Marine Fisheries Research and Management

Editors
V.N. Pillai and N.G. Menon

Central Marine Fisheries Research Institute
(Indian Council of Agricultural Research)
Tatapuram P.O., Cochin-682 014
Kerala, India

2000

3 Seaweeds

V.S.K. Chennubhotla, N. Kaliaperumal, Reta Jayasankar
S. Kalimuthu, J.R. Ramalingam, K. Muniyandi and M. Selvaraj

ABSTRACT

Research works on various aspects of seaweeds have been caried out since last five decades. They include resources survey, studies on distribution, taxonomy, ecology, biology, phycocolloids, biochemicals, culture and utilisation of marine algae growing in Tamil Nadu, Kerala, Lakshadweep and Andaman-Nicobar Islands. Information was also gathered since 1978 on the quantity of seaweeds commercially exploited from the natural seaweed beds occurring in Tamil Nadu coast. The results obtained on these aspects are reviewed in this paper. The prospects of seaweed research, industry and utilisation in India are also briefly described.

Introduction

Seaweeds or marine macro algae are non-flowering plants occurring in the sea, estuaries and backwaters. Most of the seaweeds are attached to rocks and also grow on other plants as epiphytes. The seaweeds are classified into four groups namely green, brown, red and blue-green algae based on the pigments, morphological and anatomical characters. Along the coast line of India, seaweeds are abundant where rocky or coral formation occur. This kind of substratum is found in the states of Tamil Nadu, Gujarat and in the vicinity of Bombay, Ratnagiri, Goa, Karwar, Vizhinjam, Varkala, Visakhapatnam and in the Lakshadweep and Andaman-Nicobar Islands.

Seaweeds contain different vitamins, minerals, trace elements, protein, iodine and bioactive substances. They are the only source for the production of phycochemical like agar, carrageenan and algin. Agar is extracted from red algae such as *Gelidiella*, *Gracilaria*, *Gelidium* and *Pterocladia*. Some other red algae viz. *Eucheuma*, *Chondrus*, *Hypnea* and *Gigartina* are used for the manufacture of carrageenan. Algin is extracted from species of *Sargassum*.

Turbinaria, *Laminaria*, *Undaria*, *Macrocystis* and *Ascophyllum*. These phycocolloids are used as gelling, stabilizing and thickening agents in food, confectionary, pharamaceutical, dairy, textiles, paper, paint, varnish industries etc. Other chemical products such as mannitol, iodine, laminarin and fucoidin are also obtained from marine algae. Many protein rich seaweeds such as mannitol, iodine, laminarin and fucoidin are also obtained from marine algae. Many protein rich seaweeds such as *Ulva*, *Enteromorpha*; *Caulerpa*, *Codium*, *Monostroma* (green algae); *Sargassum*, *Hydroclathrus*, *Laminaria Underia* and *Macrocystis* (brown algae); *Porphyra*, *Gracilaria*, *Eucheuma*, *Laurencia* and *Acanthophora* (red algae) are used as human food in countries like Japan, China, Korea, Malaysia, Phillippines and other southeast Asian countries in the form of soup, salad, curry etc. Jelly, jam, chocolate, pickles and wafer can also be prepared from certain seaweeds.

Since seaweeds are cheap source of minerals and trace elements, meal can be prepared by grinding the cleaned and washed seaweeds. It can be given as supplements to the daily rations of cattle, poultry and other farm animals . It can be also mixed with fish meal and used as a poultry fed. Marine algae are also used in different parts of the world as fertilizer for various land crops. There are certain medicinal properties for seaweeds. Seaweeds rich in iodine such as *Asparagopsis taxiformis* and *Sarconema* spp can be used for cotrolling goitre disease caused by enlargement of thyroid gland (Umamaheswara Rao, 1970; Kaliaperumal, 1993).

Since the inception of CMFRI in 1947, works on different aspects of seaweeds such as resources, distribution, taxonomy, ecology, biology, phytochemicals, biochemicals, culture and utilisation have been carried out. The resources, distribution and taxonomy of marine algae occurring in Tamil Nadu coast, Kerala coast Lakshadweep, Andaman-Nicobar and estuaries and backwaters of Tamil Nadu were studied.

Seaweed resources

The CMFRI carried out detailed survey of algal resources along Tamil Nadu coast for a period of five years during 1971 to 1976 in collaboration with the CSMCRI and Dept. of Fisheries, Govt. of Tamil Nadu (Anon, 1978). The area covered was from Athankarai to Rameswaram in the Palk Bay and from Mandapam to Colachel and adjoining islands in the Gulf of Mannar form high water mark to a depth of 4 m. The standing crop in the coastal area of

17125 ha was estimated as 22044 tons (wet wt) consisting of 1709 tons of agarophytes, 10266 tons of alginophytes and 10069 tons of other seaweeds. The resources of commercially important species are as follows - *Gelidiella acerosa* - 74 tons; *Gracilaria* spp - 974 tons, *Hypnea* spp - 798 tons, *Sargassum* spp - 9381 tons and *Turbinaria* spp - 714 tons.

The CMFRI and CSMCRI have jointly surveyed the seaweed resources in deep waters (5 to 22 m depth) of Tamil Nadu from Dhanushkodi to Kanyakumari during 1986-1991. The total estimated standing crop from 1863km^2 was 75375 t consisting of 6225 tons of agarophytes, 2750 tons of alginophytes and 66400 tons of other seaweeds (Kaliaperumal, 1991). Resources survey of algae and seagrasses in 63 estuaries and backwaters existing from Madras to Athankarai in Tamil Nadu and Pondichery was made during 1988-1989. The agar yielding seaweeds by *gacilaria arcuata* and *G. verrucosa* and carrageenan yieldling seaweed *Hypnea valentiae* occurred in harvestable quantities in some estuaries (Kalimuthu *et al.*, 1995).

Survey of seaweed resources of Kerala coast was conduted during 1986-1987. The standing crop of seaweeds was estimated as 1000 tons (wet wt) of which 150 tons are economically important seaweeds. The agarophytes formed 27 tons followed by alginophytes and agaroidophytes (Chennubhotla *et al.*, 1988). Survey of seaweeds and seagrasses resources of Lakshadweep was carried out in 1987. The estimated total standing crop of marine algae was 19345 tons (wet wt) consisting of 370 tons of *Gelidiella acerosa*, 798 tons of *Gracilaria edulis*, 97 tons of *Sargassum* spp, 3300 tons of *Trubinaria* spp and 14780 tons of other seaweeds (Kaliaperumal *et al.*, 1989).

Ecology and biology of seaweeds

Ecological observations were made on zonation and seasonal changes of some intertidal algae growing in the Gulf of Mannar and Palk Bay near Mandapam. Studies were made on the seasonal variation in the growth of several economically important seaweeds of Mandapam area. This study revealed that the life span of many seaweeds is one year and some algae occur only in part of the year. Every year fresh plants develop from the reproductive bodies liberated by the plants of previous generation or from the perennial basal portion of old plants. The life span of different seaweeds and their peak growth period are given in Table 1. In some seaweeds two peak growth periods with half yearly growth cycle and in others only a single peak growth

period were observed (Chennubhotla *et al*, 1987 a).

Table 1.Periods of occurrance, growth and havest of economically important seaweeds of Mandapam area.

Sl No.	Name of the Seaweed	Period of occurance	Peak Growth Period	Suitable period for harvest
Agarophytes				
1.	*Gelidiella acerosa*	Throughout	January-March	January-March
			July-September	July-September
2.	*Gracilaria edults*	-do-	January-April	January-March
			August-September	August-September
3.	*G. crassa*	-do-	-do-	-do-
4.	*G. folifera*	-do-	-do-	-do-
5.	*G. corticata var. corticata*	-do-	June-September &	June-August &
6.	*G. corticate var. cylindrica*	-do-	November-February	November.February
7.	*G. arcuate var. arcuata*	January-May	January-April	January-April
		October-December		
Alginophytes				
8.	*Sargassum wightii*	Throughout	October-January	October-December
9.	*S. myriocystum*	-do-	May-August	May-August
10	*S.ilicifolium*	-do-	July-October	July-September
11.	*Turbinaria conoides*	-do-	October-December	October-December
12.	*T. ornata*	-do-	September-December	October-December
13.	*T.decurrens*	-do-	November-February	December-February
Edible Alga				
14.	*Enteromorpha compressa*	April-Feabruary to June-August		June-August

Studies were made on the effect of repeated harvesting of commercially important agar yielding seaweeds *Gelidiella acerosa*. *Gracilaria corticata* var. *corticata* and algin yielding seaweeds *sargassum cristaefolium*, *S. ilicifolium*,

S. myriosystum, *S. wightii* and *Turbinaria conoides* growing in Mandapam-area on the regeneration, growth and interval required for attaining harvestable size plants and to know the suitable period for commercial exploitation. This investigation indicated that the regrowth of these algae depended on the harvesting period and interval between successive harvests (Kaliaperumal *et al.*, 1996; Kalimuthu *et al.*, 1993).

Chemical composition and utilisation of seaweeds

Studies were made on different aspects of chemical composition of marine algae growing at Mandapam and other parts of Tamil Nadu, Kerala and Lakshadweep. The protein, carbohydrate, lipid and ascorbic acid (Vitamin-c) contents of marine algae of Mandapam coast were estimated. The results obtained on these biochemicals are given in *Table 2*.

Table 2. Protein, carbohydrate, lipid and ascorbic acid content's of Indian marine algae of Mandapam coast

Sl. No.	Name of Seaweed	Protein (%)	Carbo-hydrate (%)	Lipid (%)	Ascorbic acid(mg/ 100 g. fr.weed).
Green Algae					
1.	*Enteromorpha compressa*	23.8	24.8	11.4	-
2.	*E. prolifera*	-	-	-	0.2
3.	*Ulva lactuca*	25.8	16.0	7.4	6.1
4.	*U. reticulata*	24.4	16.9	8.6	-
5.	*Chaetomorpha aerea*	10.1	31.5	8.6	-
6.	*C. antennina*	19.7	27.0	11.5	-
7.	*C. brachygonia*	-	-	-	5.9
8.	*C. linoides*	16.7	27.0	12.1	-
9.	*Cladophora fascicularis*	15.5	49.5	15.7	-

10.	*Cladophora sp*	9-2	6.6	6.5	-
11.	*C. frttschii*	-	-	-	6.0
12.	*Caulerpa cupressoides*	7.4	51.8	10.9	-
13.	*C.chemnitzia*	11.8	32.6	11.4	-
14.	*C. fergusonii*	7.8	23.6	7.2	-
15.	*C. taetevirens*	8.8	56.3	8.8	-
16.	*C. peltata*	24.4	45.0	11.4	-
17.	*C. racemosa var. macrophysa*	24.8	33.8	10.6	-
18.	*C. sertularioides*	22.7	49.5	6.9	-
19.	*C. scalpelliformis*	25.2	10.7	7.6	-
20.	*C. taxifolia*	23.6	9.7	4.1	-
21.	*Veloplopsis pchynema*	18.8	31.5	9.1	-
22.	*Bryopsis plumosa*	19.2	27.0	9.0	-
23.	*Dictyospheria cavernosa*	6.1	42.8	10.5	-
24.	*Boergesenia forbesii*	7.4	21.4	11.4	-
25.	*Codium adhaerens*	7.3	40.5	7.4	-
26.	*C. decorticatum*	6.9	50.6	9.0	-
27.	*C. tomentosum*	5.1	29.3	7.2	-
28.	*Microdictyon agardhiapum*	20.9	27.0	9.4	-
29.	*Cladophorophsis zoolingerii*	10.3	0.3	0.5	-
30.	*Halimeda gracilis*	Trace	Trace	Trace	-
31.	*H.macroloba*	5.4	32.6	9.1	-

Brown Algae					
32.	*Sargassum wightii*	16.3	24.9	1.2	-
33.	*S. myriocystum*	15.6	23.8	0.5	66.6
34.	*S. ilifolium*	15.1	24.0	1.1	-
35.	*Stoechospermum marginatum*	14.9	15.4	3.7	-
36.	*Hormophysa triquetra*	16.6	3.3	0.6	-
37.	*Padina australis*	-	-	-	7.9
38.	*P.gymnospora*	13.0	13.2	1.3	-
39.	*Turbinaria conoides*	15.2	14.0	3.6	-
Red Algae					
40.	*Janta rubens*	1.5	1.8	0.4	-
41.	*Centroceras clavulatm*	3.8	4.8	3.4	-
42.	*Hyppen musciformis*	-	-	-	8.6
43.	*H.valentiae*	6.1	37.8	6.1	-
44.	*Gracilaria edulis*	3.9	45.8	2.4	7.3
45.	*G.corticata*	6.1	45.5	6.0	-
46.	*G.crassa*	4.3	30.4	0.9	-
47.	*Grateloupia lithophila*	5.8	36.9	0.7	-
48.	*Gelidiella acerosa*	8.8	57.0	3.6	-
49.	*Acanthophora spicifera*	4.8	29.7	0.5	4.0
50.	*Laurapncia papillosa*	4.3	11.6	0.6	5.9

Detailed investigations were made to extract agar from different species of *Gracilaria* and *Gelidiella acerosa* in order to know the yield and physical

properties of agar obtained from these seaweeds *(Table 3)*. As a result *Gelidiella acerosa* was found to be an excellent source for the manufacture of high quality agar. It was observed that in *Gracilaria edulis* there were 60-90% of minerals and good amount of sulphur, nitrogenous matter and carbohydrates occurring in water soluble form and these compounds which come as impurities while extracting agar could be removed by pulverising, soaking and washing the weed. Based on this important observation, a cottage industry method was developed in the Institute for manufacturue of pure agar from *Gracilaria edulis*. In this cottage industry method the impurities are removed from the seaweeds before extraction and not from the gel. The leaching process will minimise the cost of production since large scale equipments are not used for freezing the gel. The yield from the pulverised weed is also higher than that observed from other methods. Another method was also described for extraction of agar from *Gelidiella acerosa* in which freezing technique is employed to retain the cold water soluble fraction of agar but without being able to remove the impurities from the weed effectively as in the case of *Gracilaria edulis* (Kaliaperumal *et. al.*, 1987).

Table : 3 Yield and physical properties of agar from seaweeds of India.

Sl.	Name of seaweed	Place	Yield (%)	Gel strength (g/cm^2)	Gelling temp.(°C)	Melting temp.(°C)
1.	*Gelidiella acerosa*	Mandapam	50.8	325	36	86
		Manapad	36.3	119	50	98
		Lakshadweep	36.3	278	46	99
2.	*G.indica*	Tiruchendur	28.1	13	47	97
		Kovalam	48.3	46	42	98
		Manapad	28.5	23	48	92
3.	*Gracilaria arcuata*	Kilakkarai	52.2	67	47	99
		Lakshadweep	37.8	67	52	89

4.	*G. corticata var. corticata*	Mandapam	42.8	22	40	60
		Tiruchendur	27.2	9	36	72
		Manapad	21.5	9	36	72
5.	*G.corticata var.cylindrica*	Kilakkarai	48.6	67	45	99
		Idinthkarai	37.9	15	45	99
6.	*G.crassa*	Mandapam	23.0	140	48	84
		Tuticorin	18.1	11	31	86
7.	*G.edulis*	Mandapam	49.2	139	42	78
		Tuticorin	43.0	9	39	65
		Lakshadweep	43.1	77	48	96
8.	*G.folifera*	Mandapam	50.4	55	38	70
		Idinthakarai	27.5	15	37	84
		Kovalam	26.8	11	36	78
9.	*G.obtusa*	Idinthakarai	43.7	41	42	63
10.	*G.verrucosa*	Chilka Lake	23.0	41	40	55

Studies were made on the alginic acid and mannitol contents of several brown algae growing at Mandapam and other parts of Tamil Nadu coast and Lakshadweep *(Table 4)*. Studies were conducted on 30 marine algae collected from Mandapam and other areas of Tamil Nadu for their hemolytic and anti-microbial activities. The results indicated that these algae in general showed antibiosis against the Gram negative microbes *Enteromorapha compressa, Cladophoropsis zoolingeri, Padina gymnospora, Sargassum wightii* and *Gracilaria corticata* and against the Gram -positive cultures of *Bacillus*. Strong hemolytic activities was shown by *C. zoolingerii* and *Grateloupia lithophila* (Rao *et. al.*, 1991).The methods of preparing some food stuffs adding agar and different recipes from seaweeds such as gelly, jam, pickle and wafer were developed. Some experiments were also conducted to control flavour changes,

oxidation of fats, dehydration etc. in frozen seafoods during storage using sodium alginate as coating material (Thivy, 1960; Pillai, 1964; Chennubhotla *et al.*, 1981).

Table : 4 Alginic acid and mannitol contents of Indian seaweeds

Sl.	Name of seaweed	Place	Alginic acid (%)	Mannitol (%)
1.	*Sargassum duplicatum*	Lakshadweep	19.1	2.6
2.	*S.ilicifolium*	Mandapam	30.8	5.0
		Tuticorin	26.5	-
3.	*S.myrtocystum*	Mandapam	34.5	5.0
		Mandapam	22.8	-
		Idinthakarai	19.4	-
		Kovalam	16.7	-
4.	*S. wightii*	Mandapam	31.7	7.3
		Manapad	21.3	-
		Tiruchendur	17.7	-
		Kovalam	16.7	-
5.	*Turbinaria conoides*	Mandapam	35.6	7.4
		Tuticorin	27.3	-
		Lakshadweep	27.3	-
6.	*T. decurrens*	Mandapam	26.3	8.7
7.	*T.ornata*	Mandapam	32.2	7.1
		Lakshadweep	26.1	6.0
8.	*Hormophysa triquetra*	Mandapam	25.5	6.0
9.	*Cystoseira trinodis*	Mandapam	30.5	7.8

10.	*Padina boergesenii*	Mandapam	24.8	2.1
		Tuticorin	9.7	-
		Manapad	12.1	-
		Lakshadweep	9.2	9.5
11.	*P.pavonica*	Idnthakarai	8.7	-
12.	*P.tetrastromatica*	Turuchendur	10.0	-
13.	*Stoechospermum marginatum*	Mandapam	23.8	2.8
		Tuticorin	15.9	-
		Trirchendur	23.8	-
		Manaopad	21.0	-
		Identhakarai	25.7	-
14.	*Rosenvingea intricata*	Mandpam 20.5	1.5	
		Tuticorin	19.8	-
15.	*Colpomenia sinuosa*	Mandapam	14.1	1.9
16.	*Hydroclathrus clathratus*	Mandapam	14.7	2.2
17.	*Chnoospora implexa*	Kovalam	34.0	-
		Lakshadweep	10.0	5.1

Commercial exploitation of seaweeds

In India, seaweeds are used as raw materials for the production of agar and sodium alginate. About 25 actively functioning agar and algin industries are situated in different places of Tamil Nadu, Kerala, Karnataka, Gujarat and Pondichery. At present the red algae *Gelidiella acerosa, Gracilaria edulis, G. crassa* and *G. folifera* are used for agar production and brown algae *Sargassum* spp and *Trutbinaria* spp for sodium alginate. All these seaweeds are harvested since 1966 from the natural seaweed beds of south Tamil Nadu coast from Rameswaram to Kanyamumari. Data were collected from 1978 onwards on the quantity of seaweeds landed at different centres of Tamil Nadu. During the period 1978 to 1996, the quantity of agar yielding seaweeds

Gelidiella acerosa, *Gracilaria edulis*, *G. crassa* and *G. foliifera* in a year varied from 248 to 1289 tons (dry wt). Algin yielding seaweeds *Sargassum* spp and *Turbinaria* spp from 651 to 5537 tons (dry wt) and all the above seaweeds from 1173 to 6420 tons (dry wt) depending on the avilability of seaweeds in the natural beds and raw material requirement from the seaweed industries (Kalimuthu *et al.*, 1990; Kalimuthu and Kaliaperumal, 1996).

Seaweed culture

The natural resources of seaweeds available in Tamil Nadu coast are insufficient to meet the raw material requirements of Indian seaweed insustries as many agar and algin manufacturing industries are coming up every year. With a view to develop suitable technology for commercial scale cultivation of seaweeds to augment supply of raw material to seaweed industries and to conserve the natural stock of seaweeds, CMFRI has attempted experimental cultivation of agarophytes, carrageenophytes and alginophytes in different field environments using various culture techniques (Chennubhotla *et. al.*, 1987 b). These experiments revealed that *Gelidiella acerosa* can be successfully cultivated on coral stones and *Gracilaria edulis* and *Acanthophora spaicifera* on long line ropes and nets. The location of culture sites, techniques adopted and results obtained for these three species are given in *Table 5*. Based on the results obtained in the field cultivation, the CMFRI has developed a viable technology for commercial scale cultivation of agar yielding

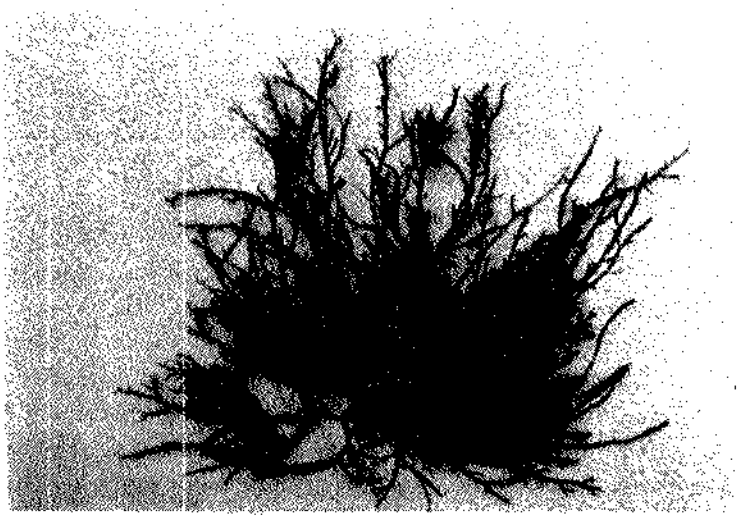

Fig.1 *Gracilaria edulis*

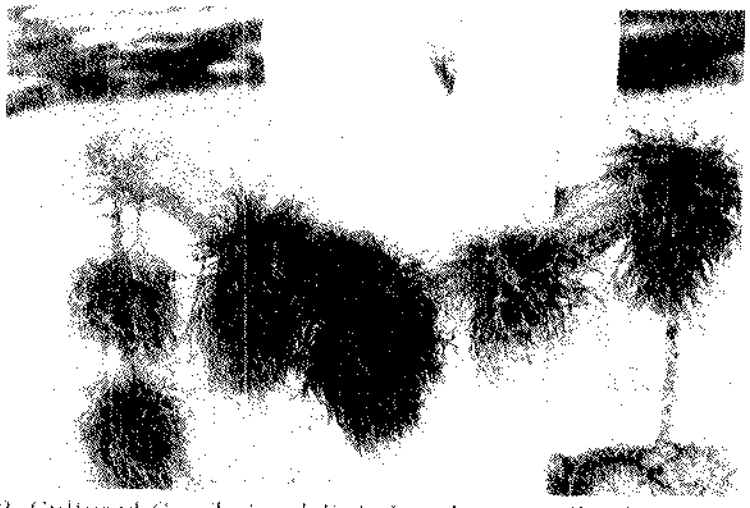

Fig.2 Cultured *Gracilaria edulis* in long line rope (30 days growth)

seaweed *Gracilaria edulis* using coir rope nets (Fig. 1 & 2) (Chennubhotla and Kaliaperumal, 1983).

Table 5 : Field cultivation of commerically important seaweds

Sl. No.	Name of seaweed	Culture site	Culture method	Culture period (days)	Growth/ production	Reference
1.	*Gelidiella acerosa*	Mandapam	Coir rope nets	75	1.0 to 2.0 kg	Chennubhotla *et. al.* 1987b
		-do-	Coral stones	150	1.0 to 3.0 kg	Chennubhotla *et. al.*, 1987b
		do-	HDP rope nets	60	2 fold	do
2	*Gracilaria edulis*	Mandapam	Coir rope frames	80	14fold	Umamaheswara Rao, 1974
		do-	Coir rope nets	60	3 fold	Chennubhotla and Kaliaperumal, 1983
		Mimicoy	Long line coir	60	7 fold	Kaliaperumal,

	(Lakshadweep)	ropes nets			*et al.*, 1992
	-do-	-do-	50	31 fold	Chennubhotola *et.al.*, 1992
3. *Acanthophora spicifera*	Mandapam	Nylon monolines	25	2.6 fold	Kaliaperumal *et.al.*, 1986
	-do-	HDF rope nets	45	3.6 fold	Chennubhotla *etc. al.*, 1987b

Seaweed culture and utilisation technology transfer and training.

The technology developed for commercial scale cultivation of *Gacilaria edulis* was transferred to the local fish farmers of Mandapam area under the Lab-to- Land programme of the Institute during 1979- 1980. They were also given training in the post-harvest technology of seaweeds and extraction of agar by cottage industry method . The CMFRI is conducting every year a short term training course on seaweed culture and utilisation to the interested farmers, seaweed utilisers, private entrepreneurs and Govt. officials under the Trainers Training Centre of CMFRI .

Prospects

The reassessment of the natural stock of seaweeds in Indian waters should be made since many seaweed based industries have come up in recent years. For this purpose resurvey of seaweed resources in all maritime states has to be undertaken as the earlier estimates were done several years back. The seaweed resources survey of Andaman-Nicobar Islands has to be made as quantitative data for different algal species growing in this region is not available. It is also necessary to conduct surveys of deep water algal species from other parts of Indian coast as it was done in Tamil nadu in order to locate the seaweed beds occuring in deep waters. Our knowldge on the taxonomy of seaweeds occurring in Andaman- Nicobar Islands, deep waters, estuaries and backwaters are still incomplete. Much work in this direction is needed. Information on the local flora of each region is necessary for proper utilisation of various commercially important seaweeds by the industries.

At present commercial harvest of seaweeds for the production of agar and sodium alginate is made mainly from Tamil Nadu coast. The seaweeds

occurring in other parts of Indian coast, Lakshadweep and Andaman-Nicobar islands are still unexploited. There is a good demand in foreign countries for some unexploited. There is a good demand in foreign countries for some unexploited seaweeds available in India. Seaweeds which are in short supply to Indian seaweed industries can be imported. Seaweed industries for producing carageenan and agarose have to be established in India.

Now technology is available for commercial scale cultivation of *Gracilaria edulis* and *Gelidiella acerosa*. The seaweed utilisers and private entrepreneurs have to undertake large scale cultivation of seaweeds to meet the raw material requirements of Indian seaweed industries. Seaweed cultivation on large scale could not only augment supply of raw material to the seaweed industries, but it would also provide employment to the people living in the coastal areas of mainland, Lakshadweep and Andaman-Nicobar Islands. This would help in improving their economic status and quality of life.

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