Indian seaweed resources and sustainable utilization: Scenario at the dawn of a new century

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The history of Indian seaweed research is not more than seventy-five years. The state of the Indian seaweed resources was last reviewed in 1998 and subsequently lot of new information relating to resources, utilization and commercial cultivation has been added. The main objective of the present review is to gather and analyse all such additional information made available by recent workers in the last eight years. The most recent quantitative estimates for seaweed biomass recorded in the literature for different coastal areas of India are given. An attempt has also been made to provide information on commercial utilization of natural resources, import–export trend for seaweeds and seaweed phycocolloids. Industrial utilization of seaweeds and cultivation of economically important seaweeds in India, socio-economic profile of seaweed collectors, future possible utilization strategies to be adopted for conservation of germplasm and introduction of legislation policies for their controlled harvesting and sustainable utilization are elucidated in detail. When compared with the world scenario, estimates for India do not suggest the existence of rich seaweed resources. Though data on different coastal states are abundant qualitatively as well as quantitatively, they are inconsistent and incomplete and methods adopted for estimation varied considerably. The quantitative data are generally confined to estimates of corresponding harvest or of standing stalk; however, there is little direct evidence of how these estimates are related to sustainable annual harvest.

Keywords: Cultivation, Indian seaweed resources, utilization.

SEAWEEDS refer to any large marine benthic algae that are multicellular, macrothallic, and thus differentiated from most algae that are of microscopic size[1]. These plants form an important renewable resource in the marine environment and have been a part of human civilization from time immemorial. Reports on the uses of seaweeds have been cited as early as 2500 years ago in Chinese literature (c.f. Tseng[2]). The long history of seaweed utilization for a variety of purposes has led to the gradual realization that some of their constituents are more superior and valuable in comparison to their counterparts on land. Seaweeds synthesize a wide range of chemicals, some of which stand the only natural resource, e.g. agar, carrageenan and alginates. Every year about 7.5–8 million tons of wet seaweeds are being produced along the coastal regions world wide[3], the value of which was not realized in the past. It was only after the First World War and more specifically during the Second World War that many countries, including India started utilizing this neglected renewable marine resource. In India, especially the Second World War reduced agar resources to such an extent that active steps were taken by the Board of Scientific and Industrial Research to manufacture it at the 'Research Department of University of Travancore', from species of *Gracilaria* (c.f. Thivy[4]). In spite of the interest shown during the subsequent period to develop the agar industry in India, the same got the set back, primarily due to the difficulty in obtaining sufficient raw material for sustaining the industry. The survey for raw material became a pre-requisite to start such industries and top priority was given to quantify the economically important seaweeds on the Indian coast.

India (08.04–37.06 N and 68.07–97.25 E), a tropical South Asian country (Figure 1) has a stretch of about 7500 km coastline, excluding its island territories with 2 million km^2 Exclusive Economic Zone (EEZ) and nine maritime states (Table 1). The seaweed flora of India is highly diversified and comprises mostly of tropical species, but boreal, temperate and subtropical elements have also been reported. In all, 271 genera and 1153 species of marine algae, including forms and varieties have been enumerated till date from the Indian waters[5]. Many of the rocky beaches, mudflats, estuaries, coral reefs and lagoons along the Indian coast provide ideal habitats for the growth of seaweeds. The coast is characterized by mixed tides and generally with narrow intertidal regions. However, due to the geographical, climatic and physiographic influences, the coast harbours predominantly subtidal algal community. There has been no particular zonation in general; however, some kind of precinct was reported for seaweed vegetation at regions along the east coast, viz. Mahabalipuram[6], Visakhapatnam[7], the west coast, viz. Okha[8]; Diu (Mantri and

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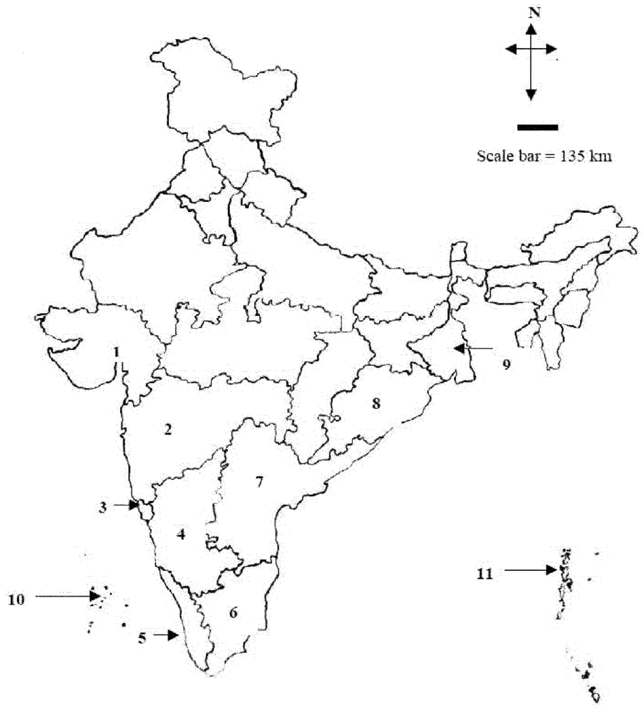
Table 1. Places of algal interest along coastal states of India

State	Coastline (km)	Places of algal interest
Gujarat	1700	Okha (22.15 N, 69.1 E), Dwarka (22.14 N, 69.1 E)
Maharashtra	572	Malvan (16.03 N and 73.30 E)
Goa	104	Panaji (15. 03 N and 73. 55 E)
Karnataka	280	Karwar (14.48 N and 74.11 E)
Kerala	560	Quilon (8.54 N and 76.38 E), Varakala (8.28 N and 76.55 E)
Tamil Nadu (including Pondicherry)	980	Krusadai Island (9.14 N and 79.13 E) Idinthakarai (8.10 N and 77.43 E)
Andhra Pradesh	960	Visakhapatnam (17.44 N and 83.23 E) Pulicat lake (13.20–13.40 N and 80.14–80.15 E)
Orissa	432	Chilka lake (19.50 N and 85.30 E)
West Bengal	280	Sundarbans (21.33–22.45 N and 88.06–89.05 E)
Andaman and Nicobar Islands	1500 (approx.)	6–14 N and 92–94 E
Lakshadweep Islands	120 (approx.)	8–12 N and 72–74 E



1. Gujarat 2. Maharashtra 3. Goa
4. Karnataka 5. Kerala 6. Tamil Nadu
7. Andhra Pradesh 8. Orissa 9. West Bengal
10. Lakshadweep Islands 11. Andaman and Nicobar Islands

Figure 1. Map of peninsular India showing maritime states and union territories.

Subba Rao unpublished). Iyengar[9] was the first Indian algologist who gave a detailed descriptive account of Indian marine algae occurring on the southeast coast, especially Krusadai island. However, Børgesen[10–17] contributed much to the taxonomic account on Indian marine algae. Since then, attempts have been made on different aspects of seaweed research in India. Seaweed resources of India are partially reviewed elsewhere[18–20]. Resource estimations for seaweeds along the Indian coast have been done regularly by several workers. However, Horenel[21] gave the first estimates of seaweed resources for the drift *Sargassum* on Okhamandal coast, over 40 km of the then Baroda state. Before 1962, as a preliminary study, workers estimated the seaweeds at definite pockets, especially by spot-surveying methods on the Indian coast[4,22,23]. Subsequent to 1962, several workers attempted to estimate standing crop available at certain localities on the Indian coast, but failed to arrive at a correct picture.

Major intertidal seaweed surveys along the Indian coast – statewise review

Distribution of economic seaweed resources along the Indian coast was first mapped by Thivy[24]. Attempts were made to determine specifically, the alginophytes and agarophytes at their place of abundance, keeping in mind their economic importance. Workers have surveyed different parts of the coastal areas of the Indian peninsula. A series of systematic and scientific surveys along the Indian coast for seaweed resources have been initiated by the Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar, under the ‘Survey of economic seaweed resources’ during 1961–91, as a national agenda funded by the National Committee on Science and Technology (NCST), New Delhi, in collaboration with different research and government organizations. Unfortunately, after 1980, due to scarcity of funds very few attempts by individuals, especially academicians have been made at the regional level to assess the seaweed wealth. Some surveys revealed only economic seaweeds, while others provided the entire standing crop of seaweeds of the concerned regions.

The survey was carried out along Gujarat coast during 1971–75, only for the Saurashtra region from Okha to Mahuva, in five sectors covering a distance of 47.3 km out of 1215 km coastline by CSMCRI, in collaboration with Department of Fisheries, Government of Gujarat. The standing crop for economically important seaweeds ranged from 282 to 610 tons (fresh weight)[25]. The standing crop estimates of seaweeds in Maharashtra have come from the work of two independent surveys. In 1976, the survey was undertaken by CSMCRI in collaboration with Department of Fisheries Government of Maharashtra; Konkan Krishi Vidyapeeth, Ratnagiri and National Institute of Oceanography (NIO), Goa, covering 22.5 km of the 653 km coastline. Estimates for two species, viz. *Sargassum* and *Ulva* were only given, recording 315 tons (fresh weight)[26]. In another survey, the entire coast of Maharashtra was surveyed by NIO during 1979 and an estimate of 20,000 tons (fresh weight) of seaweeds was reported[27]. Data on surveys for Goa and Karnataka did not reveal encouraging results. Survey along the Goa coast was conducted by NIO in 1975 and 255 tons (fresh weight) of seaweeds were reported from Donapaula to Chapora region (c.f. Untawale *et al.*[28]), whereas Dhargalkar[29] reported 2000 tons (fresh weight) of seaweeds for the entire coast of Goa. The Karnataka coast supported poor seaweed growth and data for qualitative survey only were available[30]. The seaweed resources of Kerala coast were given by Chennubhotla *et al.*[31]. The total standing crop of 1000 tons (fresh weight) was estimated. The Tamil Nadu coast was surveyed during 1971–76, covering a distance of 320 km from Rameswaram and adjoining islands to Melmidalam (Colachal) by CSMCRI, in collaboration with Central Marine Fisheries Research Institute (CMFRI), Cochin and Department of Fisheries, Government of Tamil Nadu. The survey was conducted in five sectors. The total standing crop of seaweeds in the intertidal region of Tamil Nadu was estimated as 22,044 tons (fresh weight) in a potential area of 9891.35 ha of the 20,000 ha total area surveyed[32]. As of now, among the coastal states and union territories, Tamil Nadu ranks first in resource potential (c.f. Kaladharan and Jayasankar[33]). The Andhra Pradesh coast was surveyed by CSMCRI, in collaboration with Department of Fisheries, Government of Andhra Pradesh during 1979–82 in three sectors. The average standing crop was found to be about 7500 tons (fresh weight)[34]. As such, data for seaweed resources of Orissa coast were not available, but a few surveys were made for Chilka Lake, which are summarized here. First estimates for seaweed resources of this lake came from Mitra[22], who reported 4–5 tons (fresh weight) *Gracilaria* per year. However, more recently, Rath and Adhikari[35] gave potential estimates of 26,970 tons (dry weight) of macroalgae for the lake for the year 1999–2000. The West Bengal coastline has not been surveyed for its resource availability. Mukhopadhyay and Pal[36] only provided an idea of the biodiversity of seaweeds along the coastal regions of South and North 24 Parganas of West Bengal. As such, no data are available for standing crop of seaweeds of West Bengal coast. Coastal union territories have been neglected and systematic survey was conducted only for the islands of Lakshadweep during 1977–79 by CSMCRI, in collaboration with Department of Fisheries, Union Territory of Lakshadweep, Kavarathi. The estimated values ranged from 4955 to 10,077 tons (fresh weight) for all the ten islands surveyed, with an average value of 7519 tons (fresh weight)[37]. The Andaman and Nicobar Islands have been partly surveyed by CMFRI. The standing crop of 19,111 tons (fresh weight) was estimated for an area of 40 km^2 out of 212 km shoreline of South Andaman Island[38]. However, it was estimated to be 3385 and 3432 tons (fresh weight) for an area of 22 and 25 km^2, out of 73 and 52 km shoreline of Middle Andaman and North Andaman island respectively[39]. An estimate of 120 tons (fresh weight) of seaweeds was recorded for Little Andaman island by Gopinathan and Panigrahy[40]. Unfortunately, remoteness and lack of logistic support hampered the detailed and complete survey of seaweed wealth for many of the islands. No systematic survey was undertaken for the union territories of Pondicherry, Daman and Diu and the scattered information available was for species diversity, distribution pattern, etc.

Subtidal, drift seaweed survey and specific survey for iodinophytes

Two attempts have been made so far on the Indian coast: one to estimate the subtidal seaweeds of Gujarat, including the Gulf of Kutch and the other, that of Tamil Nadu. Chauhan and Krishnamurthy[41] estimated 4000 tons (fresh weight) of alginophytes from 10.65 km^2 subtidal area of the Gulf of Kutch during 1966–67. The deep-water survey covering 5–20 m depth was conducted for the Tamil Nadu coast during 1986–91 by CSMCRI, in collaboration with CMFRI. The survey was conducted in four sectors. The total standing crop estimated in all the four sectors surveyed was 75,375 tons (fresh weight) in a productive area of 297.5 km^2 of the 1863 km^2 total area surveyed[42]. Only one attempt was made to estimate the drift seaweed resources along the Indian coast. A large quantity of seaweeds used to be caste ashore along the coast during stormy/strong winds, indicating the seaweed potential of a particular location of the coast. With a view to assess this cast-ashore or drift seaweed potential, Krishnamurthy[43] carried out an extensive survey during 1965–66 at five localities along the Indian coast (Table 2). The resource estimates given included Agarophytes – *Gracilaria* and *Hypnea* and Alginophytes – *Sargassum* and *Turbinaria*. A total standing crop of 1260.18 tons (fresh weight) was recorded from 343 km coastline. The drift seaweed exhibited seasonality in relation to quality and quantity. However, it was observed that the peaks in the drifts of agarophytes and alginophytes exhibited more or less the same trends in different regions. Specific survey of the iodine-rich seaweed, *Asparagopsis delilei* (= *A. taxiformis*) was carried out at Boria reef (Gulf of Kutch) and Okha reef, covering an area of 0.067 km^2 during 1972–73, and 12.15 tons (fresh weight) were estimated[44]. In another survey, eight islands in the Gulf of Mannar, viz. Shingle Island, Krusadai Island, Pulli–Pullivasal Island, Putty Island, Manali Island, Hare Island, Mully Island

Table 2. Drift seaweed survey along the Indian coast (values are in tons (fresh weight))

Place	Length of coastline (km); per cent cover by drift	Agarophytes	Alginophytes	Other seaweeds	Total
Visakhapatnam	10; 50	0.02	0.43	0.05	0.50
Pamban (Mandapam–Kilakkarai)	100; 40	29.92	120.00	49.20	199.12
Idinthakarai (Tiruchandur–Kanyakumari)	128; 30	22.80	830.30	176.70	1029.80
Quilon	5; 60	0.09	12.39	0.03	12.51
Porbandar	100; 25	Nil	18.00	0.25	18.25

Table 3. Standing stalks of seaweed along different coastal states of India

State/seaweed	Standing stalk	Source
Gujarat		
Gulf of Kutch	1,00,250*	Desai[69]
Gulf of Kutch	4000	Chauhan and Krishnamurthy[41]
Okha to Dwarka and Vumani reef	1011	Bhanderi and Trivedi[44]
Adhatra reef	60	Sreenivasa Rao *et al.*[70]
Saurashtra	282–610	Chauhan and Mairh[25]
Maharashtra		
Konkan	315	Chauhan[26]
Entire coast	20,000	Untawale *et al.*[27]
Goa		
Donapaula to Chapora	255	c.f. Untawale *et al.*[28]
Entire coast	2000	Dhargalkar[29]
Kerala	1000	Chennubhotla *et al.*[31]
Tamil Nadu		
Madras coast	690	Umamaheswara Rao[71]
Cape Comorin to Colachal	5	Koshy and John[23]
Calimare to Cape Comorin	66,000	Chacko and Malu Pillai[72]
Pamban	1000	Verma and Krishna Rao[73]
Palk Bay	631	Umamaheswara Rao[71]
South east coast	20,535	c.f. Untawale *et al.*[28]
Gulf of Mannar	33,000*	Desai[69]
Entire coast (intertidal)	22,044	Anon.[32]
Entire coast (subtidal)	75,375	Kaliaperumal *et al.*[42]
Andhra Pradesh	7500	Anon.[34]
Orissa		
Chilka lake	5	Mitra[22]
Chilka lake	2,69,700*	Rath and Adhikari[35]
Lakshadweep	4955–10,077	Anon.[39]
Iodinophytes		
Gujarat	12.15	Bhanderi and Trivedi[44]
Gulf of Mannar Islands	61.54	Subba Rao and Ganesan (unpublished)
Andaman		
South Andaman	19,111	Muthuvelan *et al*[38]
Middle and North Andaman	6817	Muthuvelan *et al.*[39]
Little Andaman	120	Gopinathan and Panigrahy[40]
Drift seaweeds	1260.18	Krishnamurthy[43]
Total	6,77,308.87 to 6,82,758.87	

All values are in tons (fresh weight).
*Values have been converted into tons (fresh weight) with conversion factor[69].

and Valai Island were surveyed in 1993 and the standing crop estimated was 61.54 tons (fresh weight) in a potential area of 6.23 ha out of the 30.75 ha total area surveyed (Subba Rao and Ganesan, unpublished).

The standing crop of seaweeds estimated from different coasts of India (Table 3) and species encountered during these surveys are summarized (Table 4). The total standing crop varied from 6,77,308.87 to 6,82,758.87 tons (fresh

Table 4. Species composition encountered during different surveys along the Indian coast

State	Green	Brown	Red	Blue-green	Total	Source
Gujarat	29	24	39	Nil	92	Chauhan and Mairh[25]
Gujarat (subtidal)	Nil	Nil	Nil	Nil	35	Dhargalkar and Deshmukhe[81]
Maharashtra	11	11	14	Nil	36	Chauhan[26]
Karnataka*	16	10	16	1	43	Agadi[30]
Kerala	13	3	17	2	35	Chennubhotla *et al.*[31]
Tamil Nadu (intertidal)	113	83	225	5	426	Anon.[32]
Tamil Nadu (subtidal)	8	8	12	1	29	Kaliaperumal *et al.*[43]
Andhra Pradesh	23	7	34	1	65	Anon.[34]
West Bengal*	9	Nil	5	Nil	14	Mukhopadhyay and Pal[36]
Orissa* (Chilka lake)	8	Nil	6	Nil	14	Sahoo *et al.*[74]
Lakshadweep Islands	33	10	39	Nil	82	Anon.[37]
Great Nicobar Island*	18	15	18	Nil	51	Ravindran *et al.*[75]
South Andaman Islands	29	15	11	Nil	55	Muthuvelan *et al.*[38]
Middle and North Andaman Islands	11	11	5	Nil	27	Muthuvelan *et al.*[39]
Diu*	27	14	29	Nil	70	Mantri and Subba Rao[76]

*Qualitative survey only.

weight) along the Indian coast, while the World natural resources were estimated to be 2,00,54,590 tons (fresh weight)[45]. When compared with the world seaweed resources, the Indian resource is almost negligible (about 3.4%). However, estimates presented here may not give a clear picture of the standing crop available at present, since most of the surveys were conducted at different times by different methods during the past 20 years from 1971 to 1991, except for the Andaman group of islands.

Methodology followed during surveys

The salient features for the method followed during the intertidal seaweed surveys along Tamil Nadu, Andhra Pradesh and Lakshdweep are described here. The sampling station was fixed according to the seaweed information provided by local people and field observations. Line transects were fixed at a regular interval of about 1–3 km, depending on the length of the shore/availability of seaweed stalks. Lagoon and reef areas were treated separately for sampling purpose (especially for Lakshdweep islands). At each station three transects were established, one on either side at a distance of 100 m. The transects were laid perpendicular to the shore. Several equidistant sampling points (more than four) were fixed using a sextant taking into consideration the breadth of the reef or lagoon, thus dividing the area into parallel belts which lay horizontally to the coastline. The sampling points had thus no relation to the slope of the reef or depth of the lagoon and depend only on the area available. For sampling, 1 m^2 quadrant was used. Area, density and standard error for each available species were calculated to estimate the standing crop[32,34,37]. However, the method followed by Chauhan[26] and Chauhan and Mairh[25] for standing crop estimates of Maharashtra, and Saurashtra coast of Gujarat differed. Belt-transect method was used, in which transects of 1 m width, 100 m apart were fixed at right angles to the shoreline and the entire seaweeds lying within the transects were collected. Finally the standing crop was computed taking into account the mean weight of seaweeds in the transect and the total length of the seaweed growing on the coastline. The standing crop of seaweeds of Andaman islands was arrived at using a compass survey method, in which the central transect perpendicular to the shore was laid and lateral transects were fixed 100 m apart on both the sides of the transects. Sampling points were fixed on the transects. Seaweeds were collected from the prefixed sampling points in a marked area and subsequently the data were computed to the entire area. Quadrant of size 0.25 m^2 was used for the sampling[38].

The subtidal survey of Tamil Nadu coast was done following a similar procedure as that of the intertidal survey, except that the distance between the two transects was 5 km and the distance between each sampling point on the transect was 500 m, and an eco-sounder was used to determine the depth at a particular location. Patent log was used to measure the distance between the sampling points and the survey was conducted from 5 to 20 m depth and the number of sampling points varied according to depth[42]. However, for subtidal survey of algin-bearing seaweeds in the Gulf of Kutch[41], the method followed was the one suggested by Walker[46].

It is necessary that a comprehensive uniform method be adopted to determine the real-time standing crop of a particular area in the peak growing season of the year. The new methodologies involving remote sensing may also be adopted for seaweed resource mapping and estimations by which near accurate estimates may be achieved.

Sustainable utilization of seaweed resources

To utilize seaweed recourses in a sustainable manner, conservation as well as proper husbanding of these resources is a prerequisite. Unplanned and continuous harvesting of these seaweeds from their natural habitats resulted in depletion of standing crop. Continuing such activities for longer periods might exhaust these resources completely, without even leaving the basic nuclei needed for propagation in the succeeding season. In order to avoid this, utilization of seaweeds is to be done according to the pattern of growth and life cycle. Certain economically important seaweeds like *Gelidiella acerosa*, *Gracilaria edulis*, species of *Sargassum* and *Turbinaria* have been advocated for proper harvesting after conducting studies on the harvesting procedure. *G. acerosa* needs 8 months for complete recuperation by partial harvest[47] and harvesting has been recommended twice a year, once during July–August and the other during January–February[47,48]. Complete recuperation takes place within 6 months at Veraval on Gujarat coast[49]. In case of *G. edulis*, recuperation was found to be 3–4 months and harvest could be done preferably twice a year, in April and also in July[50]. For species of *Sargassum* and *Turbinaria*, about 7 months would be necessary after harvest for recovery of harvestable biomass, which could be done during September to January[51]. A time-table for commercial harvest of economically important seaweeds from Tamil Nadu and Gujarat coast was given based on the maturity of the crop (Table 5), which might aid the utilization in a more sustainable manner. This in turn might result in better conservation of the germplasm. Countries like France, Spain, Zanzibar, etc. have brought legislation to regulate the harvest of seaweed resources and have specified certain 'closed periods' during which collection of seaweeds is totally prohibited (c.f. Desikachari[18]). This type of legislation could be implemented in India as well to conserve and utilize the seaweed resources in a sustainable manner.

Seaweed landings and socio-economic profile of seaweed collectors in India

Unlike in many developed countries, the situation in India is different and seaweeds are collected manually from their natural habitats. This harvesting is one of the important sources of livelihood to the coastal fisher-folk community. Seaweed collections are mainly centred along the southeastern coast of India from Rameswaram to Kanyakumarai. There appeared to be 13 seaweed landing centres on the southeastern coast. The seaweed collections for agarophytes (*G. acerosa*, *G. edulis*, *G. crassa*, *G. foliifera* and *G. verrucosa*) during 1978–79 to 2002–03 ranged from 240 to 1518 tons (dry weight), whereas those for alginophytes (species of *Sargassum* and *Turbinaria*) for the same period varied from 651 to 5534 tons (dry weight). The total seaweed landings ranged from 1173 to 6417 tons (dry weight)[52,53]. Details of landings for agarophytes and

Table 5. Time-table for commercial harvest of economically important seaweeds from Tamil Nadu and Gujarat coast

Seaweed	Period of occurrence	Suitable period for harvest
Agarophytes		
Gelidiella acerosa	Throughout the year	January to March
Gracilaria edulis	Throughout the year	July to September
G. crassa	Throughout the year	January to March, August and September
G. foliifera	Throughout the year	January to March, August and September
G. corticata var. *corticata*	Throughout the year	June to August, November and December
G. verrucosa	March to November	May to August
Alginophytes		
Sargassum wightii	Throughout the year	October to December
S. myriocystum	Throughout the year	May to August
S. ilicifolium	Throughout the year	July to September
*S. swartzii**	October to February	November and December
*S. tenerrimum**	October to February	December and January
*S. merrifieldii**	December to April	January and February
*S. johnstonii**	September to January	November and December
Turbinaria conoides	Throughout the year	October to December
T. ornata	Throughout the year	October to December
T. decurrens	Throughout the year	December and January
Carrageenophytes		
Hypnea musciformis	Throughout the year	December to March
H. valentiae	Throughout the year	January to March

Source: Kaliaperumal and Kalimuthu[52].
*Data for Gujarat coast; Source: Joshi[77].

Table 6. Seaweed landings from Tamil Nadu

	Agarophytes		Alginophytes		
Year	*Gelidiella acerosa*	*Gracilaria edulis*	*Sargassum* spp.	*Turbinaria* spp.	Total
1978–79	288	395	3636	1021	5340
1979–80	541	342	4253	1281	6417
1980–81	247	213	3090	438	3988
1981–82	131	117	2522	222	2992
1982–83	102	225	3176	704	4207
1983–84	293	291 (85)[a]	2070	375	3114
1984–85	210	320 (96)[a]	780	235	1641
1985–86	189	269 (45)[a]	2096	385	2984
1986–87	261	233 (28)[a]	491	160	1173
1987–88	217	317 (34)[a]	868	250	1686
1988–89	366	330 (15)[a]	2605	523	3839
1989–90	370	400 (2)[a]	3106	459	4337
1990–91	307	982	2867	224	4380
1991–92	274	318 (3)[b]	5000	160	5755
1992–93	312	399 (50)[b]	2921	122	3804
1993–94	261	187	2867	256	3571
1994–95	232	105 (110)[b]	2249	307	3003
1995–96	280	601 (20)[b]	2298	257	3456
1996–97	423	323	2922	336	4004
1997–98	322	974	3479	244	5019
1998–99	365	496 (35)[a]	1704	180	2780
1999–2000	491	664 (28)[a] (25)[b] (310)[c]	2066	99	3686
2000–01	560	352 (224)[c]	1424	9	2569
2001–02	571	464 (130)[c]	1760	50	2975
2002–03	665	279 (21)[a]	2011	274	3250

[a]*Gracilaria crassa* (= *G. canaliculata*); [b]*G. foliifera*; [c]*G. verrucosa*.
All figures are in tons (dry weight).
Source: Kaliaperumal and Kalimuthu[52], Kaliaperumal *et al.*[53].

alginophytes from 1978–79 to 2002–03 are given in Table 6. It is noted here that the collections for both the species, *G. acerosa* and *G. edulis* have shown wavering trends from year to year leading sometimes to over-utilization, which ultimately resulted in denudation of natural habitat. This situation is to be stopped and for this batch harvesting at appropriate time and growth stage of the seaweed may be adopted for natural conservation. Among the alginophytes, during the same period *Sargassum* collections amounted to 2587 tons (dry weight), whereas *Turbinaria* collections were only 265 tons (dry weight). Now there is no dearth of raw materials for the alginate industry. The data presented in Table 6 for these seaweeds fluctuated indirectly reflecting that the alginate requirement in the country was less during the particular year. It should be noted that these seaweeds whether collected or not, would die back after completion of the growth period, since they are annuals.

It has been estimated that at present 5000 women in southeastern India are dependent on seaweed-related activities for their livelihood. If all the available resources are harvested to their optimal level, it can provide employment to another 20,000 coastal fisherfolk in the harvesting sector and an equal number in post-harvest activities[54]. Both men and women in the Gulf of Mannar region of Tamil Nadu are involved in seaweed collection. The main source of income for these fisherfolk is derived through collection of seaweeds. Most of them belonged to the young age group with primary level education. Restriction to collect seaweeds from the islands of Gulf of Mannar, middleman exploitation, seasonal employment, lack of adequate place for drying the collected seaweed are some of the problems reported/encountered. The socio-economic profile of seaweed collectors is given (Table 7). Since the domain of the seaweed-collecting industry is mainly dominated by women, special efforts could be taken for its optimal utilization and market expansion through diversified product development and its popularization.

Industrial utilization of seaweeds in India

Approximately 7.5–8 million tons of wet seaweeds are harvested worldwide per year. In India, seaweeds are utilized by the industries, mainly for commercial production of agar and alginate. Carrageenan industries are least developed due to non-availability of sufficient raw materials for carrageenan production. Agar production in India started in 1940 on a cottage industry-scale, using *G. edulis* as raw material. Subsequently, a viable cottage industry method for the manufacture of agar from

Table 7. Socio-economic profile of seaweed collectors in India (after S. Immanuel and R. Sathiadhas[54])

Profile characteristics	Category			
Age	Young 18 (60%)	Middle 8 (27%)	Old 4 (13%)	
Education	Illiterate 4 (13%)	Primary 20 (67%)	Middle 4 (13%)	High 2 (7%)
Occupation	Main 25 (83%)	Subsidiary 5 (17%)		
Experience	Low 10 (33%)	Medium 12 (40%)	High 8 (27%)	
Type of family	Nuclear 21 (70%)	Joint 9 (30%)		
Mass media contact	Low 8 (27%)	Medium 14 (47%)	High 8 (26%)	
Social participation	Low 9 (30%)	Medium 14 (47%)	High 7 (23%)	
Extension agency contact	Low 8 (27%)	Medium 15 (50%)	High 7 (23%)	

Figures in parenthesis indicate percentage.
$n = 30$.

Gracilaria lichenoides (= *G. edulis*) was developed by Thivy[4]. Later a process for industrial manufacture of agar was developed by Kappana and Rao[55] using *Gelidium micropterum* (= *G. acerosa*) as raw material. With the development of this industrial method, a few industries started agar production using either *G. acerosa* or *G. edulis* as raw material. Currently, there are 46 seaweed-based industries – 21 agar and 25 alginate – but not functioning up to their rated capacity, as there has been a short supply of raw materials[56]. Among the 21 agar factories, only ten are presently functioning. Although Indian requirement of agar is about 400 tons per annum, only about 30% of it has been produced indigenously. Among the existing agar industries, M/s Marine Chemicals, Cochin contributes 50% of the indigenous production. Similarly, Indian requirement of alginate is 1000 tons per annum, and indigenous production is less than 40%. Among 25 alginate industries, only 12 are actively involved in production. However, M/s SNAP Natural and Alginate Products Ltd, Ranipet contributes half of the indigenous production. Phycocolloid production in India is summarized in Tables 8 and 9. These industries, most of which are located in Tamil Nadu, South India, collect seaweed raw materials from the specific selected sites along the Indian coast. Compared to the world phycocolloid production of 1,46,730 tons during 2001 (c.f. McHugh[3]), Indian phycocolloid production was 430 tons only during the same period; this is found to be meagre (0.2%).

The recent trends in the export of seaweeds and agar agar has drastically declined over the years (Table 10). To meet the demand of internal consumption of phycocolloids, they have been imported (Table 10).

Seaweed cultivation in India

Seaweed cultivation in India is still in the experimental stage and field cultivation of some economic seaweeds has been attempted. Over-utilization coupled with short supply of seaweeds on the one hand, and their loss due to natural calamities like cyclones on the other hand, has prompted such cultivation. Cultivation conserves the natural resources and improves the elite germplasm. Cultivation technologies for important agarophytes like *G. acerosa*[57,58], and *G. edulis*[59], and important carrageenophytes like *Hypnea valentiae*[60] and *Kappaphycus alvarezii*[61] have been developed. Among all the cultivation methods developed for *G. acerosa*, bottom-culture method using coral stone as a substratum is found to be the best-suited for cultivation. A crop yield of 4 tons (dry weight)/ha/yr was achieved in two harvests over 0.5 ha area by the above-mentioned method using coral stone as substrata[62]. Based on the pilot-scale experiments, 20 tons (dry weight)/ha/yr in three harvests was obtained for *G. edulis* using long-line rope method, in which a coir rope was used as substrate[63,64] and 30 tons (dry weight)/ha/yr in five harvests was obtained for the same seaweed using Single Rope Floating Raft Technique (SRFT) method[62]. *Hypnea valentiae* has been cultivated using vegetative fragments by long-line method and a crop yield of 4 tons (dry weight)/ha/yr could be obtained in 14 harvests[60]. Recently, the large-scale cultivation of *Kappaphycus alvarezii*, a potential carrageenophyte along the Tamil Nadu coast, has given a crop yield of 25 tons (dry weight)/ha/yr for net bag method, 40 tons (dry weight)/ha/yr for raft method and 45 tons (dry weight)/ha/yr for open culture method in eight harvests.

Table 8. Production of agar (in tons) by different industries in India (Nehemiah, SNAP, Ranipet, pers. commun.)

	Agar production										
Industry	1994–1995	1995–1996	1996–1997	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	Total
Marine Chemicals Madurai (2 factories); Pamban (1 factory), Kerala (1 factory)	8	30	45	120	120	120	120	120	120	120	923
Golden Agar Agar, Madurai	12	12	12	5	5	5	5	5	5	5	71
Swamy, Madurai	15	15	15	15				No production			
Other small factories at Iliyankudi, Madurai, Kerala, etc.	15	15	15	20	20	20	20	20	20	20	185

Table 9. Production of alginate (in tons) by different industries in India (Nehemiah, SNAP, Ranipet, pers commun.)

	Alginate production										
Industry	1994–1995	1995–1996	1996–1997	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	Total
SNAP Natural and Alginate Products Ltd, Ranipet	162	238	150	150	150	150	160	160	160	165	1645
Hariharamatha, Kerala	30	30	30	15	15	30	30	30	30	10	250
Ekatanantha (2 units) Kerala	60	40	30	10	10	Industry has been closed					150
Seachem Chemicals, Karaikudi	40	40	40	10	10	10	10	Industry has been closed			160
Bharamavaram Chemicals, Manglore	30	30	30	30	30	30	30	30	30	30	300
Best Chemicals, Madurai	20	30	40	5	5	Industry has been closed					100
Perumal, Madurai	Functional only after 1997			25	25	25	25	25	20	15	160
Rajaganapathy Chemicals, Madurai	30	30	20	10	10	10	10	10	10	10	150
Srinivasa Chemicals	20	20	15	20	20	20	20	20	10	5	170
Algae Organic Chemicals, Kerala	20	5	5	5	5	Industry has been closed					40
Hyderabad Parties	Functional only after 1996		15	5	5	Shifted for seaweed liquid fertilizer production					25
Ahmedabad	10	10	10	–	–	–	–	–	–	–	30

Table 10. Import and export of phycocolloids and seaweeds

	Import of phycocolloids*							
	Agar		Alginate		Carrageenan		Export of agar agar/seaweed**	
Year	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
1992–93	–	–	–	–	–	–	15.26	3.53
1993–94	11.9	106.40	45.4	71.10	–	–	–	–
1994–95	66.6	90.20	141.8	140.11	36.1	122.96	2.19	4.01
1995–96	11.7	93.79	79.2	147.29	14.9	67.40	16.08	1.84
1996–97	12.4	104.98	84.4	167.70	163.3	714.81	0.55	1.43
1997–98	29.1	101.60	55.8	112.03	138.5	640.90	0.77	2.23
1998–99	7.5	93.10	48.2	64.90	139.4	675.21	0.99	1.77
1999–2000	4.1	42.24	59.4	109.73	43.0	242.60	0.05	0.51
2000–01	–	–	–	–	–	–	0.02	0.20

*Source: *Chemical Weekly*.
**Source: MPEDA[78].
Figures for quantity are in tons and value are in rupees (lakhs).

In preliminary experiments at Okha, northernwest coast of India, a crop yield of 22 tons (dry weight)/ha/yr in five harvests for the raft method was achieved. Innovative methods like developing seed material from tissue culture and *in vitro* somatic embryogenesis have given encouraging results during trials[65]. Cultivation technology for this alga was commercialized, and taken up by Pepsico India Holdings Ltd. So far, 200 tons (dry weight) *Kappaphycus* was exported (c.f. Anon.[66]). Although the alga can be grown round the year on the southeast coast, this scenario is entirely different on the northernwest coast of India due to distinct monsoon and tidal currents, where the growth period is only eight months from September to April. An important food alga, *Enteromorpha compressa* is cultivated on a pilot scale at Okha, and yielded 14.5 tons (fresh weight)/ha/yr in five harvests during the period from September to April[67]. In India, total rural employment has been growing at the slow rate of 0.58% per year, with the rural population growing at 1.7% per year[68]. The large-scale cultivation in this context could provide a facelift to rural employment by providing vast infrastructure. It could play a catalytic role in rejuvenating the rural economy. It is not only responsible for indigenous industrial development but also for export of raw materials and products as well.

1. Smith, G. M., *Marine Algae of the Monterey Peninsula*, Stanford Univ., California, 1944, 2nd edn.
2. Tseng, C. K., The past, present and future of phycology in China. *Hydrobiologia*, 2004, **512**, 11–20.
3. McHugh, D. J., A guide to the seaweed industry. FAO Fisheries Technical Paper, 2003, 441, p. 105.
4. Thivy, F., Seaweed utilization in India. In Proceedings of the Symposium on Algology, Indian Council of Agricultural Research, New Delhi, 1960.
5. Anon., *Seaweeds: Wonder Plants of the Sea* (ed. Krishnamurthy, V.), Aquaculture Foundation of India, Chennai, 2005, p. 30.
6. Srinivasan, K. S., Ecology and seasonal succession of the marine algae at Mahabalipuram. (Seven pagodas) near Madras. In *M.O.P. Iyenger Commemoration Volume,* (ed. Sahni, B.), Indian Botanical Society, Silver Jubilee Session, Allahabad, 1947, pp. 267–278.
7. Umamaheshwara Rao, M. and Seeramulu, T., An ecological study of some intertidal algae of the Visakhapatnam coast. *J. Ecol.*, 1964, **52**, 595–616.
8. Misra, J. N., The ecology, distribution and seaweed succession of the littoral algae on the west coast of India. In *Proceedings of the Symposium on Algology* (ed. Kachiroo, P.), ICAR, New Delhi, 1960, pp. 187–203.
9. Iyengar, M. O. P., Krusadai Island Flora. *Bull. Madras Govt. Mus. New Ser. Nat. Hist.*, 1927, **1**, 185–188.
10. Børgesen, F., Some Indian green and brown algae, especially from the shores of the presidency of Bombay – III. *J. Indian Bot. Soc.*, 1933, **12**, 1–16.
11. Børgesen, F., Some Indian Rhodophyceae, especially from the presidency of Bombay – III. *Bulletin of Miscellaneous Information*, Royal Botanic Gardens, Kew, 1933, pp. 113–142.
12. Børgesen, F., Some Indian Rhodophyceae, especially from the shores of the presidency of Bombay – IV. *Bulletin of Miscellaneous Information*, Royal Botanic Gardens, Kew, 1934, pp. 1–30.
13. Børgesen, F., Some marine algae from the northern part of the Arabian Sea with remarks on their geographical distribution. *Dan. Vidensk. Selsk. Biol. Med.*, 1934, **11**, 72.
14. Børgesen, F., List of marine algae from Bombay. *Dan. Vidensk. Selsk. Biol. Med.*, 1935, **12**, 64.
15. Børgesen, F., Contribution to a south Indian marine algal flora – II. *J. Indian Bot. Soc.*, 1937, **16**, 311–357.
16. Børgesen, F., Two species of *Scinaia* from south India. *Bot. Not.*, 1938, 183–189.
17. Børgesen, F., Contribution to a south Indian marine algal flora – III. *J. Indian Bot. Soc.*, 1938, **17**, 205–242.
18. Desikachari, T. V., Seaweed resources of India. In Proceedings of the Seminar on Sea, Salt and Plants (ed. Krishnamurthi, V.), Bhavnagar 1967, pp. 7–24.
19. Untawale, A. G., Dhargalkar, V. K. and Agadi, V. V., Status report on marine algal resources of the Indian coast for research and development. Technol. Report National Institute of Oceanography, Goa, 1981, p. 62.
20. Mairh, O. P., Reddy, C. R. K. and Raja Krishna Kumar, G., The seaweed resources of India. In *Seaweed Resources of the World* (eds Critchley, A. T. and Ohno, M.), Japan International Cooperation Agency, 1998, pp. 110–126.
21. Hornell, J., Report on the further development of fishery resources of Baroda state, 1918.
22. Mitra, C., Report on development of Chilka Lake, Cuttack, 1946.
23. Koshy, T. K. and John, C. C., Survey of *Gracilaria* resources of Travancore. Dept. Res. Univ., Travancore, Rept. Septen. 1948, pp. 35–53.
24. Thivy, F., Economic seaweeds. In *Fisheries of West Coast of India* (ed. Jones, S.), Central Marine Fisheries Research Institute, Mandapam Camp, 1958, pp. 74–80.
25. Chauhan, V. D. and Mairh, O. P., Report on survey of marine algal resources of Saurashtra Coast, India. *Salt Res. Ind.*, 1978, **14**, 21–41.
26. Chauhan, V. D., Report of the survey of marine algae resources of Maharashtra coast. *Salt Res. Ind.*, 1978, **14**, 1–10.
27. Untawale, A. G., Dhargalkar, V. K., Agadi, V. V. and Jagtap, T. G., Marine algal resources of Maharashtra coast. Technical Report, National Institute of Oceanography, Goa, 1979, p. 48.
28. Untawale, A. G., Dhargalkar, V. K. and Agadi, V. V., List of Marine Algae from India. Technical Report National Institute of Oceanography, Goa, 1983, p. 42.
29. Dhargalkar, V. K., Studies on marine algae of the Goa coast, PhD thesis, Bombay University, 1981, p. 168.
30. Agadi, V. V., Distribution of marine algae in the littoral zone of Karnataka coast. In *Marine Plants* (eds Krishnamurthy, V. and Untawale, A. G.), Seaweed Research Utilization Assoc., Madras, 1985, pp. 35–42.
31. Chennubhotla, V. S. K., Ramachandrudu, B. S., Kaladharan, P. and Dharmaraj, S. K., Seaweed resources of Kerala coast. *Aquat. Biol.* 1988, **7**, 69–74.
32. Anon., A report on the survey of marine algal resources of Tamil Nadu, 1971–1976, Central Salt and Marine Chemicals Research Institute, Bhavnagar, 1978, p. 137.
33. Kaladharan, P. and Jayasankar, R., Seaweeds. In *Status of Exploited Marine Fishery Resources of India* (eds Joseph, M. and Jayaprakash, A. A.), Central Marine Fisheries Research Institute, Cochin, 2003, pp. 228–239.
34. Anon., A report on the survey of marine algal resources of Andhra Pradesh, 1979–1982, Central Salt and Marine Chemicals Research Institute, Bhavnagar, 1984, p. 30.
35. Rath, J. and Adhikari, S. P., Algal biomass of Chilka Lake, East coast of India. Seaweeds – 2004. National Symposium and Exposition, Cochin, Abst., 2004, p. 24.
36. Mukhopadhyay, A. and Pal, R., A report on biodiversity of algae from coastal West Bengal (South and North 24-Parganas) and their cultural behaviour in relation to mass cultivation programme. *Indian Hydrobiol.*, 2002, **5**, 97–107.
37. Anon., A report on the survey of marine algal resources of Lakshadweep, 1977–1979, Central Salt and Marine Chemicals Research Institute, Bhavnagar, 1979, p. 48.
38. Muthuvelan, B., Chennubhotla, V. S. K., Nair, K. V. K., Sampath, V. and Ravindran, M., Standing crop biomass and comparative distribution of agarophytes, alginophytes and other algae in South Andaman. *Indian Hydrobiol.*, 2001, **4**, 130–138.
39. Muthuvelan, B., Chennubhotla, V. S. K., Nair, K. V. K., Sampath, V. and Ravindran, M., Seaweed standing crop biomass and com-

parative distribution in eastern shoreline of Middle and North islands. *Indian Hydrobiol.*, 2001, **4**, 139–148.
40. Gopinathan, C. P. and Panigrahy, R., Seaweed resources. In Mariculture potential of Andaman and Nicobar islands – an indicative survey. *Bull. CMFRI*, 1983, **34**, 47–51.
41. Chauhan, V. D. and Krishnamurthi, V., An estimate of algin-bearing seaweeds in the Gulf of Kutch. *Curr. Sci.*, 1968, **37**, 648.
42. Kaliaperumal, N. *et al.*, Seaweed resources and distribution in deep waters from Dhanushkodi to Kanyakumari, Tamilnadu. *Seaweed Res. Util.*, 1998, **20**, 141–151.
43. Krishnamurthy, V., Seaweed drift on the Indian coast. In Proc. Symp. Indian Ocean, Natl. Inst. Sci. India, 1969, vol. 38, pp. 657–666.
44. Bhanderi, P. P. and Trivedi Y. A., Seaweed resources of Hanumandandi reef and Vumani reef near Okha port, Gujrat. *Indian J. Mar. Sci.*, 1975, **4**, 97–99.
45. Zemke-White, L. W. and Ohno, M., World seaweed utilization: An end of century summary. *J. Appl. Phycol.*, 1999, **11**, 369–376.
46. Walker, F. T., Sublittoral seaweed survey. *J. Ecol.*, 1947, **35**, 166–185.
47. Subba Rao, P. V., Biology and propagation of *Gelidiella acerosa* (Forsskal) Feldmann et Hamel in the Mandapam region. Ph D thesis, Banaras Hindu University ,1983, p. 127.
48. Thomas, P. C., Rama Rao, K. and Subbaramaiah, K., Periodicity in growth and production of agar of *Gelidiella acerosa* (Forsskål) Feldmann et. Hamel. *Indian J. Mar. Sci.*, 1975, **4**, 210–212.
49. Joshi, H. V. and Chauhan, V. D., Effect of repeated harvesting on the growth of *Gelidiella acerosa* (Forsskål) Feldmann et. Hamel. *Seaweed Res. Util.*, 1985, **7**, 94–100.
50. Shyam Sundar, K. L., Natural growth and polyscaccharide production in some abundant red algae (Rhodophyta) from southeastern shores of India. Ph D thesis, Madurai Kamaraj University, 1985, p. 173.
51. Kaliaperumal, N., Kalimuthu, S. and Ramalingam, J. R., Effect of repeated harvesting on the growth of *Sargassum* spp. and *Turbinaria conoides* occurring in Mandapum area. *Seaweed Res. Util.*, 1996, **18**, 57–66.
52. Kaliaperumal, N. and Kalimuthu, S., Seaweed potential and its exploitation in India. *Seaweed Res. Util.*, 1997, **19**, 33–40.
53. Kaliaperumal, N., Kalimuthu, S. and Ramalingam, J. R., Present scenario of seaweed exploitation and industry in India. *Seaweed Res. Util.*, 2004, **26**, 47–53.
54. Immanuel, S. and Sathiadhas, R., Employment potential of fisherwomen in the collection and post harvest operations of seaweeds in India. *Seaweed Res. Util.*, 2004, **26**, 209–215.
55. Kappanna, A. N. and Rao, A. V., Preparation and properties of agar agar from Indian seaweeds. *Indian J. Technol.*, 1963, **1**, 222–224.
56. Silas, E. G. and Kalimuthu, S., Commercial exploitation of seaweeds in India. *Bull. CMFRI*, 1987, **41**, 55–59.
57. Subbaramaiah, K., Rama Rao, K., Thomas, P. C., Nair, M. R. P., Gopal, B. V. and Nagulan, V. R., Cultivation of *Gelidiella acerosa*. *Salt Res. Ind.*, 1975, **11**, 33–36.
58. Patel, J. B., Gopal, B. V., Nagulan, V. R., Subbaramaiah, K. and Thomas, P. C., Experimental field cultivation of *Gelidiella acerosa* at Ervadi in India. Proc. of the Symp. Coastal Aquaculture, 1986, vol. 4, pp. 1342–1343.
59. Raju, P. V. and Thomas, P. C., Experimental field cultivation of *Gracilaria edulis* (Gmel.) Silva. *Bot. Mar.*, 1971, **14**, 71–75.
60. Rama Rao, K., Nair, M. R. P. and Subbaramaiah, K., Experimental field cultivation of *Hypnea valentiae* (Turn.) Mont. at Krusadai Island. In *Marine Plants* (eds Krishnamurthy, V. and Untawale, A. G.), Seaweed Research Utilization Association, Madras, 1985, pp. 205–208.
61. Eswaran, K., Ghosh, P. K. and Mairh, O. P., Experimental field cultivation of *Kappaphycus alvarezii* (Doty) Doty ex. P. Silva. at Mandapam region. *Seaweed Res. Util.*, 2002, **24**, 67–72.
62. Subba Rao, P. V., Eswaran, K. and Ganesan, M., Cultivation of agarophytes in India: Retrospect, prospects and future strategies. *Seaweed Res. Util.* (*Spl. Issue*), 2004, **26**, pp. 181–184.
63. Krishnamurthy, V., Seaweed resources of India and their utilization. *Seaweed Res. Util.*. 1971, **1**, 55–67.
64. Krishnamurthy, V., Raju, P. V. and Thomas, P. C., On augmenting seaweed resources of India. *Seaweed Res. Util.*, 1977, **2**, 37–40.
65. Reddy, C. R. K., Raja Krishna Kumar, G., Siddhanta, A. K., Tewari, A., and Eswaran, K., *In vitro* somatic embryogenesis and regeneration of somatic embryos from pigmented callus of *Kappaphycus alvarezii* (Doty) Doty (Rhodophyta, Gigartinales). *J. Appl. Phycol.*, 2003, **39**, 610–616.
66. Anon., Bi-annual Progress Report (2002–2004), Central Salt and Marine Chemicals Research Institute, Bhavnagar, 2004, p. 110.
67. Anon., Progress report of the DBT project ‘Studies on field cultivation and harvesting of seaweeds *Porphyra* (Nori), *Enteromorpha* (Ao Nori), *Eucheuma* (Tosaka Nori) and their use in processed foods’, October 2003–June 2004, Central Salt and Marine Chemicals Research Institute, Bhavnagar, 2004, p. 9.
68. Singh, G., Trigger for rural development. *Employment News*, 2005, **30**, 32.
69. Desai, B. N., Seaweed resources and extraction of alginate and agar. In Proceedings of the Seminar on Sea, Salt and Plants, (ed. Krishnamurthi, V.), Bhavnagar, 1967, pp. 343–351.
70. Sreenivasa Rao, P., Iyengar, E. E. R. and Thivy, F., Survey of algin bearing seaweed at Adatra reef, Okha. *Curr. Sci.* 1964, **33**, 464–465.
71. Umamaheswara Rao, M., Seaweed potential of the seas around India. Proc. Symp. Living Resources of the Sea around India. 1973, pp. 687–692.
72. Chacko, P. I. and Malu Pillai, C., Studies on utilization of the seaweed resources of Madras State. *Contrib. Mar. Biol. Stn., Krusadai Island, Gulf of Mannar*, 1958, **6**, 1–12.
73. Verma, R. P. and Krishna Rao, K., Algal resources of Pamban area. *Indian J. Fish*, 1962, **9**, 205–211.
74. Sahoo, D., Sahu, N. and Sahoo, D., A critical survey of seaweed biodiversity of Chilika Lake, India. *Algae*, 2003, **18**, 1–12.
75. Ravindran, V. S., Thangaradjou, T. and Kannan, L Qualitative and quantitative distribution of seaweeds in the Great Nicobar Island. Seaweeds – 2004 – National Symposium and Exposition, Cochin, Abst. 2004, p. 27.
76. Mantri, V. A. and Subba Rao, P. V., Diu island: A paradise for tourists and seaweed biologists. *Curr. Sci.*, 2005, **89**, 1795–1797.
77. Joshi, H. V., Studies on Indian seaweeds physiological ecology of *Sargassum* of Okha. Ph D thesis, Bhavnagar University, 1984, p. 229.
78. MPEDA, Statistics report of Marine Products Export Development Authority, Cochin, 2001.
79. Ramlingam, J. R., Kaliaperumal, N. and Kalimuthu, S., Seaweed exploitation in India. *Seaweed Res. Util.*, 2000, **22**, 75–80.
80. Kaliaperumal, N., Kaladharan, P. and Kalimuthu, S., Seaweeds and seagrass resources. *Bull. CMFRI*, 1989, **43**, 162–175.
81. Dhargalkar, V. K. and Deshmukhe, G. V., Subtidal marine algae of Dwarka coast (Gujarat). *Indian J. Mar. Sci.*, 1996, **25**, 297–301.

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