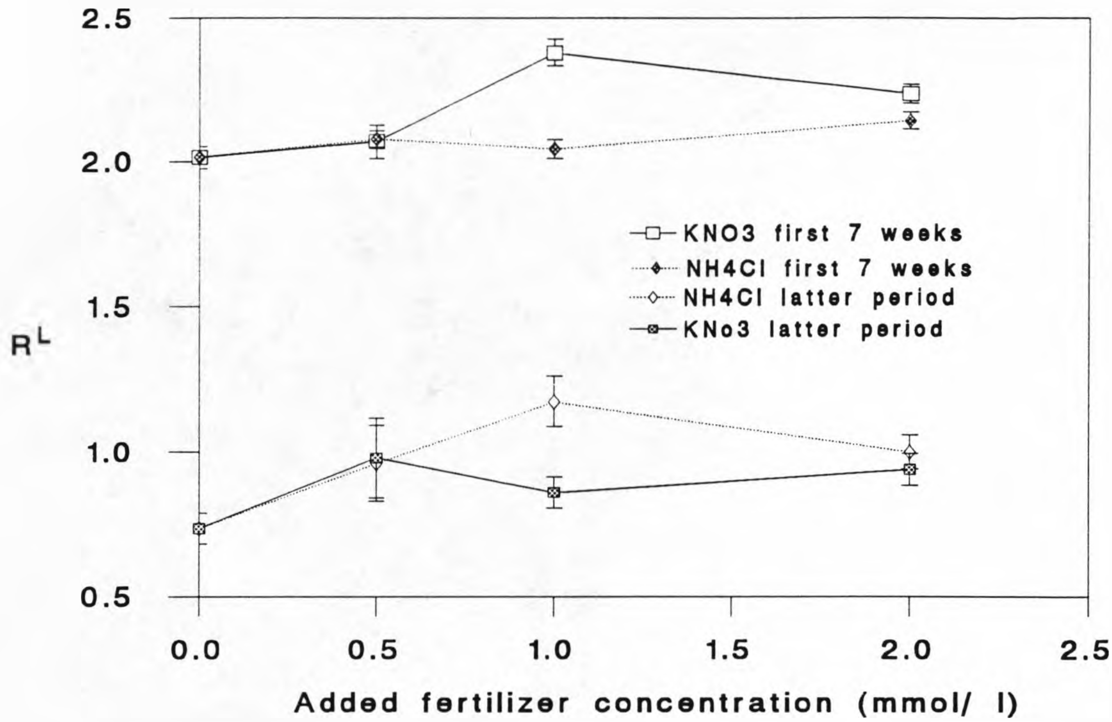

Fig.3.5 Mean relative growth rates in lengths (R^L % /day) at first 7 weeks and at latter 7 weeks (culture period= 24th Aug. to 5th Dec. 1992, bars = $\pm$ S.E.).

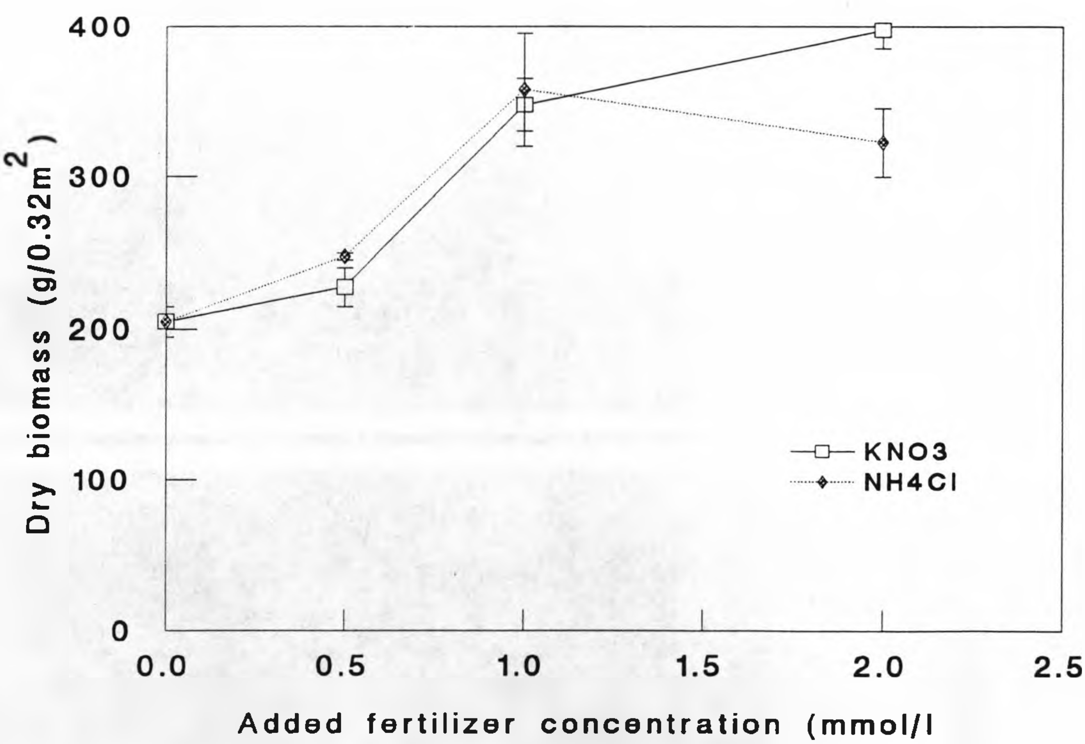

Fig.3.6 Mean dry biomass/frame with different fertilizer concentrations (culture period= 24th Aug.-05th Dec.1992), control= 0 concentration, bars=$\pm$ 1S.E.).

Wet weight (g)	Sun dried weight (g)	Oven dried weight (g)
510	52.5 (10.2%)	52.9 (10.3%)
575	60.1 (10.4%)	56.3 (9.7%)
600	65.2 (10.8%)	60.2 (10.0%)

Table 3.1 The wet and dry weights (with the % dry weights) of three samples of *Gracilaria edulis* from Puttalam Lagoon (oven dried weight was taken by drying them in the oven at 70°C for 24 hrs).

SOURCE	DF	SS	MS	F	p
TREATMENT	3	1.2536	0.4179	11.03	0.0005
ERROR	29	1.0683	0.0379		
TOTAL	32	2.3519			

TABLE 3.2a. One-way analysis of variance on different growth rates with different concentrations of NH4Cl during the first 7 weeks of the culture period.

	NH_4Cl 2mmol/l	NH_4Cl 1mmol/l	NH_4Cl 0.5mmol/l
NH_4Cl 1mmol/l	N.S.		
NH4Cl 0.5mmol/l	N.S.	N.S.	
control	*	*	*

TABLE 3.2b. Tukey's pairwise comparisons test showing the significant differance on the mean relative growth rates during the first 7 weeks (* = significant difference at $p < 0.05$; N.S. = not significant).

SOURCE	DF	S	MS	F	p
TREATMENT	3	1.0326	0.3442	4.71	0.009
ERROR	27	1.9724	0.0731		
TOTAL	30	3.0049			

TABLE 3.3a. One-way analysis of variance on the mean relative growth rates with different NH_4Cl concentrations during the second 7 weeks of the culture period.

	NH_4Cl 2mmol/l	NH_4Cl 1mmol/l	NH_4Cl 0.5mmol/l
NH_4Cl 1mmol/l	N.S.		
NH_4Cl 0.5 mmol/l	*	N.S.	
control	*	N.S.	N.S.

TABLE 3.3b. Tukey's pairwise comparisons test showing the significant difference on the mean relative growth rates during the second 7 weeks of the culture period (* = significant difference at $p < 0.05$); N.S. = not significant).

SOURCE	DF	SS	MS	F	p
TREATMENT	3	5546.5	1848.8	28.55	0.004
ERROR	4	259.0	64.5		
TOTAL	7	5805.5			

TABLE 3.4a. One-way analysis of mean dry biomass with different concentrations of NH_4Cl.

	NH_4Cl 2mmol/l	NH_4Cl 1mmol/l	NH_4Cl 0.5 mmol/l
NH_4Cl 1mmol/l	N.S.		
NH_4Cl 0.5mmol/	*	*	
control	*	*	N.S.

TABLE 3.4b. Tukey's pairwise comparisons test showing the significant difference on the mean dry biomass with different NH_4Cl concentrations (* = significant differance at $p < 0.05$); N.S. = not signifiant).

SOURCE	DF	SS	MS	F	p
TREATMENT	6	0.8689	0.1448	10.1 3	0.0005
ERROR	51	0.7279	0.0143		
TOTAL	57	1.5977			

TABLE 3.5a. One-way analysis of variance on the mean relative growth rates with different nitrate and ammonium fertilizers during the first 7 weeks of the culture period.

	KNO_3 2mmol/l	KNO_3 1mmol/l	KNO_3 .5mmol/l	NH_4Cl 2mmol/l	NH_4Cl 1mmol/l	NH_4Cl .5mmol/l
KNO_3 1mmol/l	N.S.					
KNO_3 0.5mmol/l	N.S.	*				
NH_4Cl 2mmol/l	N.S.	*	N.S.			
NH_4Cl 1mmol/l	N.S.	*	N.S.	N.S.		
NH_4Cl 0.5mmol/l	N.S.	*	N.S.	N.S.	N.S.	
control	*	*	N.S.	N.S.	N.S.	N.S.

TABLE 3.5b. Tukey's pairwise comparisons test showing the significant level with each treatment (* = significant difference at $p < 0.05$; N.S. = not significant).

SOURCE	DF	SS	MS	F	p
TREATMENT	6	65218	10870	14.42	0.001
ERROR	7	5275	754		
TOTAL	13	70493			

TABLE 3.6a. One-way analysis of variance on the mean dry biomass with different nitrate and ammonium fertilizers.

	KNO_3 2mmol/l	KNO_3 1mmol/l	KNO_3 0.5mmol/l	NH_4Cl 2mmol/l	NH_4Cl 1mmol/l	NH_4Cl 0.5mmol/l
KNO_3 1mmol/l	N.S.					
KNO_3 0.5mmol/l	*	*				
NH_4Cl 2mmol/l	N.S.	N.S.	N.S.			
NH_4CL 1mmol/l	N.S.	N.S.	N.S.	N.S.		
NH4Cl 0.5mmol/l	*	N.S.	N.S.	N.S.	*	
control	*	*	N.S.	*	*	N.S.

TABLE 3.6b. Tukey's pairwise comparisons test showing the significant difference of the mean dry biomass with different fertilizer concentrations (* = significant difference at $p < 0.05$); N.S. = not significant).

controls except that at 2 mmol/l KNO_3 (Table 3.5b). Although the growth rates obtained for the latter part of the growing period were lower than those in the first 7 weeks, 1 mmol/l NH_4Cl solution supported the highest mean relative growth rate during this period. No fouling problems were observed on the frames of any of the nutrient experiments.

The highest mean dry biomass (1.24 kg m^{-2}) was observed from the plants which were in 2.0 mmol/l KNO_3 solution (Fig. 3.6). The overall effect on the mean dry biomass with ammonium and nitrate concentrations was significant ($F = 14.42$; $p < 0.001$, Table 3.6a). However the Tukey's test showed that the mean dry biomass obtained for 1 mmol/l concentrations of both ammonium and nitrates were not significantly different from the same obtained for 2 mmol/l concentrations (Table 3.6b). It also showed that the dry biomass on 1 and 2 mmol/l concentrations were significantly different from the biomass obtained for 0.5 mmol/l and controls.

3.4 DISCUSSION

The colour change of the *Gracilaria* plants in both experiments, into a dark reddish colour in the higher concentrations of NH_4Cl and KNO_3 solutions may be due to the formation of nitrogen storage pools which includes light harvesting phycobiliprotein pigments (Grantt, 1981; Lapointe, 1981). The continued pale colours of the plants at the concentration of 0.5 mmol/l and the control suggested possible nitrogen deficiency in the lagoon.

The significant increase of the mean relative growth rates with the addition of NH_4Cl showed that the growth rates were enhanced by the absorption of nitrogen from the NH_4Cl solutions. This same phenomenon was supported by the culture studies done on *Gracilaria* species by several other scientists (DeBoer, 1979; Lapointe and Ryther, 1979; Ryther *et al.*, 1979; Parker, 1982; Nelson *et al.*, 1980; Fujita and Goldman, 1985; Friedlander *et al.*, 1991). DeBoer *et al.*(1978) reported a specific growth rate of over 12 % was obtained for *G. folifera* with an enriched medium with ammonia. He also reported that a specific growth rate of only 3.5 % was obtained for the same species in unenriched seawater.

DeBoer (1979) stated that the inorganic nitrogen content of the seawater, which varies seasonally, appears to be a major factor influencing the phycocolloid content and growth rate of natural seaweed populations. D'Elia and DeBoer (1978) suggested that enhanced uptake of nitrogen only occurs if the thallus is nitrogen starved. The control plants showed lower growth rates compared to the plants with nutrients. Therefore it was clear that there may be a nitrogen deficiency in the Puttalam Lagoon. Since there was no significant difference between the growth rates in 2mmol/l and 1mmol/l concentrations during the second half of the culture period the saturation point for optimum growth rate may be found at around 1 mmol/l concentrations (Fig.3.3). The work carried out by Friedlander *et al.*(1991) by pulse feeding found that the maximum growth rate of *Gracilaria conferta* was supported by 0.5 mmol/l ammonium solution.

In the second experiment the mean relative growth rates showing a significant effect with both fertilizers indicated that the addition of inorganic nitrogen would influence the growth of these plants. This shows that there was no significant difference between nitrate and ammonium fertilizers. Several studies have been done on uptake of ammonium and nitrate by different *Gracilaria* species (Lapointe and Ryther, 1979; Bird *et al.*,1981; Bird *et al.*,1982; Ryther *et al.*,1982; Lapointe, 1985; Thomas *et al.*,1987).

Obtaining the significantly highest mean relative growth rate in the 1.0 mmol/l KNO_3 solution during the first 7 weeks showed that 1.0 mmol/l nitrate solution may be optimal for the maximum growth of these plants (Fig. 3.5). Simultaneous uptake of ammonium and nitrate has also been observed in field grown *Laminaria longicruris* (Harlin & Craigie, 1978). The low intertidal *Gracilaria pacifica* with a higher carbon/nitrogen ratio (suggesting greater nitrogen limitation) than the high intertidal *G.pacifica* showed a higher affinity for nitrate (Thomas *et al.*,1987). It appeared that a certain degree of nitrogen deficiency prevented the inhibition of nitrate uptake by ammonium. It is energetically favourable for the plant to utilize ammonium rather than nitrate (Syrett, 1962); under nitrogen limitation, however the immediate requirement for nitrogen may outweigh this advantage and when maximum rates of nitrate and ammonium uptakes are maintained simultaneously, a plant can acquire a greater amount of nitrogen per unit time (Thomas *et al.*,1987). Ryther *et al.*(1982) have shown that *Gracilaria tikvahiae* can maintain maximum growth rates if only exposed to nitrogen-enriched seawater for 6 h every week.

The higher growth rate observed in the plants at 1 mmol/l fertilizer concentrations during the second half of the study may be due to the storage of nitrogen in the pigments of the *Gracilaria* plants. This phenomenon was also shown by Ryther *et al.*(1979) in experiments on ammonium uptake with *Gracilaria tikvahiae* at Woods Hole. It was also found that the pulse feeding of nitrogen one to 24 h per week (1 mmol/l ammonium) to cultures of *G. tikvahiae* doubled the nitrogen content, increased growth rate, decreased epiphytic contamination and was as efficient when applied in the light or dark (Ryther *et al.*,1982; Bird *et al.*,1982). It was also suggested by Edelstein *et al.*(1976); Lapointe & Ryther(1978) and Bidwell *et al.*(1985) that the development of epiphytes can be limited by a pulse feeding regime. The lack of epiphytes on the frames of these nutrient fed experiments may also be explained due to the same manner.

Both experiments proved that there was a significant increase of dry biomass with nutrient fed plants. This is supported by the statements given by Dawes *et al.* (1974), DeBoer *et al.* (1978) and Neish & Shacklock (1971) that the supply of inorganic nitrogen in the seawater may have a significant effect on both the phycocolloid content and the biomass production of macroscopic red algae. Friedlander and Dawes (1985) pointed out that the pulse fed plants showed an increase in protein, a decrease in carbohydrate and a decrease in the carbon/nitrogen ratio. DeBoer (1979) pointed out that the nitrogen concentration range for maximum biomass production and for the highest phycocolloid content coincide. According to him the optimum range of 0.4-1.5 μmol concentration of inorganic nitrogen should be maintained for intensive seaweed mariculture systems with fertilizers to obtain a maximum phycocolloid production. Although ammonium can be stored the present study confirms the both additions of nitrate and ammonium were equally effective for the growth and production of *Gracilaria edulis*.

Both experiments showed that there was a insignificant difference in mean dry biomass of the plants in 1 mmol/l and 2 mmol/l ammonium and nitrate solutions (Table 3.6a & 3.6b). This showed that the optimum level of nitrogen concentration could be 1 mmol/l for the growth of *Gracilaria edulis* plants.

4 EXPERIMENTS ON ALTERNATIVE SUBSTRATA AND OPTIMUM DEPTH

4.1 INTRODUCTION

Culture of *Gracilaria* by using vegetative fragments was first started on the Atlantic coast of the United States (Kim & Humm, 1965). Determining the optimum substratum and depth for the growth of *Gracilaria* plants would be very important before commencing a proper culture system. For successful cultivation of *Gracilaria*, the substratum for growing the algae should be readily available, easily manipulated, should permit easy attachment of the plant and should be able to be recovered easily at the time of harvesting (Raju & Thomas, 1971).

It was observed that most of the areas of the Puttalam Lagoon seem to be turbid and this may be due to the vast areas of muddy substratum (Perera & Siriwardena, 1982). Therefore, the consideration of percentage surface irradiance is equally important in culturing seaweed especially in Puttalam Lagoon. One should know the depth where the plants obtain the optimum irradiance for growth. Experimental culture trails of the above aspects are necessary before commencing the small scale farming systems.

4.2 MATERIALS AND METHODS

4.2.1 Experiment on alternative substrata

PVC pipes of 2 cm in diameter were used to make one square meter rectangular frames. Sixteen of these frames were prepared for this experiment. Four different substrata, coir rope, coir net, plastic net and nylon rope were fixed to these open frames in duplicate and they were transferred to the site at Kalpitiya. The other eight frames on which were fixed the same substrata in duplicate were transferred to the site at Puwarasankudawa.

Healthy *Gracilaria* plants were collected and they were cut into 5 cm pieces. It was taken in to consideration that each fragment had a apical portion of the thallus. Fifty fragments were tied at equal distances to each of these substrata. This was done near the lagoon bank and the frames were dipped in the water while the plantlets were being tied on to the substrata. The fragments were weighed separately before fixing them to the frame. Each frame was fixed to remain in the lagoon at 10 cm depth by tying styrofoam cubes at all four sides of the frame and hanging equal size four cement block weights at the bottom. Several preliminary experiments done with different depths showed that upper depth levels promoted better growth than the bottom levels. Therefore the depth level of 10 cm was chosen for this experiment. The growth of the plants were monitored by measuring the length of ten plants in each frame fortnightly. Growth rate was measured by plotting the log lengths of individual plants with time. Regression lines were fitted to each graph and the slopes were taken as growth rates. The final weight of the plants was taken by harvesting the respective frames separately after three months.

4.2.2 Optimum depth for the culture of *Gracilaria* plants

The same type of one square meter frames which were used in the above substratum experiment were used in duplicate for this experiment also at the site of Kalpitiya. Since the frames made out of plastic net showed the maximum growth in the previous experiment it was used as the substratum for this experiment. Frames were used in duplicate at five different depths 10, 20, 40, 60 and 80 cm from the surface of the water. Styrofoam floats and weights were used to immerse the frames at the appropriate depths. Each frame bore of 50, 5 cm *Gracilaria* fragments. The growth of the plants were monitored by measuring the length of ten plants in each frame fortnightly. The initial and the final total weight of the fragments were measured as in the previous experiment.

4.3 RESULTS

4.3.1 Experiment on alternative substrata

The plants grown on plastic net appeared healthier and more luxuriant than the others (Plate 4.1). The plants on the coir rope grew well at the beginning and later they started breaking off due to lack of support. The coir net seemed to get stretched and it sagged due to the absorption of water; it was also observed that there was heavy silting on the coir net which may have prevented the growth of the plants. The plants on the nylon rope did grow well at the beginning, however the plants started breaking off during the later period. The plastic net seemed to support the plants when they were large better than the other substrata.

The highest mean relative growth rate was observed for the plants on coir rope and the lowest was observed for nylon rope (Fig. 4.1). A highly significant difference ($F = 32.41$; $p < 0.0005$) was shown for mean relative growth rates with different substrata (Table 4.1a). However Tukey's comparison showed that there was no significant difference between the growth rate of coir rope and the plastic net (Table 4.1b).

Plate 4.1. *Gracilaria edulis* plants grown on plastic net substratum at Kalpitiya. (after three months of culture period.)

Plate 4.2. *Gracilaria* plants grown for three months at 10 cm depth. (Tips of the plants shown pale in colour.)

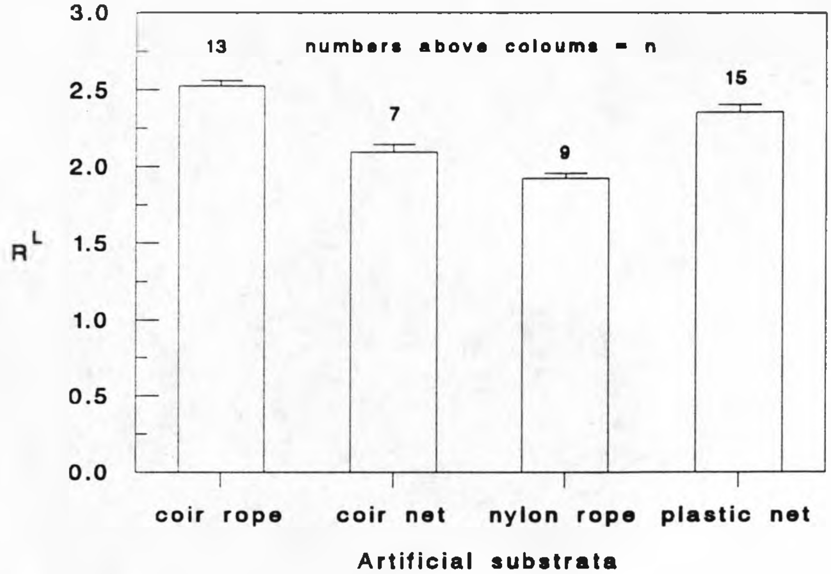

Fig.4.1 Mean relative growth rates in length (R^L % day-1) with different substrata (culture period = 23rd April to 30th July 1992, bars=±1 S.E.).

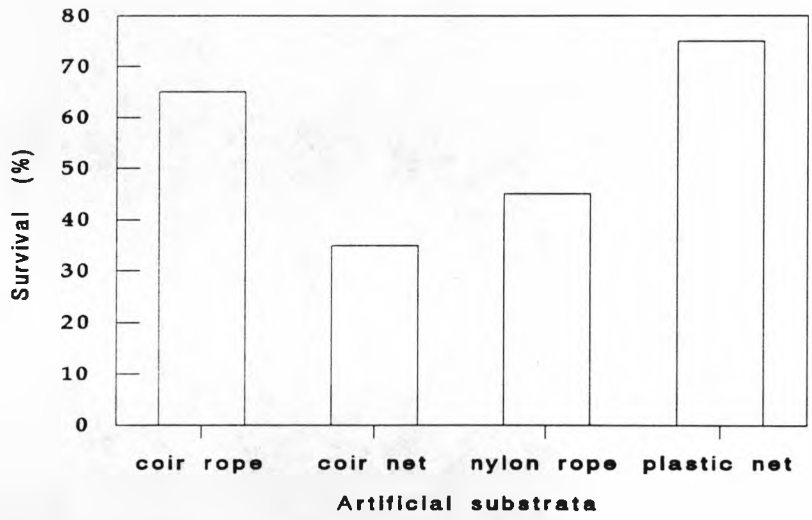

Fig.4.2 Percentage survival of plants with different substrata

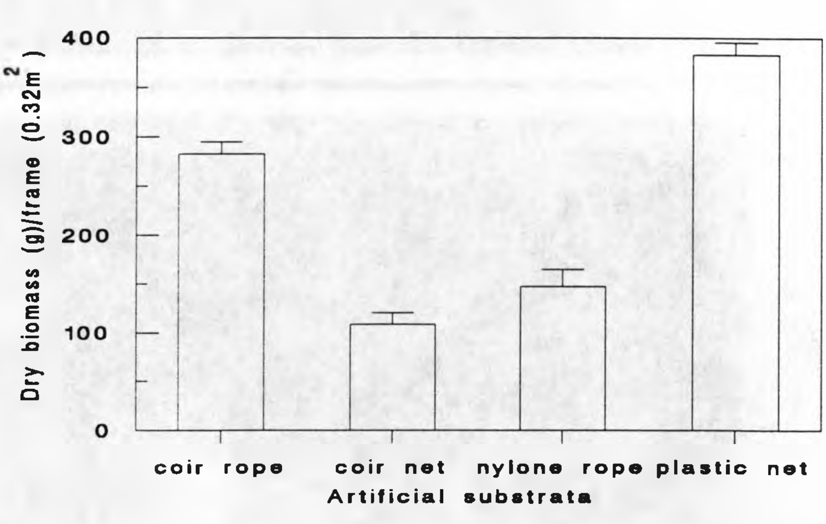

Fig.4.3 Mean dry weight of harvested biomass /frame (0.32m2) in different substrata (bars = ± 1S.E.).

SOURCE	DF	SS	MS	F	p
SUBSTRATA	3	2.2736	0.7579	32.41	0.0005
ERROR	40	0.9354	0.0234		
TOTAL	43	3.2091			

TABLE 4.1a. One-way analysis of variance on mean relative growth rates with different substrata.

		coir net	nylon rope
coir net	*		
nylon rope	*	N.S.	
nylon net	*	*	*

TABLE 4.1b. Tukey's pairwise comparisons test showing the significant difference on growth rates with different substrata (* = significant difference at $p < 0.05$; N.S. = not significant).

SOURCE	DF	SS	MS	F	p
SUBSTRATA	3	94918	31639	85.54	0.0005
ERROR	4	1480	370		
TOTAL	7	96398			

TABLE 4.2a. One-way analysis of variance on mean dry biomass with different substra.

	coir rope	coir net	nylon rope
Coir net	*		
Nylon rope	*	N.S.	
Nylon net	*	*	*

TABLE 4.2b. Tukey's pairwise comparisons test showing the significant difference on mean dry biomass obtained in different substrata (* = significant difference at $p = 0.05$; N.S. = not significant).

The highest survival rate (75 %) was observed on the plastic net substratum whereas the lowest was observed on coir net frames (Fig 4.2).

There was a highly significant difference ($F = 77.58$; $p < 0.0005$) between the mean dry biomass on different substrata (Fig.4.5, Table 4.2a). The highest mean fresh biomass of 3.65 kg was observed on plastic net. The mean dry biomass observed for plastic net was significantly different from all the other substrata (Table 4.2b).

4.3.2 Experiment on the optimum depth

The plants at the 10 cm depth showed the maximum mean relative growth rate in length of 2.39 %/day (Fig. 4.4) and the plants looked very fleshy and healthy at the early stages. However, at the later stages when the plants became larger they were seen emergent from the water and some parts of the thalli looked pale in colour (Plate 4.2). The plants at 20 cm showed a healthy and steady growth throughout the culture period. The plants at 40 cm and 60 cm showed a stunted growth with pale colours and later they started decaying.

Although there was a significant difference between the mean relative growth rates at different depths ($F = 140.80$; $p < 0.0005$, Table 4.3a) the Tukey's comparisons showed that the mean relative growth rates of the plants at 10 cm depth was not significantly different from the plants at 20 cm (Table 4.3b). Although there was a sharp decrease of the survival rates with the increasing depth, the plants at 10 cm and 20 cm did not show a large difference (Fig. 4.5).

Mean fresh biomasses of 3.95 kg and 3.60 kg were observed for the plants at 10 cm and 20 cm respectively (Fig. 4.6). No plants were visible on the frames at 60 cm depth at the end of the culture period.

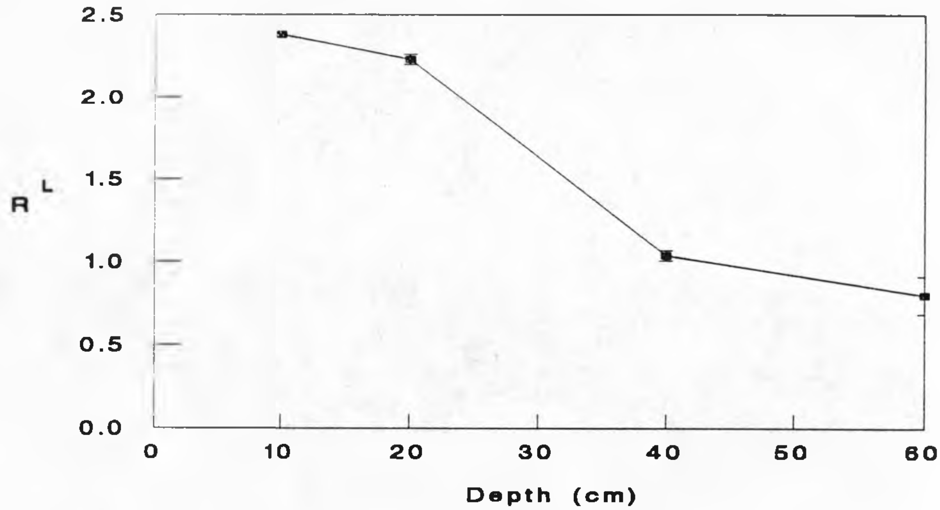

Fig.4.4 Mean relative growth rates in length (R^L % /day) with differnt depths (culture period = 24th April-31st July 1992, bars=± 1S.E.).

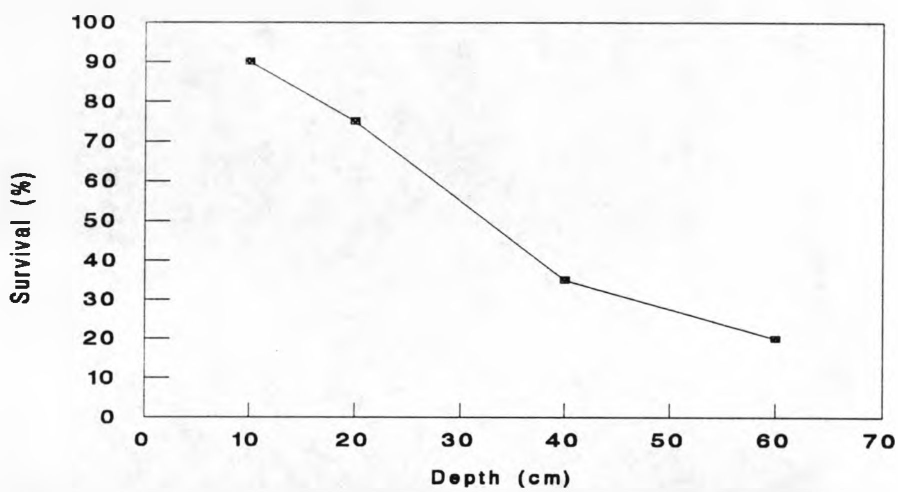

Fig.4.5 Percentage survival of the plants at different depths.

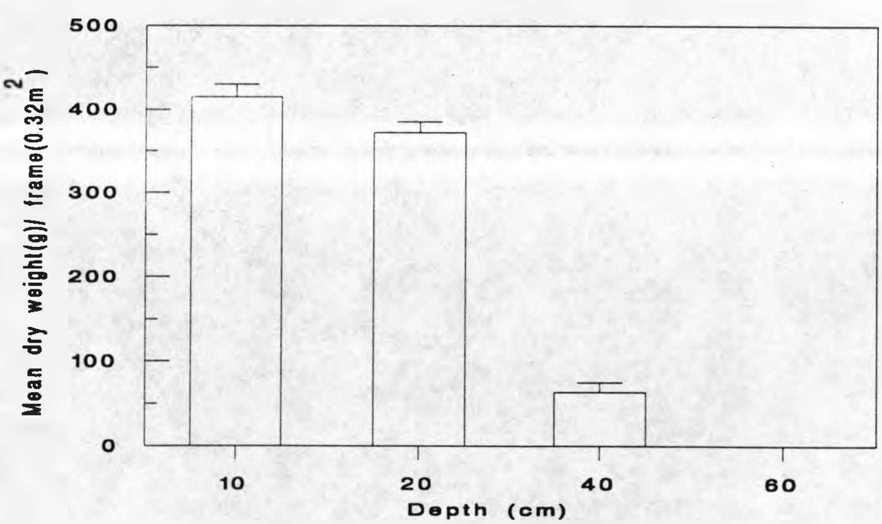

Fig.4.6 Mean dry weight of the harvested biomass/frame (0.32m2) at different depths (bars = ± 1S.E.).

SOURCE	DF	SS	MS	F	p
DEPTH	3	15.5867	5.1956	140.80	0.0005
ERROR	40	1.4760	0.0369		
TOTAL	43	17.0626			

TABLE 4.3a. One-way analysis of variance on mean relative growth rates of *Gracilaria edulis* at different depth levels.

	10 cm	20 cm	40 cm
20 cm	N.S.		
40 cm	*	*	
60 cm	*	*	N.S.

TABLE 4.3b. Tukey's pairwise comparisons test showing the significant difference on growth rates at different depths (* =significant difference at $p < 0.05$; N.S. = not significant).

SOURCE	DF	SS	MS	F	p
DEPTH	3	267927	89309	347.84	0.0005
ERROR	4	1027	257		
TOTAL	7	268954			

TABLE 4.4a. One-way analysis of variance on mean dry biomass at different depth levels.

	10 cm	20 cm	40 cm
20 cm	N.S.		
40 cm	*	*	
60 cm	*	*	N.S.

TABLE 4.4b. Tukey's pair wise comparisons test showing significant difference on dry biomass with different depth levels (* = significant difference at p = 0.05; N.S. = not significant).

Table 4.4a shows a highly significant difference ($F = 347.84$; $p < 0.0005$) between the dry biomass obtained at different depth levels. Although the highest mean dry biomass was observed on the frames at 10 cm, the Tukey's test shows it was not significantly different from the dry biomass achieved at 20 cm depth (Table 4.4b).

4.4 DISCUSSION

4.4.1 Experiment on alternative substrata

Various artificial substrata such as sisal rope, nylon cable, polyethylene rope, coir rope, plastic mesh fruit sacks, fixed and floating rafts have been used in order to culture vegetative cuttings of *Gracilaria* in field conditions by several scientists throughout the world (Friedlander & Lipkin, 1982; Li Ren *et al.*,1984; Smith *et al.*,1984; Camara-Neto, 1987; Hurtado-Ponce, 1990). Several culture studies have been done on *Gracilaria edulis* in Indian waters by using coir rope and coir nets as substrata (Raju & Thomas, 1971; Umamaheswara Rao, 1974; Krishnamurthy *et al.*,1975; Chennubhotla *et al.*,1978; Silas *et al.*,1986; Chennubhotla *et al.*,1986). In the present study the plants grown on coir rope achieved the highest mean relative growth rate by length (2.53 % day^{-1}) compared with the other material. The growth rate in length achieved with coir rope in this study was higher than the growth rate achieved in weight by Raju & Thomas (1971) for *Gracilaria edulis* grown on coir ropes (2.2%/ day^{-1}) in the eastern side of Krusadai Island, India. When increase in length is taken, this value would become much lower. A mean relative growth rate in length of 3.1% day^{-1} was obtained for *Gracilaria edulis* grown on coir ropes in Mandaitive island near Jaffna peninsula in Sri Lanka (Sivapalan & Theivendirarajah, 1985). This is also higher than the growth rates achieved on coir ropes or the other substrata used during this study. However the fresh biomass achieved on coir net in this study (1.025 kg m^{-2}) was lower than that achieved (4.4 kg m^{-2}) for *G. edulis* with the coir net frames in the near shore areas around Mandapam (Umamaheswara Rao, 1974). The growth rate achieved for nylon rope substratum (lowest mean relative growth rate in length of 1.92% day^{-1}) may be lower than the specific percent development (by weight) per day ($SPD.d^{-1}$ = 7%) achieved for *Gracilaria verrucosa* grown on polyethylene rope in Buzius beach in Brazil (Camara-Neto, 1987). If the growth rate was measured by weight it would be two to three times higher than the rate in length.

However, the growth rates of *Gracilaria* plants in the Puttalam Lagoon change with the season of the year. This experiment was conducted from April to June 1992. The highest RGR in weight (8.3 % day^{-1}; Fig.2.1a) was observed during June to early August in Puttalam Lagoon (see Section 2).

In the present study the highest dry biomass achieved on plastic net substrata (0.382 kg m^{-2}) was higher than the same that achieved (0.079 kg m^{-2}) for the same species in the Puttalam Lagoon on coir ropes (Sivapalan, 1975). The plastic net substrata showed significantly higher mean dry biomass than on all the other substrata and the highest survival rate (75%). The lowest dry biomass achieved on coir net was not significantly different from the dry biomass achieved on nylon rope (Table 4.2b).

Although the coir rope showed the highest growth rate it showed a lower survival rate (65%) than the plastic net. A good substratum should be a material which can hold the fragment until its final stages of the growth period. The plastic net seemed to support the plants when they are large, better than coir rope. Therefore, the plastic net substratum might be used in commercial culture practices. The fully grown seaweeds on coir ropes tend to break off easily due to lack of support. The existence of the plants on the coir net was heavily affected by the sagging condition of the substratum. Most of the plants get covered due to silt deposits on the coir nets. Although the plastic net showed the highest biomass in this study the coir rope showed the highest growth rate. As a substratum coir rope is cheaper than the plastic net and it is also commonly available in Sri Lanka. Although coir rope has a little lower survival rate than plastic net, coir rope can be used in small scale culture practices which can be organised among fisherman in the Puttalam area as an additional income to enhance their living standards.

4.4.2 Experiment on the optimum depth

There is little evidence that *Gracilaria* growing in the sea, from clear oceanic waters to extremely turbid estuaries and bays is sensitive to high levels of radiation (McLachlan & Bird, 1986). Generally, the best growth occurs at or near the surface of the water at an irradiance of nearly full sunlight, and production usually declines with increasing depth (McLachlan & Bird, 1986). Therefore, the *Gracilaria* plants which were close to the surface (10 cm) during this study showed the maximum mean relative growth rate (2.39 % day^{-1}). Kim *et al.*(1969) in Kim (1970) showed that the growth rate of *Gracilaria* is higher in shallow waters than in deep waters. However, the mean relative growth rate of the plants at 20 cm (2.24 % day^{-1}) was not significantly different from the plants at the 10 cm depth (Table 4.3b). Therefore, plants at 20 cm may have achieved the saturation point of the % surface irradiance. The plants at both levels showed a healthy growth due to the high % irradiance compared to the plants at 40 and 60 cm. Largo *et al.*(1989) showed that higher growth rates were achieved with *Gracilaria verrucosa* and *G. salicornia* cultured at 30 cm than at 1 meter depth in Cebu Province in Manila. Rueness *et al.*(1987) during field studies on *G. verrucosa* in Oslofjord, Norway, found that the thalli grew best above three meters depth while below three meters light was limiting. In the present study, however, at the later stages parts of the thalli at 10 cm depth seem to be emergent from the water and finally those parts started bleaching. Even though the survival rates of the plants showed a sharp decrease with the increasing depth the plants at 10 and 20 cm did not show a great difference. The plants at 40 and 60 cm depth showed very low growth rates and plants at these depths showed very pale colouration. This is likely to be due to the high turbidity and the poor light penetration in the lagoon.

Since there was no significant difference between the biomass at 10 and 20 cm it may be practical to choose the 20 cm level for commercial culture. Plants at 10 cm would be too shallow since they would protrude from the water at the later stages.

The plants at 60 cm started deteriorating after a few weeks and at the end of the culture period there was no biomass to be harvested. This may be due to the very low light intensities at this depth. Therefore it is clear that the depth of 20 cm in this lagoon would be ideal for the culture of *Gracilaria* plants.

5. EXPERIMENTS ON OPTIMUM DENSITY OF *GRACILARIA EDULIS*

5. 1 INTRODUCTION

The growth rate of *Gracilaria* decreases with increasing density of the culture (Ryther *et al.*,1978). The growth rate and its relationship to culture density are also influenced by other factors, of which incident solar radiation is probably the most important (Ryther *et al.*, 1978). They also explained that at low densities, the seaweeds are unable to utilize all the incident radiation, while at high densities, self shading of the plants decreases growth.

The main aim of this experiment was to identify an optimum density to culture *Gracilaria* in the Puttalam Lagoon for small scale as well as commercial scale cultivation. Farming *Gracilaria* by vegetative propagation seems to be profitable in Sri Lanka because of the low cost of labour. The fishing communities around the Puttalam Lagoon could be engaged in small scale seaweed farming for an additional income. Therefore, a knowledge about optimum density would be essential before commencing these culture practices.

5.2 MATERIALS AND METHODS

The experiment was done at two sites of the lagoon, at Kalpitiya and at Puwarasankudawa from 5th June to 12th September 1992. PVC frames of 80 cm x 40 cm with a substratum of plastic net (Plate 5.1) were used for this experiment in both places.

Healthy stocks of *Gracilaria* were selected from adjoining natural grounds as the seeding material as in the above experiments. Four different numbers of 5 cm fragments (8, 16, 32, 64) were fixed to each frame in duplicate at both sites. All the frames were arranged to float horizontally at a depth of 20 cm. These frames were fixed randomly inside the pilot farm at both sites. Length measurements were taken weekly from ten fragments of each frame. The mean relative growth rates in length were calculated in each individual plants in the same way as in section 3. The wet and dry weight of the harvest from each frame was measured after three months.

5.3 RESULTS

5.3.1 Growth rates of *Gracilaria* with different densities

During the first few weeks of the experiment the *Gracilaria* plants on all the frames at both sites looked very fleshy and healthy. However, after two to three weeks it was observed that the frames with low densities (8 and 16 fragments/ frame) were covered with epiphytes and detritus material. The plants on the frames with 32 fragments looked very fleshy and healthy at both sites (Plate 5.1). The frames with 64 fragments appeared too densely covered with *Gracilaria* plants at both sites (Plate 5.2).

The plants on low density frames (8 and 16 /frame) at Kalpitiya showed the highest growth rates during the first 7 weeks of the culture period (Fig 5. 1). One-way analysis of variance showed that the density had a significant effect on the mean relative growth rate ($F = 35.59$; $p < 0.0005$) during the first 7 weeks at Kalpitiya (Table 5.1a). The Tukey's pairwise comparisons test showed that the mean relative growth rates of

Plate 5.1. *Gracilaria* plants grown with the density of 32 fragments per frame at Kalpitiya after three months of culture.

Plate 5.2. *Gracilaria* plants grown with the density of 64 fragments per frame at Kalpitiya after three months of culture.

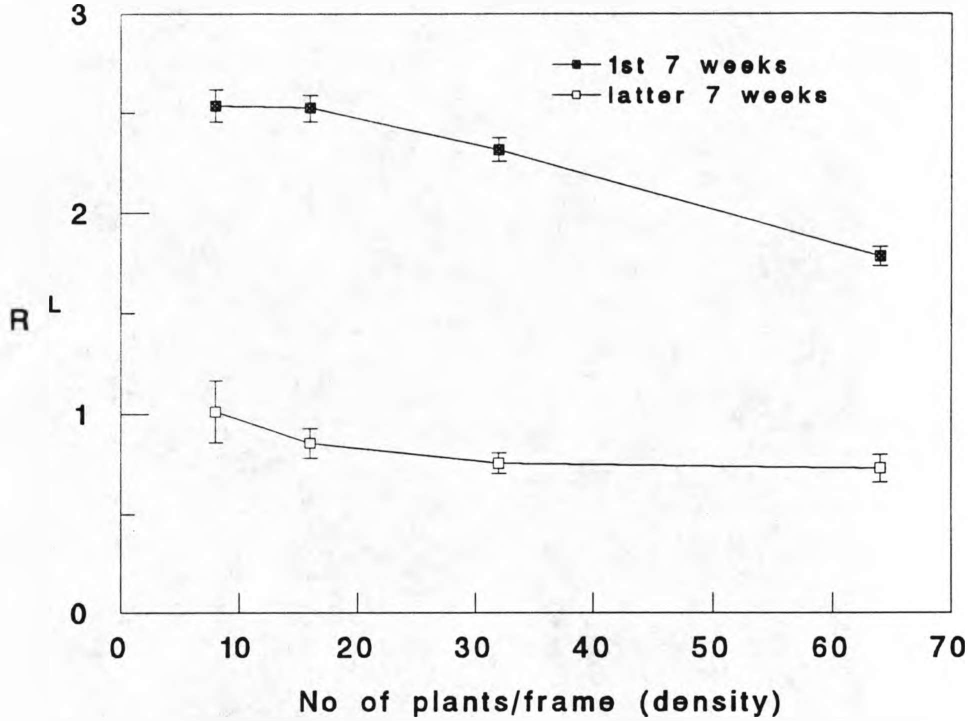

Fig.5.1 Mean relative growth rates in length (R^L %/day) with different densities at Kalpitiya (culture period= 5th June-12th Sep. 1992, bars=±1S.E.).

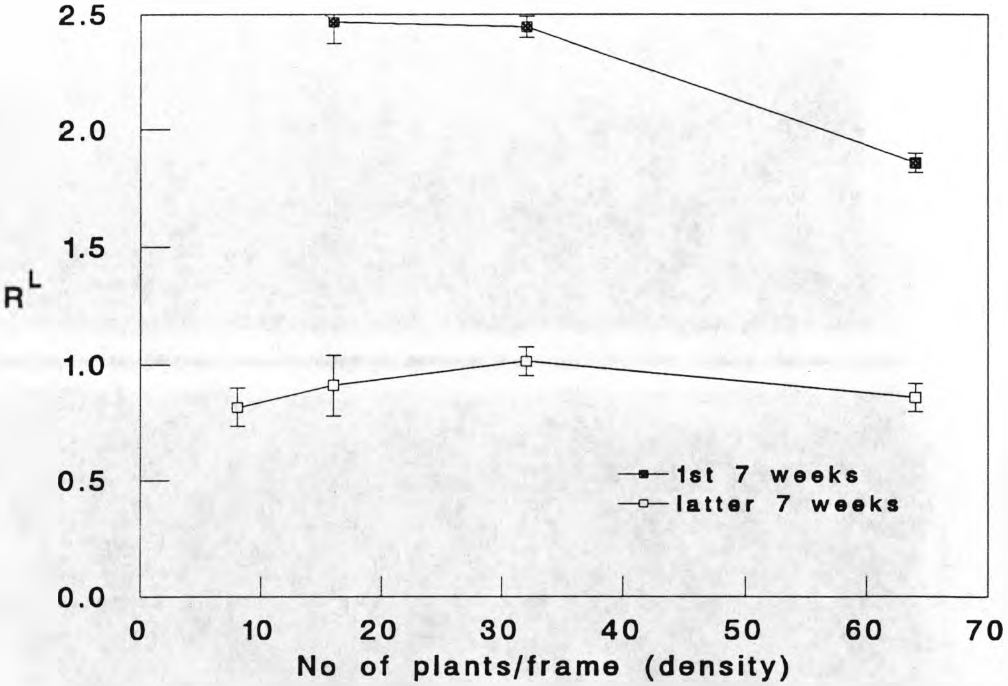

Fig.5.2 Mean relative growth rates in length (R^L %/day) with different densities at Puwarasankudawa (culture period= 5th June-12th Sep.1992, bars=±1S.E.).

SOURCE	DF	SS	MS	F	p
TREATMENT	3	3.3893	1.1298	35.59	0.0005
ERROR	27	0.8571	0.0317		
TOTAL	30	4.2464			

TABLE 5.1a. One-way analysis of variance on the mean relative growth rates of *Gracilaria edulis* during the first 7 weeks of the culture period with different densities at Kalpitiya.

	8 fragments /frame	16 fragments /frame	32 fragments /frame
16 fragments /frame	*		
32 fragments /frame	*	N.S.	
64 fragments /frame	*	*	*

TABLE 5.1b. Tukey's pairwise comparisons test showing significant differences on mean relative growth rates at different densities at Kalpitiya.

SOURCE	DF	SS	MS	F	p
DENSITY	3	2.7808	0.9269	31.29	0.0005
ERROR	26	0.7702	0.0296		
TOTAL	29	3.5511			

TABLE 5.2a. One-way analysis of variance on mean relative growth rates of *Gracilaria* plants during the first 7 weeks of the cilture period at Puwarasankudawa.

	8 fragments /frame	16 fragments /frame	32 fragments /frame
16 fragments /frame	N.S.		
32 fragments /frame	N.S.	N.S.	
64 fragments /frame	*	*	*

TABLE 5.2b. Tukey's pairwise comparisons on the growth rates of the first 7 weeks at Puwarasankudawa (* = significant difference; N.S. = not significant)

the densities of 16 and 32 were not significantly different but that all the other comparisons were (Table 5.1b).

The plants at both sites showed the lower mean relative growth rates during the latter half of the culture period with no significant difference between the densities.

One-way analysis of variance showed that there was a significant difference ($F = 31.29$; $p < 0.0005$, Table 5.2a) in the growth rates observed for different densities at Puwarasankudawa (Figure 5.2). Although the higher growth rates were achieved from the low density frames it was observed that the mean relative growth rate of the density of 32 fragments/frame was not significantly different from the growth rates of the plants at 8 and 16 fragments/frame at Puwarasankudawa (Table 5. 2b).

5.3.2 Harvested biomass with different densities

At both sites the plants on the frames with the density of 32 fragments/frame showed the highest dry biomass after a culture period of 102 days (Fig. 5.3 and 5.4). At Kalpitiya the frames with the highest density (64 fragments/frame) showed a mean dry biomass of 419.5 g while at Puwarasankudawa the frames with the same density showed a mean dry biomass of 335 g. At both sites the lowest dry biomass was observed from the frames with the lowest density (8 fragments/frame). The lowest mean dry biomass observed at Kalpitiya (37.5 g) was higher than at the same density (10.5 g) observed at Puwarasankudawa. The paired T-test showed that the harvested dry biomasses at all three densities of both sites were significantly different ($p \leq 0.04$). At both sites the density of 32 fragments/frame showed the highest relative growth rate in

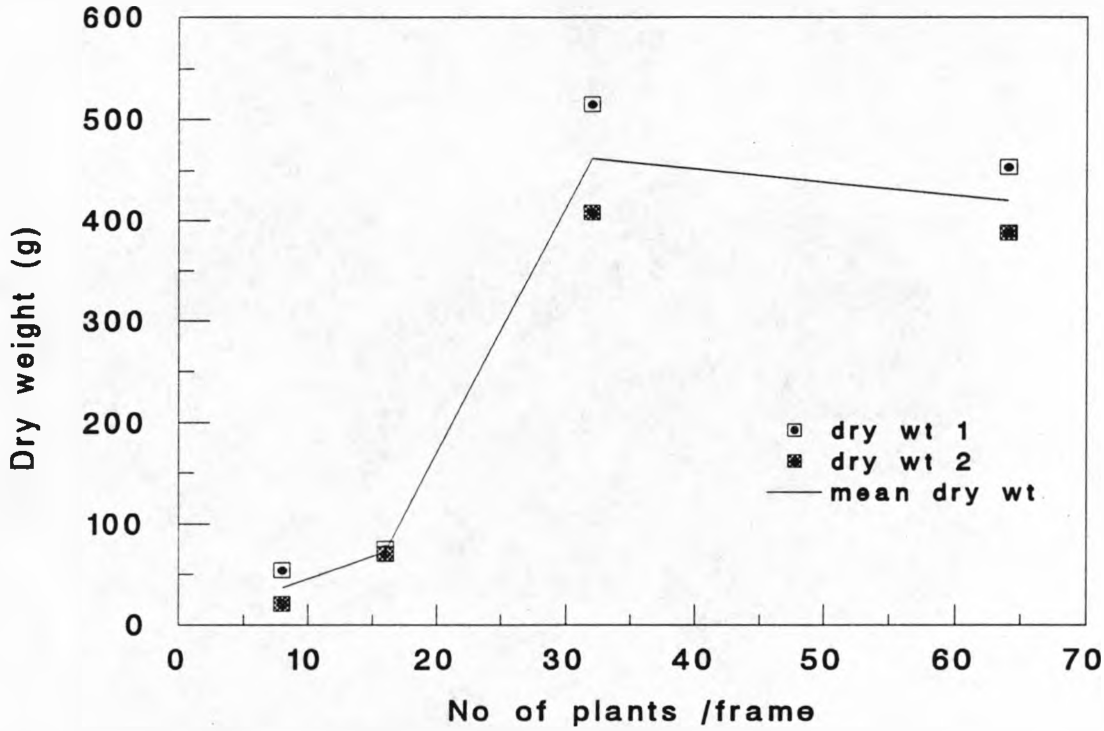

Fig.5.3 Dry biomass in different densities at Kalpitiya.

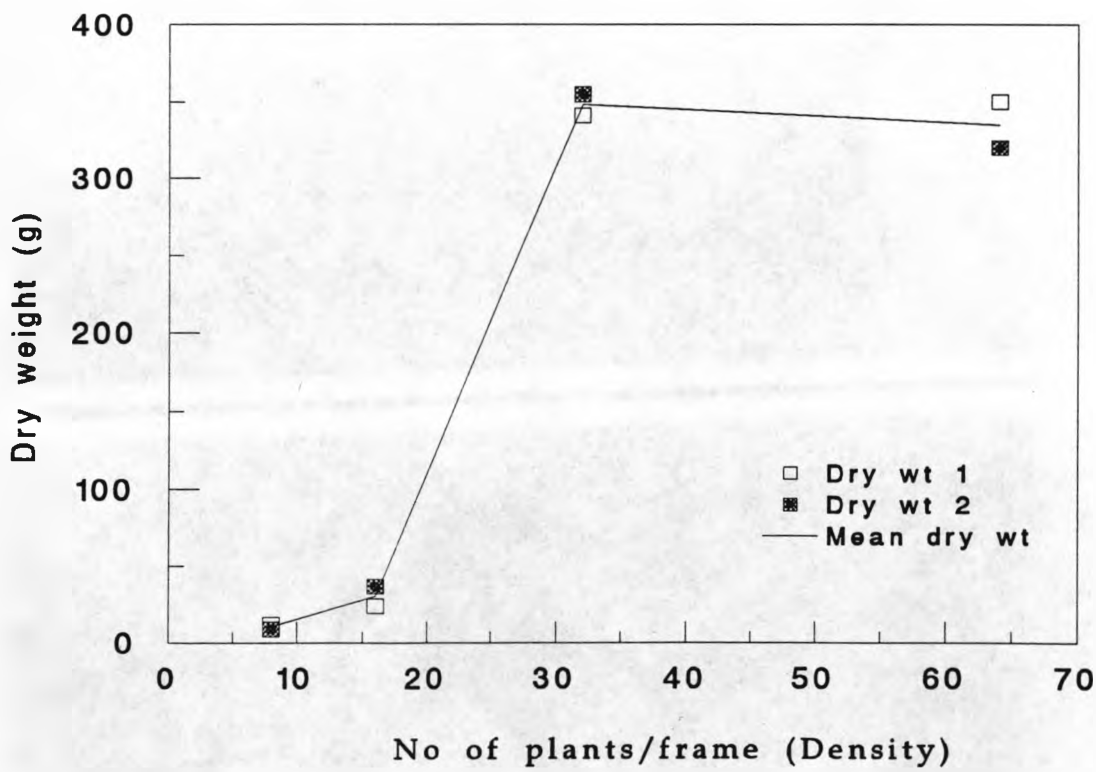

Fig.5.4 Dry biomass in different densities at Puwarasankudawa.

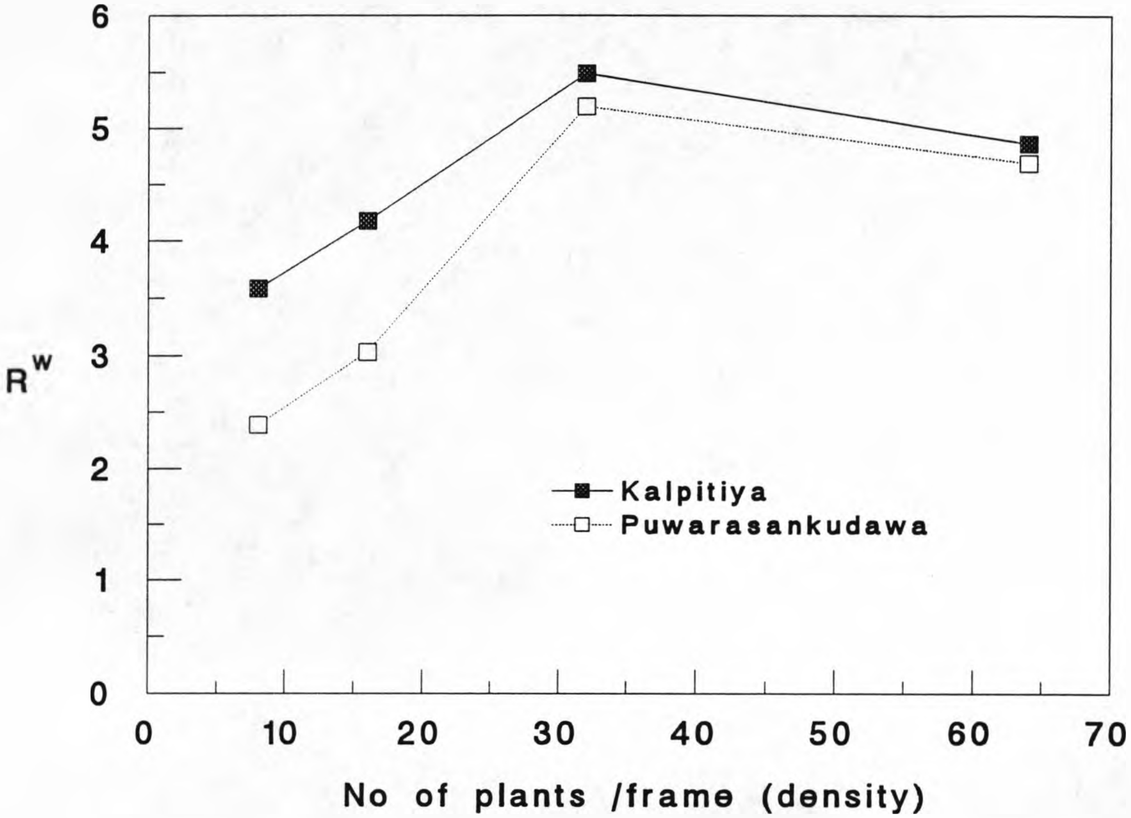

Fig.5.5 Mean relative growth rate in fresh weight (R^w % day-1) at different densities.

frames (8 and 16 fragments/frame), and could have mainly caused the decrease of the growth rates and subsequently affected the biomass of the *Gracilaria* plants on those frames. Edding *et al.* (1987), while culturing *Gracilaria* plants in outdoor tanks in Chile, also showed that the low density frames were affected by several epiphytes. Li Ren *et al.*(1984) undertaking culture work on *G. verrucosa* and *G. sjoestedtii* with different densities in Qingdao, China, pointed out that closer planting can prevent epiphytic algae from attaching. The low density frames at Puwarasankudawa showed higher growth rates than the higher densities even during the latter 7 weeks of the culture period. However the biomass on these frames were affected badly due to heavy epiphytism. The plants with the highest density showed lower growth rates in the first 7 weeks as well as in the latter 7 weeks in both sites. Although there were no epiphytes on those frames the self shading effect of plants may have caused the low growth rates (Ryther *et al.*,1978).

The mean relative growth rates (in fresh weight) of 5.48 % day^{-1} and 5.19 % day^{-1} were observed with the density of 32 fragments/ frame at Kalpitiya and at Puwarasankudawa respectively. The lower growth rate achieved at Puwarasankudawa may be due to the significantly lower ($p < 0.0001$, Section 2) % surface irradiance (Fig.5.6) observed at this site than at Kalpitiya. These growth rates were higher than the growth rates reported for *Gracilaria cornea* at three different densities (1.4% to 2.4% day^{-1}) on the north-west coast of Venezuela by Rincones Leon (1989). According to his studies the maximum growth rate (2.4 % day^{-1}) was achieved at the density of 200 fragments/m^2 equivalent to 64 fragments/frame in the present study. The growth rate achieved in this study was also higher than the daily growth rates observed for *Gracilaria* in outdoor tanks at La Herradura Bay in Chile (4.3 %day^{-1}) by Edding *et*

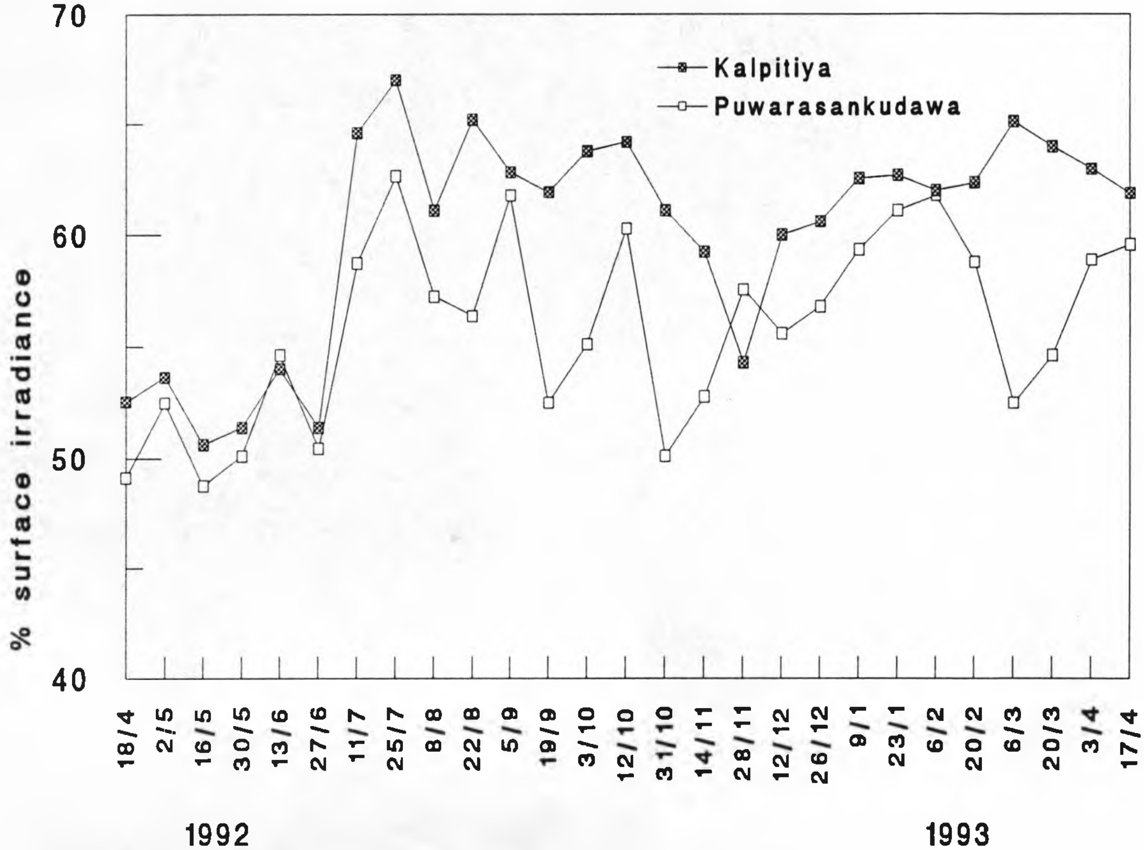

Fig.5.6 Percentage surface irradiance at Kalpitiya and at Puwarasankudawa from April 1992 to April 1993.

al. in 1987. The growth rate observed at Kalpitiya was almost equal to the growth rate of *Gracilaria* achieved by Doty (1979) in Taiwan (5.6 g m^{-2} day^{-1}). However, the achieved growth rates were lower than the maximum growth rates observed (up to 10.5 % day^{-1}) with different densities for *Gracilaria* species in Philippines by Hurtado-Ponce (1990).

Achieving the highest mean dry biomass (Fig 5.3 & Fig 5.4) in the density of 32 fragments/frame (100 fragments m^{-2}) at both sites showed that was the optimum density for the culture of *Gracilaria* in this lagoon. Rincones Leon (1989), in his culture studies from May to September with *G. cornea* in Venezuela, showed that the best results (growth rate of 2.07 % day^{-1}) was obtained at the density of 100 plants m^{-2} with less epiphytism. Therefore it was equal to the optimum density obtained at the present study. The mean fresh biomasses observed at the density of 32 fragments /frame were 4309 g and 3296 g at Kalpitiya and at Puwarasankudawa respectively. These are equal to the yields of (fresh weight) 12.92 kg m^{-2} and 9.88 kg m^{-2} (dry weight) at 1.38 kg m^{-2} and 1.04 kg m^{-2} respectively. This biomass was a little lower than the fresh biomass achieved for *Gracilaria verrucosa* (14.8 kg m^{-2}) by Camara Neto (1987) in Brazil.

6. SPORE SETTING TECHNIQUES

6.1 INTRODUCTION

The cultivation of *Gracilaria* species in the sea has been attempted several times in different regions of the world. Most experiments dealt with the propagation of vegetative branches while only a few considered propagation by spores (eg. De Oliveira & Alveal, 1990).

Spore germination and growth of *Gracilaria* have been repeatedly described (Oza & Krishnamurthy, 1967; Rama Rao & Thomas, 1974; Oza, 1975; Bird *et al.*,1977a) and no ecological difference has been found either in the pattern of growth or in the ecology of tetraspores or carpospores, except perhaps temporal differences in their seasonal formation and discharge (Santelices & Doty, 1989). Busby & Goldstein (1977) utilized unglazed ceramic tiles to collect *Gracilaria* spores in natural beds in Atlantic Canada. They reported that the method was efficient when there was a large number of tetrasporic plants, based on sporeling counts in the laboratory. This could be an effective way to increase natural recruitment of selected species (De Oliveira & Alveal,1990). Wood (1945) noted that the spores of *Gracilaria* settle and grow on suitable substrata (usually oyster shells), and he suggested this might be a way of expanding the natural beds. Lin *et al.* (1979) attempted to develop *Gracilaria* farming from spores grown on bamboo blocks in fish ponds but without economic success.

The spore method, in short, consists of spores from selected fertile adult thalli attaching themselves to materials which after a time are outplanted. This method requires some equipment but also provides farmers with better control in starting or enhancing *Gracilaria* productivity in a favourable site (Santilices & Doty, 1989). The method used in this study was the same as developed in Malaysia and Hawaii (Santilices & Doty, 1989). The main advantage of this method is that more vigorous specimens can be selected as seed material and a larger production can be achieved in a shorter time due to inoculation of larger biomasses than in the vegetative propagation method (De Oliveira & Alveal, 1990).

6.2 MATERIALS AND METHODS

6.2.1 Preparation of a hatchery for the spore setting technique

A hatchery was built up near the lagoon bank at Kalpitiya in front of the NARA Regional Research Centre to carry out the spore setting experiments. This facility comprises a (12 x 6 m) rectilinear shelter constructed with six concrete pillars and an asbestos roof. It contains two concrete tanks each 3 x 3 x 0.5 m deep. An electrically- driven air compressor provides aeration through a series of PVC pipes bearing small holes. The air lines are placed on the floor of each tank with one line along each of the four sides and additional lines at roughly one meter intervals.

A portable fuel-driven pump was used to pump seawater to a sand filter from which it was gravity fed to the seeding tanks. The sand filter was a tank which was filled with three different sizes (20-1 mm) of gravel and sand in layers in order to filter the turbid lagoon water. The pipelines which supplied water extend some distance out across the intertidal sand/mud flats and lagoon water could only be obtained during high tide periods.

6.2.2 Collection of seeding material

Cystocarpic plants were used as seeding material and they were collected mostly from the natural seaweed grounds which are based some distance from the culture sites. Boat trips were made to reach the natural seaweed beds and the collecting was done by hand. A monthly survey has also being carried out since 1989 to find out the occurence of cystocarpic plants in the Puttalam lagoon. The material was collected in plastic buckets and brought to the boat for further separation. Cystocarpic plants were separated and cleaned of dirt and epiphytes. Around 8-10 kg (wet wt.) of seeding plants were used for each experiment. The buckets were covered with wet paper while transporting, to protect them from sunlight.

6.2.3 Preparation of frames for the settlement of spores

PVC pipes (diameter 2 cm) were used to make 80 x 40 cm rectangular frames. The following different substrata lines were wound around the longer side of the frames with approximately 0.5 cm spacing between lines to permit spores to settle on them on the underside of the frames during the spore settlement process (Fig 6.1):

a. Coir rope (8 mm in diameter)

b. Synthetic raffia (high density polyethylene rope)

c. Nylon rope (5 mm in diameter)

6.2.4 Preparation of seeding tanks

The cement tanks were filled to a depth of 25 cm with filtered lagoon

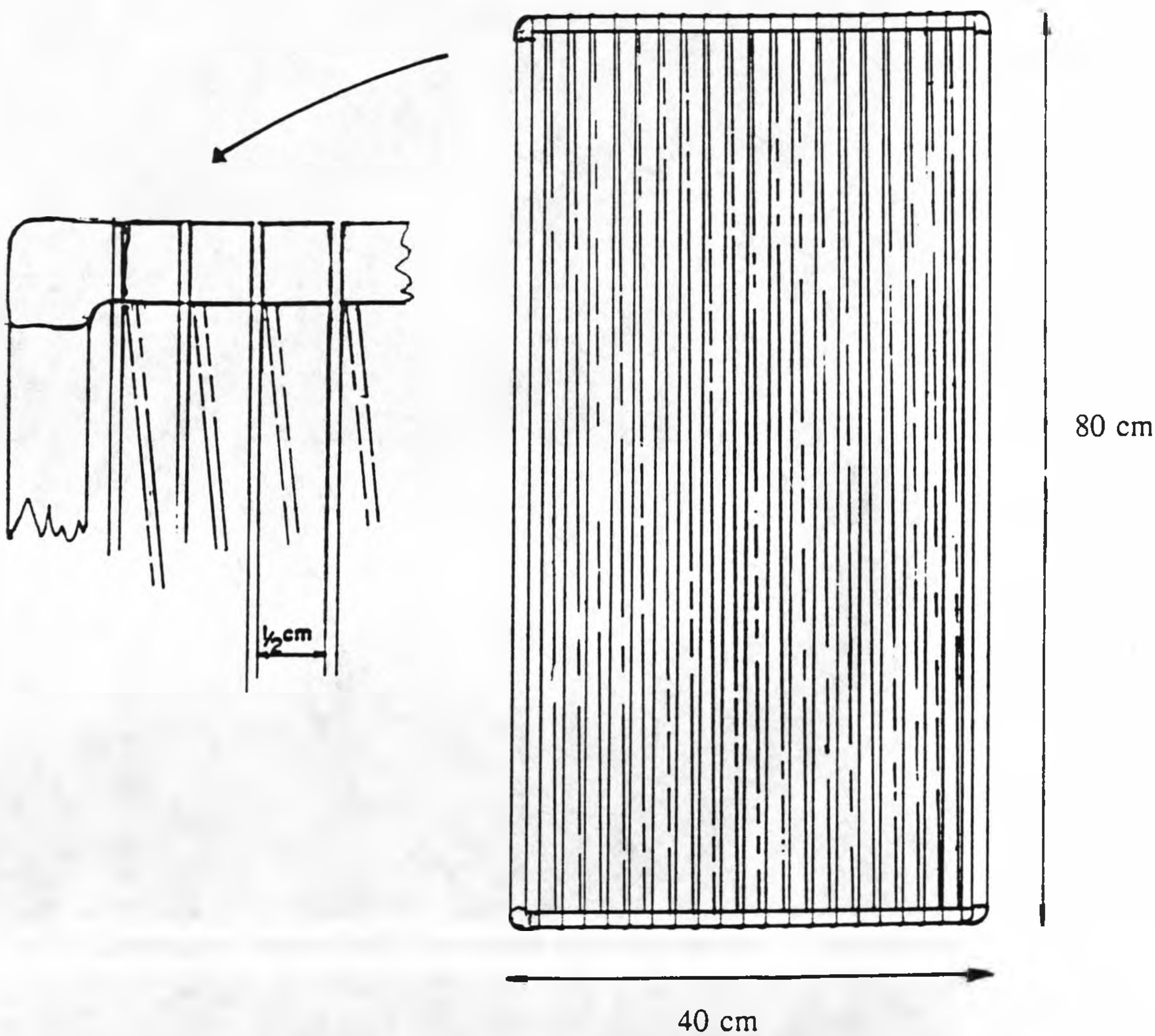

Fig. 6.1 Frames showing lines wound on them.

water. Two frames made out of PVC pipes (2.8 x 2.8 m) and covered with fishing nets (0.5 cm mesh size) were arranged to float on the water of each tank (Plate 6.1).

6.2.5 Spore settlement procedure

During each spore setting 6 kg of cystocarpic *Gracilaria* plants were broken into pieces and sprinkled over the net frame floating inside one of the tanks. Nine frames (80 x 40 cm) made out of each of the above three substrata in triplicate were kept in the bottom of the tank (Plate 6.2). Another set of nine frames made out of same manner were kept in the bottom of the other tank as a control. Frames were kept for four nights in the tanks by frequently turning them up side down to enable the spores to settle on both sides. Glass slides were kept on the frames and they were examined under the microscope each night for signs of spore settlement.

The frames were then removed from the tanks and four rectangular styrofoam cubes attached to each of them. These frames were then transferred to the pilot farm in the lagoon. Development of the plants was monitored by counting the number of plants on the frames. All the plants were harvested from the frames after three months of growth and the wet and dry weight of the plants were determined.

6.2.6 Settlement of spores with different light conditions

The above two cement tanks were used for this experiment. The cystocarpic *Gracilaria* plants were brought from the natural beds and both tanks were sprinkled with them. Eighteen frames (8 x 40 cm) were

Plate 6.1. The spore setting hatchery at Kalpitiya showing the seeding tanks.

Plate 6.2. Frames wound up with high density polyethylene (raffia) for the settlement of spores.

made and every six of them with coir rope, plastic net and raffia respectively. They were divided into two identical groups and nine of them were placed in the bottom of each tank. One of the tanks was given five hours extra light per day by keeping an artificial light on top of the tank during the night from 6 pm to 11 pm. The other tank was covered by black polythene during the night to prevent any other light entering to the tank. The frames in both tanks were turned upside down frequently as in the above experiment. After four nights of incubation the frames were transferred to the lagoon. Development was monitored by counting the number of plants in each frame and measuring the wet and dry weights of the final harvest.

6.3 RESULTS

6.3.1 The settlement of spores on different substrata

Table 6.5 showed the availability of cystocarpic *Gracilaria* plants in the Puttalam Lagoon. It took two to two and a half months for 1-2 mm length *Gracilaria edulis* seedlings to appear on the frames (Plate 6.3). Frames with synthetic raffia showed the highest mean number of plants and those with coir rope showed the lowest on the three types of substrata (Fig.6.1). No sporelings were visible on the frames which were used as controls.

The effect of substrata on sporeling number was significant ($p < 0.011$, Table6.1a.) and the number on synthetic raffia was significantly greater than on the other materials (Table 6.1b.)

The *Gracilaria* plants on the frames showed healthy growth and in three and a half months they reached up to 30 to 35 cm in length (Plate

	Months											
Year	J	F	M	A	M	J	J	A	S	O	N	D
1989	++	+++	+	-	-	+	+++	+++	+	-	-	-
1990	+	++	-	-	-	+	++	+++	+	-	-	-
1991	+	++	-	+	++	+++	++	++	-	-	-	-
1992	++	+++	+	-	+	++	+++	++	+	-	-	-
1993	+	++	+									

Table 6.5. Availability of cystocarpic *Gracilaria* plants in the Puttalam Lagoon. (+++ = abundant; ++ = common; + = rare; - = none).

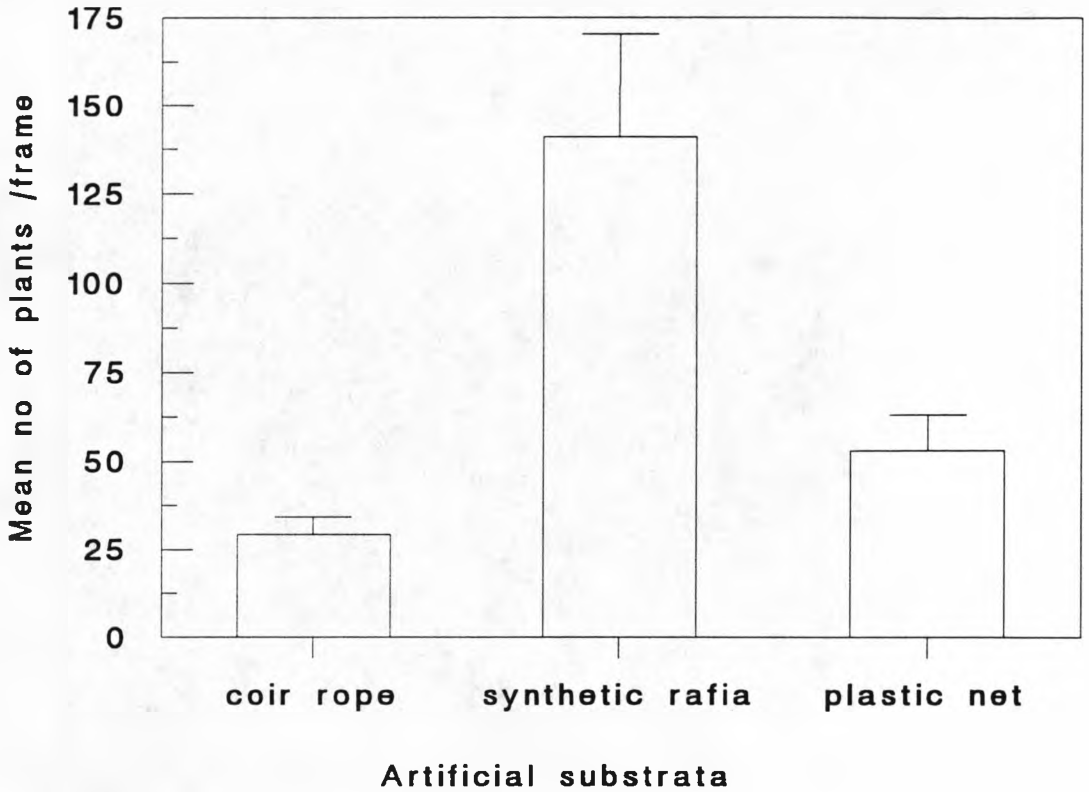

Fig.6.1 Mean number of plants on different substrata after the settelement of spores.

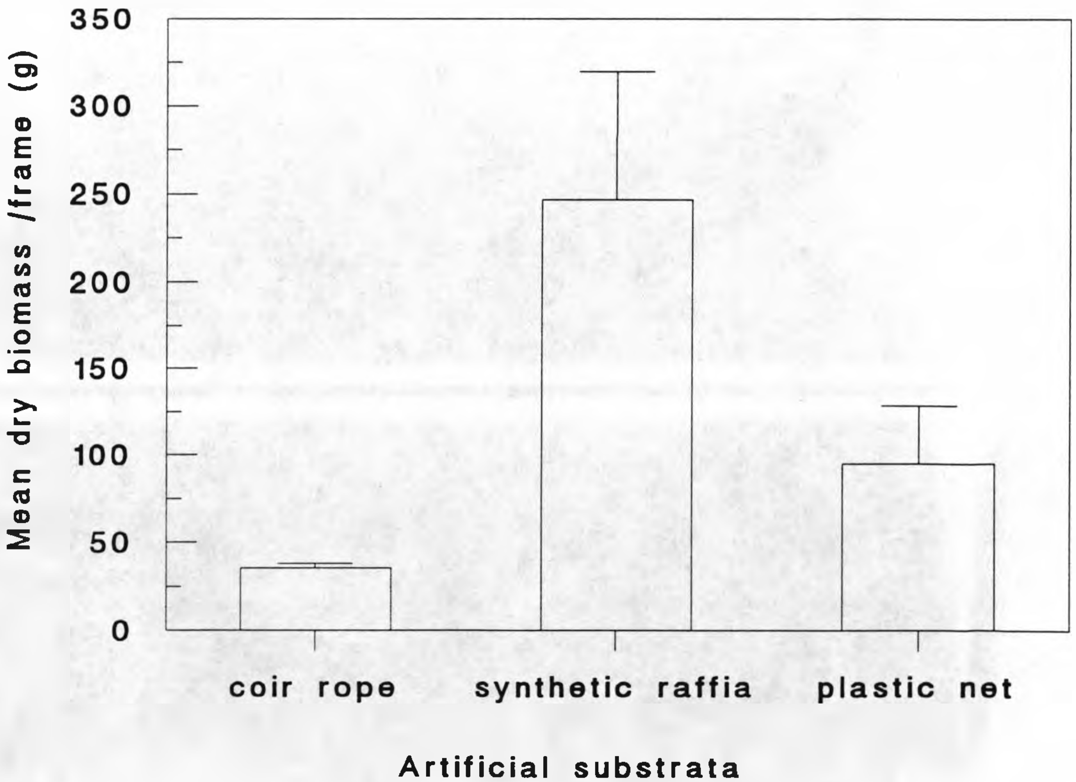

Fig.6.2 Mean dry biomass on different substrata (culture period = 10th Oct. 1992-24th Jan. 1993, bars = $\pm$ 1 S.E.).

SOURCE	DF	SS	MS	F	p
SUBSTRATA	2	20774	10387	10.48	0.011
ERROR	6	5945	991		
TOTAL	8	26718			

TABLE 6.1a. One-way analysis of variance on the number of sporelings on dfferent types of substrata.

	Coir rope	Raffia
Raffia	*	
Plastic net	N.S.	*

TABLE 6.1b. Tukey's pairwise comparisons test showing the significance of different substrata (* = significant difference; N.S.= not significant).

SOURCE	DF	SS	MS	F	p
SUBSTRATA	2	70742	35371	5.43	0.045
ERROR	6	39060	6510		
TOTAL	8	109802			

TABLE 6.2a. One-way analysis of variance on the mean dry biomass on different substrata after three and half months of culture.

	Coir rope	Raffia
Raffia	*	
Plastic net	N.S.	N.S.

TABLE: 6.2b. Tukey's pairwise comparisons test showing the significant difference of mean dry biomass with different substrata (* = significantly different; N.S. =not significant).

6.4). The fresh biomass achieved on synthetic raffia was then 2.36 kg. Mean dry biomass on the three different substrata is shown in Fig 6.2. The effect of substrata on dry biomass was significant ($F= 5.43$, $p< 0.045$); Table 6.2a). Synthetic raffia showed the highest mean dry biomass whereas the frames with coir rope showed the lowest. The differences were significant (Table 6.2b).

6.3.2 Settlement of spores in different daylengths

The frames which were in the tank with normal daylength bore a higher number of plants than the frames with day extension conditions (Fig 6.3). Synthetic raffia bore the highest number of plants in both conditions. The lowest mean number of plants appearing after natural daylength treatment was higher than the highest mean number of plants appeared after day extension treatment. The effects of two light treatments and the different substrata on the settlement of spores were highly significant ($F = 72.69$, $p< 0.0005$; $F = 12.59$, $p< 0.001$; Table.6.3). There was also a significant interaction between the light treatments and substratum ($F =8.32$; $p< 0.005$).

Higher mean wet and dry biomass were achieved on the frames in the natural daylength treatment than in the day extension (Fig.6.4). The mean fresh biomass achieved on different substrata after natural daylength was 1.19 kg and it was very much higher than it was (0.19 kg) after day extension treatment (Plate 6.4 & 6.5). The mean dry biomass after natural daylength treatment was also significantly greater than that after day extension ($F =36.84$;$p< 0.0005$, Table 6.4). It also showed a significant difference between the three substrata and the light treatments ($F = 4.0$; $p< 0.047$, Table 6.4).

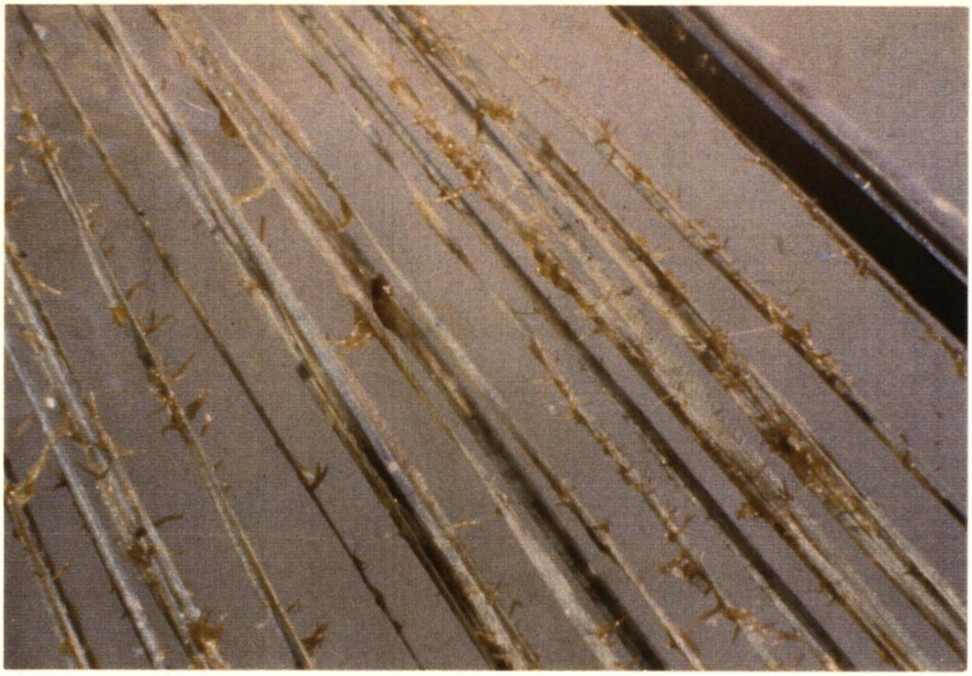

Plate 6.3. Small seedlings (5-10 mm length) showing on the frames of raffia (3 months after the settlement of spores.)

Plate 6.4. Healthy *Gracilaria* plants shown on frames with raffia after 3 and half months of culture.

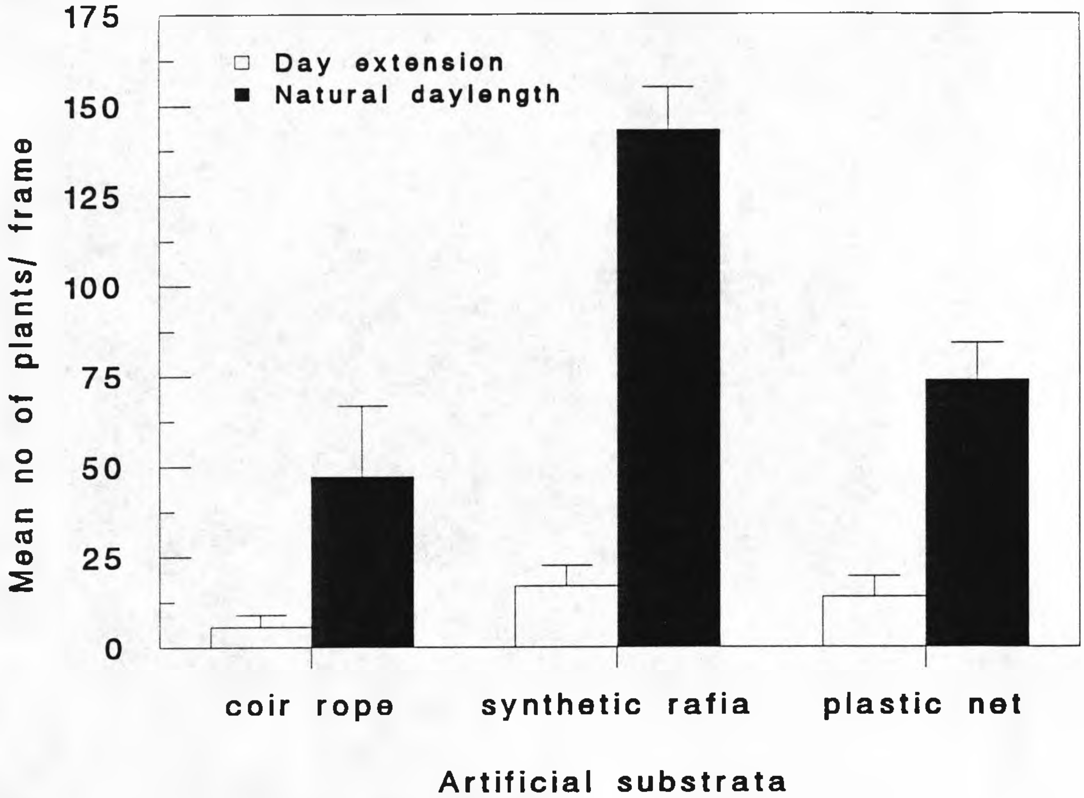

Fig.6.3 Mean number of plants on different substrata with day extension and natural daylength conditions (bars = ± 1S.E.).

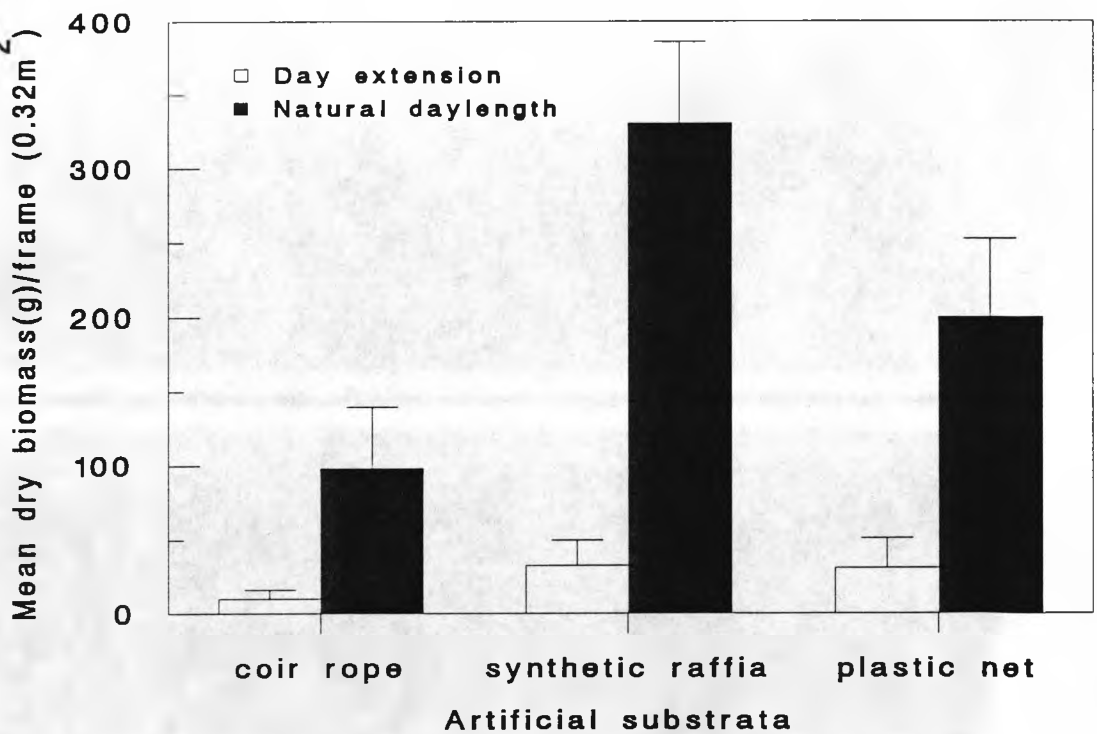

Fig.6.4 Mean dry biomass on different substrata with day extension and natural daylength conditions (culture period = 15th Oct 1992 to 30th Jan.1993, bars = ± 1 S.E.).

Plate 6.5. *Gracilaria* plants grown on raffia frames at natural daylength treatment.

Plate 6.6.*Gracilaria* plants grown on raffia frames after 3 and half months culture. (Length of the plants were 35-40 cm.)

SOURCE	DF	SS	MS	F	p
SUBSTRAT (A)	2	8941.4	4470.7	12.58	0.001
TREATMENT(B)	1	25840.2	25840.2	72.69	0.0005
A X B	2	5918.1	2959.1	8.32	0.005
ERROR	12	4266.0	355.5		
TOTAL	17	44965.8			

TABLE 6.3. Two-way analysis of variance on the number of sporelings on different substrata at each treatment.

SOURCE	DF	SS	MS	F	p
SUBSTRATA(A)	2	48406	24203	5.79	0.017
TREATMENT(B)	1	154012	154012	36.84	0.0005
A X B	2	33441	16721	4.0	0.047
ERROR	12	50165	4180		
TOTAL	17	286025			

TABLE 6.4. Two-way analysis of variance on the dry biomass obtained from different substrata at two different treatments.

6.4 DISCUSSION

The time taken for the sporelings to appear after the settlement of spores in these experiments was due to the time period taken for spore germination. Goldstein (1974) pointed out that the complete germination of a *Gracilaria* spore would take around 10 to 12 weeks.

Synthetic raffia, on which the highest number of sporelings was observed, could be considered as the best substratum for the settlement of spores among other substrata tested in this experiment. The number of sporelings settled on coir rope and plastic net were not significantly different. Although the coir rope is cheaper and freely available in Sri Lanka, the carpospores of *Gracilaria* do not settle on it successfully.

The spore setting work carried out in Penang State, Malaysia (Anon, 1987) showed that the mean wet weights of the harvested *Gracilaria* plants on synthetic raffia were 3 g m^{-1}, 33 g m^{-1} and 224 g m^{-1} in January, March and July respectively in 1984. Although the harvest data of the present study were not calculated per metre it is clear that these numbers are very much lower than the present harvest (7.375 kg m^{-2}) on the raffia lines. However the final harvest data of the present study was achieved by extrapolating the actual numbers on smaller frames. Therefore the final biomass per m^2 of the present study may be a little lower than the value given.

No previous studies have been carried out on the shedding of carpospores in *Gracilaria edulis* in Sri Lanka. According to the observations made during previous years, cytocarpic plants were abundant in the Puttalam Lagoon during July to August and January and February (Table 6.5). Rama Rao and Thomas (1974) pointed out that the daily shedding of carpospores in *Gracilaria edulis* has a definite rhythm and a gradual decrease in spore output from July-August to January and again from February to April. In *Gracilaria verrucosa* growing at Okha a single peak in carpospore output was found by Oza and Krishnamurthy (1968) with maximum shedding in December. In England, too, a single peak in growth and spore production was observed by Jones (1959) in *Gracilaria verrucosa* present throughout the year, with a maximum discharge of tetraspores and carpospores between July and September. Therefore more studies such as seasonal % fertility should be carried out to find out the particular season for the shedding of the local *Gracilaria* species.

Obtaining a higher number of sporelings on the frames in the normal day length condition may be due to the higher liberation of carpospores during the dark conditions. The work done on *Gracilaria corticata* in the Gulf of Mannar, Mandapam showed that the light and dark periods of the day control the liberation of spores in *G. corticata* (Umamaheswara Rao, 1976). He also showed that the carpospore emission was maximum during the night time between 22.00 h to 06.00 h and a decreasing trend of liberating carpospores was observed in the cystocarps, exposed up to 24 h light period. In the present study the day extension condition received only 06.00 h of dark period while the normal day length condition received almost 11.00 h. The higher number of sporelings on the frames in the normal day length condition may be due to the higher liberation of carpospores during the extended dark hours.

It would be more profitable to use synthetic raffia in normal daylength as the substratum for the spore settlement procedures since it achieved the highest mean dry biomass. However it was observed that the cystocarp bearing plants are not freely available throughout the year in the lagoon (Table 6.5) and tetrasporic plants were also not observed during this study.

7. DISCUSSION (PART 1)

The culture experiments carried out on *Gracilaria edulis* in Puttalam Lagoon revealed that the maximum mean relative growth rate value of 8.3 % day^{-1} is in the range (5-10 % day^{-1}) considered typical for *Gracilaria* spp. by McLachlan & Bird (1986). When comparing these growth rates with those shown in other work on *Gracilaria* there seems to be a confusion between the relative growth rate (R) and percentage increase per unit time (Kain, 1987). However, it was pointed out by Kain (1987) that for the smaller growth rates (less than 15 % day^{-1}) the percentage increase per unit time is almost equal to the percentage relative growth rate. Table 7.1. gives the percentage relative growth rates in length (R^L) or weight (R^W) of different *Gracilaria* spp. grown in various parts of the world. In several instances spectacular growth rates have been reported; Lapointe *et al.*(1976) employed conditions close to steady state whilst Ryther et al.(1977) adjusted the density to achieve their rates (McLachlan & Bird, 1986). Nevertheless it is unlikely that such high rates are sustainable for any period of time. Growth rates reported under field conditions (Table 7.1.) are similar to those determined for cultures. However, it was shown that the relative growth rates observed in the present study for *G. edulis* are higher than the growth rates achieved for the same species in other countries. However, it was observed that the growth pattern of the *Gracilaria* in the Puttalam Lagoon showed a distinct seasonal variation. The variation of growth rates may be mainly due to the monsoonal changes which subsequently affect the fluctuation of the total nitrogen content in the lagoon. Therefore the small scale culture practices, which would be dependent on natural conditions, can best be conducted during the peak growth seasons of the year.

Species	Condition	R^L	R^W	Authors
G. tikvahiae	field, embayment		up to 5.1	Edelstein *et al.*,1981
G. verrucosa	field,intertidal	4.7		Saunders & Lindsay, 1979
G. folifera	field,	0.09		Causey *et al.*,1946
G.sjoestedtii	field, canals	8-9		Hansen, 1984
G. secundata	field,bay	4.6-0.17		Luxton, 1981
G. edulis	field	2.2		Raju & Thomas, 1971
G. verrucosa	field	5-12		Li Ren *et al.*, 1984
G. folifera	field	5.2		Rosenberg & Ramus, 1981
G. confervoides	ponds cultivated		7.0	Friedlander & Zelikovitch, 1984
G. folifera	tanks	9.9-12.8		DeBoer *et al.*,1978
G. tikvahiae	aquaria	2.2-5.7		Edelstein *et al.*,1976
G. tikvahiae	aquaria		10-36	Lapointe *et al.*,1984
G. edulis	aquaria	2.5-5.1		Nelson *et al.*,1980
G. tikvahiae	tanks	8-60		Ryther *et al.*,1977
G. arcuata	aquaria	2.1-3.5		Nelson *et al.*,1980
G.tikvahiae			7.8	Bird *et al.*,1977
G. verrucosa			5.2	Jones, 1959
G. exasperata			8.0	Waaland, 1977
G. exasperata			5.3	Waaland, 1981
G.exasperata			3.5	Waaland, 1979
G. *edulis*	field	0.25	8.3	present study

Table. 7.1. The percentage relative growth rate in length ($R^{L)}$ or weight (R^W) of *Gracilaria* species.

The commercial culture systems could be organised by using ammonium fertilizers. The fertilizer experiments showed some important implications that can be done on aquaculture practices. The pluse fertilization with ammonium or nitrate on *Gracilaria edulis* suggests that it can produce high growth rates without some of the disadvantages of continuous fertilization (as suggested by Ryther *et al.*, 1982). Therefore the pulse feeding of nutrients may be more effective in a *Gracilaria* farm than the continual pumping of deep water nutrients (Bird *et al.*, 1982). However pumping of deep water may not be feasible in the Puttalam Lagoon due to the absence of nearby deep water.

The percentage surface irradiance is another important factor which regulates the growth of *Gracilaria edulis* in the Puttalam Lagoon. The two sites tested in the present study showed that the lower growth rates observed at Puwarasankudawa were probably due to the % low surface irradiance at the culture depth.. This was due to the turbid water in these areas as a result of wave action and current. Particles in suspension absorb and scatter light, decreasing available light to benthic plants (as for example quantified by Connor, 1979 in Chesapeake Bay). However, it would have been better if more sites could be tested with Secchi disk readings since water turbidity is likely to be an important factor for site suitability. Therefore the small scale farms should be set up in enclosed areas where there is less wave action and turbulance.

From the experiments done on different substrata it was suggested that coir rope can be used for small scale culture practices since it is cheap and freely available local product. The fragments can be easily inserted in to the twists of the coir rope but if it is a plastic net the fragments of *G. edulis* should be tied to the mesh intersections of the nets with the help of nylon twine. Santelices & Doty (1989) stated that the delicate *G. dominguensis* tends to break where inserted in braided polypropylene ropes, which are rather stiff and harsh, though unusually enduring and inexpensive. They recommended coir rope which is softer and less damaging, but it is weak and endures only in calm water. The optimum density suggested for *G. edulis* (100 fragments /m^{-2}) can also be used for small scale cultures. Since all the family members of each fisherman can be involved in farming, the need for large amount of labour would not be a problem in Sri Lanka. The 20 cm depth which was determined as optimal would be ideal for commercial practices.

The spore setting technique of culturing *Gracilaria* could also be done commercially or on small scale whenever the adequate quantity of cystocarpic plants are available in the Puttalam Lagoon. The technology of this is also well suited to small scale development. Farm size can be adjusted in accordance with a household's ability to maintain and harvest it. No costly infrastructure for processing or storage is required. Spore setting units or hatcheries are needed to start a *Gracilaria* farm and these can be centralised so that one facility may supply seeded raffia to a number of farms. It is possible for several farmers to share the cost of such centres, as done in Japan and South Korea with Nori culture. The hatcheries themselves are rather simple, consisting solely of water tanks, a seawater pump and air blower, all housed under an open type shed which can be constructed of local material. The main problem of this method would be the seasonal availability of cystocarpic *Gracilaria* plants in the lagoon. The fisherman involved in the sea fishery will have an off-fishing season during the south-west monsoon period from May to September. Since most of the cystocarpic plants would be available during June to August these fisherman can be involved in *Gracilaria* farming for an additional income.

Over the last few decades interest in seaweed resources of Sri Lanka has surfaced periodically, no continuing interest in the commercial exploitation of this resource taking place in spite of the marked growth in seaweed consumption and the seaweed based industries world wide. In Sri Lanka the seaweed industry has always been a subsidiary of the fishing industry, with the collection and processing of seaweed being carried out by the fisherman to supplement their income. However, it was revealed that the natural seaweed beds are being overexploited due to over harvesting and the steps for development measures were also discussed by Jayasuriya (1992). Management programmes in Chile (Santelices *et al.*, 1984; Poblete, 1986; Westermeier, 1986; in Santelices & Doty, 1989) have addressed the questions of how, when and with what frequency to harvest, as well as what amounts of materials should be left in a sandy mud bed for regrowth. Time related restrictions on harvesting have changed the seasonal pattern of wild crop production in southern Chile to one that is still seasonal, but with harvesting allowed every other month, the yield is more regular (Santelices & Ugarte, 1987). Under these circumstances, the *Gracilaria* beds can gradually lose their productivity where harvesting is opportunistic and occurs at all seasons (Santelices & Doty, 1989). Therefore it is essential to improve the management strategies of the natural *Gracilaria* beds in the Puttalam Lagoon since they could play a major role as a seeding stock for all the culture practices.

PART 2

STANDING CROP ESTIMATION AND HARVESTING EXPERIMENTS OF IMPORTANT SEAWEEDS ALONG THE WEST AND THE SOUTH-WEST COAST OF SRI LANKA.

8. INTRODUCTION

Unlike the situation in other Asian countries, commercialization of any seaweeds except " Ceylon moss" (*Gracilaria* sp.) in Sri Lanka is presently nonexistent. However investigations by Durairatnam (1961) revealed that there are many species of algae on the west coast of Sri Lanka, and the most common seaweeds are the brown algae belonging to the genus *Sargassum*. According to Durairatnam (1961) extensive beds of *Sargassum* are found in Jaffna, Polk Strait, Gulf of Mannar, Pearl bank off Silvathurai and along the south-west coast of Sri Lanka extending from Hikkaduwa to down south (Fig.9.1).

One of the main economic uses of brown algae is the production of alginates. In Sri Lanka alginates are mainly used in the textile industry. The first attempt towards alginic acid extraction was carried out in the late 1960's by the District Development Councils. Several collecting centres were set up at Hikkaduwa on the southern coast to collect *Sargassum* plants. The collectors, mostly fishermen, were paid ten cents (U.S.) per each dried kilogram and the District Development Councils sold it at a price equal to 12 cents (U.S.) to the National Textile Corporation (N.T.C.) which collected the raw material for processing. Machinery was installed at one of the textile factories and processing was about to start when the scheme was abandoned by the Corporation as the result of the dissolution of the District Development Councils. Samples were sent to many foreign companies with a view to obtaining an export market for the dried weed, with no success.

In 1973 the Industrial Development Board (IDB) of Sri Lanka planned to commence a pilot project to produce liquid sodium alginate (unpublished report from the IDB). The product was meant to be used by the N.T.C. as a mordant in dyes for textile finishing. According to their report in 1975 the total investment of the pilot project was estimated at 5000 U.S.dollars and the total cost was estimated at 600 U.S. dollars. Annual production of alginic acid was estimated at around 3000 kg. However this project had to be abandoned unlikely due to the unavailability of natural stocks of *Sargassum* plants. Therefore there is a great need to assess the available natural resources and the regeneration period of important species. According to the customs' statistics Sri Lanka annually imports approximately 264,758 U.S. dollars (price in 1988) worth of alginates for the textile industry. If there were proper resource data a processing industry for *Sargassum* could be easily established primarily as a import substitution.

There is also potential for using local seaweeds as a green supplement for poultry feed. This was tried out in 1960s (Balasuriya, 1963) to popularise the incorporation of dried powdered seaweed (*Ulva* sp.) as a green supplement for poultry feed in place of imported alfa-alfa preparations. Laboratory studies with oven dried *Ulva* sp. gave encouraging results as this was found to have a nutrient content comparable to alfa-alfa. However, with the change in government policy on imports in the mid 70's with the removal of import quota system the local market became open to imported seaweed products. Therefore this project was abandoned with the influx of cheaper seaweed material. These industries could be reestablished if the resource data on these seaweeds were identified properly. Therefore it is necessary to have knowledge on resource potential of local seaweeds which would subsequently help to reduce the foreign exchange used to import most of the seaweed products.

9. STANDING CROP ESTIMATION OF COMMERCIALLY IMPORTANT SEAWEEDS ALONG THE WEST AND SOUTH-WEST COAST OF SRI LANKA

9.1 INTRODUCTION

Much of the work done on intertidal algae around the world has been on seasonal variations and distributional patterns (e.g. Lundberg, 1981; Druehl & Green, 1982; Lawrence, 1986; Jernakoff, 1986; Murray & Horn, 1989). Some scientists have worked on seasonal variations in the biomass of commercially important seaweeds in intertidal areas (Murray & Littler, 1984; McQuaid, 1985).

Few scientists have worked on standing crop estimations of commercially important marine algae around the world. Work on this aspect has mainly been done in Norway (Baardseth, 1955), Nova Scotia (MacFarlane, 1952; McLachlan *et al.*,1987), Scotland (Walker, 1947; Gibb, 1950), Sweden (Kornfeldt, 1979), Central and Northern Adriatic (Span, 1969; Munda, 1973) and in Southern Australia (Cheshire & Hallam, 1988). Very little work has been done in the tropics, e.g. on Karachi coast (Saifullah, 1973) and in Gulf of Kutch (Chauhan & Krishnamurthy, 1968).

A few studies were done using nondestructive methods of sampling such as photogrammetric and remote sensing techniques (Chapman, 1948; Murray & Littler, 1984). The method followed in some of the quantitative studies was destructive random sampling using quadrats along transects (Munda, 1973; Kornfeldt, 1979).

In Sri Lanka the standing crop of *Sargassum* sp was estimated by Durairatnam in 1966. His estimation was based on two months work on intertidal and as well as subtidal areas. Commercial harvesting of seaweeds from intertidal areas is more economical than harvesting them from the subtidal areas which involves expenses for diving. Therefore it is important to estimate the exact potential of all the economically important seaweed resources on the intertidal areas which can be easily reached by the people.

9. 2 MATERIALS AND METHODS

9.2.1 Observations along the west coast of Sri Lanka

General observations of the intertidal reefs were made along the west coast of Sri Lanka from Chilaw area down to the Rekewa area in the south (Fig.9.2). Visits were made to these areas in January and in June 1992, to cover the monsoon and off-monsoon seasons. Observational notes were made on the occurrence of reef areas, the types of the reefs and the presence or absence of seaweed species on them. More information was gathered by talking to local residents in these areas. The lengths of small reefs were directly measured and the longer reefs were referred from the maps. A map was prepared from the observations above, to show the extent of the intertidal reef areas along the west coast of Sri Lanka.

9.2.2 Detailed sampling, monitoring and estimation of seaweed populations

Four sampling sites (Fig.9.1), Beruwala, Hikkaduwa, Tangalle and Rekewa (Plates 9.1-9.8) were selected along the west coast of Sri Lanka for monitoring and seasonal sampling of commercially important seaweed species. The sampling technique consisted of two main methods, mapping of all major seaweeds and quadrat sampling for qualitative and quantitative analysis, both every three months.

At all four sites, the biomass estimates were made by using transects with destructive quadrat analysis. A rope which was marked in every 50 m was placed parallel to the shore to create a fixed (but easily removable) middle rope transect. Belt transects (0.5 m wide) with alternate quadrats were taken along another line which was laid perpendicularly to the middle rope transect. At different sites, according to the length of the reef, 3 or 4 vertical transect lines were made (Table 9.1). At Beruwala four transect lines were taken at every 100 m. On other reefs transect lines were marked at 100 or 50 m distances. 0.25 m^2 quadrats were placed intermittently along these transect lines and the plants within each were removed completely and placed in polythene bags. At Hikkaduwa and Rekewa where there are longer zones the quadrats were taken every 2 or 3 metres along the length of the zone and this was followed consistently in every sampling month. Quarterly surveys (December, March, June, September and December) were made in each site taking care not to place quadrats along the same lines as previously. However in different quarters different number of quadrats were placed on the same reef according to the distribution of seaweeds on the reef in that particular period (Table 9.1).

Plants from each quadrat were preserved separately in 4% formalin and brought to the laboratory for further analysis. Each sample was washed in fresh water, followed by shaking and squeezing in a cooking sieve to remove excess water. Then all the species were sorted out and the wet weight was taken separately from each major species by weighing

Sampling site	Beruwala		Hikkaduwa		Tangalle		Rekewa	
Sampling month	T	Q	T	Q	T	Q	T	Q
Dec. 91	4	68	4	72	4	48	3	48
Mar. 92	4	64	4	58	3	37	3	14
Jun.92	4	68	4	68	3	45	3	49
Sep. 92	4	72	4	76	4	46	3	40
Dec.92	4	70	4	64	4	35	3	45

Table 9.1 The number of transects and quadrats taken in every sampling month at each sampling site (T = transects, Q = quadrats).

them in a foil dish. Wet weight of unimportant species were taken together as "others." Each foil dish was marked with the quadrat position and the name of the species and then placed in an oven at 70°C for 24 hours for dry weight measurements. Some of the samples of important seaweeds were sent to the Central Salt and Marine Chemicals Research Institute in Bhavnagar, India for identification.

Mapping was also done at all four sites, placing a line parallel to the first shore line in the middle of the reef. Another measuring (transect) line was kept perpendicular to the first line with its zero at the seaward side. A subjective judgement was made as to where the junctions between the major zones were and notes were taken of their distance along the transect. This line was placed every 5 m along the shore and the process repeated. Drawings were made for every three months on all the reefs using the coordinates taken along the transects. Maps were drawn for each reef by transferring these drawings to a computer drawing package (Canvas TM) using a graphics tablet. This package was also used to calculate approximate areas of the patches of different seaweed species. Maps were redrawn after deciding that the first version was too complex. Zones with the same dominant species were amalgamated. The original demarkation lines remain on the figures.

9.3 RESULTS

9.3.1 Seaweed survey along the coast

The intertidal reefs along the west and the south-west coast are illustrated in Fig.9.2. Table 9.2 showed the lengths of each reef along the surveyed coastal area. The reef seen in the Chilaw area is a narrow sandstone reef

Name of the area	Approximate length of the reef (m)
Chilaw	430
Iranawila	325
Negombo	450
Pamunugama	170
Uswatakeiyawa	210
Colombo	100
Uthuru Payagala	400
Payagala	310
Lansiawatta	150
Maggona	700
Ginnanguliya	120
Beruwala other areas	600
Beruwala	500
Hikkaduwa	310
Hikkaduwa other areas	650
Narigama	400
Dodanduwa	1500
Modaragama	425
Rathgama	1150
Dadalla	600
Galle	400
Unawatuna	350
Mihiripanna	400
Uduwatta	300
Koggala	270
Ahangama	400
Aranwala	1500
Midigama	500
Dikwella	175
Tangalle	200
Tangalle other areas	550
Netolpitiya	450
Rekewa	300
Rekewa other areas	700
Total	15995

Table 9.2 Approximate length of the reefs found in different areas in the western and the south-west coast of Sri lanka

with a width varying from 1 to 5 meters (Plate 9.9). This reef extends along the shore from the Chilaw town towards the Iranawilla area about 2 km. However this reef is underwater in most of the places and approximately 430 m bore the algal coverage. The upper part of the reef appears bare and at low tide dries out completely. The lower part of the reef has a very narrow (0.5 m width) *Ulva* sp layer followed by a *Sargassum* zone with a width of 1 to 1.5 meters.

From Iranawilla to Negombo the reef is submerged in the sea and it is not visible from the shore. This sandstone reef extends from the mouth of the Negombo Lagoon to near the mouth of the Kalani river (near Colombo Harbour). However it is visible only at Negombo area and at Uswatakeiyawa area. In Negombo the reef is made out of sandstone and its average width is around 28 m (Arudpragasam, 1970). This reef extends for about 450 m along the shore (Plate 9.10). The lower part of the reef has a prominent *Sargassum* zone (with an average width of 8 m) and never dries out completely due to intermittent washing by waves. Amongst these weeds are also found species of *Laurencia*, *Padina*, *Ulva*, *Chaetomorpha*, and *Chnoospora*. The *Ulva* layer mixed with *Chaetomorpha* and *Laurencia*, lies in the shoreward side of the *Sargassum* zone (with a width of 3-4 m) and dries out during the off monsoon season. During the monsoon season it is very difficult even to reach the reef due to heavy wave action. However it was noted that more luxuriant patches of weeds can be seen during this period.

The sandstone reef at Uswatakeiyawa extends for about 210 m and *Sargassum* is the dominating weed on the lower parts of the reef. Genera like *Ulva* and *Laurencia* and *Gracilaria* sp can be seen on the upper side of the reef.

Another reef lies immediately south of the south-west breakwater

Plate 9.9. The intertidal sand stone reef at Chilaw area.

Plate 9.10. The intertidal sand stone reef at Negombo.

of Colombo Harbour. It consists of a group of granitic rocks (Arudpragasam, 1970). Genera such as *Turbinaria*, *Gracilaria*, *Ulva* and *Sargassum* can be seen on this reef. This reef is fairly narrow (8-10 m wide) and it extends further south (Mount Lavenia) up to about 10 km. However it is submerged and lies further seaward.

From Payagala to Ginnanguliya the reefs consist of granite rocks. However, on these reefs the vegetation mainly consists of *Gracilaria* sp. and *Gracilaria corticata* and a low coverage of *Sargassum*. From Beruwala to Bentota the reefs consist of hard coral substratum. *Gelidium* could be seen only on the reefs at Beruwala. Comparatively large reefs with dense vegetation of *Sargassum* sp. could be seen from Hikkaduwa to Koggala. The reefs from Hikkaduwa to south seem to be made of a coral and granite mixture. A fairly long reef (1500 m) with a average width of 40 m could be seen at Dodanduwa which seemed to be made out of granite. *Ulva, Sargassum* and *Caulerpa* were the dominant genera on this reef. In Koggala a large amount of *Gracilaria corticata* was seen on the reefs. However, *Sargassum* seems to be the dominant species on most of the southern reefs (from Devenuwara to Rekewa).

9.3.2 Seasonal variation of zonation on the four reef areas

The maps (Figs.9.3-9.6) of different reefs show the seasonal variation of seaweed species at quarterly intervals of the year. In these maps it is shown that different seaweed species or different groups of species occur at different quarters of the year. It is also shown that on most of the maps the zones in December 1991 and 1992 show a similar pattern (Figs.9.3-9.6). It is clear on all the reefs that *Sargassum* species seem to be the dominants.

Plate 9.1. The sampled reef area at Beruwala

Plate 9.2. A view of the lower part of the intertidal reef at Beruwala.

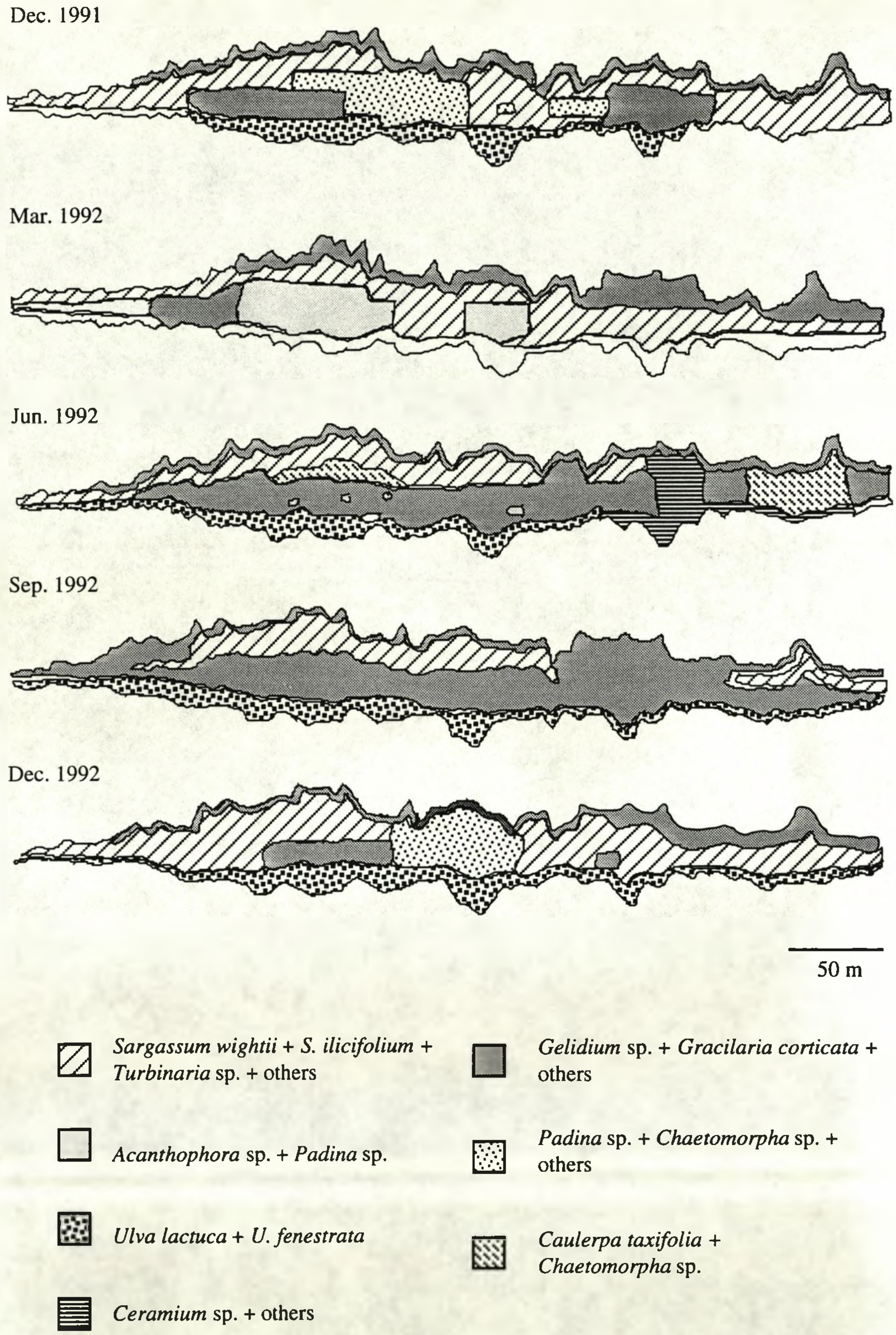

Fig. 9. 3 Maps showing the seasonal distribution of seaweed species in different quarters of the year from Dec. 1991 to Dec. 1992 at Beruwala reef (upper side of each map is the seaward side).

Plate 9.3. The sampled reef area at Hikkaduwa.

Plate 9.4. A closer view of the intertidal reef area at Hikkaduwa.

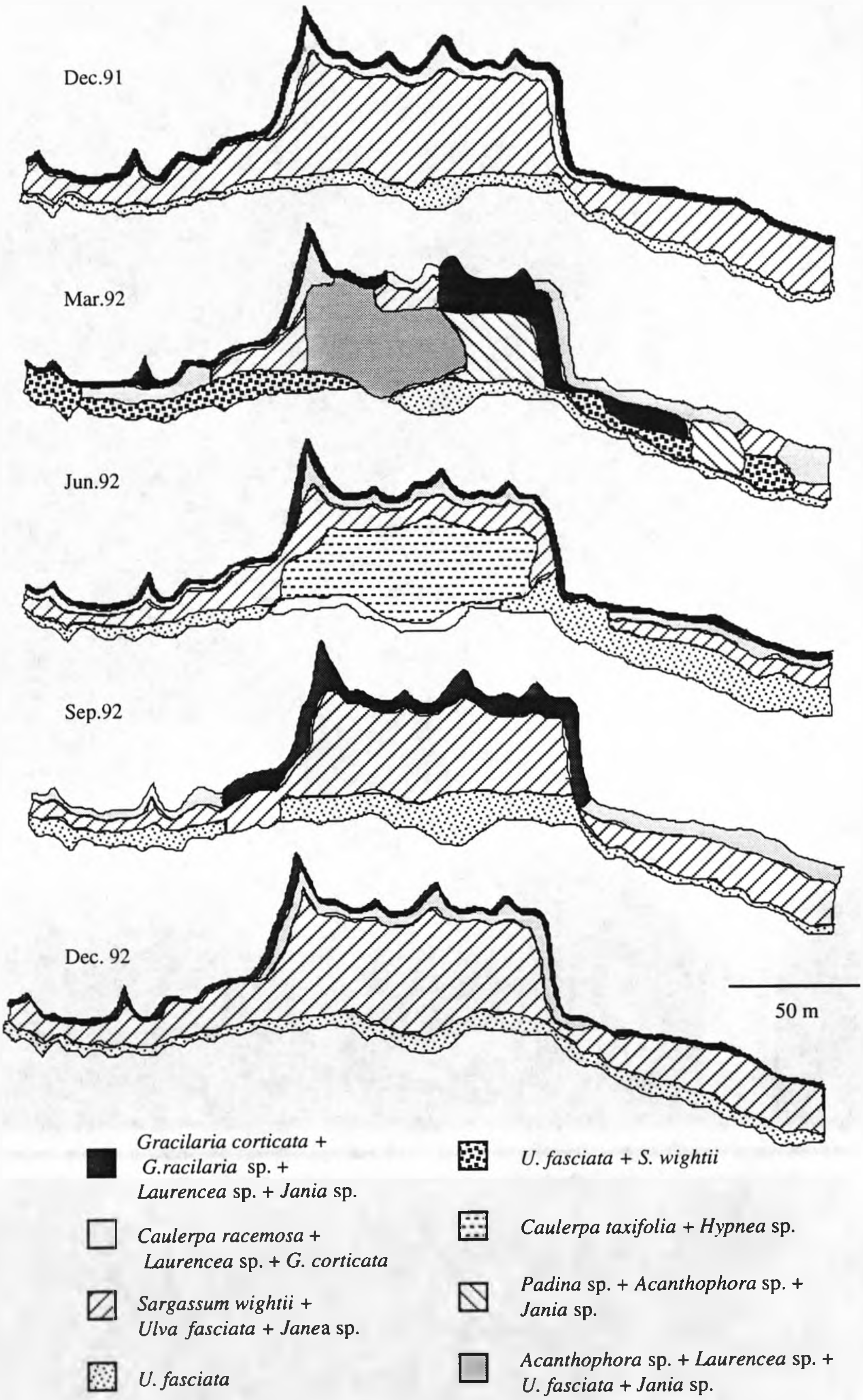

Fig. 9. 4 Maps showing the seasonal distribution of seaweed species in different quarters of the year from Dec. 1991 to Dec. 1992 at Hikkaduwa reef (upper side of each map is the seaward side).

At Beruwala *Gelidium* sp. appeared with smaller patches in December 1991 and in June it appeared to be spread around half of the reef and by September it covered about two thirds of the reef (Fig. 9.3). In December 1992 the same species had decreased to a small patch and the *Sargassum* plants became dominant. *Padina* species showed a distinct patch in December 1991 and by March *Acanthophora* species appeared in between these patches. However this species disappeared in June and September and appeared again in December 1992 (Fig. 9.3).

At Hikkaduwa, *Sargassum* sp. seemed to be dominant in two quarters of the year (Fig.9.4). A comparatively large patch of *Acanthophora* mixed with other species appeared in March and it disappeared in other quarters of the year. An extensive patch of *Caulerpa taxifolia* mixed with a little *Hypnea* sp. appeared in June at Hikkaduwa but was replaced by *Sargassum* sp. by September and December. *Ulva fasciata* seemed to be dominant in the shoreward side of the reef in most of the months (Fig. 9.4).

At Tangalle also *Sargassum* spp. seemed to be occurred throughout the year (Fig. 9.5). However, in March several patches of *Caulerpa racemosa* appeared on the seaward side of the reef. These patches extended to the middle of the reef by June. A wide stretch of the shoreward side of the reef appeared with *Chaetomorpha* sp. in June and it was replaced by *Ulva* sp. in September (Fig. 9.5).

At Rekewa in December 1991 three quarters of the reef was covered with *Sargassum* plants and the other parts mostly with *Ulva* sp. (Fig. 9.6). However, most of the *Sargassum* and the *Ulva* sp. disappeared and the reef seemed to be almost bare in March. In June small *Ulva* plants started appearing on this bare reef area. Part of this *Ulva* bed was replaced by *Sargassum* sp. by September and it was almost completely

Plate 9.5. The sampled reef area at Tangalle.

Plate 9.6. A closer view of the intertidal reef area at Tangalle.

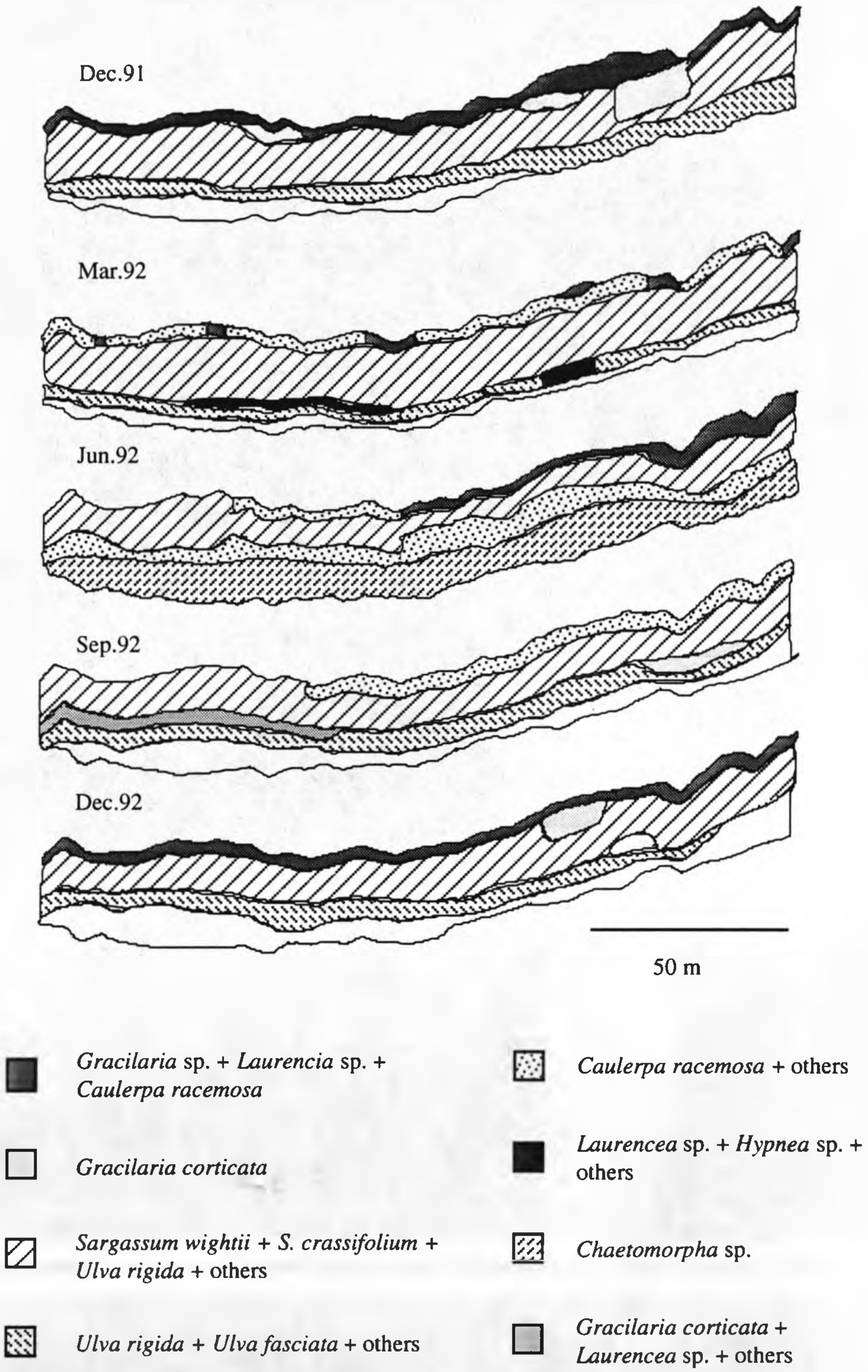

Fig. 9. 5 Maps showing the seasonal distribution of different seaweed species in different quarters of the year from Dec. 1991 to Dec. 1992 at Tangalle reef (upper side of each map is the seaward side).

Plate 9.7. The sampled reef area at Rekewa.

Plate 9.8. A closer view of the reef at Rekewa, showing the length of a *Sargassum* plant.

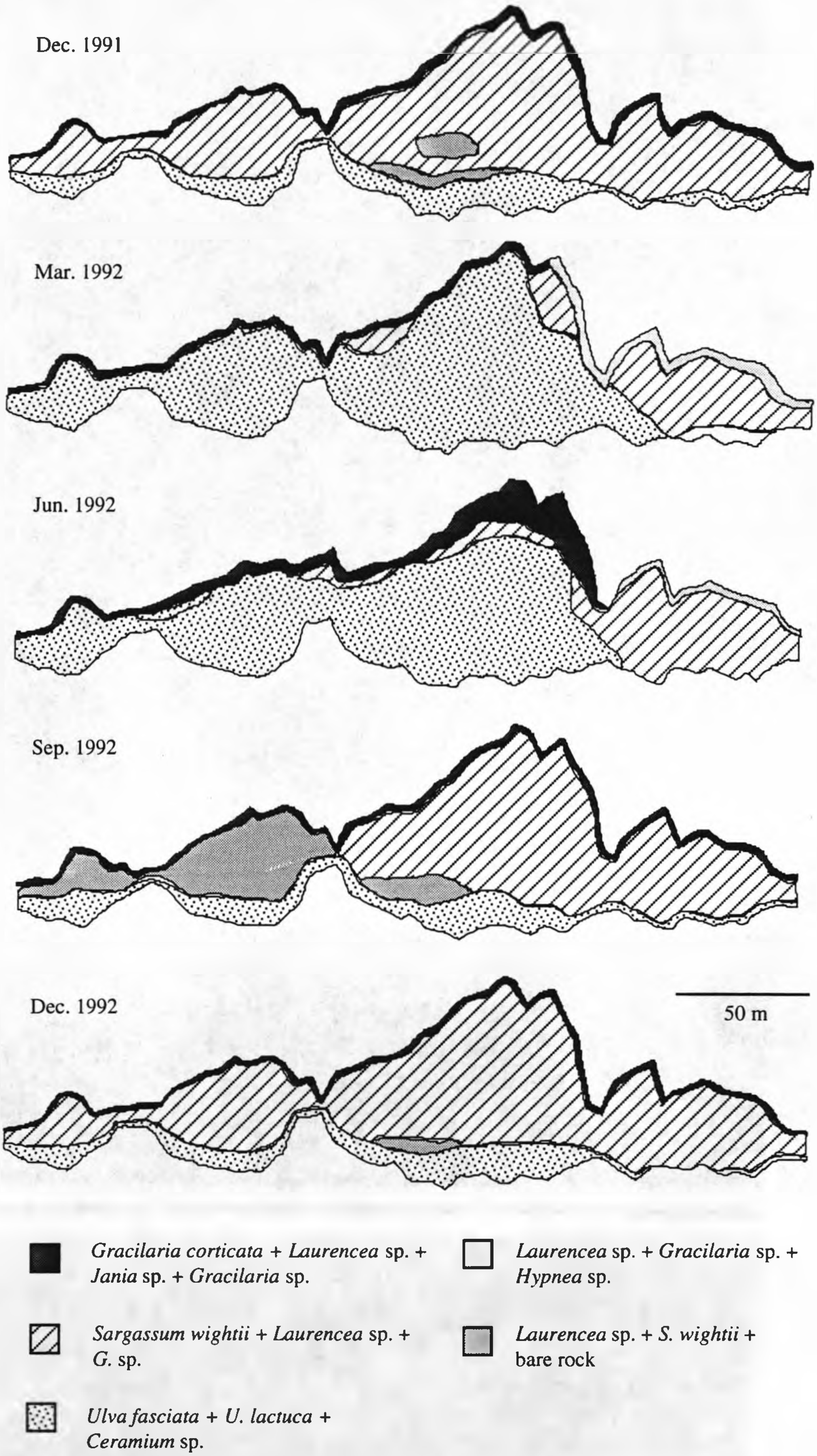

Fig. 9.6 Maps showing the seasonal distribution of seaweed species in different quarters of the year from Dec. 1991 to Dec. 1992 at Rekewa reef (upper side of each map is the seaward side).

replaced by *Sargassum* by December leaving a narrow stretch of *Ulva* sp. on the shoreward side.

9.3.3 Seasonal variation in seaweed biomass on the four reef areas

Wilcoxon paired statistical tests (Zar, 1984) showed that the abundance of almost all major seaweeds at the four sampled reefs was significantly different in different quarters of the year (Tables 9.3-9.6). All the species showed an insignificant difference between the two December months. Figures 9.7-9.14 illustrate the seasonal variation of mean dry biomass of eight seaweed species in four different reef areas. The standard errors of these figures were not calculated due to the number of zeros incorporated with the absence of several species in all the quadrats. However, these figures were drawn to find out the variation of mean dry biomass in different quarters of the year. Seasonal variation of mean dry weights per 0.25 m^2 of all the seaweed species found in different reef areas are given in Appendices 1-IV. *Sargassum wightii* showed its maximum abundance in December and the lowest in March in all the reefs (Fig. 9.7). However the highest mean dry biomass of *S. wightii* was observed in Rekewa reef. *Ulva fasciata* thrived better in September in all the reefs except Beruwala where this species was absent (Fig. 9.8). It showed small peaks in March at Hikkaduwa and Tangalle. At Rekewa it had completely disappeared in March. A high population of limpets were also observed at Rekewa reef during most of the months.

Gracilaria corticata did not show a clear pattern of variation in mean dry biomass on all the reefs (Fig.9.9). However, it showed high peaks in the two December months at Tangalle. It was also low in June at Rekewa and at Hikkaduwa (Fig. 9.9). At Beruwala it showed a peak

Sargassum ilicifolium

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	***			
Jun.92		***		
Sep.92			NS	
Dec.92	NS			NS

Gelidium sp.

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	NS			
Jun.92		**		
Sep.92			***	
Dec.92	NS			***

Table 9.3 The significant difference in Wilcoxon analysis of dry weight of quadrats in different zones of the above species in different quarters of the year at Beruwala reef. (Significance: * - $p \leq 0.05$, ** - $p \leq 0.01$, *** - $p \leq 0.001$, NS = not significant)

Sargassum wightii

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	**			
Jun.92		***		
Sep.92			NS	
Dec.92	NS			NS

Gracilaria corticata

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	NS			
Jun.92		*		
Sep.92			*	
Dec.92	NS			NS

Ulva fasciata

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	**			
Jun.92		NS		
Sep.92			***	
Dec.92	NS			***

Table 9.4. The significant difference in Wilcoxon analysis of the abundance of above species at Hikkaduwa reef during different quarters of the year. (Significance : *- $p \leq 0.05$, **- $p \leq 0.01$, ***- $p \leq 0.001$, NS = not significant)

Sargassum wightii

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	***			
Jun.92		***		
Sep.92			NS	
Dec.92	NS			***

Gracilaria corticata

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	***			
Jun.92		NS		
Sep.92			NS	
Dec.92	NS			***

Caulerpa racemosa

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	***			
Jun.92		*		
Sep.92			**	
Dec.92	NS			*

Table 9.5. The significant difference in Wilcoxon analysis of dry weight in quadrats in different zones of the above species during different quarters of the year at Tangalle reef. (Significance: *- $p \leq 0.05$, **- $p \leq 0.01$, ***- $p \leq 0.001$, NS = not significant)

Sargassum wightii

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	***			
Jun.92		***		
Sep.92			***	***
Dec.92	NS			

Ulva fasciata

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	***			
Jun.92		***		
Sep.92			***	
Dec.92	NS			***

Gracilaria corticata

	Dec.91	Mar.92	Jun.92	Sep.92
Mar.92	*			
Jun.92		**		
Sep.92			**	
Dec.92	NS			*

Table 9. 6. The significant difference in Wilcoxon analysis of dry weight in quadrats in different zones of the above species during different quarters of the year at Rekewa reef. (Significance: * - $p \leq 0.05$, ** - $p \leq 0.01$, *** - $p \leq 0.001$, NS = not significant)

in March.

Caulerpa racemosa showed a high peak in March and June at Tangalle and it was almost absent in December (Fig. 9.10). A peak biomass of this species was observed in March at Beruwala. At Hikkaduwa a high biomass of *C. racemosa* was observed in December while it was completely absent in September (Fig. 9.10).

A peak biomass of *Laurencia* sp. was observed in June at Rekewa and in September at the other three reefs (Fig. 9.11). *Gelidium* sp. appeared only at Beruwala with a peak biomass in September (Fig.9.12). It was low in December and March (Fig. 9.12).

Hypnea sp. showed a peak biomass in March at Tangalle and at Rekewa (Fig. 9.13). At Beruwala and at Hikkaduwa it showed peak biomasses in June while it showed low biomasses in December on all the reefs (Fig.9.13). *Padina* sp. appeared only at Beruwala and at Hikkaduwa (Fig.9.14). At Beruwala it showed a peak in the two December months while at Hikkaduwa it appeared only in March (Fig.9.14). *Acanthophora* sp. was also recorded only at Beruwala and Hikkaduwa. The peak biomass of *Acanthophora* was in March at both reef areas (see Appendix 1 & II). *Ceramium* sp. also appeared only at the above two sites and it showed peak biomass in June on both reefs.

Figures 9.15-9.18 show the seasonal variation of mean dry biomass (g/ (0.25m^2) of green, red, brown and "other" algae in four different reef areas. Brown seaweeds achieved the high biomass in all the reefs except Beruwala where the red seaweeds achieved the highest biomass. A high biomass of "other" species were observed at Beruwala and Hikkaduwa (Figs. 9.15-9.16). *Valoniopsis patchynema* and *Chaetomorpha* species occurred abundantly at these two sites throughout the year were considered together as "others".

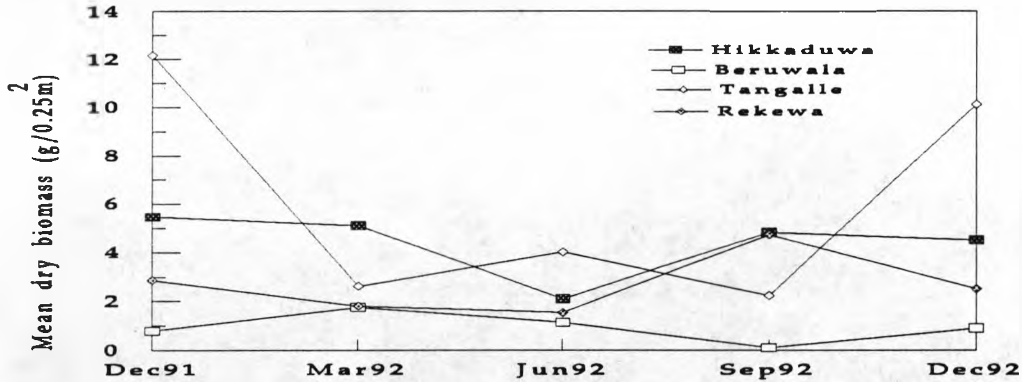

Fig.9.9 Seasonal variation of mean dry biomass of *Gracilaria corticata* on four different reefs.

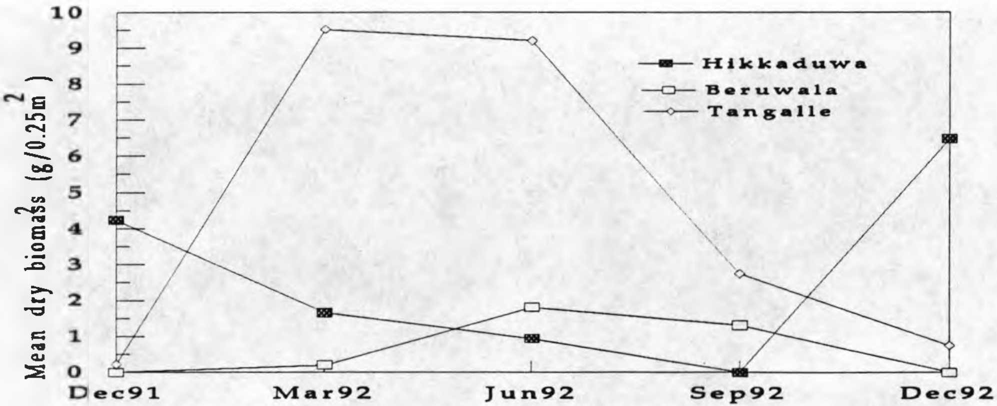

Fig.9.10 Seasonal variation of mean dry biomass of *Caulerpa racemosa* on different reefs.

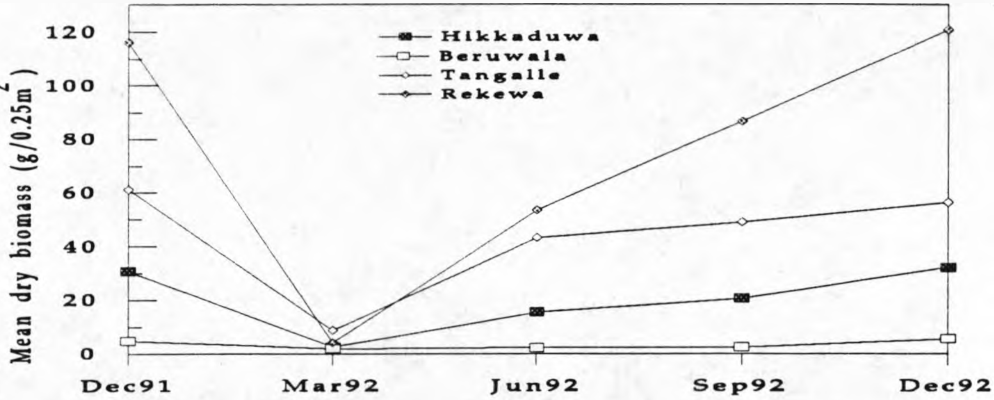

Fig.9.7 Seasonal variation of mean dry biomass of *Sargassum wightii* on four different reef areas.

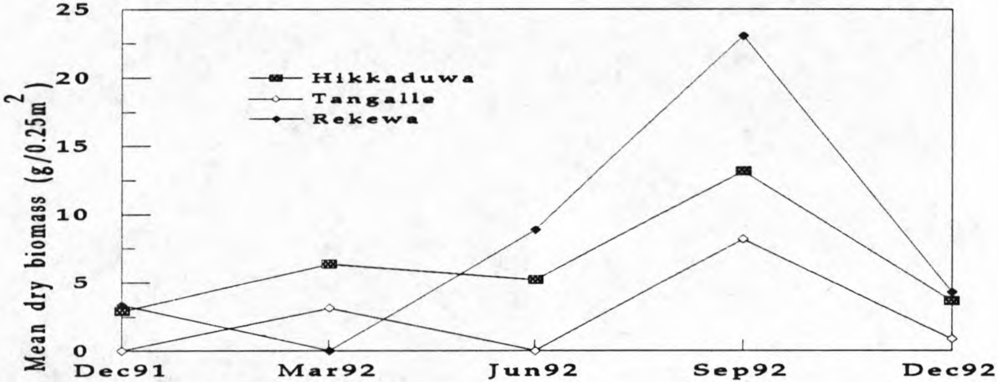

Fig.9.8 Seasonal variation of mean dry biomass of *Ulva fasciata* on four different reefs.

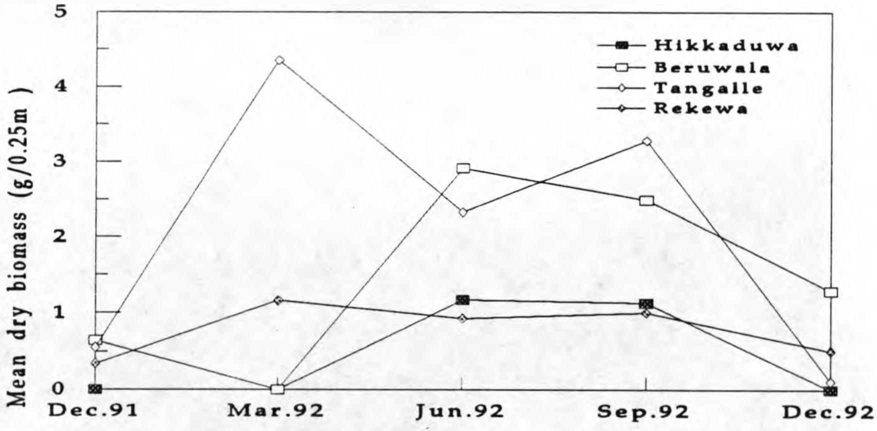

Fig.9.13 Seasonal variation of mean dry biomass of *Hypnea* sp. on four reefs.

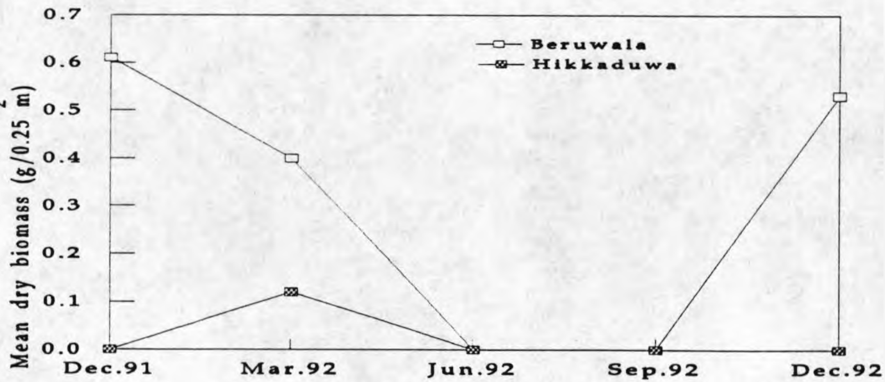

Fig.9.14 Seasonal variation of mean dry biomass of *Padina* sp. on two reefs.

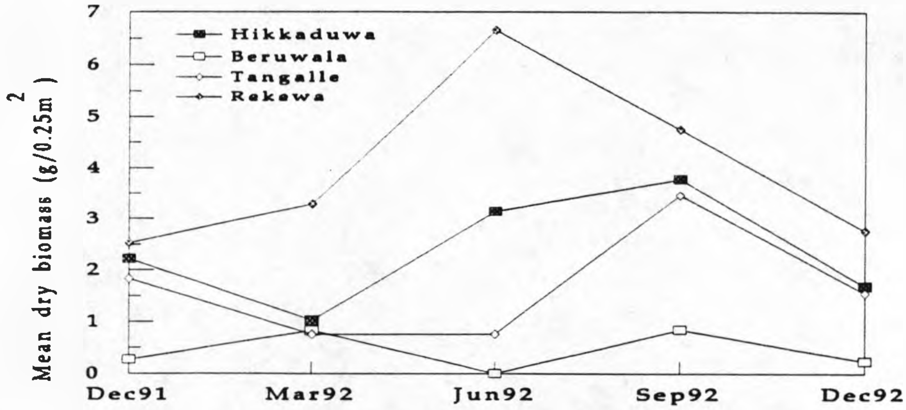

Fig.9.11 Seasonal variation of mean dry biomass of *Laurencea sp.* on four different reefs.

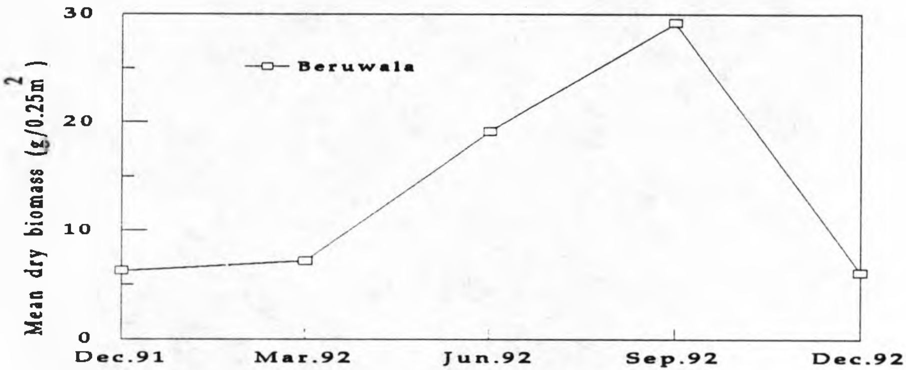

Fig.9.12 Seasonal variation of mean dry biomass of in *Gelidium* sp. on Beruwala reef.

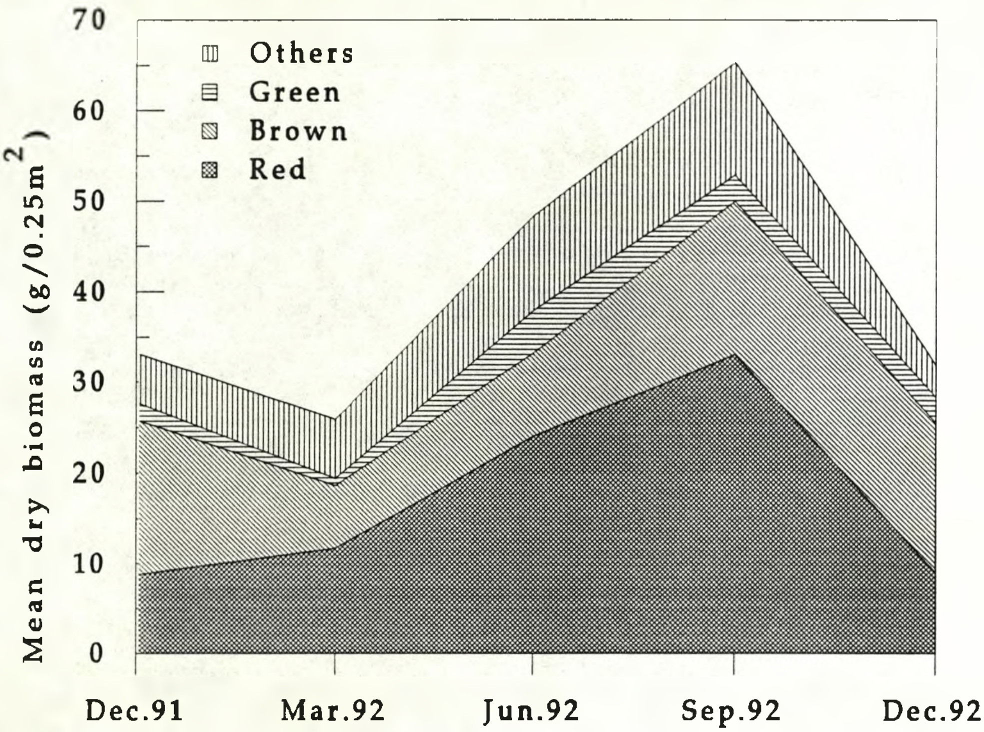

Fig.9.15 Seasonal variation of mean dry biomass of different seaweeds at Beruwala.

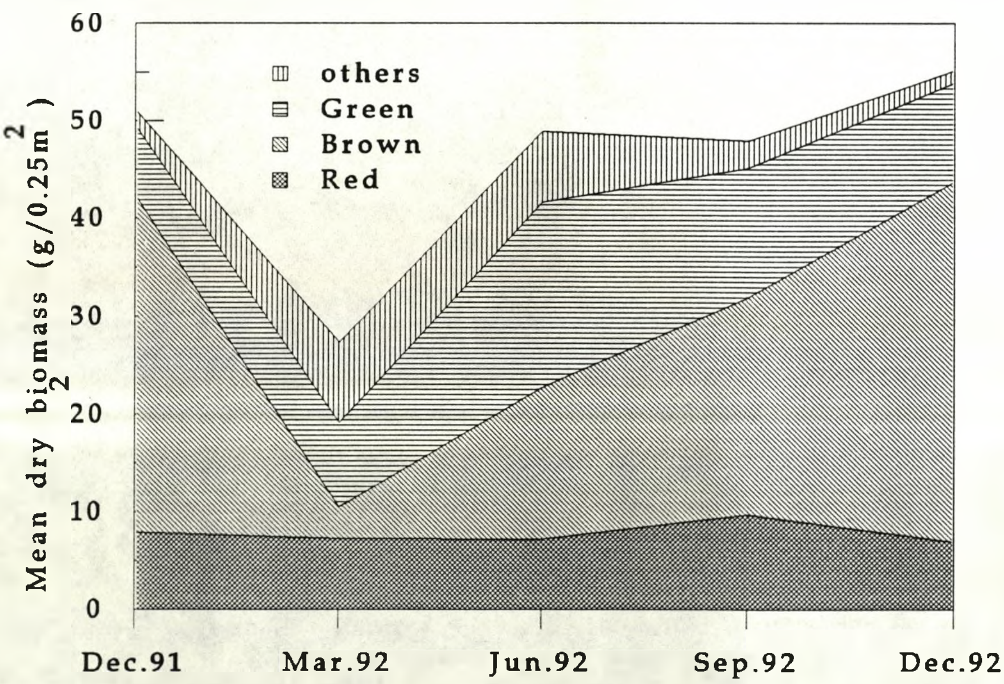

Fig.9.16 Seasonal variation of mean dry biomass of different seaweeds at Hikkaduwa.

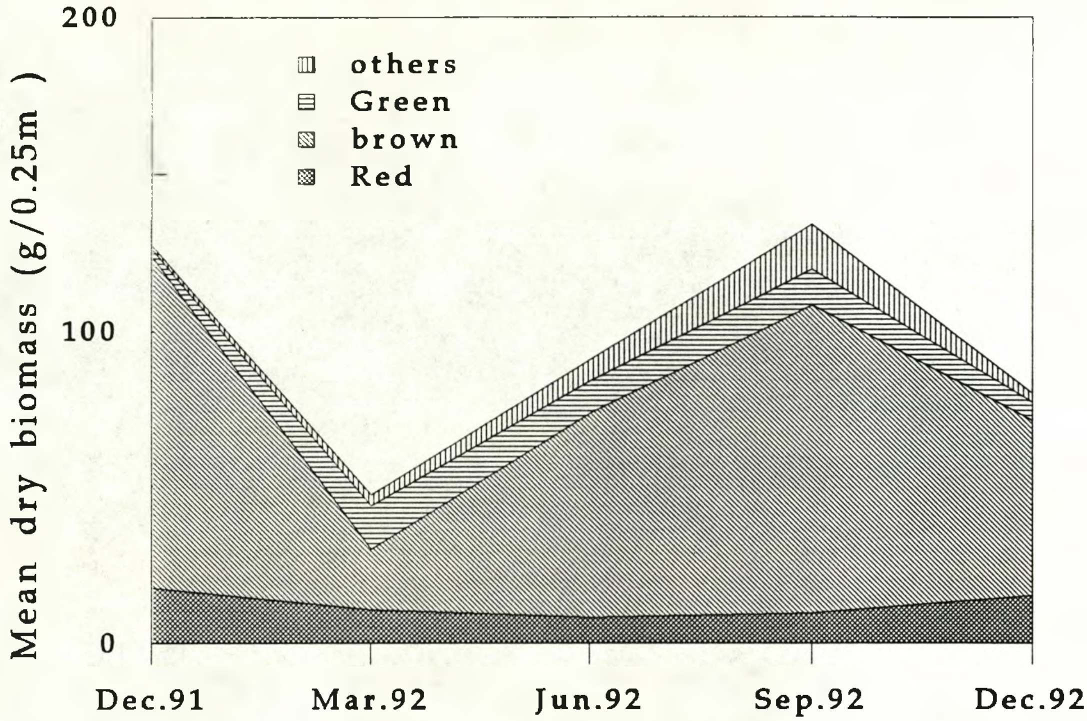

Fig.9.17 Seasonal variation of mean dry biomass of different seaweeds at Tangalle.

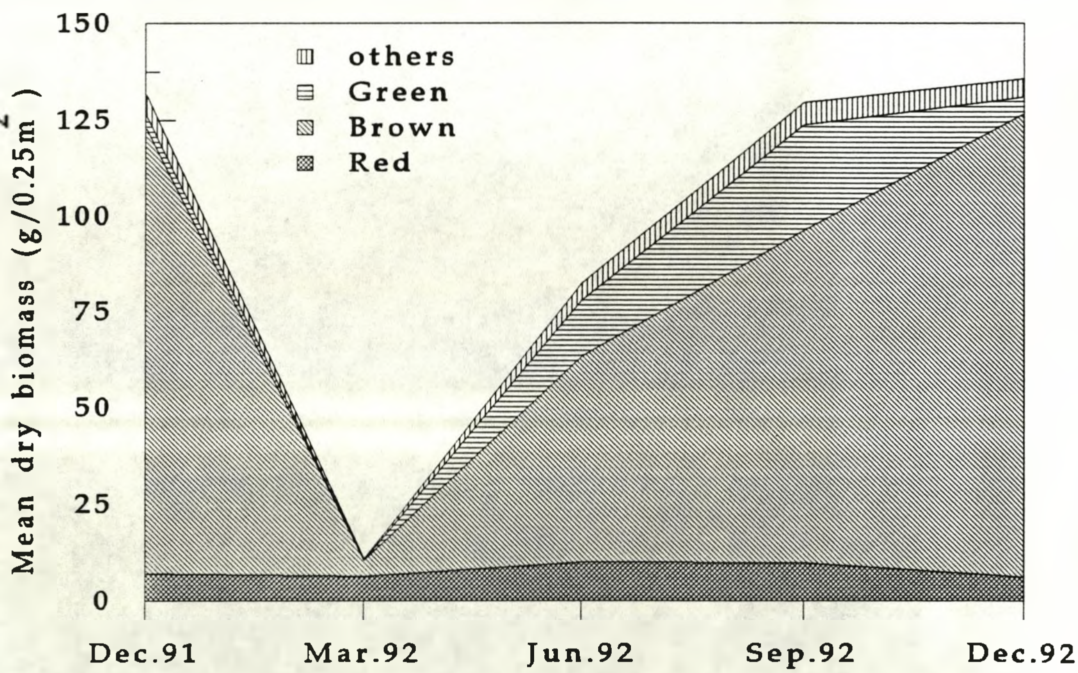

Fig.9.18 Seasonal variation of mean dry biomass of different seaweeds at Rekewa reef.

9.3.4 Maximum biomass attained by the major seaweed species and assessment of potential crop

Tables 9.7-9.10 show the total dry biomass (kg) of different seaweed species at all four reefs in different seasons of the year. The total biomass of different species in each reef area was calculated by estimating the mean dry biomass/m^2 of each species in each zone. This was multiplied by the area of each zone. *Sargassum wightii* showed the maximum biomass at Rekewa, Tangalle and Hikkaduwa while *S. ilicifolium* showed the maximum biomass at Beruwala. *Gelidium* which was recorded only at Beruwala, showed a comparatively high biomass in September (Table 9.7). At Hikkaduwa *Caulerpa taxifolia* showed a fairly high biomass in September (table 9.8). The biomass of *Ulva fasciata* was highest at Rekewa in September (Table 9.10).

Fig.9.19 illustrated the maximum dry biomass of different species in 100 meter shore line at all four reef areas. *Sargassum* species achieved the maximum dry biomass/100 m at Rekewa reef.

The estimated biomass of three different *Sargassum* species per 100 m shore line were demonstrated for each sampled reef (Table 9.11). This was estimated by dividing the total dry biomass by the length of each reef area. The total standing crop of different species was estimated by using the biomass/100 m in different reef areas. Estimates from Chilaw area to Beruwala were based on biomass/ 100 m at Beruwala reef. Estimates from Hikkaduwa to Galle (Fig. 9.1) were based on biomass at Hikkaduwa. From Koggala to Tangalle total standing crops were based on Tangalle biomass while Tangalle to Rekewa area were based on biomass at Rekewa.

Total standing crop of *Sargassum* species and five other seaweed

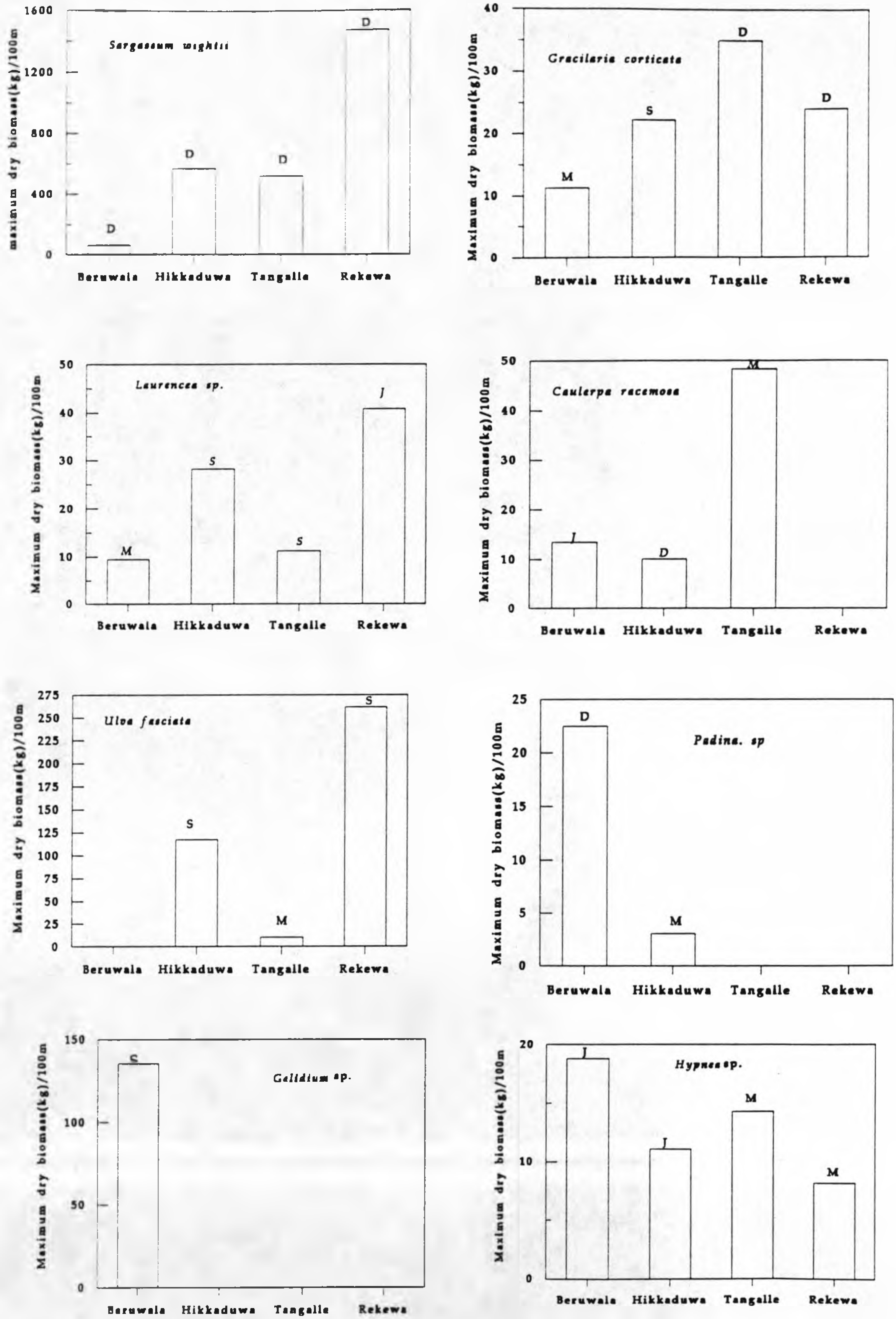

Fig.9.19 Maximum dry biomass of the above species in 100 metre reef area of the above sites in different months (D= December, M= March, J= June, S= September).

Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Gelidium sp.	349.01	331.42	515.32	692.52	298.79
Laurencia sp.	15.3	47.3	-	41.8	18.72
Gracilaria corticata	37.99	56.26	47.81	-	31.84
Sargassum ilicifolium	652.3	246	316	461	853
Sargassum wightii	297.54	215	237	242.6	322.84
Hypnea sp.	26	-	93.9	73.81	38.57
Turbinaria sp.	127.4	165.73	183	270	86.5
Padina sp.	112.44	88.64	-	-	110.68
Ulva lactuca	58.4	41.8	86.65	-	51
Ulva fenestrata	19.8	12.5	-	79.52	12.07
Caulerpa racemosa	-	14.5	67.37	58.74	-
Caulerpa taxifolia	-	-	248	-	-
Acanthophora sp.	18.4	31	12.4	26.56	21
Ceramium sp.	-	-	11.56	15.5	-
Others	47.8	62.91	78.54	96.51	35.47
Total	1762.3	1313.0	1897.5	2058.6	1880.4

Table 9. 7. Seasonal variation of total dry biomass (kg) of different seaweed species at Beruwala reef. This was estimated by using the dry weights in all the quadrats on the reef at every sampling month.

Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Gracilaria corticata	65.57	50.25	48.66	66.80	61.44
Gracilaria sp.	7.13	12.68	28.73	-	10.43
Laurencia sp.	24.03	13.5	37.34	84.74	29.8
Sargassum crassifolium	214.58	18.72	156.65	164	280
Sargassum wightii	1643	67.17	1275	1315	1707.8
Ulva fenestrata	-	-	-	24.40	4.12
Ulva fasciata	99.69	110.48	106.91	352.11	112.57
Caulerpa racemosa	24.91	18.23	15.69	-	30.47
Caulerpa taxifolia	-	14.73	540.28	-	-
Ceramium sp.	-	-	3.18	-	-
Acanthophora sp.	-	12.47	-	-	-
Hypnea sp.	-	-	33.28	18.7	-
Padina sp.	-	15.52	-	-	-
Jania sp.	50.86	76.62	47.03	21.46	22.65
Others	128.12	214.35	186.79	97.84	93.14
Total	2257.8	624.7	2479.5	2145	2352.4

Table 9.8. Seasonal variation of total dry biomass (kg) of different species at Hikkaduwa reef. This was estimated by using the dry weights in all the quadrats on the reef at every sampling month.

Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Gracilaria corticata	70.17	6.41	11.28	4.4	62.53
Gracilaria sp.	39.26	4.41	33.7	38.63	21.42
Laurencia sp.	10.45	4.86	15.1	22.4	13.46
Caulerpa racemosa	4.26	96.45	72.33	27.5	8.97
Sargassum crassifolium	291.1	153.6	-	191.1	297.8
Sargassum wightii	1034	256.5	723	760	986
Ulva rigida	40.24	14.51	56.41	6.75	16.44
Ulva fasciata	-	20.63	-	41.0	-
Hypnea sp.	15.72	28.6	20.59	12.54	9.02
Others	21.95	18.57	114.0	118.76	40.36
Total	1527.1	604.56	1046.4	1223.1	1456

Table 9.9. Seasonal variation of dry biomass (kg) of seaweeds at Tangalle reef. This was estimated by using the dry weights in all the quadrats on the reef at every sampling month.

Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Gracilaria corticata	71.99	18.8	51.58	15.72	68.6
Gracilaria sp.	7.43	7.76	-	-	6.45
Laurencia sp.	75.89	78.62	122.37	80.46	80.54
Ulva fasciata	132.58	-	363.48	783.79	170.38
Ulva lactuca	-	-	289.64	125.69	-
Sargassum wightii	4230	195.95	460.55	2609	4415
Hypnea sp.	5.13	24.54	16.89	20.13	7.81
Ceramium sp.	13.48	-	8.53	12.14	15.78
Others	124.33	23.13	248.57	304.08	192.6
Total	4660.8	348.8	1561.6	3951	4957.1

Table 9. 10. Seasonal variation of dry biomass (kg) of seaweeds at Rekewa reef. This was estimated by using the dry weights in all the quadrats on the reef at every sampling month.

Sampling site	Beruwala	Hikkaduwa	Tangalle	Rekewa
Dry biomass of *S. wightii* (kg)	322.8	1707.8	1034	4415
Dry biomass of *S. crassifolium* (kg)	-	280	297.5	-
Dry biomass of *S. ilicifolium* (kg)	853	-	-	-
Approximate length of the reef (m)	500	300	200	310
Total dry biomass/100m (kg)	235	663	666	1425

Table 9.11 Maximum total dry biomass of *Sargassum* species (kg) per 100 metres at all four sampled reefs during the month of December 1991 or 1992.

Surveyed reef areas	Estimated length of the reefs (m)	Dry biomass of *Sargassum* sp.(kg) /100 m	Total dry biomass in each area (t)
Chilaw to Beruwala	4465	235	10.5
Hikkaduwa to Galle	5435	663	36.0
Unawatuna to Tangalle	4645	666	30.9
Tangalle to Rekewa	1450	1425	20.4
Total	15995	-	97.8

Table 9.12 Biomass of *Sargassum* species in metric tonnes (t) during December (1991/1992) in different parts of the western and the south-west coast of Sri Lanka.

Reef area	*Ulva* sp. (kg)	*Gracilaria corticata* (kg)	*Gelidium* sp. (kg)	*Caulerpa* sp. (kg)	*Hypnea* sp. (kg)
Beruwala	33.2	11.2	138.5	63.0	18.7
Hikkaduwa	121.4	21.5	-	184.1	10.7
Tangalle	48.7	35.0	-	48.2	14.3
Rekewa	357.8	23.9	-	-	8.18

Table 9.13 Maximum total dry biomass (kg) of the above species per 100 metre shore line in different reef areas (the months which showed the maximum dry biomass of different species were taken into account).

Surveyed reef areas	*Ulva* sp.	*Gracilaria corticata*	*Gelidium* sp.	*Caulerpa* sp.	*Hypnea* sp.
Chilaw to Beruwala (kg)	1482.3	500	1504.0	2812.9	834.9
Hikkaduwa to Galle (kg)	6598.0	1168.5	-	10005.8	581.5
Unawatuna to Tangalle (kg)	2262.1	1625.7	-	2238.8	664.2
Tangalle to Rekewa (kg)	5188.1	346.5	-	-	118.6
Total (t)	15.5	3.6	1.5	15.0	2.19

Table 9.14 The dry standing crops of the above species in different reef areas (kg) and the total standing crop (t) of the each species (only the reef areas around Beruwala were considered to estimate the standing crop of *Gelidium* sp.).

species are given in Tables 9.12-9.14. All the *Sargassum* species along the west and the south-west coast of Sri Lanka (18.7 km of reef area) achieved a total dry biomass of 98 t (metric tonnes) (Table 9.12). The highest dry biomass of *Sargassum* species was observed from the areas between Hikkaduwa to Galle (Table 9.12).

The estimated total dry standing crops of five common seaweed species are shown in Table 9.13. Among these the high standing crops were achieved by *Ulva* and *Caulerpa* species (15.5 and 15 t respectively). The species of *Hypnea* achieved the lowest sanding crop (2.19 t) compared to those estimated.

9.4 DISCUSSION

Climatic factors seem to be the determining factor in the seasonal variation of algal biomass (Payri, 1987). In Sri Lanka as in many tropical countries the variation in climatic factors is relatively low compared to a temperate country. However Sri Lanka has a seasonal reversal of prevailing winds characterised by the two monsoons, one blowing from the north-east for approximately six months (October to March) and the other blowing from the south-west from May to September. These monsoonal winds affect the variations of tidal movements. The west coast of Sri lanka receives the south-west monsoon which prevails from May to September. During monsoonal winds relatively high waves break on the edge of the reefs, preventing desiccation and perhaps also bringing water with nutrients to the intertidal areas (Durairatnam, 1961). This may be the reason for the high biomass observed in various species during June and September. The north-east monsoons occur during November to February and it does not cause much effect to the west coast. It was observed that during March the intertidal areas of the west coast get mostly dried up due to the low tides and the low water motions. This may be the cause for the low abundance of biomass of various species during March (Fig.9.7 to 9.14). It was also observed that the inner edge of most reefs (landward side) became desiccated during March. However the complete disappearance of the algal population from the major part of the Rekewa reef in March may have been due to the grazing by limpets which was observed in December. It was observed that there were around 20-30 limpets per square meter area. It was also observed that there were small empty patches in between the *Sargassum* zone in December 1991 which may have been damaged by the invasion of limpets.

Durairatnam (1961) pointed out that in Sri Lanka during the south-west monsoon period most of the *Sargassum* blades detach from the plants and this would reduce the biomass. It is well known that most of the *Sargassum* plants shed their axes before reproduction. This was also observed in *S. duplicatum* on the reefs in Guam by Tsuda (1971). This may explain the low biomass of *Sargassum* in June compared to September in all the reefs in the present study. During this study it was observed that on most of the reefs the *Sargassum* plants occur in the middle and upper middle zone became pale and unhealthy during March. This would have been due to the low water movements and long hours of exposure to the sun. Misra (1966) reported that high temperatures and sun exposure were responsible for maxima and minima in the development of the Phaeophyta populations on the Indian coast. The low biomass of *Sargassum* sp. in March in the present study may also be due to these reasons. It was also explained by Krishnamurthy (1967) that the lack of algae found on tropical intertidal shores may be due to intense insolation.

However obtaining biomasses in both December months which are not significantly different (Table 9.1) suggests that there would be one growth cycle for most of the species each year. This was also shown by Svedelius (1906) in Sri Lanka and Conover (1958) who agreed that there is only one period of growth in tropical regions. Obtaining high biomasses of *Sargassum* species in December on all the reefs demonstrated that December would be suitable to harvest this species. In addition December month was also chosen by Durairatnam (1966) for harvesting *Sargassum* plants from the west coast of Sri Lanka. However it should also be noticed that the present survey was done only during four months of the year and the high biomass of *Sargassum* may have been occurred during

September to February.

In the present study *Sargassum* species showed the greatest biomass on all the reefs. Rekewa reef achieved the maximum biomass of *Sargassum* sp. per 100 m (1425 kg) compared to other surveyed reefs. This could have been the right level of the Rekewa reef for the growth of *Sargassum* plants. This would have influenced the biomass of *Sargassum* plants on this reef. On all the other reefs, since they are slanted towards the outer part, the *Sargassum* sp. occurred only at the middle and the upper middle part of them. In addition Rekewa is situated in the south coast which is slightly sheltered from the south-west monsoonal winds which could damage the *Sargassum* plants in other reefs. It was also observed that the *Sargassum* plants at Rekewa and other reef areas showed a distinct difference of damage during the south-west monsoon period.

The mean dry biomass of *Sargassum wightii* in Rekewa reef was 450 g/m^2. However the approximate wet weight (2.2 kg $/m^2$) in Rekewa would be much higher than the recorded wet weight of *Sargassum* sp. (450 g/m^2) in Central Buleji area in Karachi coast (Saifullah, 1973), the standing crop (1212 g/m^2) obtained for *Sargassum* sp. in the *Laminaria*-bed of Otaru city, Hokkaido, (Sakai, 1977) and the standing crop (1428 g/m^2) obtained for *Sargassum hornschouchii* by Munda (1973) in Katarina in the Northern Adriatic. However this biomass is lower than the fresh biomass obtained for *Sargassum johnstonii* (3173 g/m^2) on the coast of Okha in India (Ohno & Mairh, 1982) and the *Sargassum* sp. (2.8-5.0 kg/m^2) recorded on the coast of Japan (Umezaki, 1974; Mukai, 1971).

Obtaining a relatively high standing crop 116.8 g/m^2 of *Gelidium* species only at Beruwala reef areas suggests that there may be some factor related to this reef area would have influenced the biomass of

Gelidium species. The hard coral reef substratum with several rock pools which are peculiar to this reef area could have influenced the growth of *Gelidium* sp which was observed only on this reef. Wells *et al.* (1989) pointed out that the substratum has a significant effect on macro-algal community structure and diversity. It was also pointed out by Desai (1967) that the *Gelidium* species in Gulf of Kutch, India are restricted to rock pools near Okha. However no work has been done on the factors which influenced the abundance of *Gelidium* sp. in tropical regions.

However, the maximum mean dry biomass of 23 g/m^2 of *Ulva fasciata* observed in Rekewa reef in September (Table 9.10) was much lower than the dry biomass observed (160 g/m^2) for *Ulva lactuca* at Ohka coast (*Ulva* bed) in India by Ohno and Mairh (1982). The low standing crops of most of the algal species in Sri Lanka may be due to the limited intertidal reef areas which have seaweeds along the coastal areas of Sri Lanka. However, it is worth estimating the available quantities of economically important species even in limited areas for small scale developments. The total dry biomass of *Sargassum* species estimated during this study for the western and south-west coast of Sri Lanka (98 t) is remarkably similar to the estimate (129 t) for the same coast by Durairatnam (1966). The higher estimation of his study may be due to the addition of subtidal areas which was not considered in this study. Nevertheless his survey was carried out from Ambalangoda to Hambantota (Fig.9.2) while the present study was covered up to Rekewa on the southern coast which is about 30 km less than Durairatnam's study area. However the present study was based on more information collected systematically within one year while Durairatnam's study lasted only two months. However the total standing crop of *Sargassum* sp. observed for the western and the south-west coasts of Sri Lanka indicate that there is considerable potential for commercial harvesting.

10. REGENERATION PATTERNS OF MAJOR SEAWEEDS

10.1 INTRODUCTION

Although there is a potential to use *Sargassum* species commercially no studies has been done on the regeneration of this species in Sri Lanka. Regeneration from the holdfast after a die-back phase has been observed as a natural phenomenon exhibited by several species of *Sargassum* (Raju & Venugopal, 1971; Chauhan & Krishnamurthy, 1971; Fletcher & Fletcher, 1975; Prince & O'Neal, 1979; Ang, 1985). However, knowledge on the time period for complete regrowth and the season for regeneration are also equally important in commercial harvesting of seaweeds.

Although *Gracilaria corticata*, which is an important agarophyte, is also abundant on the south-west coast of Sri Lanka, no studies have been done on regeneration of this species. However very little work has been done on regeneration of this species in other parts of the word (Umamaheswara Rao, 1975). Similarly no regeneration studies have done on *Gelidium* sp. in Sri lanka, though it is an important species. Carter and Anderson (1985) have studied the regrowth of *Gelidium pristoides* in the eastern Cape Province of South Africa.

A knowledge of regeneration patterns of *Gelidium* sp. and *Gracilaria corticata* would be necessary for the commercial harvesting practises of these species in future.

10.2 MATERIALS AND METHODS

10.2.1 Regeneration pattern of three major seaweeds

Experimental clearances of three major seaweeds (*Sargassum wightii*, *Gelidium* sp. and *Gracilaria corticata*) were made at two reef areas at Koggala (Plate 10.1) and Beruwala (Fig.9.1). Clearances were made of *Sargassum* and *Gracilaria* species at Koggala and *Gelidium* species at Beruwala. Initial experiments which were done for the *Sargassum* species revealed that these plants gained their initial weight approximately after six months. In each area all the plants from three 0.25 m^2 quadrats were removed, scraping the rock by using a quadrat of a length of 0.5 m each side. Then all the plants were weighed separately fresh. They were also brought to the laboratory to measure the dry weight. These values were taken as initial control standing crop. 0.5 m^2 quadrats (0.71 m each side) were placed in the same places, the border areas constituting the other 0.25 m^2 were cleared and scraped, discarding the plants. Six further 0.5 m^2 quadrats within the zone were also cleared and scraped. Those areas then became the nine experimental scraped areas. Nine further 0.5 m^2 quadrats were placed within the zone and the plants cut off at 1 cm above the holdfasts. This procedure was done for all three species separately in the above areas. However (0.25 x 0.25 cm) 0.0625 m^2 quadrats were used for scraped and cut areas of *Gracilaria corticata* since those plants are smaller. A quadrat of 0.25 m^2 was used to remove the border areas of these plants. The initial experiments on *Gracilaria corticata* revealed that within 4 months the harvested plants obtained the initial weights. Therefore only six quadrats were used for cut and scraped areas for *Gracilaria corticata*.

Plate 10.1. The reef area at Koggala. Regeneration experiments of *Sargassum wightii* and *Gracilaria corticata* were conducted on this reef.

Every two months 0.25 m^2 control quadrats were sampled from an undisturbed part of the zone. Three of each scraped and cut areas were sampled by placing the 0.25 m^2 quadrats within the original 0.5 m^2, and all plants were harvested by cutting or scrapping, and collected into separate polythene bags. All the plants were preserved in 4% formalin and brought to the laboratory to measure the wet and dry weights. This process was repeated after 4 and 5 months for *Sargassum wightii* in the first harvesting experiment which was conducted from January to June. However during the second experiment which was conducted from July to December the final harvest was done after 6 months. The maximum length of the *Sargassum* plants in this reef was around 40-45 cm. Harvesting experiments were selected from the places where there was 100 % *Sargassum* cover. For *Gelidium* plants, the first two harvests were done every three months and the final harvest was done after 10 months.

10.2.2 Preliminary harvesting experiment on *Sargassum wightii*

This experiment was conducted on the reef at Hikkaduwa (Fig. 9.2) to find out the growth pattern of *Sargassum wightii* plants. Three one square meter quadrats were cleared by cutting the *Sargassum* plants 1 cm above the holdfasts in early July 1991. The regrowth of the plants was monitored by measuring the lengths of the largest plant in all three quadrats fortnightly. After 22 weeks all the plants were removed from the quadrats and measured for their lengths and weights. At the same time a one square meter control quadrat from the same area was also sampled for the lengths and weights of the *Sargassum* plants.

10.3 RESULTS

10.3.1 Harvesting experiment on *Sargassum wightii*

It was demonstrated that from January to June the cut *Sargassum wightii* plants gained the weight of the control plants in about four and a half months while the scraped plants gained the same weight in about five months (Fig.10.1 & 10.2). However during the end of second month both treatments achieved the same amount of biomass (more than 80 g dry weight) in harvested quadrats. During the second part of the year, from June to December, both took about six months to reach the control biomass (Fig.10.3 & 10.4). Table 10.1 & 10.2 indicate that the biomass of the harvested quadrats was significantly different from the control after 2 and 4 months and they were not significantly different after 5-6 months.

10.3.2 Preliminary harvesting experiment

Sargassum coverage of 85-90 % was observed in the quadrats before harvesting (cutting) at Hikkaduwa. The *Sargassum* plants in the harvested quadrats seemed to be bushier with several branches. Fig. 10.5 shows the values of mean plant lengths in every fortnight from 12th July to 15th December 1991. A correlation coefficient (r) of 0.986 was obtained by fitting a straight line to the plot. A lower correlation coefficient of 0.933 was obtained from the logarithm of length against time. Growth in length was therefore nearer to being linear than exponential. The mean relative growth rate of *Sargassum wightii* plants during this period was observed as 1.7 % day^{-1} with a linear growth rate of 0.2 cm day^{-1}. Most of the plants in the harvested quadrats were in the lower length groups (18-32

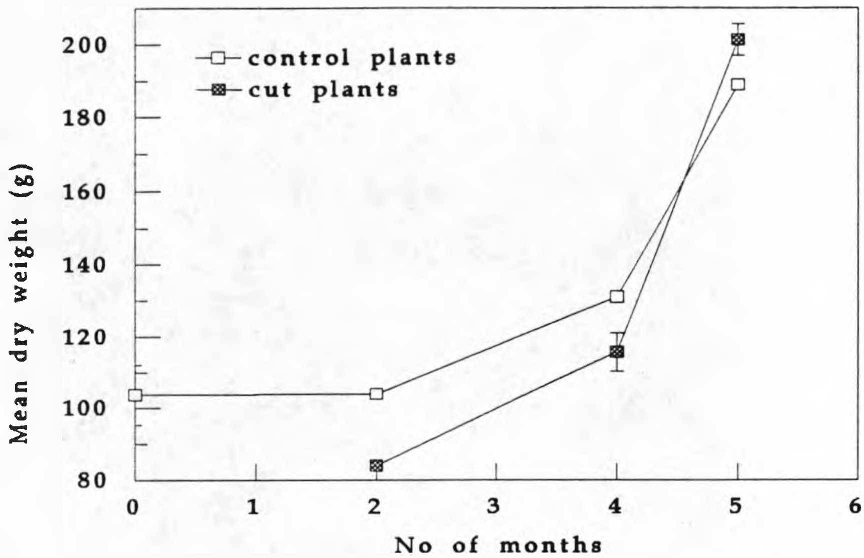

Fig.10.1 Mean dry biomass of control and cut *Sargassum wightti* plants from January to June 1992 at Koggala reef (bars = ± S.E.).

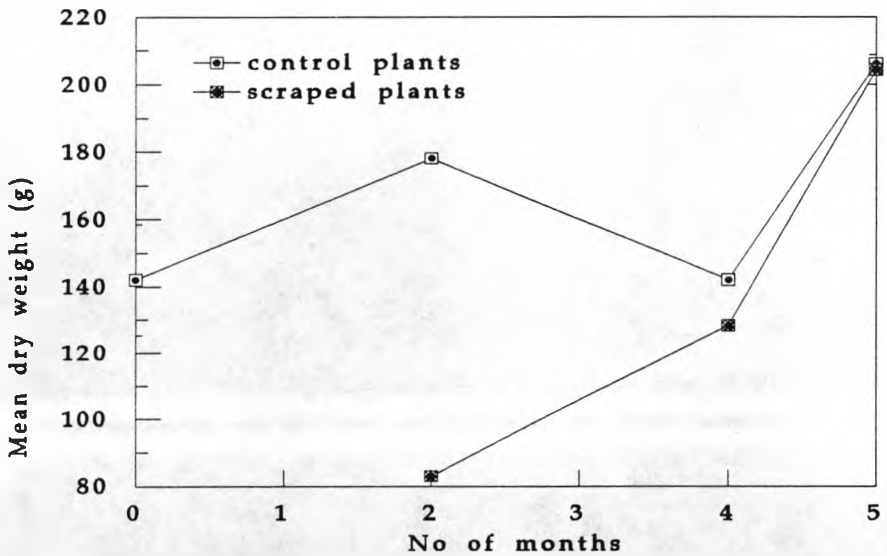

Fig.10.2 Mean dry weight of control and scraped *Sargassum* plants from January to June 1992 at Koggala reef (bars = ± S.E.).

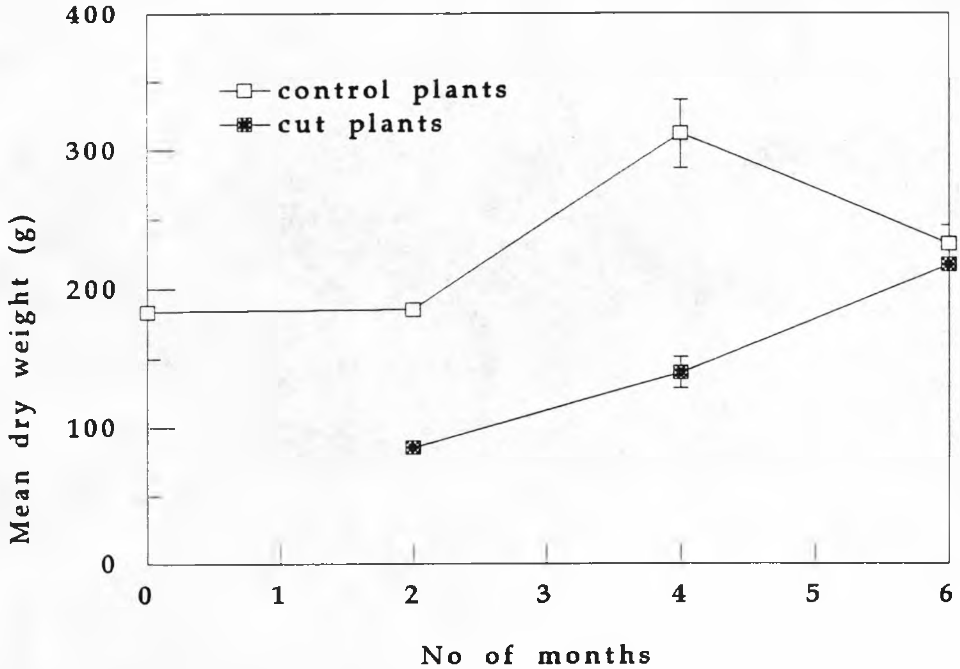

Fig.10.3 Mean dry biomass of control and cut *Sargassum wightii* plants from July to December 1992 at Koggala reef (bars = ± 1 S.E.).

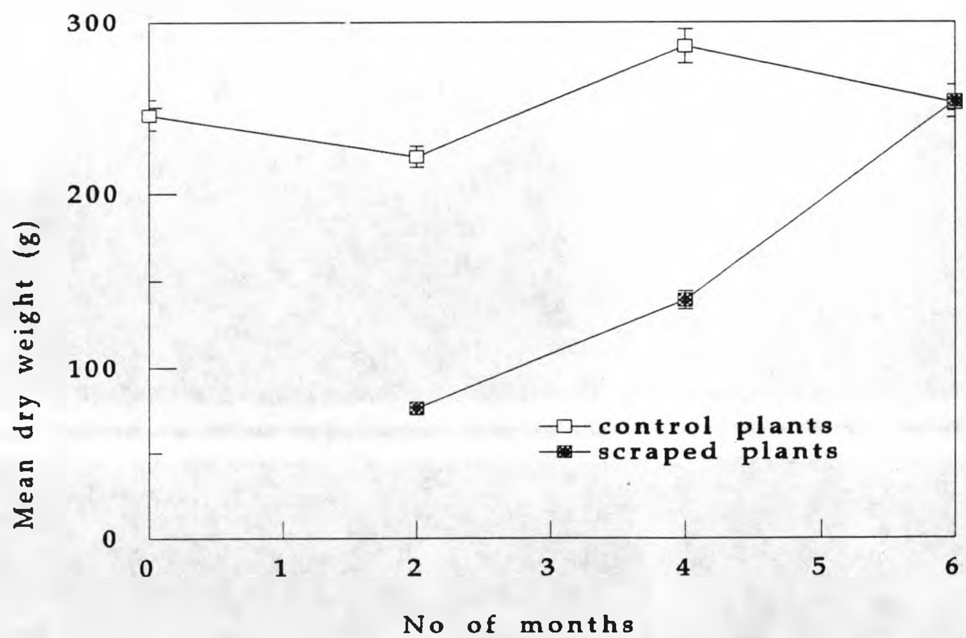

Fig.10.4 Mean dry biomass of control and scraped *Sargassum wightii* plants from July to December 1992 at Koggala reef. (bars= ±1 S.E.).

Time	DF	T value	p value
(cut x control) 2nd month	2	4.51	0.027
4th month	2	7.81	0.016
5th month	2	-0.49	0.65
(scraped x control) 2nd month	2	18.23	0.003
4th month	2	3.42	0.042
5th month	2	-0.33	0.77

Table 10.1 The t-tests results obtained in comparison of each harvest on 2nd, 4th and 5th months of the harvesting experiment on *Sargassum wightii* from 24th January to 25th June 1992.

Time	DF	T value	p value
(cut x control) 2nd month	2	18.23	0.003
4th month	2	3.42	0.042
6th month	2	-0.33	0.77
(scrape x control) 2nd month	2	8.67	0.013
4th month	2	6.86	0.021
5th month	2	1.07	0.40

Table 10.2 The t-tests results obtained in comparison of each harvest at 2nd, 4th and 6th months of the harvesting experiments on *Sargassum wightii* from 2nd July to 29th December 1992.

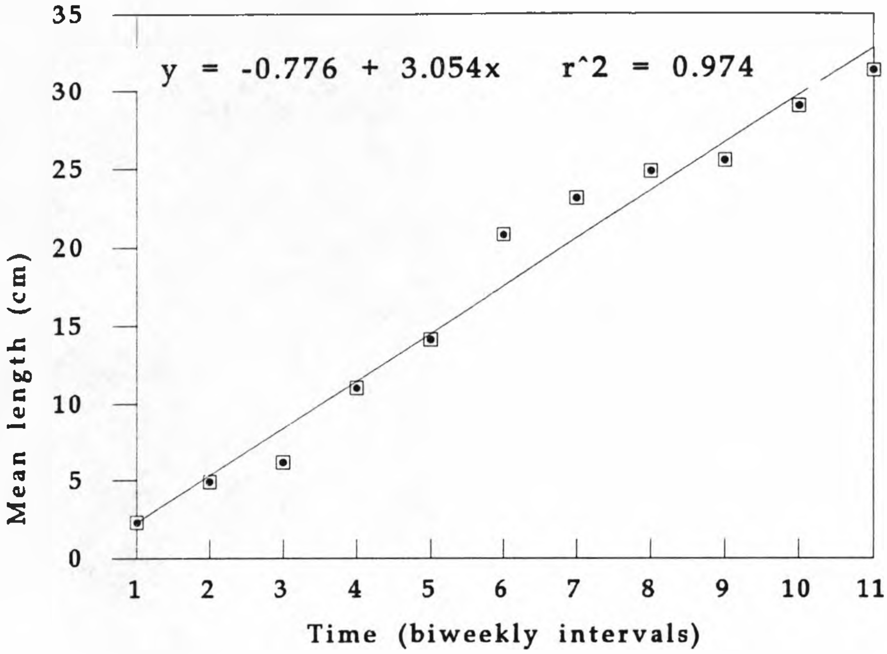

Fig.10.5 Mean length of largest plant in each of 3 quadrats with time from 12th July to 15th Dec. 1991 (the equation shows the regression coefficient, r2).

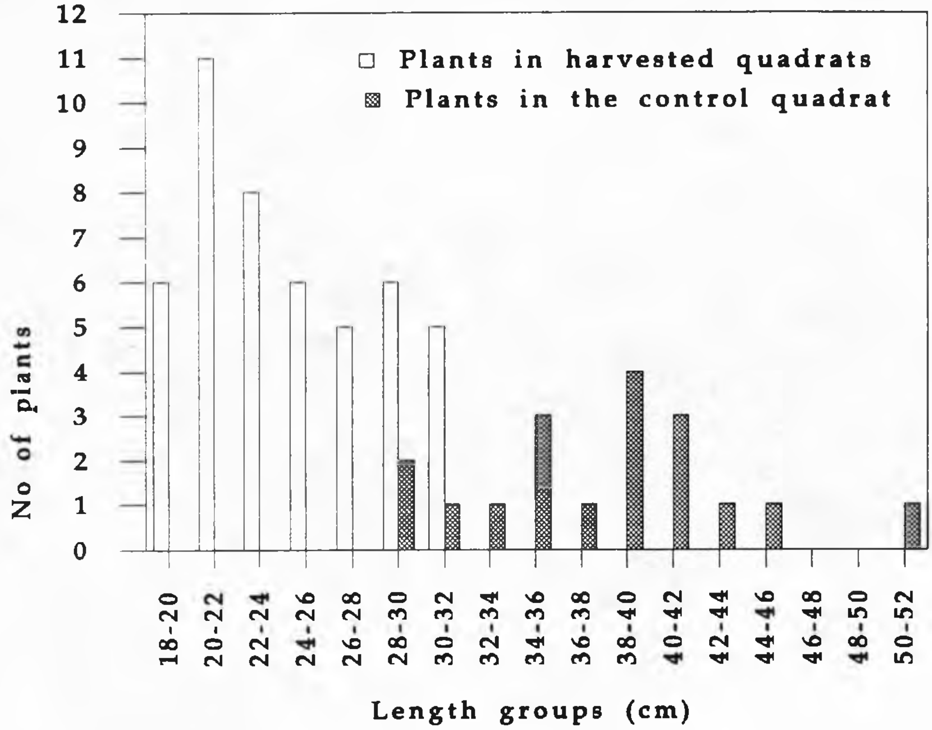

Fig.10.6 Number of plants in different length groups in three harvested quadrats and in one control quadrat in December 1991.

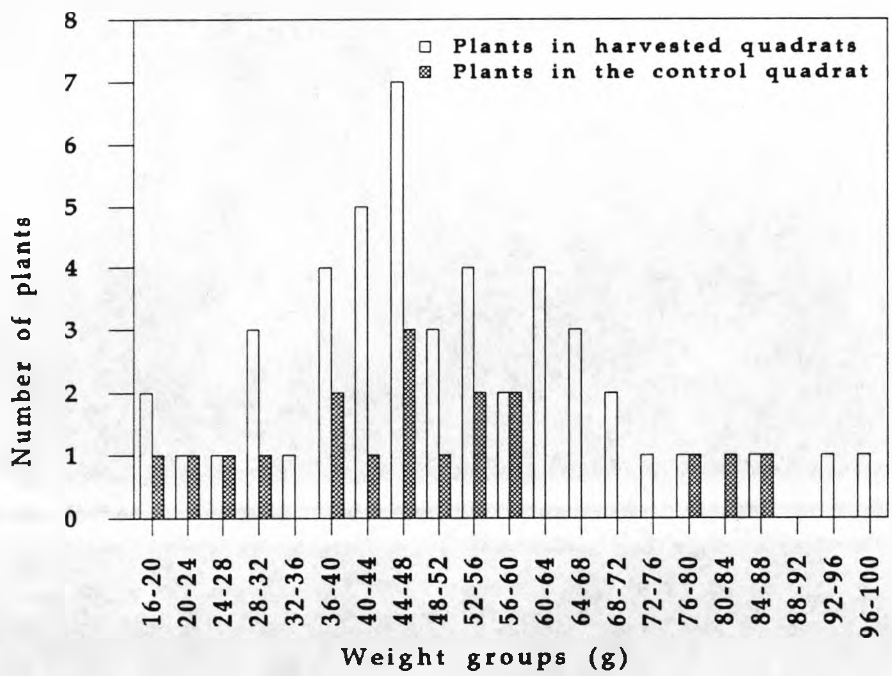

Fig.10.7 Number of plants in different weight groups in three harvested quadrats and in one control quadrat in December 1991.

cm) compared to the plants in the control quadrat which were in the higher (28-52 cm) length groups (Fig.10.6). The distribution of plant weight was very similar in control and harvested quadrats (Fig.10.7).

10.3.3 Harvesting experiment on *Gracilaria corticata*

Gracilaria corticata plants harvested by both cutting and scraping reached the standing crop of the control quadrats in about four months (Fig.10.8 & 10.9). Table 10.3 indicated that the standing crop of the cut and scraped quadrats were significantly different from the standing crop of the control quadrats after 2 months, but were not significantly different after 4 months (Plate 10.2). The plants in the both treatments showed the length of 11-12 cm after four months which is equal to the maximum length of the other plants (Plate 10.3).

10.3.4 Harvesting experiment on *Gelidium* sp

Fig.10.10 indicates that cut *Gelidium* plants had reached the standing crop of the control plants in ten months. T-test results showed that the standing crops of control and cut plants were significantly different after 3 and 6 months, but they were not different after 10 months (Table 10.4). Fig.10.11 showed that the standing crop of scraped plants had not reached the mean dry weight of control plants after 10 months. The t-test also showed that there was a significant difference between the two standing crops (Table 10.4).

Plate 10.2. *Gracilaria corticata* plants shown after four months of cutting on the reef at Koggala.

Plate 10.3. Harvested *Gracilaria corticata* plants after four months. (The lengths of the plants were 10-12 cm.)

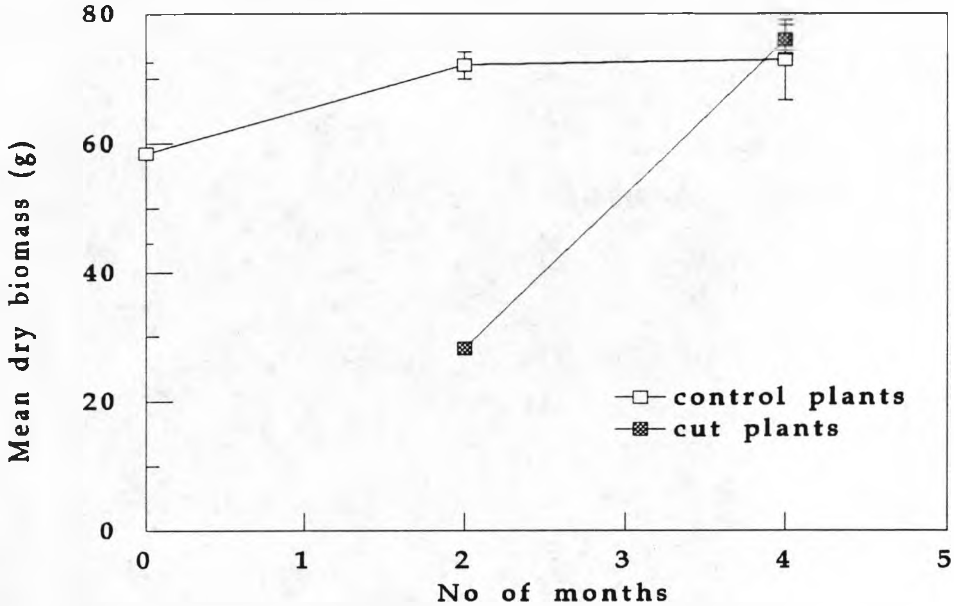

Fig.10.8 Mean dry weights of control and cut *Gracilaria corticata* plants at Koggala from 4th June to 6th October 1992 (bars = ±1 S.E.).

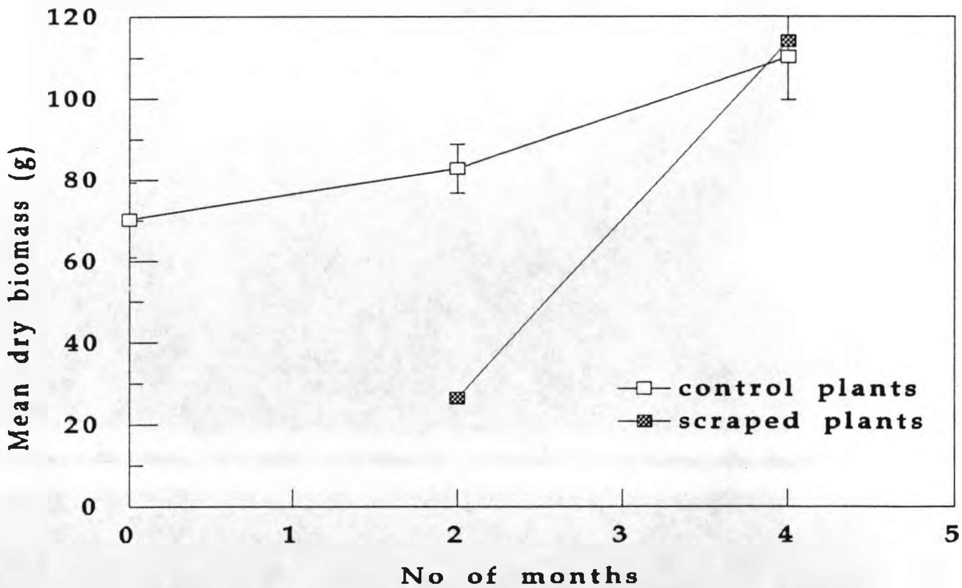

Fig.10.9 Mean dry weights of control and scraped quadrats of *Gracilaria corticata* at Koggala (bars = ±1 S.E.).

Time	DF	T value	p value
(cut xcontrol) 2nd month	2	14.33	0.0007
4th month	2	-0.39	0.72
(scraped x control) 2nd month	2	9.19	0.012
4th month	2	-0.26	0.81

Table 10.3 The t-test results obtained for the comparison of biomass at harvest level of the harvesting experiment of *Gracilaria corticata* from 4th June to 6th October 1992 at Koggala reef.

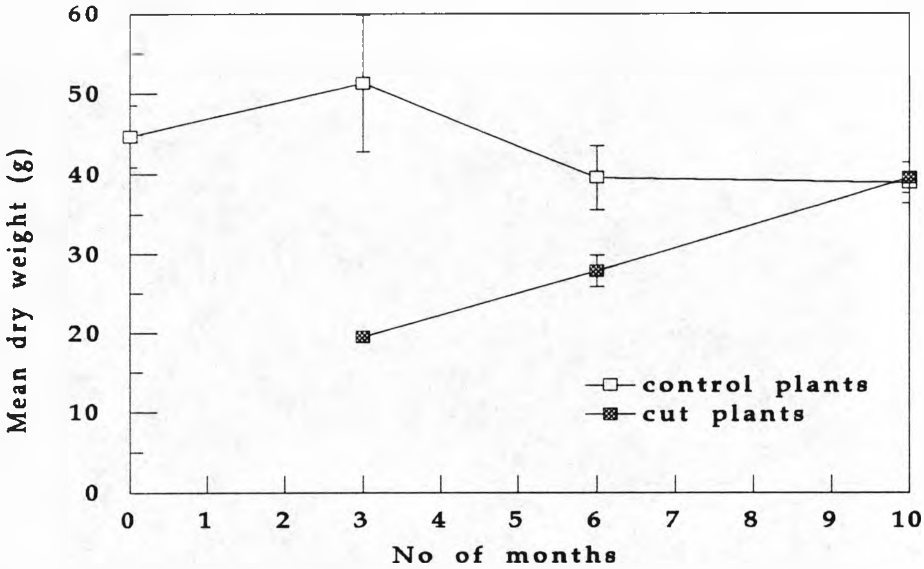

Fig.10.10 Mean dry weight of control and cut *Gelidium* plants at Beruwala from 2nd June 1992 to 4th April 1993 (bars = ±1 S.E.).

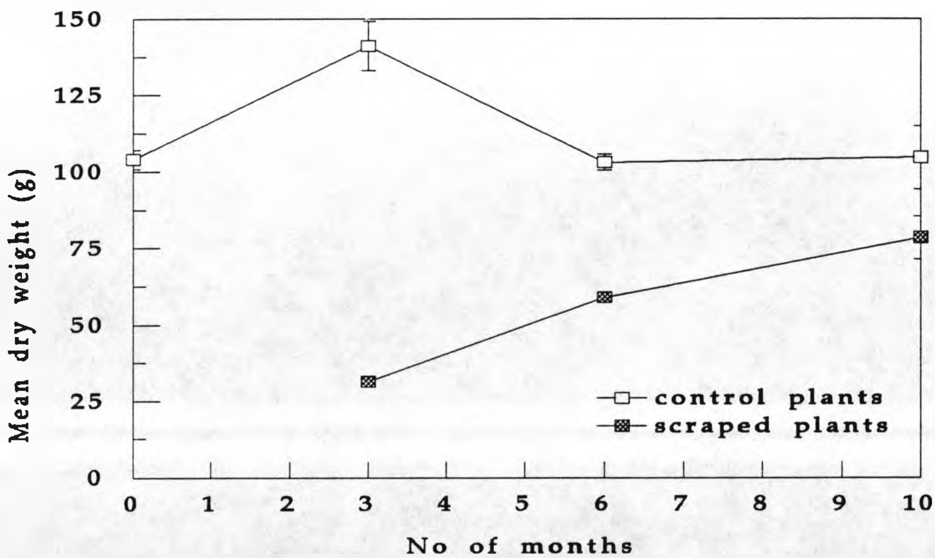

Fig.10.11 Mean dry weight of control and scraped *Gelidium* plants at Beruwala from 2nd June to 4th April 1992 (bars = ±1 S.E.).

Time	DF	T value	p value
(cut x control) 3rd month	2	3.66	0.04
6th month	2	2.65	0.05
10th month	2	0.17	0.87
(scraped x control) 3rd month	2	13.29	0.005
6th month	2	5.92	0.027
10th month	2	7.64	0.04

Table 10.4 The t-test results obtained in comparison of each harvesting experiment on *Gelidium* sp. from 2nd June to 2nd April 1992 at Beruwala.

10.4 DISCUSSION

10.4.1 Harvesting experiment on *Sargassum wightii*

Plants in the scraped quadrats, due to the difficulty in removing the whole plant, most of the holdfasts remained in the quadrats. It was shown that the *S. wightii* plants with both treatments gained the initial weight within 4-5 months. Ang (1985) showed that the *S. siliquosum* plants which were cut near the base and pulled off by hand leaving the holdfast showed a similar time period for regeneration. He pointed out that the primary axis and the holdfast are the centre of regeneration activity. In the present experiment since both treatments left the holdfasts, *S. wightii* plants also would have shown the same results. Fletcher & Fletcher (1975) also showed that the basal and the holdfast regions of *Sargassum* plants were much more active in wound healing and subsequent regeneration of branches than were middle, subapical and apical regions. Therefore in the present experiment regeneration would have occurred from the buds arise from the holdfasts in both treatments.

It was also shown in the present study that the plants harvested in June required a longer period to recover than the plants harvested in January (Figs.10.1-10.4). This may be due to the breakage of the branches of the plants which would have influenced slow growth of *Sargassum* from June to September due to heavy wave action during the monsoons. Moreover according to De Wreede (1976) the peak abundance in *Sargassum muticum* usually coincides with peak fertility. Although *S. wightii* is a tropical species it showed the same phenomenon by achieving the fertility during the peak biomass period. From the biomass studies it was shown that the peak abundance of *Sargassum wightii* appeared in

December in Sri Lanka. Fertile *S. wightii* plants were also observed during December. According to Durairatnam (1966) mature receptacles of *Sargassum* plants were observed in December and January months on the reefs along the south coast of Lanka. According to Norton (1977) *Sargassum muticum* plants showed slow growth with the increasing fertility. Therefore the *S. wightii* plants would have shown slower growth rates during the previous months. This also would have incorporated the longer period taken for recovery during the second experiment which was harvested in June.

However the standing crop studies were not done during other 8 months of the year. Therefore it is difficult to predict the exact month with the peak biomass unless with more frequent studies on standing crops of this species. In addition the method of cutting may be more effective than the method of scraping. The left over holdfasts would have been the reason for the similar biomass observed in cut and scraped quadrats.

10.4.2 Preliminary experiment on regeneration of *Sargassum wightii*

The straight line in the Figure 10.5 may be because growth occurred at the apical segments of the new branches of the *Sargassum* plants in the harvested quadrats. Several new branches came up from the cut plants could have started growing due to the activation of lateral dominance. Although the growth continued, the harvested plants remained shorter compared to the control plants (Fig. 10.6). This may be due to the several new branches observed at the base of the harvested plants. This is supported by the bushiness observed on the plants in the harvested quadrats. The plants of the harvested quadrats belonging to the higher weight groups could also be due to the bushiness of the plants with several branches (Fig.10.7). Fletcher & Fletcher (1975) pointed out that the lateral shoots of *Sargassum* could also continue growth and development in a free floating stage. According to them when the apical cell had been removed by excision its function of main shoot developer (apical dominance) was taken over by the lateral shoots. This might explain the growth of the lateral branches of the cut *Sargassum* plants in this experiment.

The growth rate by length observed for *S. wightii* (0.2 cm day-1) during July to December was much lower than the mean growth rate by length (0.8 cm day^{-1}) observed for *S. pteropleuron* in the waters off South Florida during summer by Prince & O'Neal (1979). The maximum relative growth rate of 2.5 % day^{-1} observed for *S. pteropleuron* during the same study was also a little higher than the same (1.7% day^{-1}) in the present study. The present study commenced during the south-west monsoon season during which the plants may have subjected to breakage due to heavy wave actions. Subsequently this would have hindered the growth of the plants. A higher growth rate might be achieved if this experiment was done during December to May. Therefore commercial harvesting of *S. wightii* should begin sometime in January to achieve better growth rates of the regenerated plants.

10.4.3 Harvesting experiments on *Gracilaria corticata*

Both cut and scraped *Gracilaria corticata* plants had reached the biomass of the controls in less than four months. *Gracilaria corticata* plants harvested in Gulf of Mannar reached the initial biomass within two months (Umamaheswara Rao, 1975). However recovery rate varied seasonally and rapid development of the plants occurred only during June to October (Umamaheswara Rao, 1975). In the present experiment it was difficult to scrape the holdfasts from the quadrats since the plants were firmly embedded in the coral reef. Therefore the regeneration would have occurred from the hold fasts of the scraped quadrats. According to Umamaheswara Rao (1975), *G. corticata* grows rapidly by vegetative means as well as through fruiting plants. He also pointed out that the continuous harvesting at bi-monthly intervals reduces the density of the crop and helps the colonization of the other algae of the intertidal region. Significantly different (Table 10.3) biomasses with controls during the second month in this experiment indicated that the Sri Lankan *G. corticata* plants showed a slower growth rate than the same plants during the same months in Gulf of Mannar. However the present experiment was done only in June and the best growth season for this species in Sri Lanka cannot be predicted. It might have given more rapid growth rates if it was done in another period of the year. Therefore more work should be done on *G. corticata* in Sri Lanka to determine the best growth season.

10.4.4 Harvesting experiments on *Gelidium* species

It was clear from the results that the *Gelidium* plants took longer to reach the biomass of the controls compared to other harvested species. This is consistent with the slow growth and the low capabilities for regeneration observed for *Gelidium* sp. by several other scientists in different parts of the world (Santelices *et al.*,1981; Oliger and Santelices, 1981; Barilotti and Silverthorne,1971; Stewart and Norris,1981). In the present study the scraped quadrats did not reach the biomass of the controls after 10 months. This may be due to the low number of germlings present in this area and the slow growth rates of the plants. The poor ability of *Gelidium* spp. to colonize areas was also found by Montalva & Santelices (1981). These workers found that even three years after clearing, *G. filicinum* and *G. lingulatum* had not recovered half of the space they originally occupied. The suggested reason for this was infertility of propagules. This has also been reported for other gelidioid algae (Santelices, 1974). However it was also pointed out by Barilotti & Silverthorne (1971) that the reproductive structures were found throughout the year in the intertidal populations of *Gelidium* sp. Santelices *et al.* (1981) have suggested that in spite of their continuous reproduction they do not produce a high biomass in the field. They also pointed out that in mass cultivation *Gelidium* sp. could achieve up to 3% of daily growth rate by weight.

According to the standing crop estimations in Sri Lanka the biomass of *Gelidium* sp. was comparatively low. However no studies have been done on any culture trails of the species available in Sri Lanka. Therefore more emphasis should be given to the studies on artificial cultivation of this species with a view to increase the crops for commercial utilization.

11. DISCUSSION (PART 2)

The biomass of intertidal algae is influenced by a wide range of factors, both biotic and abiotic (McQuaid, 1985). Numerous exclusion experiments have shown that various herbivores can exert a considerable influence on algal biomass (eg. Randall, 1961; Branch, 1971; John and Pople, 1973). Low levels of algal biomass were observed along the west coast of South Africa, in a limpet dominated zone (McQuaid, 1985). However he pointed out that severe grazing at some places, clearly restricted algae to particular zones. The remaining zones showed rapid algal growth, where often led to high biomass and generally swamped grazing pressure which is unlikely to influence seasonal patterns of standing crop. Although this was shown in a temperate region there may be a similar effect on the high biomass obtained at the Rekewa reef in the present study. Small patches of areas which were damaged by limpets were observed in December on the Rekewa reef during the present study, apart from the large biomass of *Sargassum* sp. observed in the same month.

According to Lawson (1957) the density of most of the intertidal algal populations in tropical countries are statistically related to the seasonal tides. Lawson (1957) also pointed out that the genera such as *Sargassum*, *Padina*, *Hypnea* and *Chaetomorpha* showed a significant relationship with the seasonal tidal movements in a tropical reef in Ghana. In Sri Lanka the changes of the tidal movements, although the tidal variations are smaller, occur during the monsoons and therefore may be the cause at the seasonal variations of many species.

In the present study although the largest number of species on all the reefs belong to the Rhodophyta, the highest biomass consisted of

Sargassum sp. (Phaeophyta). This phenomenon was also observed on the reefs of many tropical regions (eg. Untawale & Jagtap, 1989). Raju and Venugopal (1971) have reported, in relation to unpublished data from Chauhan and Krishnamurthy, that *S. swartzii* plants on the Gujarat coast, in the west coast of India have an embryonic phase, a phase of rapid growth, a phase of slow growth, a fruiting phase and a deciduous phase. According to them rapid growth takes place during the post-monsoon period of August October and fruiting occurs from November to January. The sequence of stages in *S. wightii* in the west coast of Sri Lanka seems to be similar to *S. swartzii* in India due to the occurrence of south-west monsoons during the same period of the year. Although the monsoonal winds promote the algal growth by bringing water from upwellings it can also cause harmful effects by breaking the plants due to the strong winds.

Trono (1989) pointed out that the recruitment capabilities of stocks are generally influenced by the states of fertility especially for those species where recruitment is largely dependent on the production of spores. Thus he suggested that for those species harvesting should be scheduled after the peak of fertility of the stocks in order not to unduly interfere with the recruitment process. According to the present study and Durairatnam (1966) it was found that the peak fertility of *Sargassum* plants in Sri lanka occurs in December. Therefore, it would be better if the harvesting of the local *Sargassum* plants should be done in January after the peak fertility period.

The regenerative ability of *Sargassum* from the primary axis and the holdfast points to the potential of their large scale utilization by periodic harvesting. Hand cropping (uprooting) should not be done since it might remove the holdfasts. Therefore cutting the plants by leaving the holdfasts would be more effective for rapid regeneration.

Apart from *Sargassum* sp., *Ulva* sp. seems to be the most common seaweed found in all the reef areas in Sri Lanka. The high biomass of *U. fasciata* in September in three reef areas suggests possible harvesting of this alga in that month. However, according to Trono's (1989) suggestion on harvesting the plants after peak fertility, with *Ulva* sp. it would not be easy to find a population with uniform fertility. Therefore the harvesting of *Ulva* sp. would not be easy, due to the short lived character of this plant. Because of the short life time with frequent reproduction a population of *Ulva* sp. may not be evenly aged, but a mixture of plants in different stages of development. However, Subbaramaiah (1970) suggested that *Ulva fasciata* which has characters such as large production of swarmers, and easy colonization on a variety of artificial substrata can be recommended for artificial cultivation.

Caulerpa sp. also seems to be quite common and holds a comparatively high biomass on the west coast of Sri Lanka which could be harvested for domestic or commercial purposes. However *C. racemosa* showed peak biomasses in different months on different reef areas. *Gracilaria corticata* also shows different peak times in different reef areas. Therefore the commercial harvesting seasons for different species could be spread throughout the year. This would lead to the dissemination of employment opportunities throughout the year during commercial harvesting practises. This would be more appropriate for a developing country like Sri Lanka where the cost of labour is cheap.

12. GENERAL DISCUSSION

The most common seaweeds found in Sri Lanka are the brown seaweeds belonging to the genus *Sargassum* (Durairatnam, 1961). *Sargassum* beds are known as important nursery grounds where a large number of animals including species of commercial value such as fishes, shrimps, crabs, molluscs and others live (Largo & Ohno, 1992). They are an important source of alginates and alginic acids used in many industrial products such as fabrics, cosmetics, foods etc.

Apart from *Sargassum* species the potential standing crops estimated on fourteen seaweed species belonging to 10 genera along the western and south-west coast of Sri Lanka could enhance the expansion of the seaweed industry of the island. Almost all of these species are used as raw material in several industries for the production of agar-agar, alginate, carrageenan as well as being used as additional fodder and manure. Some studies showed that local *Gracilaria corticata* contained 51% yield of crude phycocolloid (Dantanarayana *et al.*, 1981). The same study showed that *Gelidium* sp. which is commonly found on coral reefs in Beruwala, contained 48% yield of crude agar-agar.

The information on resource potential is vital in determining how much of the stocks should be harvested without unduly diminishing their productivity. The total resource potential of *Sargassum* species for the entire coastal belt of the island from Jaffna to Hambantota would be much more than the estimated quantity from the present study. Therefore the available potential resource of *Sargassum* plants is adequate to sustain commercial exploitation. The alginic acid content of the *Sargassum* species from Hikkaduwa area showed that the period of high alginic acid content was observed from December to April (Durairatnam & Grero, 1969). Therefore as discussed earlier harvesting of *Sargassum* species could achieve better results if it is done in January due to high content of alginic acid during this period and also it does not coincide with the peak fertility period.

Three types of *Ulva* species which achieved relatively high biomass along this coastal belt of Sri Lanka could be used for various purposes such as human consumption, fodder and fertilizers. Thivy (1964) found that *U. rigida* and *U. fasciata* have protein contents of 20-30% of the dry weight. Two *Caulerpa* species which achieved equally high biomass as *Ulva* sp. also can be useful for human consumption. In addition more studies on growth rates and harvesting experiments also should be carried out on these species for better management strategies of these resources.

Culture practises of *Gracilaria*, more than any other seaweed, have encouraged the development of a diversity of approaches and farming methods. As populations and markets continue their growth, these methods probably will be in large scale use in the future to supply the consumer needs. It is likely that shallow line farming techniques for *Gracilaria* either from spores or from vegetative fragments may provide substantial amount of raw material for agar-agar. Small scale or commercial culture practices in the Puttalam Lagoon with the suggested depth levels and substrata recommended in section 4 may yield relatively large amounts of good quality seaweeds. Although it is labour intensive, it would not be costly due to the developing stage of Sri Lanka.

Gracilaria produced in Sri Lanka is exported in dried form without any further processing. Most exporter countries of this seaweed have realized the benefits of exporting processed products as against the dried weed. Export of the unprocessed product has two distinct disadvantages; a) The high cost of packaging and transport, force down the price payable to collectors for the weed.

b) The fact that the raw material is processed elsewhere means that the benefits of gainful employment in manufacture are lost to Sri Lanka. Therefore a close look at the feasibility of further processing the weeds locally has to be made in order to improve the profitability and the employment generation capacity of the industry.

The rational exploitation of the wild population of *Gracilaria* in Puttalam Lagoon is also another important aspect to be considered carefully since it provides the seeding stock for all types of culture practices. The application of harvest techniques which are the least destructive is one way of assuring the fast recovery of stocks. For instance, harvest by hand picking (uprooting) is more destructive than pruning. The removal of the substratum by hand picking reduces the capacity of the stocks to regenerate. Renewal of stocks through regrowth from basal portions left after pruning is very much faster than recruitment of new thalli from spores.

However, since there is a good potential for commercial processing of *Sargassum* and *Gracilaria* species for manufacturing alginic acid and agar-agar as a substitute for imported phycocolloids, small scale production of these items could save large amount of foreign exchange which is spent annually from Sri Lanka on imports and as well it would generate employment opportunities for the people living around the coastal areas of Sri Lanka.

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APPENDICES

Species	Dec. 91	Mar. 92	Jun. 92	Sep .92	Dec. 92
Gelidium sp.	6.26	7.21	19.15	29.21	6.12
Laurencia sp.	0.27	0.82	0.0	0.84	0.24
Gracilaria corticata	0.79	1.75	1.13	0.11	0.91
Sargassum ilicifolium	8.97	3.15	5.12	6.12	7.54
S. wightii	4.81	1.84	2.15	2.34	5.23
Hypnea sp.	0.64	0.0	2.91	2.49	1.29
Turbinaria sp.	2.72	1.5	1.89	8.49	3.13
Padina sp.	0.61	0.4	0.0	0.0	0.53
Ulva lactuca	1.33	0.51	1.7	0.0	1.15
U. fenestrata	0.56	0.11	0.0	0.59	0.16
Acanthophora	0.8	1.94	0.78	0.21	0.5
Caulerpa racemosa	0.0	0.21	0.81	1.3	0.0
C. taxifolia	0.0	0.0	1.18	0.0	0.0
Ceramium sp.	0.0	0.0	0.12	0.1	0.0
others	5.4	6.5	10.5	12.2	3.6

Appendix 1 Mean dry biomass (g/0.25m^2) of seaweed species calculated from all the quadrats on the reef in different seasons at Beruwala

Species	Dec. 91	Mar. 92	Jun. 92	sep. 92	Dec. 92
Gracilaria corticata	5.47	5.11	2.10	4.82	4.51
Gracilaria sp.	0.2	0.31	0.72	0.0	0.58
Larencia sp.	2.22	1.02	3.14	3.77	1.68
Sargassum crassifolium	3.18	0.73	0.14	1.78	4.75
S. wightii	30.7	2.4	15.38	20.4	32.1
Ulva fenestrata	0.0	0.0	0.0	1.4	0.73
U. fasciata	2.92	6.36	5.2	13.17	3.68
Caulerpa racemosa	4.23	1.66	0.93	0.0	6.47
C. taxifolia	0.0	0.64	12.7	0.0	0.0
Ceramium sp.	0.0	0.0	0.06	0.0	0.0
Acanthophora sp.	0.0	0.8	0.0	0.0	0.0
Hypnea sp.	0.0	0.0	1.17	1.13	0.0
Padina sp.	0.0	0.12	0.0	0.0	0.0
others	1.64	8.25	7.27	2.83	1.23

Appendix 11 Mean dry biomass (g/0.25 m^2) of seaweed species calculated from all the quadrats from the reef in different seasons at Hikkaduwa

Species	Dec. 91	Mar. 92	Jun. 92	sep. 92	Dec. 92
Gracilaria corticata	12.15	2.64	4.02	2.23	10.1
Gracilaria sp.	3.04	2.91	0.87	0.62	3.23
Laurencia sp.	1.83	0.75	0.75	3.46	1.55
Caulerpa racemosa	0.22	9.53	9.2	2.75	0.74
Sargassum crassifolium	45.63	10.44	0.0	16.44	42.51
S. wightii	61.2	8.78	43.2	48.94	56.2
Ulva rigida	1.85	1.19	1.15	0.53	4.43
U. fasciata	0.0	3.14	0.0	8.18	0.86
Hypnea sp.	0.55	4.35	2.33	3.28	0.11
others	1.17	3.59	6.91	14.29	2.84

Appendix 111 Mean dry biomass (g/0.25 m^2) of seaweed species calculated from all the quadrats on the reef in different seasons at Tangalle

Species	Dec. 91	Mar. 92	Jun. 92	Sep. 92	Dec. 92
Gracilaria corticata	2.87	1.8	1.53	4.71	2.5
Gracilaria sp.	0.41	0.14	0.0	0.0	0.80
Laurencia sp.	2.53	3.29	6.66	4.75	2.76
Hypnea sp.	0.34	1.16	0.93	1.0	0.51
Sargassum wightii	116.2	4.1	53.4	86.5	120.7
Ulva lactuca	0.0	0.0	6.01	4.3	0.0
U. fasciata	3.37	0.0	8.84	23.07	4.28
Ceramium sp.	1.27	0.0	0.85	0.40	1.5
others	5.61	0.3	4.32	6.0	4.63

Appendix IV Mean dry biomass (g/0.25 m^2) of seaweed species calculated from all the quadrats in different seasons at Rekewa

	Areas (m^2)				
Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Caulerpa racemosa others	611.69	699.9	-	-	256.66
Gelidium sp. *Gracilaria corticata* others	1941.8	1538	1332.8	1780.5	1668.4
Gelidium sp. *Padina* sp.	1259.2	-	-	-	2557.0
Gelidium sp. *Chaetomorpha* sp. *Hypnea* sp.	2600	-	2710	1893	2214.9
Sargassum wightii *S. ilicifolium* *Turbinaria* sp.	4218.9	2123.63	3015.5	2472.7	4119
S. wightii *Gelidium* sp.	3574	4042.4	2423.8	2602	1593
Ulva sp. *Chaetomorpha* sp.	2524.8	-	2476	2523	3526.7
Gelidium sp.	1345.3	2225.5	5707	6815	1156.7
Acanthophora sp. *Padina* sp.	-	2966.72	-	-	-
Caulerpa taxifolia *Chaetomorpha* sp.	-	-	1933.9	-	-
Acanthophora sp.	-	-	139	-	-
Ceramium sp.	-	-	-	858.2	-

Appendix V Areas in m^2 of different seaweed species or groups of seaweeds at Beruwala in different quarters of the year. The areas were calculated from the quarterly maps of the reef by using the Canvas (TM) programme.

	Area (m^2)				
Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Sargassum wightii *Ulva fasciata* others	4173	1425.3	2618.5	4822.5	4108.6
Gracilaria corticata *Caulerpa racemosa* *Laurencia* sp.	646.78	815.63	813.6	1134.4	612
Gracilaria corticata *Gracilaria* sp. others	879.4	175.5	927	814	823.9
Acanthophora sp. *Jania* sp.	-	1806.7	-	-	-
S. wightii *Ulva fasciata* *Laurencia* sp.	1671.6	805.7	-	915	1865
U. fasciata *Ulva fenestrata*	1290	-	-	-	1338
G. corticata *Padina* sp.	-	1033.6	-	-	-
U. fenestrata	-	951.2	1818.6	579.4	-
Caulerpa taxifolia *Hypnea* sp.	-	-	2496.3	-	-

Appendix V1 Areas in m^2 of different seaweed species or groups of seaweeds at Hikkaduwa in different quarters of the year. The areas were calculated from the quarterly maps of the reef by using the Canvas (TM) programme.

	Areas (m2)				
Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Gracilaria sp. *Laurencia* sp. *Caulerpa racemosa*	561.22	-	343.91	582.9	552.9
Gracilaria corticata	313.2	-	-	-	254.5
Sargassum wightii *S. crassifolium* others	2042.4	-	-	-	2569.7
Ulva sp.	840.6	431.9	-	722.3	1451.8
C. racemosa	-	538.2	449.6	-	-
Gracilaria sp. *Jania* sp.	-	88.35	83	-	-
Laurencia sp. *Hypnea* sp.	-	217.3	-	-	-
S. wightii others	-	1583.8	2312.7	3060.2	-
Chaetomorpha sp.	-	-	1755.4	-	-

Appendix V11 Areas (m2) of different seaweed species or groups of seaweed species at Tangalle reef in different quarters of the year. The areas were calculated from the quarterly maps of the reef by using the Canvas (TM) programme.

	Areas (m2)				
Species	Dec.91	Mar.92	Jun.92	Sep.92	Dec.92
Gracilaria corticata *Laurencia* sp *Gracilaria* sp.	920.58	588.5	1428.2	788.8	864.63
Sargassum wightii	6075.6	1971.3	2652.6	5886.4	6456.3
S. wightii *Laurencia* sp. *Ulva fasciata*	1680.4	-	-	2081.6	1817.5
U. fasciata *Ceramium* sp.	1969.6	-	6702.6	1964	1695
G. corticata *Laurencia* sp. *Hypnea* sp.	-	580.5	-	-	-

Appendix V111 Areas (m2) of different seaweed species or groups of seaweeds at Rekewa in different quarters of the year. The areas were calculated from the quarterly maps of the reef by using the Canvas (TM) programme.