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Aerial view of the seaweed farm at Thondi, Tamil Nadu.

(Photo Credit: Johnson, B.)

Marine Fisheries Information Service Technical and Extension Series envisages dissemination of information on marine fishery resources based on research results to the planners, industry and fish farmers, and transfer of technology from laboratory to the field.

Perspective plan of ICAR-CMFRI for promoting seaweed mariculture in India

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Abstract

Seaweed mariculture is a green and climate smart technology to assure steady and continuous supply of raw materials for the production of algal polysaccharides, fodder, biofuels, manure, nutraceuticals etc. The perspective plan of ICAR- Central Marine Fisheries Research Institute on seaweed cultivation and utilization observes that (a) raw materials for value added products from seaweeds should be sourced from large scale mariculture and not from wild habitats.; (b) mariculture of species of *Gracilaria* and *Gelidiella* for agar, *Kappaphycus alvarezii* for *k*-carrageenan and *Sargassum*, *Ulva* and *Caulerpa* for their nutraceuticals and other secondary metabolites should be widely promoted; (c) seaweed mariculture can be undertaken in integrated mode with finfish or shellfish (IMTA) to double the farmers' income and (d) large scale mariculture of seaweeds should be encouraged as it can help mitigate major greenhouse gas and thereby check ocean acidification, while the farmers achieve livelihood security simultaneously.

***Key words**: Seaweed mariculture, Agar shortage, Kappaphycus alvarezii, IMTA*

Introduction

Seaweeds are marine macrophytic thallophytes belonging to the groups of green (Chlorophyta), brown (Phaeophyta) and red (Rhodophyta) seaweeds. They grow best in the tidal and inter-tidal waters and the Andaman-Nicobar and Laccadive Archipelagoes of India. With a coastline exceeding 8000 km , India has more than 0.26 million tonnes wet harvestable biomass of seaweeds belonging to 700 species. Of these, nearly 60 species accounting for about 30 % of the harvestable biomass are economically important for their polysaccharides and secondary metabolites and hence exploited commercially for agar, algin, carrageenan, bioactive metabolites, cattle fodder and plant manure. World seaweed production in 2016 was 30.1 million tonnes wet weight with first sale value estimated at 11.7 billion USD (FAO 2018). Approximately 20,000 tonnes of seaweed resources from the wild are harvested annually in India (Fig.1).

ICAR-CMFRI under the Indian Council of Agricultural Research (ICAR) an autonomous body in the Department of Agricultural Research and Education, Ministry of Agriculture & Farmers' Welfare has been working on seaweed mariculture and utilization in India since 1964. Under its Trainers' Training Centre, it had imparted more than 20 hands on training to 119 trainers from erstwhile Andhra Pradesh, Gujarat, Maharashtra, Kerala, Tamil Nadu and West Bengal. The Mandapam Regional Station of the institute developed the technology for commercial scale cultivation of *Gracilaria edulis*, an agar yielding red algae, using raft, coir-rope nets/spore method. A cottage industry method for the manufacture of agar from *Gracilaria* spp. and Alginic acid from *Sargassum* spp. during 1980s was demonstrated to many farmers and entrepreneurs which paved the way for development of many small scale agar industries in Madurai, Tamil Nadu. Providing technical inputs for the meetings and discussions on seaweed culture and commercialization

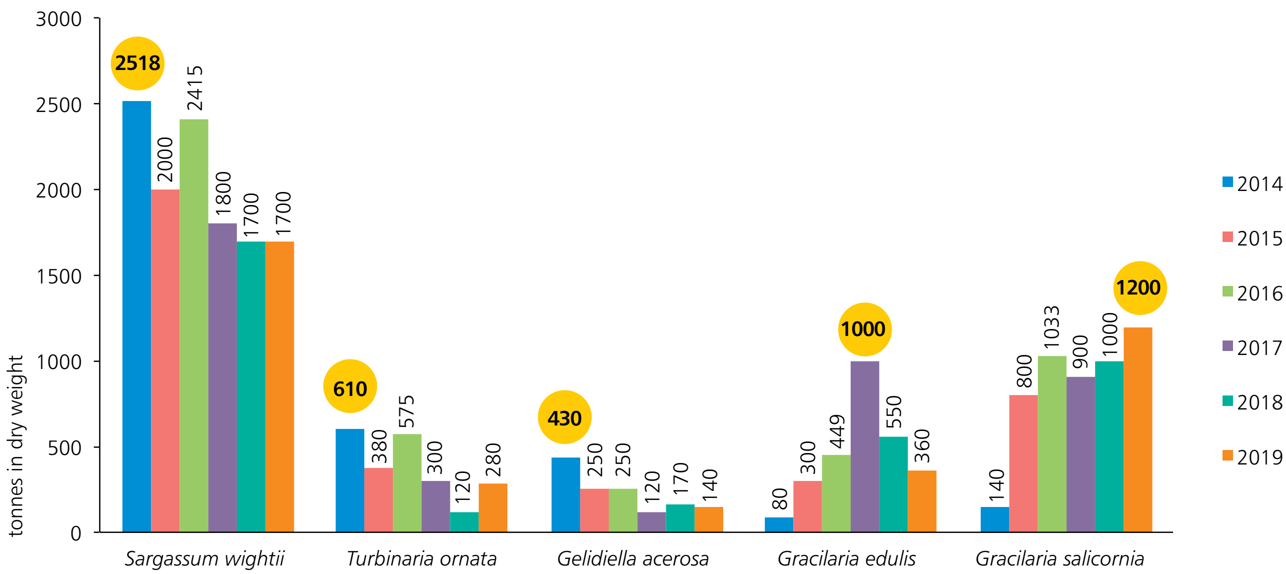

Fig.1 Production of seaweed through wild collection during the year 2014-2019 in Tamil Nadu, India

of seaweed products to the Ministry of Agriculture and Farmers Welfare, participation in preparing a policy-support document on 'Seaweed Cultivation and Utilisation (NAAS, 2003) and Action Plan on seaweed research and utilization have been significant contributions of the institute. Estimates of Annual seaweed harvest (wild collection) from India as well as mariculture production along the east coast is done by the ICAR-CMFRI with which Potential Yield of seaweeds from India was estimated. Though started in 1964, seaweed mariculture (*Gracilaria edulis* and *Gelidiella acerosa*) remained in experimental trials in India until recently. Large scale sea farming of *Kappaphycus alvarezii,* a *k*-carrageenan yielding seaweed started in 2000 with a back up by Pepsico India Holdings Ltd., in the coastal waters of Tamil Nadu, Odisha and Gujarat including Daman & Diu with technical support from the Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar. Contract farming of *Kappaphycus alvarezii* by the fisherfolk on the east coast of India touched maximum of 1500 tonnes dry weight during the year 2012 and more than 70,000 tonnes wet biomass of *Kappaphycus* in the decade between 2005 to 2015. Its concomitant purchase value per kilogram (dry) was ₹4.5 to 35 with an annual turnover of around ₹2.0 billion. However, after 2013 the production sharply declined due to mass mortality and the average production in recent years is only around 200 t dry weight per year (Fig.2). At present, commercial farming is carried out

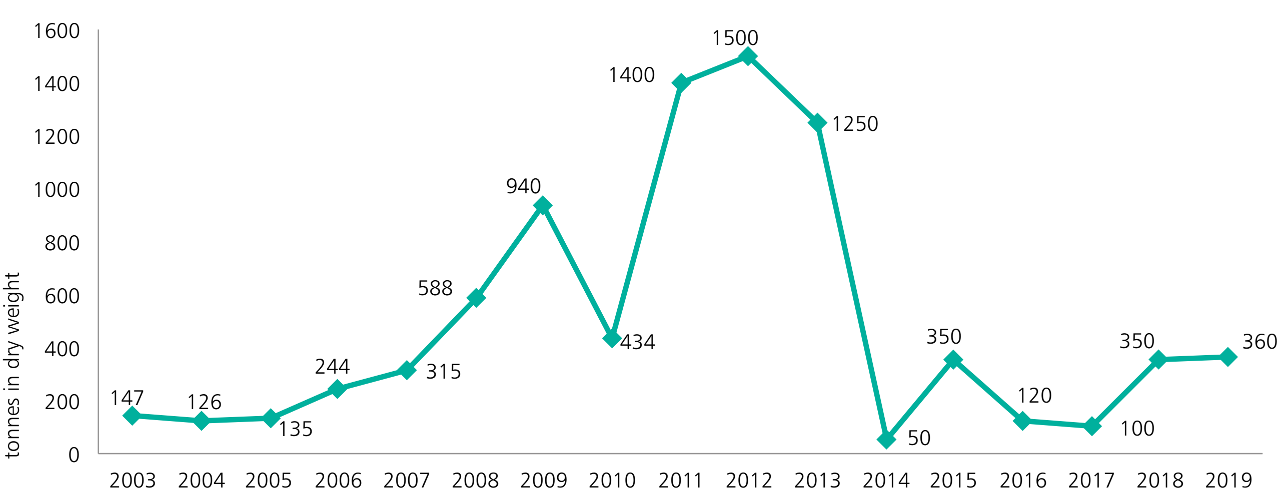

Fig. 2 *K.alvarezii* production (dry weight in tonnes) from Tamil Nadu Coast (2003-2019)

following three techniques, namely floating bamboo raft, tube net (net sleeves),and long lines, of which, the former two are widely popular. Seaweeds are renewable resources, but indiscriminate exploitation affects their resilience and standing stock. Globally the production of seaweeds through mariculture lags far behind the demand for raw seaweed materials to produce the traditional and emerging products. This communication highlights the need for large scale sustainable mariculture of seaweeds in India for various uses.

Agar production: Acute shortage of agar yielding red seaweeds all over the world can jeopardize the research programmes in biology and medicine for want of agar and agarose. In India, reduction in the quantity of wild collected seaweeds like species of *Gracilaria* and *Gelidiella* is observed. Red seaweeds are now imported from Sri Lanka, Morocco and SAARC countries with import duty varying between 4-37% and hence, most of the agar producing units in India remains shut due to lack of raw material and high costs of operation. This acute shortage in raw material supply is mainly due to indiscriminate exploitation over the years from Tamil Nadu coast (3,700- 4,500 tonnes dry weight per year) coupled with habitat destruction. The crustose red alga *Gelidiella acerosa* is the most important agarophyte that can yield pharmaceutical grade agar with gel strength above 650 g/cm^2. Standing crop estimation of *G. acerosa* in the Gulf of Mannar region over a decade revealed that the wet biomass of 1400 g / m^2 recorded during 1996- 1998 has drastically reduced to 600 g / m^2 during 2004- 2005 and recently during 2009- 2010, shrunken to just 450 g / m ^{2} (Ganesan *et al*., 2015). The farming of *G. acerosa* will ensure consistent production of quality and pure raw materials that can fetch alternative livelihood to the coastal fishers (@₹ 80,000/tonne dry weight). The CSIR-CSMCRI has already developed successful technology for the mariculture of *G. acerosa*, *G. dura* and *G. debilis* (Gracilariaceae, Rhodophyta) and their large scale culture of agarophytes and value addition is very much essential.

Fodder use: In rural India, domestic animals are engines that drive the economy. Farmers are increasingly shifting to crops that do not yield fodder and also as the country moves towards rearing animals with higher milk yields, better quality fodder and stall feeding becomes a necessity. An investigation under the AP Cess fund of ICAR to produce better quality feed / fodder for animals found saturated fatty acids predominant in *Kappaphycus, Hypnea* and *Gracilaria.* Monounsaturated fatty acids were predominant in brown seaweed *Sargassum* and the green seaweed *Ulva.* While *Sargassum wightii* contained maximum amount of omega-3 fatty acids, *Hypnea* and *Gracilaria* species had higher levels of omega-6 fatty acids.

Biofuel: In view of the increasing demand for fossil fuels and the environmental hazards caused by its use, alternatives from renewable sources (biofuels) are to be considered. Government of India initiated several programmes to promote production and use of biofuels blended with fossil fuels. Compared to crop based biofuels marine algae are regarded superior for quality biofuel production due to their rapid multiplication and growth rate (8-10 times faster) compared to terrestrial and aquatic higher plants.

Agriculture and allied business: Farmers often use chemical fertilizers and pesticides in agricultural lands to enhance the crop yield which has several undesirable effects on soil and environment. As an alternative, biofertilizers from seaweed extracts which contain many growth promoting substances like auxins, gibberllins, trace elements, vitamins and amino acids that are not found in terrestrial plants and which promote growth, flowering and better yield are being explored. As more firms, individuals and farmer cooperatives are coming forward to produce seaweed based manures and fertilizers, the demand for seaweed biomass is increasing. Regulatory mechanisms for commercial production of seaweed based fertilizers and biostimulants as it involves exploitation of wild stock and quality assurance to check addition of inorganic nitrates and micro elements have been proposed by ICAR-CMFRI and ICAR-CIFT respectively. To conserve the natural wild stock, the raw material required for producing seaweed based manures and fertilizers should be essentially sourced from large scale mariculture and not from wild habitats.

Combating climate change impacts: Seaweeds are reported to be excellent bio-remediating agents capable of improving water quality by uptake of dissolved minerals, nitrates, ammonia and phosphates. Large scale seaweed mariculture has been recognized as one of the climate resilient aquaculture techniques to mitigate ocean acidification. It is estimated that the seaweed biomass alone along the Indian coast is capable of utilizing 3,017 t CO_2/d against emission of 122t CO_2 /d indicating a net carbon credit of 2895 t/d (Kaladharan *et al*., 2009)

An experimental culture of seaweed (*Kappaphycus alvarezii*) to estimate its carbon sequestration potential was conducted at Munaikadu, Ramanathapuram district, Tamil Nadu. In each of the three bamboo rafts (12 ft × 12 ft), 3 pre-weighed bunches of seaweed were tagged and their weights were periodically (once in 15 days) measured. Sub-samples from each bunch were dried and analyzed for its carbon content using CHN elemental analyser which indicated average dry weight percentage of the harvested sea-weed was 8.75 % and the average carbon content was 19.92%. The specific growth rate of the seaweed multiplied with % composition of carbon (C) and 3.667 (mass of CO_2/ mass of C) gave an estimate of specific rate of sequestration (per unit mass of seaweed per unit time) of carbon dioxide by the seaweed as 0.018673 g per day per g dry weight. Hence, large scale mariculture of seaweeds, preferably red seaweeds, to check ocean acidification is a green technology by not being labour intensive and without the involvement of energy, fertilizers and chemical inputs.

Drugs and nutraceuticals: The research work at the Marine Bioprospecting laboratory of ICAR-CMFRI has focused on developing bioactive leads and nutraceutical products from seaweeds with pluralities of bioactive properties for use against various diseases viz., inflammation, dyslipidemia, hypercholesterolemic disorders, thyroid disorders, osteoporosis, type-II diabetes, cardiovascular, pathogenic infection, and oxidative stress. Nutraceutical formulation(s) (Cadalmin™Antidiabetic extract and Cadalmin™ Green Algal extract from seaweeds) are effective green alternatives to the synthetic drugs available in the market to combat type-II diabetes and rheumatic arthritic pains, respectively. Cadalmin™GAe, Indian patent Appl. No. 2064/CHE/2010) has been out-licensed to a Biopharmaceutical company for commercial production and marketing in India and abroad. Cadalmin™ Antihypercholesterolemic extract (Cadalmin™ACe, Indian patent Appl. No. 201711013741) and Cadalmin™ Antihypothyroidism extract (Cadalmin™ATe, Indian patent Appl. no. 202011011490) from marine macroalgae to combat dyslipidemia and hypothyroid disorders, respectively, and these products were out-licensed to a pharmaceutical company. Cadalmin™ Antihypertensive extract (Cadalmin™AHe, Indian patent Appl. No. 202011011489) and Cadalmin™ Antiosteoporotic extract (Cadalmin™AOe, Indian patent Appl. no. 202011009121) for use against hypertension and osteoporosis, respectively are being commercialized.

Semi synthetic C-4/C-6 methylene-polycarboxylate cross-linked hybrid drug delivery system and a topical antibacterial formulation developed from marine macroalgae were found to be comparable with commercially available products. This pioneering research work at ICAR-CMFRI envisages a systematic approach involving chemical profiling of major species of seaweeds for lead pharmacophores coupled with evaluation of target biological activities against different disease models, for example, 3-hydroxy-3-methylglutaryl coenzyme A reductase, type-2 diabetes modulators (dipeptidyl peptidase-4, protein tyrosine phosphatase 1B), angiotensin-I, inflammatory cyclooxygenases, lipoxygenases, alkaline phosphatase and bone morphogenic protein. Optimized physical/chromatographic procedures have been developed by this institute to isolate and purify the molecules with target bioactivities (Table 1). As the percentage recovery of such

Table 1. Various nutraceuticals produced from seaweeds by ICAR-CMFRI

Nutraceuticals from seaweeds

Cadalmin™	Mode of Action
ADe	DPP4 & Tyrosine Phosphatase inhibitor; Nullifies insulin resistance at cellular level
ATe	Activates selenodeiodinase that converts T4 to T3 (Thyroxine)
AHe	Inhibits angiotensin converting enzyme (ACE) and inhibits production of hypertension causing Angiotensin II from I
ACe	Activates lipoprotein lipase, inhibiting the production of triglycerides
GAe	Inhibits cyclooxygenase II (that causes production of inflammatory prostaglandins) and 5-lipoxygenase, thus reducing inflammation.
AOe	Stimulate alkaline phosphatase and bone morphogenic protein, along with lower serum osteocalcin levels and prominent mineralization, and effective for controlling osteoporesis and bone health development.

active principles is around 10%, large scale mariculture of seaweeds is urgently required for the steady supply of raw materials for the production of value added products and nutraceuticals from seaweeds in India.

Seaweed mariculture through Integrated Multitrophic Aquaculture (IMTA)

Seaweeds such as *Kappaphycus alvarezii, Gracilaria edulis*, *Gracilaria verrucosa* and *Gelidiella acerosa* are farmed/ being experimented under IMTA, in India. The recycling of waste nutrients by seaweed and filter-feeding shellfish is the best way to economically improve mariculture activities. Trials on seaweed *Kappaphycus* with finfish cobia (*Rachycentron canadum*) in floating cages in coastal Tamil Nadu indicated that though there were many challenges, the shift from monoculture to the IMTA resulted in increased production. Seaweed rafts integrated with cobia cage had a better average yield of 320 kg per raft while the same was 144 kg per raft which were not integrated. An addition of 176 kg of seaweed per raft was achieved due to the integration with the cobia cage farming. The total amount of carbon sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 357 kg and 161 kg respectively -an addition of 196 kg carbon credit. The presence of inorganic extractive components contribute to the periphytons to the aquaculture area as well as offer habitat for planktons to settle. Seaweeds are known to release 30-39% of their gross primary production as dissolved organic carbon (DOC) to the ambient water. Trials on IMTA with bivalves and finfish (seabass) in inshore waters of Karnataka demonstrated reduced risk of crop failure through diversification. Mortality loss of finfish (seabass) in the cages was compensated to a certain extent by bivalve production. Gross revenue realized was ₹5.34 lakhs of which 30% was contributed by mussel (₹1.6 lakhs).

Future projections of *Kappaphycus* mariculture

During 2012-13, maximum 27,000 rafts produced 15,000 tonnes of *Kappaphycus* (wet weight) from 5 coastal districts of Tamil Nadu in a 45 days culture period per crop. If an additional 73,000 rafts are deployed for cultivation in 6 states–Gujarat (15,000 rafts), Andhra Pradesh (15,000 rafts), Odisha (15,000 rafts), Kerala (10,000 rafts), Karnataka (10,000 rafts) and Maharashtra (8,000 rafts) by 2030, a total of 1,00,000 rafts can be utilized for seaweed production of the country. It is estimated that by 2030, with 4 crops of 45 days duration in a year, these 1,00,000 rafts [@ 250kg/raft] can yield a total of 1,00,000 tonnes (wet weight) of seaweeds harvest per year.

Economics

Total cost of production	₹ 3000/raft/year (including cost of seed material for 4 crops)
Seaweed production	1,000 kg/raft/year
Price of seaweed	₹ 6.50/kg (wet weight)/ raft
Total revenue generated	₹6500/year/ raft
Net profit	₹3500/raft/year (₹6500 minus ₹3000)
Additional net income (from 45 raft unit)	₹157,500/year/fisher

The perspective plan of ICAR- Central Marine Fisheries Research Institute on seaweed cultivation and utilization lists the following priorities.

a. Raw materials for processing and value added products development from seaweeds should be sourced from large scale mariculture and not from wild habitats.
b. Mariculture of species of *Gracilaria, Gelidiella* for agar, *Kappaphycus alvarezii* for *k*-carrageenan and *Sargassum*, *Ulva* and *Caulerpa* for their nutraceuticals and other secondary metabolites should be widely promoted.
c. Seaweed mariculture can be undertaken under integrated mode (IMTA) with finfish or shellfish to double the farmers' income.
d. Large scale mariculture of seaweeds should be encouraged as this can help mitigate major greenhouse gas and thus check ocean acidification, while the farmers achieve livelihood security from the seaweed harvest.
e. Seed stock/seed bank for commercially important seaweed species in controlled onshore facilities at strategic locations should be established to ensure uninterrupted supply of seed materials.
f. It is essential to bring seaweed cultivation under insurance coverage to compensate crop losses during natural calamities.
g. Cultivation of seaweeds is like Agriculture in Sea and hence the harvested seaweeds (wet/ dry) should be

treated as agricultural produce for the purpose of fiscal levies.

h. A minimum price for the farmed seaweeds and opening of marketing channels for seaweeds also should be considered before taking up large scale farming of seaweeds in the country.
i. Seaweed based bio-stimulants for use in agriculture should be duly notified as agricultural inputs by the Ministry of Agriculture and Farmers' Welfare.
j. In brackishwater areas, seaweed *Gracilaria tenuistipitata* can be cultivated integrated with fish or shrimp for improving the water quality and for doubling the farmers' income.

The Way forward

Expansion of seaweed farming in the country will improve the socioeconomic status of coastal fishermen/farmers and will be helpful in mitigating the negative effects of climate change by protecting the marine ecosystems from ocean acidification and de-oxygenation. The seaweed cultivation procedure does not requires land, fresh water, fertilizers or pesticides. The large scale cultivation can enhance rural employment opportunities and improve rural economy. Seaweed mariculture is an economically viable livelihood option for the coastal fishing community, especially fisherwomen. The Benefit Cost Ratio (BCR) is estimated above 2.0, which signifies the profitability of the activity and it can double the fisher's income.

Currently, the growth of seaweed farming is primarily constrained by lack of proper marine spatial plans, appropriate financing and insurance cover against crop losses due to natural calamities. Other challenges include difficulty in obtaining quality seed materials of native species such as *Gracilaria dura*, especially after monsoon rains, natural hazards such as cyclonic weather and grazing by herbivorous fishes. To improve production of *Kappaphycus* in India, developing *in vitro* cell culture techniques is crucial as it facilitates year-round mass supply of seed materials maintained under controlled conditions. Development of new and improved strains of *Kappaphycus* through strain development and hybridization and through protoplast fusion techniques are to be attempted. Surveys conducted by ICAR-CMFRI all along the Indian coasts could not find any settlement of *Kappaphycus* in seaweed/coral beds as well as in the beaches as drifted mass. From the impact assessment of *Kappaphycus* cultivation on the environment being attempted since 1983 from Hawaii Islands to the recent studies by CSIR-CSMCRI in Indian waters also could not observe the occurrence/establishment of non-farmed populations of *Kappaphycus*.

Seaweed cultivation can be taken up by fishermen/fisherwomen co-operatives and self-help groups (SHGs) of the coastal areas as IMTA. A minimum price for the farmed seaweeds and opening of marketing channels for seaweeds also should be considered before taking up large scale farming of seaweeds in the country. Promotion of seaweeds as healthy food for human consumption apart from its use as raw materials for the extraction of bioactive compounds and phycochemicals may also be attempted. Development agencies like National Fisheries Development Board (NFDB) can promote seaweed consumption through awareness campaigns and seaweed based food festivals organised throughout the country. Large scale mariculture of seaweeds which is a green technology can thus fuel the growth of blue economy.

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