S.E.A.W.E.E.D.S. 2026

INTERNATIONAL SYMPOSIUM, EXPO & BUSINESS MEET

Value Chains, Climate Solutions, and Blue Economy Pathways

March 5-7, 2026
Kochi, Kerala

SOUVENIR

Organized by

Kerala University of Fisheries and Ocean Studies (KUFOS)

Co-organizers

Government of Kerala
Department of Fisheries

NFDB

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Department of Fisheries, Govt. of Kerala
National Fisheries Development Board (NFDB)
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S.E.A.W.E.E.D.S. 2026

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National Bank for Agriculture and Rural Development

ICAR-CIFT
Indian Council of Agricultural Research - Central Institute of Fisheries Technology

S.E.A.W.E.E.D.S. 2026

Souvenir
March, 2026

Published in commemoration of the inauguration of "International Symposium, Expo & Business Meet Value Chains, Climate Solutions, and Blue Economy Pathways" "S.E.A.W.E.E.D.S. 2026", held from 5 – 7 March 2026, Kochi, Kerala.

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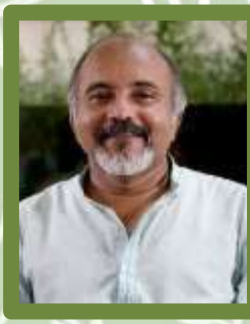

FOREWORD

KERALA UNIVERSITY OF FISHERIES AND OCEAN STUDIES (KUFOS)

കേരള ഫിഷറീസ് സമുദ്രപഠന സർവ്വകലാശാല

(Accredited with NAAC 'A' Grade)

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Prof. A. Biju Kumar

Vice Chancellor

FOREWORD

It gives me immense pleasure to present this Souvenir brought out in connection with S.E.A.W.E.E.D.S. 2026 – International Symposium, Expo and Business Meet on Value Chains, Climate Solutions, and Blue Economy Pathways, being organized at KUFOS during 5–7 March 2026. This landmark event, jointly hosted by Kerala University of Fisheries and Ocean Studies (KUFOS) and national partners, reflects the growing global recognition of seaweeds as strategic bioresources for sustainable development and innovation.

The SEAWEEDS 2026 symposium seeks to create a vibrant platform where scientists, policymakers, entrepreneurs, farmers, and development practitioners can engage in meaningful dialogue. This forum aims to bridge knowledge gaps, promote interdisciplinary collaboration, and chart a forward-looking roadmap for India's seaweed sector.

This Souvenir reflects the evolving understanding of seaweed science, technology, and enterprise. It stands as both a record of current progress and a source of inspiration for future innovations in the field.

I take this opportunity to acknowledge the dedicated efforts of the organizing committee, editorial team, collaborators, sponsors, and all contributors whose commitment has made this publication possible. Their collective support underscores the shared vision of advancing seaweed-based solutions for sustainable marine development.

I warmly welcome all delegates, industry partners, farmers, and readers to SEAWEEDS 2026 and hope that the deliberations, partnerships, and insights emerging from this symposium will contribute meaningfully to strengthening India's leadership in seaweed science and the broader blue economy.

May this Souvenir serve not only as a cherished memento of the symposium but also as a catalyst for future collaborations, innovations, and transformative pathways in the seaweed sector.

Prof. (Dr.) A. Biju Kumar

Vice Chancellor

SEAWEEDS 2026

MESSAGE

राजेंद्र विश्वनाथ आर्लेकर
राज्यपाल, केरल
RAJENDRA VISHWANATH ARLEKAR
GOVERNOR OF KERALA

രാജേന്ദ്ര വിശ്വനാഥ് ആർലേക്കർ
ഗവർണ്ണർ, കേരളം

27th February 2026

MESSAGE

I am pleased to know that Kerala University of Fisheries and Ocean Studies (KUFOS) proposes to publish the Souvenir **'S.E.A.W.E.E.D.S 2026'** in connection with its International Symposium on *"Seaweeds: Value Chains, Climate Solutions and Blue Economy Pathways"*, being organised in association with the Department of Fisheries, Government of Kerala from 5 to 7 March 2026 at Kochi.

Seaweeds provide immense potential for strengthening the Blue Economy by promoting sustainable livelihood for coastal communities, and in addressing pressing climate challenges through carbon sequestration and ecosystem restoration. I am confident that this publication will serve as a valuable compendium of knowledge, fostering innovation, encouraging sustainable practices, and enhancing collaborative efforts in the seaweed sector, while further advancing Kerala's vision of a resilient and inclusive blue economy.

I convey my hearty greetings to KUFOS and the people behind this endeavour and wish the Symposium as well as the Publication all success.

Rajendra Vishwanath Arlekar

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SEAWEEDS
2026

MESSAGE

GOVERNMENT OF KERALA

Pinarayi Vijayan

CHIEF MINISTER

No. 237/Press/CMO/26 25 February, 2026.

MESSAGE

I am glad to note that Kerala University of Fisheries and Ocean Studies, along with NFDB, Ministry of Fisheries, Govt. of India, is organising "*SEAWEEDS 2026 International Symposium, Expo and Business Meet: Value Chains, Climate Solutions and Blue Economy Pathways*", to be held from 5 to 7 March 2026.

Seaweed is an important marine resource with powerful benefits. It can provide nutritious food, create jobs for coastal communities, especially women and fishers, and help protect our environment by absorbing carbon and improving marine ecosystems. With proper support and innovation, seaweed can become an important part of sustainable development.

I am sure that this symposium, expo and business meet will bring together ideas and partnerships that will strengthen seaweed farming and support climate-friendly growth. I am sure that the outcomes of this symposium will meaningfully contribute to the overall development of our state.

Pinarayi Vijayan

The Vice Chancellor
KUFOS
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SEAWEEDS 2026

MESSAGE

जॉर्ज कुरियन
GEORGE KURIAN

राज्य मंत्री
मत्स्यपालन, पशुपालन एवं डेयरी और
अल्पसंख्यक कार्य मंत्रालय,
भारत सरकार
MINISTER OF STATE FOR
FISHERIES, ANIMAL HUSBANDRY & DAIRYING AND
MINORITY AFFAIRS
GOVERNMENT OF INDIA

MESSAGE

I extend my warm greetings to the organisers and participants of "SEAWEEDS 2026 International Symposium, Expo and Business Meet: Value Chains, Climate Solutions and Blue Economy Pathways", being held from 5 to 7 March 2026 at the Kerala University of Fisheries and Ocean Studies in collaboration with the NFDB, Ministry of Fisheries, Govt. of India. Seaweed is a simple but valuable marine resource for India's future. It helps reduce climate change by absorbing carbon dioxide, improves water quality and supports marine life. It is also nutritious and useful in food, health, agriculture and industry. With our long coastline, India has great potential to grow and add value to seaweed, creating jobs for coastal communities, especially women and youth.

This symposium supports the vision of a strong, self-reliant and environmentally responsible India. By bringing together experts, policymakers and industry leaders, it will help turn seaweed into an important driver of sustainable growth.

I congratulate the organisers and wish the symposium great success.

(George Kurian)

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SEAWEEDS
2026

MESSAGE

SAJI CHERIAN
MINISTER FOR FISHERIES, CULTURE & YOUTH AFFAIRS
GOVERNMENT OF KERALA

THIRUVANANTHAPURAM
Date 27/02/2026

MESSAGE

It gives me immense pleasure to extend my warmest greetings to the organizers and participants of the SEAWEEDS 2026 International Symposium, Expo, and Business Meet, hosted by the Kerala University of Fisheries and Ocean Studies (KUFOS).

As India advances toward the visionary goal of India@2047, the transition toward sustainable and inclusive growth becomes paramount. Seaweed, as a fast-growing and versatile marine resource, stands at the forefront of this transformation. Beyond its contributions to food and nutritional security, it serves as a critical raw material for diverse industries, mitigates environmental impacts, and, most importantly, creates sustainable livelihoods for our coastal families.

Kerala, blessed with an extensive and vibrant coastline, holds immense potential for seaweed cultivation. This sector can unlock new employment avenues, particularly empowering our women and young entrepreneurs, while significantly strengthening coastal resilience.

In this context, the theme of this symposium—"Value Chains, Climate Solutions, and Blue Economy Pathways"—is both timely and significant. I congratulate KUFOS for taking this proactive lead in bringing together global expertise to Kochi. I am certain that the deliberations held from March 5 to 7, 2026, will pave the way for a robust Blue Economy.

I wish SEAWEEDS 2026 every success.

With regards,

SAJI CHERIAN

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SEAWEEDS
2026

MESSAGE

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मुख्य कार्यपालक
Dr. B.K. Behera, ARS
Chief Executive

राष्ट्रीय मात्स्यिकी विकास बोर्ड
National Fisheries Development Board
मस्त्य पालन विभाग/ Department of Fisheries
(मत्स्यपालन, पशुपालन एवं डेयरी मंत्रालय, भारत सरकार
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MESSAGE

Dr B. K. Behera, ARS
Chief Executive,
National Fisheries
Development Board, India

India's seaweed sector represents a vital frontier in the nation's Blue Economy, offering transformative solutions for climate resilience, food security and sustainable livelihoods. With an estimated standing stock of nearly seven million tonnes and vast untapped potential along the 11,099 km coastline, the country is uniquely positioned to harness these "forests of the sea" for ecological balance and industrial innovation. Seaweeds not only sequester carbon and support marine biodiversity, but also open pathways for nutraceuticals, pharmaceuticals, biofuels, bioplastics and functional foods-making them indispensable to both environmental stewardship and economic progress.

Recognizing this immense opportunity, the Government of India has prioritized seaweed development under the Pradhan Mantri Matsya Sampada Yojana (PMMSY). Support has been extended for installation of seaweed cultivation units, establishment of seed banks and hatcheries, creation of Multipurpose Seaweed Park and initiatives for training, capacity building, research and pre-feasibility studies. Additionally, seaweed culture units are being sanctioned under the Climate Resilient Coastal Fishermen Villages (CRCFVs) initiative too, ensuring that coastal communities become economically vibrant while embracing climate-resilient practices.

In this context, the inaugural S.E.A.W.E.E.D.S. 2026: International Symposium on Seaweed-Value Chains, Climate Solutions and Blue Economy Pathways, organised by the Kerala University of Fisheries and Ocean Studies (KUFOS), marks a historic milestone. By convening global scientists, policymakers, industry leaders and community representatives, this landmark event will catalyse collaboration and showcase cutting-edge innovations. Beyond science and trade, SEAWEEDS 2026 underscores inclusive growth by empowering coastal women and youth, strengthening community-based enterprises and building resilient seaweed value chains aligned with the Sustainable Development Goals. As a joint organiser, the National Fisheries Development Board (NFDB) extends its best wishes for a successful symposium, advancing India's leadership in the global seaweed revolution and charting a sustainable, fair and resilient future for our oceans and people.

(Dr. B. K. Behera)

SEAWEEDS
2026

MESSAGE

KERALA UNIVERSITY OF FISHERIES & OCEAN STUDIES
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MESSAGE

It is an honour to welcome you to "*SEAWEEDS 2026 International Symposium, Expo and Business Meet: Value Chains, Climate Solutions and Blue Economy Pathways*", a gathering that celebrates the transformative potential of seaweeds in shaping India's future. As the nation advances towards its developmental vision for India @ 2047, the scientific and economic relevance of seaweeds merits substantial attention.

Seaweeds represent a unique interface between marine ecology and societal benefit. Their capacity for carbon sequestration, bioremediation and ecosystem restoration aligns closely with national and global climate objectives. Simultaneously, their applications in nutrition, pharmaceuticals, biofuels and sustainable aquaculture reinforce their relevance within the Blue Economy framework.

Through this conference, KUFOS seeks to provide a rigorous and collaborative platform for the exchange of research findings, technological advancements and policy insights. I am confident that the deliberations will meaningfully strengthen India's leadership in seaweed science, industry and governance.

I extend my best wishes for a productive and intellectually enriching conference.

Prof. (Dr.) K. Dinesh
Registrar, KUFOS
Convener, Core Organising Committee, SEAWEEDS 2026

SEAWEEDS
2026

PREFACE

KERALA UNIVERSITY OF FISHERIES & OCEAN STUDIES
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Prof. (Dr.) Radhika Rajasree S R

DEAN

PREFACE

It is a moment of great joy and fulfillment as we release this Souvenir to commemorate the International Symposium SEAWEEDS 2026: Value Chains, Climate Solutions, and Blue Economy Pathways. While the technical deliberations of this symposium capture the scientific spirit of the event, this Souvenir is a testament to the collective effort, collaboration, and shared vision of the global seaweed community.

Organizing an international event of this magnitude at the Kerala University of Fisheries and Ocean Studies (KUFOS) has been an enriching journey, much like the expanding frontiers of the Phyconomy itself. This Souvenir has been curated to reflect not only the academic depth of seaweed research but also the collaborative spirit of its creation. It stands as a tribute to the researchers, industry leaders, and policymakers who have gathered from across 15 countries to harness the potential of macroalgal resources and chart a resilient, seaweed-based future for our blue economy.

This publication would not have been possible without the generous support of our sponsors and well-wishers, whose contributions are gratefully acknowledged within these pages. Their belief in the potential of the seaweed sector has been a pillar of strength for the organizing committee.

I wish to express my deepest gratitude to our Hon'ble Vice-Chancellor and Chairman for his constant motivation and guidance. I also thank the members of the Souvenir Committee and the Editorial Team for their dedicated efforts in bringing this volume to life.

To the delegates and readers: we hope this Souvenir serves as a cherished memento of your time in Kochi and remains a source of inspiration for your future endeavors in the world of seaweed science.

May this symposium mark the beginning of many lasting partnerships and a brighter, bluer economy for all.

Dr.Radhika Rajasree S.R.
Dean, FOST & Organizing Secretary
KUFOS, Kochi, India

SEAWEEDS
2026

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SEAWEEDS 2026

IMPORTANCE OF SEAWEEDS AND NUTRACEUTICALS APPLICATION OF SEAWEEDS

Dr. T. K. Srinivasa Gopal

Former Director (ICAR-CIFT) and Professor, Chair, Centre of Excellence in Food Processing Technology, KUFOS, Cochin

Seaweed is a famous delicacy in some parts of Asia and also a well-known source of important food hydrocolloids, such as agar, alginates, and carrageenan. In addition to its nutritional value, several health benefits have been reported for this valuable food source. It is presumed that the unique features of the marine environment where seaweeds are grown are mainly responsible for their properties. Among the functional effects of the seaweed, nutritional and health-related benefits have been widely studied. Compared to terrestrial plants and animal-based foods, seaweed is rich in health-promoting compounds, including dietary fibre, ω-3 fatty acids, essential amino acids, and vitamins A, B, C, and E. The nutritive value of seaweed and the functional effects of its soluble fibre are discussed with a special reference to the promotion of digestive health in humans.

Seaweeds are natural sources of Phytocolloids such an agar, alginates, and carrageenan, and they are rich in minerals, itamins, proteins, and essential amino acids, and are low in fat content. There are three major groups of seaweeds, viz., brown, red and green. World seaweed cultivation production tonnage increased 1000-fold from 34.7 tons to 34.7 million tons between 1950 and 2019. The largest seaweed producers as of 2022 are China (58.2%), Indonesia (28.6%), followed by South Korea (5.09%) and the Philippines (4.19%). Other noticeable producers include North Korea (1.6%), Japan (1.15%), Malaysia (0.53%), Tanzania (0.5%) and Chile (0.3%). In India, the leading state with

Dr. T. K. Srinivasa Gopal is the Former Director of ICAR - CIFT and he is specialized in Retort pouch technology, Modified Atmosphere Packaging and extruded products. He developed various retort pouch food products based on vegetables, dairy, coconut, meat and fish products.

significant seaweed production is Tamil Nadu. In India, Gracilaria edulis has been identified as a species suitable for farming. At present, approximately 221 species of seaweeds are used worldwide, of which about 10 species or genera are intensively cultivated, viz. Brown algae *Laminaria japonica* and *Undaria pinnatifida*; red algae Porphyra Euchenma, Kappaphycus, and Gracilaria; and green algae *Monostroma, Enteromorpha*, and two other microalgae. There is a high demand for seaweeds, mainly from cottage industries. In Tamil Nadu, wild seaweeds are harvested for the production of agar (*Gracillaria edulis, Gellidiella acerosa*) and algin (*Sargassum* species, *Turbinaria* species), especially in the Gulf of Mannar. Several hundred women depend on wild seaweed collection. Just to earn their livelihood, they are the victims of the Tsunami with loss of life and property.

From time immemorial, man has been utilizing seaweeds as food. Agar, alginic acid and carrageenan are the most important phycocolliod prepared from seaweeds. Agar is prepared from the agaraphytes *Gelidium aaerosa, Gelidium pusillum, Gracilaria edulis, Gracilaria verruca, Gracilaria corticate* and *Gracilaria crassa*.

Most of the brown seaweeds are potential sources of alginates. The properties of alginates vary from one species to another. The main commercial sources are Ascophyllum, Drvillaea, Eckmer, Laminaria, Lessonia, Marcrocystis, Sargassum and Turbinaria. Of these, the most important are Laminaria macrocystes and Ascophyllum. In India, Sargassum and Turbinaria are the two seaweed species used to produce alginic acid. The Indian alginate industry depends on sargassum grown along the coasts of Tamil Nadu, Kerala, and Gujarat. The species growing on the Gujarat coast produces low-viscosity alginates, which are unsuitable for the main Indian textile printing market. Sargassum found in the Philippines is exported to Japan for use in animal feeds and fertilizers.

Carrageenans are the most important hydrocolloid after starch and gelatin. They are extracted from the main plant group, the carrageenophytes. The Philippines is the world's largest producer of carrageen. Important species of seaweeds used for the production of carrageenan are *Chondrus crispus and other Chondrus species, Euchema cottani, Furcellaria fortilgita and Hypnea species.* Of all these species, only a few are commercially exploited and used to manufacture carrageenans.

The food value of seaweeds depends on the proteins, minerals, trace elements and vitamins. Several algal food products are used in Southeast Asian countries, including jellies from *Gelidiella* and *Gracilaria*, jams from *Enteromorpha* and *Ulva*, and pickles from *Acanthophora, Gracilaria, Hypnea*, and *Laurencia* species. Agar is added in the preparation of foodstuffs such as tomato sauce, ice cream, jelly, lime jelly and marmalade. Marine algae are a rich source of water-soluble (alginic acid, agars, laminarin and porphyrin) and water-insoluble fibres (cellulose, mannans and xylan), which contain some valuable nutrients and also behave as functional foods. Seaweed protein contents differ greatly from phylum to phylum. Brown algae contain 5-16% of protein, while green algae have 10-30% of protein, and red algae possess 15-20% of protein.

Seaweed lipid contents are polyunsaturated fatty acids with Omega-3 and Omega-6 acids, which are important to prevent cardiovascular diseases, diabetes and osteoarthritis. Seaweeds are also an important source of a variety of minerals of nutritional importance. Seaweeds contain high levels of calcium, iodine, iron, potassium, phosphorus, and sodium. Some red seaweeds, e.g. Palmaria palmate and Porphyra tenara, have a large quantity of vitamins A, B1, B2 and B12. Beta carotene (provitamin A) found in Codium fragile and Gracilaria chilensis exceeds that measured in carrots. Seaweeds are rich in the antioxidant vitamins C and E in higher concentrations than land plants. Vitamin C prevents scurvy, while Vitamin E helps manage neurological problems caused by poor nerve function and anaemia due to oxidative damage to red blood cells.

Edible seaweeds (macroalgae) have the potential to provide a rich and sustainable source of macronutrients and micronutrients to the human diet, particularly in regions where seaweed makes a significant contribution to regular meals, eg, in Japan, where approximately one-fifth of meals contain seaweed. Inclusion of seaweeds in Western diets has traditionally been limited to artisanal practices and coastal communities but has gained wider consumer interest in recent years, courtesy of the health-food industry. The recent surge of interest in seaweed is fuelled by attention to its bioactive components, which have potential applications in the lucrative functional food and nutraceutical industries, with a focus on alleviating metabolic risk factors such as hyperglycemia, hypercholesterolemia, and hyperlipidemia. The candidate bioactive components of interest to industry include isolated polysaccharides (e.g., alginate, fucoidan), proteins (e.g., phycobiliproteins), polyphenols (e.g., phlorotannins), carotenoids (e.g., fucoxanthin), and n-3 long-chain polyunsaturated fatty acids (e.g., eicosapentaenoic acid). Scientific experiments and human studies to date have focused predominantly on brown seaweeds and derivatives, largely because of their commercial abundance and perceived sustainability.

Despite the nutritional attributes of red seaweeds such as *Porphyra* spp (also known as nori) and *Palmaria palmata* (dulse), which have a high protein content, relatively few investigations have focused on red seaweeds as a source of bioactive components. The current understanding of the health-promoting activities of red seaweeds derives from numerous in vitro and in vivo animal studies. There are only limited reports of green seaweeds contributing to dietary intake of either essential nutrients or bioactive components, despite the potential for transient algal blooms to be exploited.

Aquaculture is recognized as the most sustainable means of seaweed production and accounts for approximately 27.3 million tonnes (96%) of global seaweed production per annum, yet the growing demand for seaweed-based food ingredients calls for more established guidelines and regulations to ensure sustainability. Future considerations for stakeholder management include resource ownership; best practices for cultivation; harvesting rights/licensing; certification/validation of origin; overexploitation; biomass regrowth; environmental impacts; and the development of a sustainable value chain within the agrifood sector.

An abundance of commercially available seaweed products, including whole seaweed and seaweed extracts, is marketed directly and indirectly as value-added supplements for promoting health in the supplement market. The health claims associated with seaweed products are often based on insufficient (or completely absent) evidence from human intervention studies to substantiate such statements. Furthermore, there are significant safety concerns regarding potential adverse events associated with seaweed consumption, particularly given the variable and potentially dangerously high concentrations of iodine and heavy metals (including arsenic species) in certain seaweeds. There is currently limited legislation to require food or supplement companies to disclose mineral, heavy metal, or iodine content of seaweed products or to provide guidance on a safe portion size of certain whole seaweeds in order to prevent excess intakes. Ultimately, if seaweeds are to contribute to future global food security, either in their whole form or via the extraction of their nutrients, the industry should develop a sustainable heavy metal/iodine monitoring program or, alternatively, identify novel processing technologies to ensure that unsafe components such as arsenic are minimized to safe levels, thus protecting the food chain.

The health benefits of seaweed, beyond the provision of essential nutrients, have been supported by in vitro studies and some animal studies; however, many of these studies have inappropriate biomarkers to substantiate a claim and have not progressed to suitably designed human intervention trials to evaluate efficacy. The limited evidence available makes some seaweed components attractive as functional food ingredients, but more human evidence (including mechanistic evidence) is needed to evaluate the nutritional benefits conferred and the efficacy of purported bioactives, and to determine any potential adverse effects. Through an evaluation of the nutritional composition of edible seaweeds, this review summarizes the available evidence and outlines the potential risks and health benefits of consuming whole seaweeds, extracted bioactive components, and seaweed-based food products in humans. Additionally, it identifies future opportunities for functional food and nutraceutical applications.

REIMAGINING INDIA'S SEAWEED RESOURCES: FROM "WEEDS" OF THE SEA TO PILLARS OF INDIA'S BLUE ECONOMY

Vijayan KK
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Seaweeds (marine macroalgae) resources of Indian coastal seas have long been a significant yet underdeveloped component of coastal livelihoods and the emerging blue economy. Ecologically vital yet economically marginal, they are often perceived as nuisance growths, "*weeds*" that entangle nets, foul shorelines, and obstruct fishing activities. In conventional agricultural terminology, a *weed* is an unwanted plant that competes with crops and must be removed to sustain crop productivity. Carrying this terminology into marine systems has unintentionally shaped attitudes toward seaweeds as organisms to be cleared rather than cultivated. In an era where India aspires to harness the Blue Economy and nature-based solutions for climate resilience, this perception urgently needs revision with reimagination.

Globally, seaweeds are increasingly recognised as multifunctional marine resources—supporting food systems, climate mitigation, coastal livelihoods, and industrial value chains (FAO, 2022; Duarte et al., 2022). In contrast, India's seaweed sector remains at a nascent stage, despite decades of discussion, policy intent, and scientific awareness. Despite having immense ecological diversity (about 844 recorded seaweed species of red, brown, and green algae) and a long coastline, our contribution to global seaweed production remains simply marginal. Reimagining seaweeds not as "weeds" but as deliberately cultured marine crops is a necessary first

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step toward building a sustainable and economically viable seaweed sector.

India's Seaweed Paradox: Ambition versus Reality

India's extensive 11000 km coastline and rich biodiversity offer a natural advantage for seaweed farming and exploitation, with diverse applications ranging from food and health products to industrial inputs such as agar, carrageenan, bioactive compounds, and novel fertilizers. India possesses an estimated standing seaweed biomass of nearly 7 million tonnes, distributed along the coasts of Tamil Nadu, Gujarat, Maharashtra, Odisha, Andhra Pradesh, and the islands (CMFRI, 2018; Kaliaperumal et al., 2019). However, India's annual seaweed production is around 72,385 tonnes (wet weight), which is a relatively small share of global seaweed output, which totals tens of millions of tonnes, contributing less than 1% of global production. Actual seaweed utilisation in India remains extremely low and largely dependent on seasonal wild collection by the coastal folks. More than 80–90% of seaweed biomass used in India is still sourced from natural beds, particularly for agar and alginate industries (FAO, 2022). While global seaweed production exceeded 35 million tonnes (wet weight), valued at an estimated US$16+ billion, it mainly comes from China, Indonesia, Japan, and Korea. Under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), India has set an ambitious target of 1 million tonnes of seaweed production, positioning seaweed cultivation as a livelihood and export-oriented activity. However, current production levels are well below 0.01 million tonnes, exposing a stark gap between vision and ground reality. This gap is not merely technological—it is conceptual, structural, and institutional.

What Are We Farming? The Species Narrowness Problem

Despite India's rich algal biodiversity, nearly 99% of seaweed farming in the country revolves around a single species—*Kappaphycus alvarezii*, and a small quantity of *Gracilaria edulis and Gracilaria salicornia.* Farming is concentrated mainly in Ramanathapuram and Pudukottai districts of Tamil Nadu, driven historically by carrageenan demand during the early 2000s, when the multinational industry (Pepsi and Coca-Cola) support catalysed expansion.

Other economically important species, such as Sargassum spp. and Gelidiella spp., are primarily harvested from the wild, seasonally and location-specifically, and are poorly integrated into organised farming systems (Kaliaperumal *et al*., 2019). This narrow species base makes the sector ecologically fragile and economically vulnerable.

Insufficient and timely availability of high-quality seed stock and reliable germplasm remains the main limiting factor in scaling up seaweed cultivation efforts. Significantly, continuous vegetative propagation of the same seed stock year after year has raised concerns about inbreeding depression, reduced growth rates, increased disease susceptibility, and declining productivity—an issue well recognised in aquaculture genetics but rarely addressed in seaweed farming in India.


Fig 1. Kappaphycus alvarezii Fig 2: Gracilaria edulis

Production Reality Check: How Much Area Is Actually Needed?

A standard narrative suggests that achieving 1 million tonnes of seaweed production requires vast ocean areas. A simple calculation, however, shows that the challenge is less about space and more about planning, seed systems, and operational efficiency.

Based on field observations and prevailing farmer practices, seaweed cultivation in India typically follows a small-raft production model. A standard raft of about 3 m × 3 m (9 m^2) yields approximately 150 kg of wet biomass per crop, with an average crop cycle of around 45 days. Considering the effective farming window from April to December, which allows for roughly six crop cycles per year after excluding rough monsoon months, the annual production per raft is about 900 kg of wet seaweed. This corresponds to an estimated productivity of ~100 kg m^{-2} $year^{-1}$ (wet weight). On this basis, achieving a national production target of 1 million tonnes (1 × 10^9 kg) would require approximately 1,000 hectares. Even after accounting for losses, operational inefficiencies, and regional variability, the spatial requirement remains relatively modest by coastal standards. The key constraints to scaling up production, therefore, lie not in space availability but in seed material availability, climatic and weather windows, infrastructure, labour continuity, and market absorption capacity.

Where Can We Farm? Environmental and Seasonal Constraints

Most commercially farmed seaweeds in India require salinity levels above 30 ppt, which confines cultivation essentially to open coastal waters rather than estuarine environments. Monsoons,

Fig 3: Kappaphycus farming, Tamil Nadu coast

cyclones, and other extreme climatic events strongly influence these coastal farming areas. Consequently, the effective seaweed farming window is generally restricted to April to December, as the southwest monsoon causes unavoidable interruptions due to strong winds, high wave action, increased turbidity, and physical damage to farming structures.

Offshore seaweed farming is often projected as the next frontier. While technically promising, offshore systems involve high capital investment, specialised moorings, and increased operational risks, making commercial viability uncertain without strong government support and standardised protocols.

Land-based and pond-based seaweed farming trials are emerging. However, they face challenges such as high production costs, nutrient management issues, biofouling, and lower growth rates than in open-sea systems. These approaches require further research, SOP development, and techno-economic validation before large-scale adoption.

Seed Systems: The Missing Foundation

One of the least discussed, yet most critical bottlenecks, is the absence of a formal seaweed seed production and supply system. At present, farmers retain a portion of their harvest as seed material for the next cycle. While this circular practice sustains short-term continuity, it prevents accurate scaling.

A farmer holding 1 tonne of seed stock can only expand production incrementally and cannot rapidly scale up without external seed sources. Over time, repeated clonal propagation from the same stock exacerbates genetic fatigue. Unlike finfish or shrimp aquaculture, India lacks seaweed hatcheries, motherplant banks, or genetic improvement programmes.

Without regional seed banks, biosecure nurseries, and selective breeding initiatives, sustainable expansion remains improbable.

Value Chains, Business, and the Expo Question

Beyond farming, a fundamental question remains: Who is doing business with seaweeds in India today? Outside the traditional agar and alginate industries—largely dependent on wild harvest—there are very few large-scale commercial players. Functional foods, nutraceuticals, pharmaceuticals, and biomaterials remain niche and fragmented.

Products such as liquid seaweed fertilizers exist, but value addition beyond this is limited. Compared to East Asian countries, where seaweed is embedded in food culture, industrial processing, and global trade, India's seaweed value chain is still embryonic (FAO, 2023).

This reality should not discourage dialogue. Instead, forums like S.E.A.W.E.E.D.S. 2026 provide a necessary platform to critically examine what exists, what does not, and what must be built, rather than merely repeating Aspirational narratives that have remained unchanged since the 1980s. Need scientific evaluation and reality checks for a way forward.

Seaweeds, Climate, and the Blue Economy: Promise with Prudence

Seaweeds are increasingly discussed as climate solutions—such as carbon capture, ecosystem services, and nature-based mitigation pathways. While scientifically valid, these benefits must be framed carefully. Carbon sequestration through seaweed farming involves complex pathways, including biomass export, decomposition, and life-cycle emissions, and should not be oversimplified (Krause-Jensen & Duarte, 2016; Duarte et al., 2022).

Nevertheless, seaweed ecosystems undeniably support coastal biodiversity, fisheries habitats, and livelihood diversification. In India, only limited linkages—such as the *Penaeus semisulcatus* fishery along the Mandapam coast—are well documented, highlighting the need for further ecosystem-level research.

Way Forward: From Thought to Transformation

India has been advocating sustainable seaweed development for over 4 decades. What is different today is policy push, visibility, political interest, and global momentum. Translating this into impact requires:

1. Reframing seaweeds as farmed marine crops, not weeds
2. Diversifying farmed species beyond *Kappaphycus*
3. Establishing seed banks, hatcheries, and genetic improvement programmes, including the use of novel methods such as tissue culture for the production of seed material.
4. Standardising offshore and land-based farming systems with public investment and scaling up with public-private partnership
5. Building realistic value chains, with sustainable farming, production, and harvest, before scaling expos and business meets

Seaweeds can indeed become forests of the sea and pillars of the Blue Economy, a major contributor to sustainable growth and coastal prosperity -but only if ambition is matched with biological realism, institutional support, and long-term commitment, in a framework of prudent seaweed vision.

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SEAWEED PROCESSING AND PRODUCT DEVELOPMENT IN INDIA

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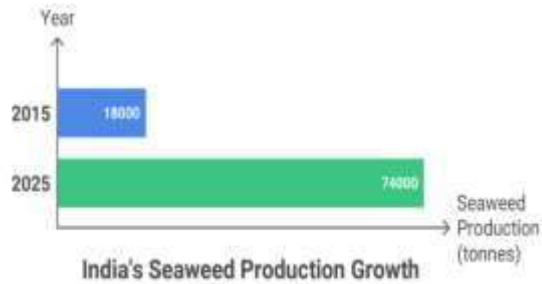
India, with its sprawling 8129 km coastline and an Exclusive Economic Zone (EEZ) of over 2 million square kilometres, has a great potential to strengthen production and utilisation of Seaweeds under "Blue-Green" revolution. Once a neglected marine resource used primarily for subsistence in coastal pockets, seaweed has emerged as a strategic pillar for India's bio-economy. As of 2026, the sector is transitioning from traditional wild harvesting to high-tech cultivation and sophisticated downstream processing, driven by government mandates and a surge in biotechnology startups.

Present Status: Growth and Modernisation:

As of early 2026, India's seaweed sector has reached a critical point. The production of seaweed has nearly tripled over the last decade, growing from roughly 18,000 tonnes in 2015 to over 74,000 tonnes in 2024-25. The industry is currently concentrated in Tamil Nadu, Gujarat, and Maharashtra, with newer hubs emerging in Lakshadweep and Kerala. The mainstay species remains Kappaphycusalvarezii (for carrageenan) and Gracilaria species (for agar). However, there is a shifting focus toward indigenous species like Ulva and Sargassum. Under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), the government has allocated over ₹640 crore specifically for seaweed cultivation,



India's Seaweed Production Growth (2015-2025)

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Post-Harvest Processing:

Processing in India has traditionally been limited to the extraction of hydrocolloids (Agar, Alginate, and Carrageenan) used as thickening agents in the food and pharmaceutical industries. However, 2026 sees the rise of Integrated Seaweed Biorefineries. These facilities utilize a "zero-waste" approach, extracting multiple products from a single batch of biomass - such as liquid bio-stimulants for agriculture, followed by protein extraction for food, and finally using the fiber for packaging. Despite the recent growth, India is currently harvesting only a fraction of its potential. Scientific mapping by the ICAR-Central Marine Fisheries Research Institute, has identified 333 suitable locations for seaweed farming, covering approximately 24,000 hectares.

One of the most significant potentials lies in Seaweed Liquid Fertilizers. In a country where soil health is a major concern, seaweed-based bio-stimulants offer a path to reduce chemical fertilizer use by up to 25% while increasing crop yields. Major Indian Agri industries are already integrating seaweed extracts into their product portfolios to cater to the growing organic farming segment.

Product Development:

The innovation landscape in India is rapidly diversifying. The current trend focuses on high-value applications that address global sustainability challenges. Under Food and Nutraceuticals category, the "Plant-Based" movement in urban India has created a vacuum that seaweed is perfectly positioned to fill. As Superfoods, Seaweed-based nutritional powders, protein-rich snacks, and "vegan gelatin" are hitting mainstream retail shelves. As Functional Ingredients, Extracts like Fucoidan and Laminarin are being researched for their anti-inflammatory and anti-viral properties, leading to a new wave of Indian-made nutraceuticals. With India's strict regulations on single-use plastics, seaweed-based bioplastics have moved from the lab to pilot-scale production. Startups are developing biodegradable films, coatings for paper cups, and edible sachets that decompose within weeks, providing a circular solution to the plastic crisis. Recent advancement in seaweed research has shown immense pharmaceutical potential of seaweeds by virtue of their bioactive compound which are functionally diverse and compatible. Along with bifunctionality, value added products from underutilized seaweeds species also has a great opportunity to expand and contributes towards livelihoods of resource poor fisher folk and startups across the coastline.

The nutraceutical market in India is expected to grow at the compound annual growth rate (CAGR) of 20 percent, mainly in functional food products, antioxidants, immune-booster etc. Seaweed has potential to contribute to the nutraceutical markets immensely. Some of the nutraceutical and food products developed using seaweeds available are;

- Anti-arthritic nutraceutical known to relief joint pain by competitively inhibiting proinflammatory cyclooxygenase-2 and lipoxygenase. The bioactive compounds are extracted from selected brown seaweeds, viz., Turbinaria ornata and Turbinariaconoides.

- Anti-diabetic nutraceutical helps to fight type-2 diabetes by inhibiting dipeptidyl peptidase-IV and tyrosine phosphatase 1B, and is extracted from brown seaweeds, viz., Sargassum wightii and Turbinaria ornata.

- Anti-dyslipidemic nutraceutical combats dyslipidemia. Attenuates high fat-induced hyperlipidemia and lowers the level of serum LDL.

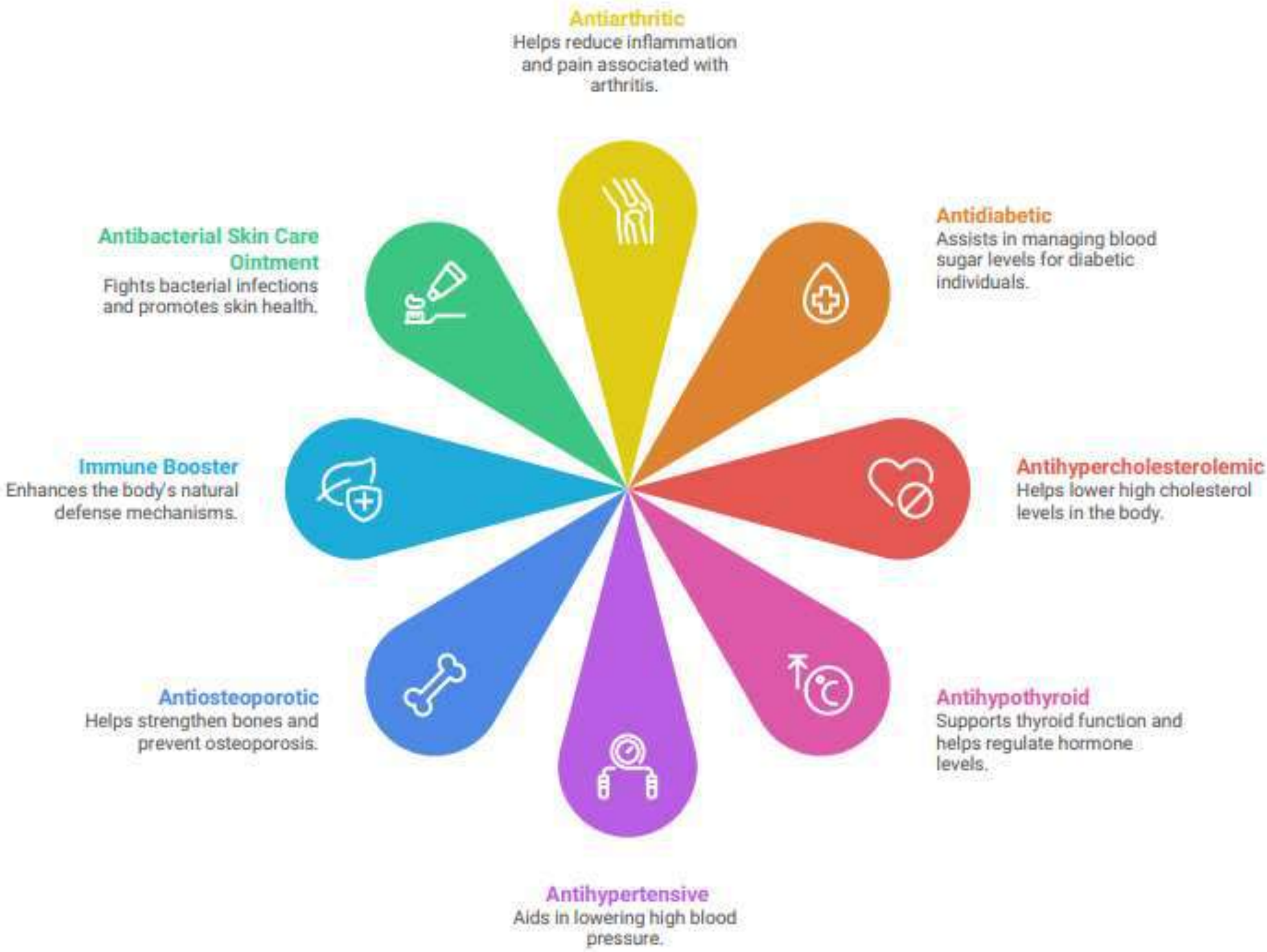
- Anti-hypothyroid compounds extracted from brown seaweeds, like Sargassum wightii, Turbinaria ornata, Turbinariaconoides, and red seaweed Kappaphycusalvarezii combats hypothyroid disorder.

- Novel immunity-boosting formulations which helps to improve the non-specific innate immune system has also been formulated using commonly available seaweed along the Indian coast.

- Fucoidan extracted from Sargassum wightii is a source of essential micronutrients, taurine and antioxidant pigment fucoxanthin.

- Seaweed Nutridrink a formulation of seaweed (Sargassum wightii) and grape juice. The drink is rich in fucoidan, which has established health benefits.
- Seaweed cookies, rich in protein and dietary fibre, with high phenolic content and antioxidative potential.

Some of the products developed using seaweeds



Some of the seaweed-based nutraceuticals

Future Perspectives:

The trajectory for the next five to ten years suggests that seaweed will become a cornerstone of India's Net Zero 2070 strategy. Future policy frameworks are expected to integrate seaweed farming into Carbon Credit markets. Seaweed grows 30 to 60 times faster than land-based plants, making it an elite tool for carbon sequestration. Large-scale offshore "forests" could offset industrial emissions while simultaneously de-acidifying local ocean waters, protecting coral reefs and fish stocks. Keeping in view the huge scope seaweeds attract, technological Integration with AI and Robotics is going to play a major role. The future of Indian seaweed farming is going to be "Smart", and we are likely to see AI-driven monitoring using satellite imagery and underwater sensors to monitor crop health and nutrient levels and Automated Harvesting to reduce the labour intensity of the sector, which currently relies heavily on manual labour by coastal women's cooperatives.

India is positioning itself as a global processing hub, competing with China and Indonesia. By focusing on Value Addition rather than just exporting raw dried biomass, India aims to capture the higher end of the global $16 billion seaweed market. The seaweed growth in India has several drivers which have the potential to realise the aim of becoming a global player in the seaweed market.

Challenges to Address:

To reach the ambitious goals for scaling seaweed production in India, several critical bottlenecks must be addressed, including maintaining seed quality amid environmental stressors like fluctuating temperature, salinity, the occurrence of cyclones, etc. Creating logistic infrastructure, resolving the issues of skilled labourers, are a few other challenges. Moreover, streamlining the cumbersome "Coastal Regulation Zone" (CRZ) clearances for large-scale offshore farming, and boosting consumer awareness to transition seaweed from a niche health food to a staple ingredient in the Indian diet. The latter requires an intensive and targeted campaign highlighting its nutritional profile, such as the presence of antioxidants, PUFA, dietary fibre, etc. Moreover, integration of seaweeds into daily dishes, such as snacks and integration of seaweeds into millet-based meals and so on. Though the government is encouraging seaweed production through mariculture and giving impetus to create seaweed value chain initiatives under Pradhan Mantri Matsya Sampada Yojna (PMMSY), still a lot is needed. Key areas include the allotment of quotas, i.e., clear allocation of open-sea zones for exclusive culture to prevent overexploitation and conflicts with fishing communities; framing of comprehensive quality standards aligned with FSSAI and export norms to ensure contaminant-free products; and widespread training programs on value addition techniques such as drying, milling into powders, and extraction of high-value compounds like alginates and carrageenan. Additionally, challenges like inadequate infrastructure for post-harvest processing, limited R&D on indigenous seaweed strains resilient to Indian coastal conditions, and financing gaps for small-scale farmers hinder progress. Addressing these through public-private partnerships and incentives could unlock seaweed's potential as a sustainable, climate-resilient crop, supporting nutritional security and blue economy growth.

Conclusions:

The seaweed sector in India is no longer just about agar and carrageenan; it is a multi-dimensional industry spanning food security, climate action, and rural empowerment. With the government targeting a production of nearly 10 million tonnes by 2030, the humble marine algae are set to become "Blue Gold," transforming the socio-economic fabric of India’s coastal communities. In spite of government support and innovations by research organizations the sector needs policy reforms, robust cold chain and logistic infrastructure, skill development for coastal fisher folk and incentives to the workers during off seasons.

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SEAWEEDS AS STRATEGIC RESOURCES FOR VALUE ADDITION, NUTRACEUTICAL INNOVATION, AND BLUE ECONOMY ADVANCEMENT IN INDIA

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Introduction

Marine macroalgae, commonly referred to as seaweeds, are emerging globally as high-value bioresources with wide-ranging applications in food, nutraceuticals, pharmaceuticals, agriculture, cosmetics, and bio-based industries. Unlike conventional terrestrial crops, seaweeds do not require arable land, freshwater, or chemical fertilizers, yet they generate substantial biomass rich in structurally diverse and biologically active compounds. Over the last decade, advances in marine biotechnology and growing demand for natural, health-promoting products have transformed seaweeds from low-value raw materials into strategic industrial commodities.

For India, seaweeds represent an underutilised but highly promising component of the blue economy. With an extensive coastline, favourable tropical conditions, and a rich diversity of economically important macroalgal species, the country is well positioned to develop seaweed-based value chains that support industrial growth, nutritional security, and coastal livelihoods. However, realising this potential requires a paradigm shift - from primary biomass exploitation towards value-added processing, nutraceutical innovation, and policy-driven industrial integration.

Seaweed Resources in India: From Biomass to Bioeconomy Assets

India's coastline, spanning over 7,500 km and encompassing the Arabian

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Sea, the Bay of Bengal, and island ecosystems, supports a rich assemblage of red, brown, and green seaweeds. Species such as *Sargassum*, *Gracilaria*, *Gelidiella*, *Ulva*, *Kappaphycus*, and *Turbinaria* are well recognised for their commercial relevance. Estimates suggest that India possesses several million tonnes of standing seaweed biomass (Ushakiran et al., 2017), yet only a small fraction is systematically harvested or cultivated.

Historically, seaweed utilisation in India was largely confined to agar and alginate extraction, with minimal downstream diversification (Ganesan et al., 2019). While these industries laid an important foundation, they did not capture the higher economic value associated with bioactive compounds, functional ingredients, or branded consumer products. In contrast, leading seaweed-producing nations have successfully transitioned towards integrated value chains, linking cultivation with food processing, nutraceutical manufacturing, and export-oriented industries.

For India, the strategic opportunity lies not merely in expanding production volumes, but in redefining seaweeds as bioeconomy assets capable of generating high-value products for domestic and global markets.

Value Addition: The Core of Seaweed Sector Transformation

Value addition is central to the economic viability and competitiveness of the seaweed sector. Raw or minimally processed seaweed offers limited returns, whereas processed derivatives and formulated products command significantly higher market value. Seaweeds are reservoirs of structurally complex polysaccharides, proteins, polyphenols, pigments, fatty acids, and micronutrients, each of which can serve as inputs for multiple industries (Xie *et al*., 2023; Lomartire and Gonçalves, 2022).

Key value-added seaweed products include:

- Hydrocolloids (agar, alginate, carrageenan) are used extensively in food, pharmaceuticals, and biotechnology;
- Bioactive extracts rich in antioxidants, anti-inflammatory agents, and immunomodulatory compounds;
- Functional ingredients such as soluble dietary fibre, mineral concentrates, and natural emulsifiers;
- Speciality ingredients for cosmetics, cosmeceuticals, and biomedical applications.

The adoption of biorefinery-based processing models, in which multiple fractions are sequentially extracted from the same biomass, offers a pathway to zero-waste utilisation and improved profitability. Developing such models in India will require targeted investments in processing infrastructure, skilled manpower, and industry-academia collaboration.

Seaweeds and the Nutraceutical Industry

One of the most promising avenues for seaweed value addition lies in the nutraceutical and functional food sector. Seaweeds are nutritionally dense, providing dietary fibre, iodine, iron, calcium, magnesium, vitamins, and essential amino acids. More importantly, they contain unique marine-derived bioactives such as fucoidan, laminarin, phlorotannins, ulvans, and sulfatedgalactans, that are rarely found in terrestrial plants (Cader et al., 2025).

Scientific studies have demonstrated that these compounds exhibit a wide range of health-promoting properties, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, lipid-lowering, and gut-modulatory effects. Such attributes position seaweeds as ideal candidates for:

- functional foods and beverages,
- dietary supplements,
- nutraceutical capsules and powders,
- fortified traditional foods adapted to local dietary habits.

In India, where non-communicable diseases and micronutrient deficiencies coexist, seaweed-based nutraceuticals offer significant public health relevance. However, mainstreaming seaweeds into the food and health sectors requires rigorous standardisation, safety assessment, bioavailability studies, and regulatory clarity.

The nutraceutical industry, supported by India's strong pharmaceutical and food processing sectors, can act as a major driver for the seaweed sector growth, provided that raw material supply, quality assurance, and innovation pipelines are strengthened.

Integration into the Blue Economy Framework

The blue economy emphasises sustainable utilisation of ocean resources for economic growth, improved livelihoods, and industrial innovation. Within this framework, seaweeds occupy a unique position as renewable biological resources that can support multiple high-value industries without competing with terrestrial resources.

Seaweed-based industries align closely with several national priorities, including:

- diversification of marine-based industries,
- promotion of bio-based and green products,
- enhancement of coastal livelihoods through enterprise development,
- expansion of export-oriented value chains.

By moving beyond extractive use and embedding seaweeds into industrial, nutritional, and pharmaceutical supply chains, India can strengthen the economic dimension of its blue economy. Importantly, seaweed farming and processing lend themselves well to decentralised and small-to-medium enterprises, enabling regional development along coastal belts.

Policy Environment and Institutional Support

Despite their potential, seaweeds have yet to receive the level of policy attention accorded to fisheries or aquaculture. Fragmented governance, unclear regulations for cultivation and harvesting, and limited financial incentives have constrained sectoral growth. Addressing these gaps is essential for scaling up value-added seaweed industries. Key policy priorities include:

- recognition of seaweeds as a strategic sector within national blue economy and bioeconomy frameworks;
- streamlined regulatory mechanisms for seaweed farming, processing, and product approval;
- targeted financial incentives for value addition, start-ups, and small-scale processors;
- support for research, development, and technology transfer in seaweed biotechnology;
- development of quality standards and certification systems for food and nutraceutical applications.

Institutions such as fisheries research institutes, marine universities, and biotechnology centres play a crucial role in generating scientific knowledge, while effective public–private partnerships are needed to translate research into market-ready products.

Bridging Science, Industry and Markets

The successful transformation of the seaweed sector depends on robust linkages between science, industry, and markets. Advances in strain selection, cultivation practices, post-harvest handling, and extraction technologies must be aligned with industry requirements and consumer expectations.

Equally important is market development - both domestic and international. While global demand for seaweed-derived products is expanding rapidly, Indian producers face challenges related to branding, traceability, and compliance with international quality standards. Strategic interventions in marketing, export facilitation, and intellectual property protection can significantly enhance competitiveness.

Capacity building, skill development, and entrepreneurship training, particularly for coastal communities will further strengthen the human capital base of the sector.

S.E.A.W.E.E.D.S. 2026: A Platform for Collective Action

International forums such as the International Symposium on Seaweeds: Value Chains, Nutraceuticals, and Blue Economy Pathways (S.E.A.W.E.E.D.S. 2026) provide critical platforms for dialogue among scientists, policymakers, industry leaders, and entrepreneurs. Such platforms help consolidate knowledge, identify policy gaps, and foster collaborations that are essential for sectoral advancement.

By focusing on value chains, innovation, and policy integration, these forums can contribute to shaping a coherent national roadmap for seaweed development in India.

Conclusion

Seaweeds are no longer peripheral marine resources; they are strategic inputs for high-value industries that lie at the heart of the blue economy. For India, the transition from raw biomass utilisation to value-added, nutraceutical-driven seaweed industries represents both an economic opportunity and a policy imperative.

With targeted investments, supportive regulatory frameworks, and strong science–industry linkages, seaweeds can contribute meaningfully to industrial diversification, nutritional innovation, and coastal economic development. The challenge ahead is not resource availability, but the ability to integrate science, policy, and markets into a coherent and forward-looking strategy.

Positioned correctly, seaweeds can become a cornerstone of India's marine bioeconomy -transforming coastal waters into hubs of innovation, value creation, and sustainable growth.

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BLUE IS THE NEW PINK: WOMEN AT THE HEART OF INDIA'S SEAWEED TRANSITION

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Along India's coastline, seaweed is increasingly being discussed as a solution—one that can support climate goals, diversify coastal livelihoods, and contribute to the blue economy. Much of this conversation, however, remains focused on biomass, markets, and scale. Beyond these technical discussions, a quieter but profound transformation is unfolding in coastal villages, led by women who are redefining what seaweed cultivation can mean for their families, communities, and marine ecosystems.

Blue is the New Pink is a women-centered seaweed livelihood initiative led by the Center for Women's Empowerment and Gender Equality (CWEGE) at Amrita Vishwa Vidyapeetham. The initiative approaches seaweed not merely as a natural resource, but as a livelihood system rooted in local knowledge, ecological care, and women's leadership. It reflects Amrita University's broader commitment—guided by its Chancellor, Sri Mata Amritanandamayi Devi (Amma)—to link education, research, and community well-being in ways that are socially inclusive and environmentally responsible.

"The ocean and our surrounding environment are not merely insentient objects. They possess consciousness and are integral parts of the whole. Although we might not perceive or comprehend this because of limited awareness, they are living entities. They are patient, yet not weak—indeed, they are far more powerful and intelligent than humans. So, approach them with love and reverence."

— Sri Mata Amritanandamayi Devi, Chancellor, Amrita Vishwa Vidyapeetham

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Rather than treating seaweed farming as a standalone economic activity, the project positions it as a holistic pathway—one that builds women's resilience in coastal livelihoods, enables stable and sustainable incomes, regenerates coastal ecosystems, strengthens local ownership of marine value chains, and enhances dietary nutrition through seaweed-based foods.

The project design and implementation are guided by a holistic framework we developed called the AWESOME Framework (Advancing Women's Empowerment through Systems Model Expansion). Rooted in systems thinking, this framework was developed to ensure that our interventions deliver transformational and durable change toward gender equality. It places the mental space domain (mindset, confidence, and agency) at its core, supported by awareness, access, and opportunities. It also addresses the full spectrum of women's vulnerabilities, including Economic Vitality; Health and Sanitation; Environmental Sustainability; Education and Skill Development; Society, Culture and Politics; and Safety and Security. This systems approach ensures that restoration is not treated as an isolated ecological activity, but rather as an integrated pathway for women's empowerment, community resilience, and long-term environmental stewardship.

Environmental outcomes are strengthened through participatory marine ecosystem services, including coastal clean-up drives, seagrass meadow mapping, conservation, and rejuvenation, guided by Ostrom's principles of community-based natural resource governance. A 360-degree skilling framework—covering swimming, diving, indigenous cultivation practices, and enterprise development—builds adaptive capacity while addressing the practical realities of women entering marine livelihoods.

These efforts are further supported by an AI-enabled Seaweed Monitor platform, which integrates GIS mapping, cultivation and harvest records, income analytics, and seaweed health monitoring. The platform enables data-driven decision-making and supports transparent, replicable implementation across diverse coastal geographies.

The project is currently implemented across nine coastal villages in Ramanathapuram district, Tamil Nadu, and in Kollam, Kerala—regions selected for both their ecological suitability for seaweed cultivation and their livelihood vulnerability. Villages such as Olaikuda, Thondi, Nambuthalai, and Thirupalaikudi have served as intensive pilot sites, with the initiative gradually expanding through community networks. More recently, the project has extended into coastal areas of Andhra Pradesh and Karnataka, carrying forward lessons from earlier phases.

At the heart of *Blue is the New Pink* is a deliberate focus on supporting women across the entire seaweed value chain, rather than limiting participation to cultivation alone. Over 200 women have been trained in sustainable seaweed farming practices, including the cultivation of indigenous species. Training combines technical skills with life skills and basic business and financial literacy, ensuring that women are equipped not only to grow seaweed, but also to plan collectively, manage risk, and make informed economic decisions.

To enable practical application, the project has supported women with cultivation infrastructure and safety measures. A total of 340 rafts, 860 monoline poles, poyaboats, and essential safety equipment have been distributed. Recognizing the risks associated with marine work, the initiative places strong emphasis on safety practices, tool-use awareness, and swimming lessons—an often-overlooked but critical enabler for women's participation in ocean-based livelihoods.

As cultivation stabilized, attention shifted toward enterprise development and value addition. Women received training in developing seaweed-based products such as soaps and pickles, alongside support for product testing and early market entry. These efforts have resulted in the sale of over 1,000 soaps and more than 400 jars of pickles, generating realized profits exceeding ₹90,000 as of February 2026. While modest in scale, these outcomes point to the potential of women-led micro-enterprises to diversify incomes and retain value locally.

"Previously, we would wait for the men to return from the ocean. Now, we enter the ocean ourselves and share the livelihood of the household."

— Mrs. Karthicka, Thirupalaikudi Village, Tamil Nadu

Ecological action remains a core component of the initiative. Women have played an active role in mapping seagrass across shallow coastal waters and restoring 2.8 hectares of degraded seagrass habitats.

Awareness sessions on seagrass conservation have reached more than 2,000 beneficiaries across nine villages, while clean-up drives covering approximately 12 kilometres of coastline have reinforced the connection between healthy ecosystems and sustainable livelihoods.

Integrated Multi-Trophic Aquaculture (IMTA) cages installed in Kerala and Tamil Nadu further strengthen the project's ecological foundation. Together, these efforts underscore a central principle of *Blue is the New Pink*: that economic activity in coastal zones must advance hand in hand with environmental care.

Beyond livelihoods and ecosystems, the project has also emphasized recognition and long-term skill validation. Thirty women have received certification from the National Skill Development Corporation (NSDC), strengthening professional credentials and future employability within the growing seaweed sector. Equally important—though less visible—are gains in confidence, leadership, and collective agency as women take ownership of assets, knowledge, and decision-making processes.

"I used to fear talking to a government official, but now I confidently take training sessions in front of these officials."
— Mrs. Ilangiammal, Thondi Pudhukudi Village, Tamil Nadu

Looking ahead, the initiative aims to build further on women's existing capabilities, expand participation to ensure sustainable seaweed supply chains, and deepen the integration of ecological conservation into livelihood systems. The approach remains grounded in community ownership, strong links between research and field practice, and partnerships with government agencies, industry stakeholders, and local institutions.

As India's seaweed sector continues to grow, *Blue is the New Pink* offers an alternative lens—one that views women not as passive beneficiaries of development, but as drivers of resilient coastal economies. In doing so, it suggests that the future of the blue economy will depend as much on social foundations and ecological care as it does on scale and technology

PHYCONOMY IN INDIA- POTENTIALS AND FUTURE

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Introduction

Seaweeds are exploited commercially for their cell wall polysaccharides, such as agar, algin, carrageenan, etc., and for manure, fodder, and bioactive metabolites. They are marine macrophytic thallophytes, comprising taxonomically distinct groups of green (Chlorophyta), brown (Phaeophyta), and red (Rhodophyta) seaweeds. Seaweed resources grow best when attached to hard substrata such as rocks, pebbles, dead corals, or other hard structures in the tidal and intertidal waters along our peninsular coastline and in the Andaman-Nicobar and Laccadive Archipelagos. A number of tropical seaweeds, including green algae (*Ulva, Enteromorpha, Monostroma, Caulerpa),* brown seaweeds (*Dictyota, Laminaria, Cladosiphon, Padina)* and red seaweeds (*Gracilaria, Porphyra, Eucheuma)* are eaten directly (sea vegetables) for their minerals, vitamins, proteins, essential amino acids and low-fat content. Seaweeds are cultivated for the supply of raw materials for the blue industry, such as the production of algal polysaccharides, as well as for their use as food, sources of enzymes, dyes, manure, animal feed, drugs, antibiotics, nutraceuticals, etc. (Kaladharan, 2017). Globally, the production of seaweeds through mariculture lags far behind demand for raw materials for traditional and emerging applications of seaweeds and their products (Callaway, 2015). India has a 11098 km coastline and more than 0.26 million tonnes of wet, harvestable seaweed biomass belonging to 896 species. Of these nearly 60 species, to the tune of 30 % of the harvestable biomass, are economically important for their polysaccharides and

Dr. Kaladharan P, Principal Scientist (Retd), has been served as Head of Fisheries Environment and Management Division,ICAR- CMFRI. His focus of research include Marine fisheries environment, Primary productivity, Seaweed mariculture, Seagrass ecology , Coastal pollution and impact assessment, Climate change impacts and carbon sequestration secondary metabolites. As the term mariculture generally denotes the culture of marine organisms of commercial importance in the sea, I chose Phyconomy to mention seaweed cultivation practices similar to Agronomy for terrestrial cropping. This article will briefly touch on the various seaweed resources available on our coasts, their role in aquapreneurship, their cultivation methods, the need for large-scale cultivation at sea, and the value-added products from seaweeds.

Seaweed Resources

Throughout the world, 145 species (66%) were used for food: 79 Rhodophytes, 28 Chlorophytes and 38 Phaeophytes. Just over half of the Rhodophyte and Phaeophytes were used for phycocolloid production; 41 species for alginates, 33 for agar and 27 for carrageenan. 24 species were used in traditional medicines. 25 species were used in agriculture, including animal feed and fertilizer, while at least 2 species (*Ulva laetevirens* and *Gracilaria verrucosa*) were used in the production of paper in Italy. There was an annual total of 108,229 t (d.wt) of agarophytes, 81,858 t (d.wt) carrageenophytes and 826,178 t (d.wt) of alginophytes produced in 1994/1995 (White and Ohno, 1999).

Economically important seaweed resources of the world, as per the harvests made during 1971-1973, were estimated to be 2105 million tons wet weight (about 1460 million tons of brown algae; 261 million tons of red algae; 384 million tons of other algae), dominated by brown seaweeds (Michanek, 1975). In India, the southeast and northwest coasts and the Andaman-Nicobar and Laccadive Archipelagos harbour a variety of seaweeds with rich biomass and species diversity. Rich seaweed beds occur at Goa, Karwar, Mumbai, Ratnagiri, Thikodi, Varkala, Vizhinjam, Idinthakarai and Rameswaram coasts as well as in Pulicat and Chilka Lakes. Very recently, a large bed of seaweed off Kovalam, measuring more than 2000 sq. ft, has been discovered along the southern Kerala coast, dominated by brown seaweeds Padina and Sargassum (The New Indian Express, 2nd August 2017). This discovery, made by an NGO, Friends of Marine Life, indicates the possible occurrence of similar seaweed beds in deeper waters along the south-west coast of India and the need for a deep-water survey for seaweed resources. There were about 40 seaweed industries in India, producing algin and agar, relying solely on natural resources. The Indian coastline has 896 species of marine algae belonging to 250 genera and 64 families; of these, nearly 60 species are commercially important. A revised checklist of marine algae reported by Oza and Zaidi (2001) and Umamaheswara Rao (2011) indicates a considerable increase in the number of seaweed species in India. The harvestable biomass of seaweeds along the Indian coastline has been estimated at 0.26 million tonnes of wet biomass (Chennubhotla *et al*., 1996). Approximately 20,000 tonnes of these resources are harvested annually from the wild in India (CMFRI, 2016).

Seaweeds and Aquapreneurship

Although global utilization of marine algae is a multibillion-dollar industry, their bioactive potential is still underexplored. For centuries, the medicinal properties of marine macroalgae were limited to traditional and folk medicines (Smith, 2004). However, in recent years, industries from different branches (fuel, varnish, textile, paints, plastics, cosmetics, pharmaceutical and food) have been focusing their attention on the discovery and development of compounds from marine algae (Andrade et al. 2013). Seaweeds are the only sources of industrially important phycocolloids such as agar, carrageenan, and alginate. They have a lot of applications as stabilizers, viscosifiers, gelling and emulsifying agents. Recently, seaweeds or their extracts have been extensively used as biostimulants or organic manure in agriculture. World seaweed production in 2016 was 30.1 million tonnes wet weight, with the first sale value estimated at 11.7 billion USD (FAO, 2018). With cooperatives and aquapreneurs showing interest in taking up seaweed cultivation on a large scale, the business is projected to reach USD 26 billion by 2026.

Mariculture is gaining importance nowadays as the catch from the seas are stagnating. World seaweed production through mariculture is expected to increase to 35 million tonnes by the year 2025. In 2016, Phyconomy or production of seaweeds in the sea (44% of all aquaculture) was estimated at about 30.1 million tons wet weight, registering an annual growth rate of 8% and valued at 11.7 billion US$ (FAO, 2018). Seaweed farming is encouraged in developing countries, as it provides employment for poor fishermen in growing seaweed and in processing industries. One of the biggest exporters of cultured seaweed is China, where the industry employs between 100,000 and 120,000 people. Presently, seaweed cultivation is expanding rapidly due to growing demand for its use in pharmaceuticals, nutraceuticals, and antimicrobial products, as well as in biotechnological applications. Seaweed mariculture, the fastest-growing component of global food production, can also offer a number of opportunities to mitigate and adapt to climate change.

Benefits of seaweed farming

a) Seaweed cultivation is being integrated with intensive fish farming to provide nursery grounds for juvenile commercial fish and crustaceans.
b) Seaweed farms filter undesired nutrients and improve the marine environment and reduce eutrophication.
c) Seaweed mariculture sites enhance marine fish habitats.
d) Can support seaweed industries by a constant supply of raw materials of the same quality and maturity stage, unadulterated with non-commercial species, thereby reducing the exploitation pressure and conserving the natural beds.
e) Harvest is easy, and hence the supply of raw material is assured.
f) Since seaweed mariculture, a green aquaculture practice, does not require application of either fertilisers or pesticides, it can sequester dissolved CO2 and mitigate ocean acidification.
g) Indirectly, seaweed farming has reduced over-fishing in many regions, providing coastal communities with an alternative livelihood.
h) In India, women's self-help groups involved in *Kappaphycus* farming have become economically active for the first time.

Phycosaccharides

Agar is the major constituent of the cell wall of certain red algae (Rhodophycae), especially the members of families Gelidiaceae, Gelidiellaceae and Gracilariaceae. Agar-agar is the Malay word for the gelling substance extracted from Eucheuma, but now known to be carrageenan. The term agar is now generally applied to those algal galactans which have agarose, the disaccharide agarobiose as their repeating unit. Raw materials for the production of agar are red algae such as *Gelidiellaacerosa, Gracilaria edulis, G. verrucosa* and species of *Gelidium, Pterocladia* and *Ahenfeltia.*

Agar is an important colloid used extensively in biomedical and R&D laboratories as a basal medium for the culture of microbes, cells, and tissues. In the food sector, agar is used for gelling and thickening in confectionery and bakery purposes and as a stabilizer for the preparation of cheese. In the fish and meat processing industries, agar is applied to canned products as a protective coating against the effects of metal containers. In the brewery, agar is used as a clarifying agent for wines, beer and liquors. In the pharmaceutical industry, agar is used as a laxative for chronic constipation, as a drug vehicle. Agar is an ion exchanger used in the manufacture of ion exchange resins. In cosmetic industry agar serves as a constituent of skin creams and ointments. Agar is also employed in paper and textile industries as finishing and sizing agents.

Algin or alginic acid is a membrane mucilage and a major constituent of all alginates. The various salts of alginic acid are termed "alginates" (eg., sodium alginate, calcium alginate etc). In pharmaceutical industry alginic acid is used as emulsifiers in watery emulsions with fats, oils and waxes as filters in the manufacture of tablets, pills and as base of any ointments. An alginate gauze is used as a blood stopping plaster. As a slimming agent, the alginate forms a jelly in the stomach which produces the feeling of satiation. Ammonium alginate wool is used as a filter for microorganisms for laminar flowhood.

Carrageenan is a sulphated galactan polymer obtained from various red seaweeds belonging to families such as Gigartinaceae, Soliriaceae and Hypneaceae.In food industry carrageenan finds its use in bakery, confectionery and for the culinary purposes especially in the preparation of condiments, syrups, whipped creams, ice disserts, cheese etc. Carrageenan is used for clarifying fruit juices and other beverages. Quality of wheat flour is improved for making spaghetti and parotta by adding carrageenan. The food sector accounts for nearly 70% of the world market for carrageenan.

Mannitol is an important sugar alcohol of the hexite series found in the cell sap of brown algae. Mannitol also occurs as mannitan. The chief raw material for the extraction of mannitol are *Fucus vesiculosus, Bifurcariabrassiformis, Sargassum* spp, *Turbinaria*sppetc. In pharmacy mannitol is used for the preparation of tablets, for making diabetic diet, chewing gum etc. Mannitol is also used in explosives and other pyrotechniques. Mannitol finds its use as plasticizers for the production of resins

Phycofertilizer and biostimulants for crops

Seaweed extract or seaweed sap is made into mineral rich liquid seaweed fertilizer (LSF) and marketed under various trade names. Studies have proved that extracts of *Sargassum wightii, Ulva lactuca,* and *Spathoglossum asperum* at 1% strength show favourable response on the germination, seedling vigour, fruit setting and on the weight of the fruit in crops such as groundnut, maize, gingelly, tomato and ber. Liquid seaweed extract was first patented in the year 1912. Another patent was offered in 1962 by Maxicrop Ltd and marketed as “Maxicrop” and “Bioextract”. When foliar feeding became an orthodox method of plant nutrition in the 1950s ‘Marinure’, ‘SM-3’ and ‘Trident’ brands were made in the UK in 1966 and ‘Algifert’ in Norway in 1970. In India SPIC manufactures and markets LSF in the name of ‘Cytozyme’ and SNAP markets in the name of ‘Organic six’. The sap of *Kappaphycusalvarezii*is known to improve grain and biomass yield in wide range of crops ascertained across 20 States in India. The sap production of M/s. Aquagri Processing Pvt. Ltd. has escalated from 5.25 kL in 2008 to 1875 kL in 2015. Indian Farmers Fertilizer Cooperative Limited (IFFCO) is marketing another plant bio-stimulant produced from seaweeds (Mantri *et al*., 2017).

Cultivation of seaweeds in India

The indiscriminate exploitation of certain seaweed species from specific localities, especially *Gelidiella* and *Gracilaria* from the Tamil Nadu coast, resulted in depletion and consequent shortage in the supply of raw material. This situation has encouraged production of seaweed resources through cultivation. In India mariculture of seaweed was attempted by CSIR-Central Salt and Marine Chemicals Research Institute, ICAR- Central marine Fisheries Research Institute and CSIR- National Institute of Oceanography.

The Central Marine Fisheries Research Institute (CMFRI) at its Regional Centre at Mandapam Camp since 1970s ventured into cultivation of seaweeds like *Gracilaria edulis* and *Acanthophoraspicifera.* The cultivation of agar yielding seaweeds *Gelidiellaacerosa, Gracilaria edulis,* carrageenophyte*Hypnea*spp., alginophyte*Sargassum* spp., and edible seaweeds *Ulva fasciata*and *Enteromorpha compressa*at different locations on Northwest and Southeast coast of India by the CSMCRI using various culture techniques were of noteworthy. In 1964 seaweed culture experiments were conducted for the first time in ponds at Porbander by attaching small plants of brown alga *Sargassum* to coir nets (Thivy, 1964). The plants of Sargassum grew to a height of 15-52 cm in 40 days from the initial height of 5-10 cm. This experiment revealed good possibilities for cultivation of *Sargassum* and other seaweeds in India. Agar yielding seaweed *Gracilariaedulis* was first cultured by long line rope method in a sandy lagoon on the eastern side of the Kurusadi Island (Rameswaram).

In the beginning, seaweed cultivation was taken up by CSIR-CSMCRI and ICAR- CMFRI along the Gujarat coast and Tamil Nadu, and was confined to experimental status only. These experiments revealed that *Gelidiella acerosa could be successfully cultivated on dead corals and hollow cylindrical cement girdles, and Gracilaria edulis and Hypneamusciformis on long line ropes, and Ulva fasciata and Enteromorpha compressa on* nets. Among these different seaweed species, the commercial cultivation has been proved economically viable only for *Kappaphycusalvarezii.* Already, countries like China, Japan, the Philippines and the Korean Republics are widely cultivating seaweeds, and wild harvests are regulated.

Mariculture of *Kappaphycus*in India

The CSIR- Central Salt and Marine Chemical Research Institute introduced this fast-growing species of seaweed in the Diu coast (Gujarat) in 1995 for experiments in confined waters from the Philippines. The species is a source of *k*-carrageenan, a gel-forming polysaccharide widely used in the pharmaceutical and food industries. After successful introduction and acclimatization, this Institute has commercialized the culture technology and transferred the material and the technology to Pepsi Co India holdings Ltd., only after convincing itself that its cultivation would be ecologically safe. Later it was transferred toMs. Aquagri (P) Ltd, New Delhi and to Indian Seaweed Industries, Vijayawada.In India seaweed farming, as common pool resources, stands out as the best example of community based coastal resources management (CBCRM) approaches that have enhanced the levels of employment and income among coastal communities (Krishnan and Narayanakumar, 2010). Aquagri Ltd is currently engaged in promoting *Kappaphycus* cultivation through self-help groups in India which provide livelihood opportunity to coastal communities. The Aquagri model using self-help groups mainly comprising of women is an innovative model not practiced anywhere globally. Offering a fixed pre-determined price to provide a predictable income is also been put into practice for the first time, which eliminates the cultivators' risk in India as the market risk is the biggest impediment faced by the cultivators in other countries.

Feasibility of *Kappaphycus* cultivation in Gujarat coast has been successfully demonstrated along the Okha Mandal region at Mithapur, Okha and Beyt Dwaraka which indicated that, out of nine stations Okha Mandal and Diu coastal area most suitable for *Kappaphycus alvarezii* culture in summer, winter and monsoon seasons (Rao and Rao, 1999).Gujarat Livelihood Promotion Company(GLPC) under the Sagarlaxmi project in association with the technical assistance from the Bhavnagar based CSMCRI, initiated large scale mariculture of Kappaphycus along select centers of Gujarat coast aimed at self-employment generation and livelihood improvement of more than 10000 fisher families. Subsequently cultivation of this seaweed was carried out at different locations on Indian coast such as Kerala – Vizhinjam (Bindu, 2010) and Thangaserry (Kaladharan, 2005), Narakkal (Reeta, 2006) and Padanna (Gulshad, 2015); Tamil Nadu – Mandapam, Kilakarai, Tutocorin and Kanyakumari caost; Andhra Pradesh – ChepalaTimmapuram and Mukkam and Gujarat – Okha; Porbandar and Diu coast (Periasamy, 2016). It is estimated that the entire global harvest of *Kappaphycus*production is 1, 83, 000 tons (dry) and it comes from cultivation alone. The Philippines and Indonesia contribute (92%) of the entire global production. According to the recent report of FAO (2013) rapid expansion of *Kappaphycus*and *Eucheuma* cultivation has resulted in production increase from 944000 wet tons in 2000 (48% of total red seaweed production) to 5.6 million wet tons in 2010 (63%) with corresponding value from USD 72 million to USD 1.4 billion. The production of other countries v*iz.* Malaysia, China and Solomon Island is considerable, while Indian contribution is so meagre (Periasamy, 2016).

Contract farming of *Kappaphycusalvarezii* by the fisher folks of east coast of India has touched maximum of 1,500 tonnes dry weight during the year 2012 and has produced more than 70,000 tonnes wet biomass of *Kappaphycus* in a decade between 2005 to 2015 with concomitant purchase value of <4.5 to 35 Rs kg−1 (dry) and having an annual turnover of around Rs 2.0 billion. However, the production sharply declined after 2013 due to mass mortality and the average production in recent years is only to the tune of 200 t dry weight /year. Cultivation of this seaweed generated employment for hundreds of thousands of fisher folk in some coastal districts of Tamil Nadu *viz.*, Ramanathapuram, Pudukkottai, Tanjavur, Tuticorin and Kanyakumari districts earning Rs. 15000/- to Rs. 16000/- per person per month (Johnson and Gopakumar, 2011). At present, commercial farming is carried out following three techniques, namely floating bamboo raft, tube net (net sleeves), and long lines; of which the former two are widely practiced. Establishments such as M/S Linn Plantae Private Limited, Madurai and M/S SNAP Natural and Alginate Products Pvt Ltd, Ranipet, are also involved in *Kappaphycus cultivation*.

Economics of Kappaphycus mariculture

Total cost of production: Rs.3,000/raft/year (including cost of seed material for 4 crops)
Seaweed production: 1,000 kg/raft/year

Price of seaweed: Rs.6.50/kg (wet weight)/ raft

Total revenue generated: Rs.6,500-/year/ raft

Net profit: Rs. 3,500/raft/year (Rs.6,500 minus Rs. 3000)

Additional net income: Rs.1,57,500/year/fisher (Johnson et al., 2017).

Phyconomy for Agar

Acute shortage of agar yielding red seaweeds all over the world is going to jeopardize the research programmes in the fields of biology and medicine for want of agar and agarose. In India too reduction in the quantity of wild collected native seaweeds like species of *Gracilaria* and *Gelidiella* is being observed. Red seaweeds are now imported from Sri Lanka, Morocco and SAARC countries with import duty varying between 4 – 37%. Most of the agar producing units in India remains shut due to lack of raw material and high import duty. 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 wt/ yr) coupled with habitat destruction. The crustose red alga *Gelidiella acerosa* growing along the intertidal regions of our peninsular coasts as well as the reef flats of Andaman and Laccadive Islands is the most important agarophyte that can yield pharmaceutical grade agar with gel strength above 650 g/cm^2. Studies carried out on standing crop estimation of *G. acerosa* in the Gulf of Mannar region over a decade of time revealed that the wet biomass of 1400 g / m^2 recorded during 1996- 1998 (Ganesan *et al*., 2008) has drastically reduced to 600 g / m^2 during 2004- 2005 and recently shrunken to just 450 g / m ^{2} during 2009-2010. The farming of *G. acerosa* will ensure consistent production of quality and pure raw materials that can fetch alternative livelihood to the coastal fishers (@ Rs.80,000/tonne dry weight). The Central Salt and Marine Chemicals Research Institute (CSIR) has already developed successful technology for the mariculture of *G. acerosa*, *G. dura* and *G. debilis* (*Gracilariaceae,* Rhodophyta). Large scale mariculture of agarophytes and their value addition through linkage with industrial partners is very much essential.

Seaweed mariculture for fodder

Shrinkage of cultivable land due to urbanization and shortage of water limit the possibility of producing more feed and fodder to livestock from land. Sea remains untapped and the seaweed resources has got immense potential to fill the gap in India. Seaweeds as animal feed had been in use as early as first century BC by the Greeks. Seaweed has been used by farmers living near the sea in Europe. In Norway*Ascophyllum* is used as pigmeal. *Rhodymenia palmata* a redseaweed is called cow weed in Brittany and horseweed in Norway. Dried and processed seaweeds have been used as animal feed in Europe and North America.

Seaweeds are rich in protein (20-25%), carbohydrate (50-70%), vitamins, minerals and certain drugs. When used in animal feed, cows produced more milk, chicken eggs became better pigmented and horses and pets became healthier (White and Keleshian, 1994). Feed supplemented with *Gracilaria*and /or *Spirulina* to layer chicks (white leghorn) increased the number of eggs, size and colour of yolk (Chaturvedi *et al.* 1985). Dave *et al* (1977) assessed the possibility of seaweeds being used as supplementary animal feed and they reviewed the feeding trials of farm animals with seaweeds conducted in Japan, Germany, the UK and Norway. ICAR-National Dairy Research Institute, Karnal jointly with the ICAR- CMFRI did pioneering studies on cattle feed production from *Sargassum* spp. for the ruminate animals.

Rural India today is not fodder-secure, and the grim reality is that food security in this country is impossible without fodder security. In rural India, domestic animals are not pets but engines that drive the economy. They provide resilience and wealth. But our country lack policies on how to feed these 500 million animals. Our agriculture production is stagnating and our farmers are shifting to crops that do not yield fodder resulting into a crisis. As we go for rearing animals with higher milk yields *ie.,* the hybrids- need better quality fodder, they require stall feeding. Hence an investigation was attempted through the AP Cess fund of ICAR to produce better quality feed / fodder for animals. Saturated fatty acids were found predominant in *Kappahycus, Hypnea* and *Gracilaria*; Monounsaturated fatty acids were predominant in brown seaweed *Sargassum* and the green seaweed *Ulva. Sargassum wightii* contained maximum amount of Omega-3 fatty acids, whereas *Hypnea* and *Gracilaria* contained higher levels of Omega-6 fatty acids.

Seaweed mariculture for biofuel

Demand for fossil fuel is ever increasing day by day. India spends about 120 billion USD per year for the import of crude oil which is a huge drain on our foreign exchange reserves. In view of the increasing demand for crude oil and coal and the environmental hazards caused while burning fossil fuels, production of alternative fuels from renewable sources (biofuels) is highly imperative for our future needs. Biofuels are low carbon replacements for fossil fuels. Government of India initiated several programmes to promote production and use of biofuels in the year 2000. The National Biofuel Mission launched in 2003 has initiated ethanol blended petrol programme (EBPP) and biodiesel blending programme (BDBP) by which biofuel will be blended with fossil fuels upto 20% in a phased manner.

Crop based biofuels such as biodiesel from oilseeds and ethanol from sugarcane and corn are unsustainable as they compete with food crops for arable land, atmosphere, water and fertilizers. Marine algae are regarded as highly promising biomass sources for high-quality biofuel production due to their rapid growth rate (8-10 times faster) compared to terrestrial and aquatic higher plants. It is estimated that 3% of the world's coastal waters with seaweeds grown would produce 230 billion L of ethanol. Though the majority of seaweeds lack lignin and pectin on their cell walls, their breakdown and fermentation can be hastened and enhanced by the involvement of suitable microbes (*Bacillus spp*., *Vibrio splendidens*, etc.). The bioethanol thus produced from seaweeds can be blended with petrol. The energy content of algal biomass is roughly 4700 k cal/kg compared to the energy value of coal (3600-4200 k cal/kg).

Seaweed mariculture for agriculture and allied businesses

Looking at the process chain of seaweed from production through processing to final products, the growth of seaweed production lags far behind the demand for seaweed biomass for the many traditional and novel applications for this expanding marine crop. The growing population in India is placing a tremendous strain on food demand. To meet this challenging demand, farmers are forced to use chemical fertilizers and pesticides on agricultural land to increase crop yields. Chemical fertilizers have degraded the physical properties and fertility of the soil and also accumulated toxic chemicals present in the inorganic fertilizers in plant products, causing serious health problems in humans through biomagnification. The undesirable effect of inorganic fertilizers on soil and the environment is the foremost reason to examine alternative biofertilizers. In recent years, seaweed extracts have been produced and marketed as liquid fertilizers or gels, and as dry biomass as mulch or granules, because they contain many growth-promoting substances, such as auxins, gibberellins, trace elements, vitamins, and amino acids. Extracts of seaweeds are known to contain many growth hormones, as well as many micronutrients and rare trace elements that are not found in terrestrial counterparts, which are responsible for promoting growth, flowering, and better yields in field crops.

As more and more firms, individuals, and farmer fertilizer cooperatives come forward to produce seaweed-based manures and fertilizers, demand for seaweed biomass is increasing steadily. Regulatory mechanisms should be framed on the commercial production of seaweed-based fertilizers and biostimulants, as it involves the exploitation of wild stock by CMFRI and its quality assurance by CIFT to check the addition of inorganic nitrates and micro elements. Hence, to conserve the natural stock, the raw material for producing seaweed-based manures and fertilizers should be sourced from large-scale mariculture rather than from wild habitats.

Seaweed mariculture for combating climate change impacts

Seaweeds have been proven to be excellent bio-remediating agents and can improve water quality by taking up dissolved minerals, nitrates, ammonia, and phosphates. It is estimated quantitatively that seaweeds are also capable of sequestering dissolved CO_2 at the rate of 80.5 mg/g wet weight/day, while their rate of emission through respiration is only 10 mg/g wet weight/day. Large-scale seaweed mariculture has been recognised as one of the climate-resilient aquaculture techniques to mitigate ocean acidification. Being highly autotrophic, seaweed vegetation can utilise the carbon dioxide for photosynthesis, which can remove the dissolved CO_2 from the seawater. Seaweed beds and farms are considered significant CO2 sinks and can play an active role in mitigating and adapting to climate change. It has been proven beyond a doubt by a recent review (Jensen et al., 2018) that seaweeds have been accepted as a blue carbon sink on par with other coastal and marine macrophytes. It is estimated that the seaweed biomass alone along the Indian coast is capable of utilising 3,017 t CO2/d against the emission of 122 t CO2/d, indicating a net carbon credit of 2,895 t/d.

An experiment to estimate the carbon sequestration potential of seaweed (*Kappaphycus alvarezii*) cultured on three bamboo rafts was conducted at Munaikadu, Ramanathapuram district, Tamil Nadu. In each of the rafts (12 ft × 12 ft), 3 pre-weighed bunches of seaweed were tagged, and their weights were periodically (once every 15 days) measured. Further, sub-samples from each bunch were collected, dried and preserved. The samples were analysed for their carbon content using a CHN elemental analyser. The average dry weight percentage of the harvested seaweed 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 which registered 0.018673 g per dayper g dry weight and 0.0016338875 g per dayper g wet weight of seaweed. Hence, large-scale mariculture of seaweeds, preferably red seaweeds, is very much essential to check ocean acidification, which indeed is a green technology without the involvement of energy, fertilizers and chemical inputs and is not a labour-intensive avocation.

Seaweed mariculture for drugs and nutraceuticals

The rich diversity of marine macroalgae represents an untapped reservoir of bioactive compounds with valuable pharmaceutical and biomedical uses. The research work at the Marine Bioprospecting laboratory of ICAR-Central Marine Fisheries Research Institute has been focused on developing bioactive leads and nutraceutical products with pluralities of bioactive properties from seaweeds for use against various diseases, viz., inflammation, dyslipidemia, hypercholesterolemic disorders, thyroid disorders, osteoporosis, type-II diabetes, cardiovascular, pathogenic infection, and oxidative stress. This Institute has successfully developed optimized protocols to prepare natural antidiabetic and anti-inflammatory supplements enriched with lead molecules as nutraceutical formulations (s) (Cadalmin™Antidiabetic extract and Cadalmin™ Green Algal extract from seaweeds) as effective green alternatives to the synthetic drugs available in the market to combat type-II diabetes and rheumatic arthritic pains, respectively (Chakraborty *et al.,* 2010, 2015).

Cadalmin™ Green Algal extract (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 macroalgaeto 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 commercialised.

A semi-synthetic C-4/C-6 methylene-polycarboxylate cross-linked hybrid drug delivery system and a topical antibacterial formulation have been developed from marine macroalgae and found to be comparable to commercially available products. The pioneering research work at ICAR-Central Marine Fisheries Research Institute 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 (See the Table Below and Figure 3). As the recovery rate of such active principles is around 10%, large-scale mariculture of seaweeds is urgently required to ensure a steady supply of raw materials for the production of value-added products and nutraceuticals in India.

Seaweed mariculture and Integrated Multitrophic Aquaculture (IMTA)

Inorganic extractive component of IMTA farmed/ being experimented with in India are the seaweeds such as *Kappaphycus alvarezii, Gracilaria edulis*, *Gracilaria verrucosa* and *Gelidiella acerosa*. The culture of these organisms, which are low in the food chain and extract their nourishment from the sea, requires relatively low input. The organic extractive components are the oysters *Crassostrea drasensis* and *Saccostrea cucullata*, and the mussel *Perna viridis*. During recent years, fish-farming in floating cages has also been introduced in the open waters. It is then realized that the recycling of waste nutrients by seaweed and filter-feeding shellfish is the most likely way to economically improve mariculture sustainability. Trials on IMTA of bivalves and finfish seabass were initiated in inshore coastal waters of Karnataka and seaweed Kappaphycus with finfish cobia (*Rachycentron canadum*) in floating cages in coastal Tamil Nadu. From an economic perspective, though there were many challenges, the benefits of the shift from monoculture to IMTA led to increased aquaculture production. Seaweed rafts integrated with a 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 through integration with 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 contributes to periphyton in the aquaculture area and provides habitat for plankton to settle. Seaweeds are known to release 30-39% of their gross primary production as dissolved organic carbon (DOC) to the ambient water. IMTA increased the profits and reduced the risk of crop failure through diversification, as '*natural*' crop insurance. Mortality loss of finfish (seabass) in the cage was compensated to a certain extent by bivalve production. Gross revenue realized was Rs. 5.34 lakhs, of which30% was contributed by mussel (Rs. 1.6 lakhs).

The Way forward

Expansion of seaweed farming in the country will improve the socioeconomic status of coastal fishermen and farmers and help mitigate the negative effects of climate change while protecting marine ecosystems from ocean acidification and ocean deoxygenation. Seaweed cultivation requires no land, no fresh water, and no fertilizer or pesticides. Large-scale cultivation will enhance rural employment opportunities and strengthen the rural economy. Seaweed mariculture is an economically viable livelihood option for the coastal fishing community especially for the fisherwomen. It was found that the Benefit Cost Ratio (BCR) is 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 constrained primarily by a lack of proper marine spatial plans, appropriate financing, and insurance coverage against crop losses from natural calamities. Other challenges faced by seaweed farming include difficulty in obtaining high-quality seed material for native species such as Gracilaria dura, especially after monsoon rains and natural calamities such as cyclonic weather, and grazing by herbivorous fish. To improve the 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, is 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 on the beaches, as a drifted mass. From the impact assessment of *Kappaphycus* cultivation on the environment, attempted since 1983 from the Hawaii Islands, to the recent studies by CSMCRI in Indian waters, no occurrence or establishment of non-farmed populations of Kappaphycus has been observed.

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 farmed seaweeds and the opening of marketing channels for seaweeds should also be considered before large-scale seaweed farming is undertaken in the country. Promoting seaweeds as healthy food for human consumption, in addition to their use as raw materials for the extraction of bioactive compounds and phycochemicals, may also be pursued. National fisheries development agencies like NFDB can promote seaweed consumption through awareness campaigns and seaweed food festivals organised throughout the country. Seaweed mariculture is a green and climate-smart technology which can assure a steady and continuous supply of raw materials for the production of algal polysaccharides, fodder, biofuels, manure, nutraceuticals, etc. The Central Marine Fisheries Research Institute has framed perspective plan of ICAR (Kaladharan *et al*., 2019) on seaweed cultivation and utilization which are:

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 is of dire necessity and should be widely promoted.

c) Seaweed mariculture can be undertaken under an 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 can check ocean acidification, while the farmers can enjoy livelihood security out of the harvest.

Hence, large-scale mariculture of seaweeds, which is a green technology for their nutraceuticals and other secondary metabolites, is desperately necessary, as it can help mitigate major greenhouse gases and check ocean acidification, while seaweed farmers can make a living from the harvest. Hence, seaweed culture and utilisation will fuel the growth of the blue economy.

SEAWEED MICROBIOME AND THEIR APPLICATIONS IN MARINE BIOTECHNOLOGY

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Introduction:

Seaweeds are one of the most important marine resources of the world. They contain carbohydrates, proteins, vitamins, minerals, micronutrients, macronutrients, and growth regulators such as auxins, gibberellins, and Cytokinins. They are a promising source of supplementary food, feed, fertilizers and renewable energy. In India, Seaweeds (macroalgae) are mainly used as the source for the extraction of commercial phycolloids such as agar, carrageen and alginic acid. There are numerous reports of seaweed-derived compounds with a broad range of biological activities, including antibacterial, antiviral, antifouling, anti-inflammatory, antileishmanial, and cytotoxic. It is also reported that seaweed extracts can promote growth in both prokaryotic organisms and higher plants. Currently, seaweeds are sought after as source material for the development of pharmaceuticals, botanicals, nutraceuticals, cosmeceuticals, fish and animal feed additives, agrichemicals, soil additives, natural pigments and bioactive substances (Chopin and Sawhney, 2007). Bioadsorption of heavy metals using seaweed powder was also reported (Christobel and Lipton 2015).

Seaweed Resources:

Reviews on the luxuriant growth of various species of seaweeds in India and the Southern coasts have been published by several authors (Sukhashitha *et al.*, 2025; Ganesan *et al.*, 2019; Kaliaperumal *et al.*, 2004). According to Kaladharan and Jayasankar (2003), among the coastal states and union territories, Tamil Nadu ranked

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first in resource potential. Edwin James (2008) reported about 50different species of seaweeds after the Tsunami along the South West coast of India. As of now, among the coastal states and union territories, Tamil Nadu is reported to rank first in resource potential. Based on CSIR-CSMCRI and related Indian research, the estimated standing stock of wild seaweed along the Indian coast is approximately 58,715 tonnes (wet weight). The highest diversity and standing stock are found on the Southeast coast of Tamil Nadu, Gujarat, Lakshadweep, and the Andaman & Nicobar Islands. The total harvestable seaweed biomass is estimated at over 0.26 million tonnes (wet) across 700 species (CSIR-CSMCRI). The report also indicated a total of 844 species, including 434 Red Algae, 194 Brown Algae, and 216 Green Algae. The survey also indicated that while wild stock is limited, the potential for seaweed cultivation is immense, with recent production reaching over 74,000 tonnes in 2024. Efforts are being made by the R&D and Commercial organizations for sustainable farming of species such as *Kappaphycus alvarezii* and *Gracilaria* sp., for agar and carrageenan production, respectively. The global commercial seaweed market is projected to grow from USD 12.03 billion in 2025 to USD 15.40 billion by 2035, registering a CAGR of 2.5%.

Seaweeds and Microbes:

Seaweeds have been challenged throughout their evolution by microorganisms and have developed in a world of microbes. Therefore, it is not surprising that a complex array of interactions has evolved between macroalgae and bacteria, which basically depends on chemical interactions of various kinds. Bacteria specifically associate with particular macroalgal species and even to certain parts of the algal body. Although the mechanisms of this specificity have not yet been fully elucidated, ecological functions have been demonstrated for some of the associations. Though some of the chemical response mechanisms can be clearly attributed to either the alga or to its epibiont, in many cases, the producers as well as the mechanisms triggering the biosynthesis of the biologically active compounds remain ambiguous. Positive macroalgal-bacterial interactions include phytohormone production, macroalgal morphogenesis triggered by bacterial products, specific antibiotic activities against epibionts, and elicitation of oxidative burst mechanisms.

Some bacteria can prevent biofouling or pathogen invasion, or extend the macroalgae's defence mechanisms.

Deleterious macroalgal bacterial interactions induce or generate algal diseases. To inhibit bacterial settlement, growth, and biofilm formation, macroalgae influence bacterial metabolism and quorum sensing and produce antibiotic compounds. There is a strong need to investigate the bacterial communities living on different coexisting macroalgae using new technologies, but also to investigate the production, localization and secretion of the biologically active metabolites involved in those possible ecological interactions. Ubiquitous epiphytic bacteria have been observed among the thallus surfaces of many types of seaweed. Some of the common Seaweed Associated Microbes (SAMS) species include:

1. Bacteria**:** *Proteobacteria* (often *Alphaproteobacteria*), *Bacteroidetes* (often *Bacteroidia*) and *Firmicutes* (like *Bacillus* species) are the most abundant on surfaces. Common endophytic microbiome examples include**:** *Maribacter* sp. MS6, *Bacillus pumilus*, *Azotobacter* species, *Phaeobacter* sp. BS52 and *Pseudoalteromonas* sp. PB2-1.
2. Fungi: Various species exist as endophytes, contribute to the microbiome. Common genera such as *Aspergillus, Penicillium, Cladosporium, Chaetomium* and *Alternaria* are often isolated and reported from brown (*Sargassum*), red (*Gracilaria*), and green (*Ulva*) seaweeds. The endophytic fungi are highly adapted to environmental stress including hydrostatic pressure and thus form important sources of new pharmaceutically active metabolites. Species such as *Paradendryphiella salina* and *Talaromyces pinophilus* are reported to degrade algal polysaccharides (Khan et al., 2024).

Ambient environmental conditions regulate the numbers of microbes on the surface or as endosymbionts. Research results from the Marine Biotechnology Laboratory of Vizhinjam Research Centre of CMFRI, Vizhinjam, indicated that Hypnea musciformis had the highest surface flora count (7×106 CFU/g), which could be correlated with the ambient microbial load. A study on monsoon and post monsoon scenario of the seaweed-associated bacteria indicated the highest count of endosymbionts of 6.6×106CFU/g when the monsoonal ambient seawater microbial load was 3.8×106CFU/ml, and the lower counts were recorded in the post monsoon period (Parimala Celia, 2012). Some of the important ecto and endosymbiotic bacteria isolated from seaweeds of South Tamil Nadu coast, such as *Ulva fasciata, Gracilaria corticata, Enteromorpha compressa, Sargassum wightii* and *Hypnea musciformis,* included:

1. *Halomonas* sp. (Phylum: Proteobacteria, Class: Gammaproteobacteria, Order: Oceanospirillales and Family: Noctuoidea).
2. *Alcaligenes faecalis* subsp. faecalis. (Phylum: Proteobacteria, Class: beta proteobacteria, Order: Burkholderiales and Family: Alcaligenaceae).
3. *Klebsiella* sp. (Phylum: Proteobacteria, Class: Gammaproteobacteria, Order Enterobacteriales and Family: Enterobacteriaceae).

Significances of Seaweed Microbiome:

Seaweed-associated microbes as a novel source of crop agrochemicals were recently reviewed by McKenna *et al* (2025). Several bacterial genera from seaweed samples, with variations in composition based on the hosts, abiotic parameters and geography, were reported by researchers (Burgunter-Delamare *et al*., 2023; Burke *et al*., 2011; Deutsch *et al*., 2023; Paix *et al*., 2021; Ramírez-Puebla *et al*., 2022; van der Loos *et al*., 2023; Wood *et al*., 2022). Most of these studies were accomplished using Metabarcoding. Significant efforts are currently underway to better characterise and understand the role, diversity and dynamics of the seaweed microbiome as reviewed by Saha *et al.* (2024).

Key roles and functions of microbiome include:

1. Growth & Morphogenesis**:** Seaweed-associated bacteria are reported to act as beneficial organisms as they produce algal growth-promoting factors (AGMPF), including plant hormones (auxins, cytokinins) and vitamins. For example, species such as *Maribacter* sp. MS6 (Alsufyani *et al*., 2020), *Bacillus pumilus* (Singh *et al*., 2011), or *Azotobacter* species (Head and Carpenter, 1975) have been identified as Seaweed Beneficial Microorganisms (SBMs). These organisms produce AGMPF, including phytohormones (e.g auxins-like, cytokinins-like) and vitamin B12. They also help in nutrient fixation (Li *et al*., 2023).
2. Defence Mechanism**:** Associated microbes protect seaweeds from pathogens, fouling organisms, and environmental stressors by producing

antimicrobial compounds. For example, *Phaeobacter* sp. BS52 and *Pseudoalteromonas* sp. PB2-1 can reduce the impact of the macroalgal pathogen *Pseudoalteromonas arctica* G-MAN6, responsible for bleaching disease among seaweeds such as *Agarophyton vermiculophyllum* and *Delisea pulchra* (Li *et al*., 2022). Similarly, the production of pyrenocines by *Phaeosphaeria* sp. AN596H can inhibit infection by several protistan pathogens in *Ectocarpus siliculosus*, as reported by Vallet *et al*. (2018). It is envisaged that the role of seaweed microbiome in protecting their host against disease could be modulated by a stimulation of the host's immune response (Li *et al*., 2023). This needs further research in this important area of seaweed disease management.

3. Nutrient Cycling & Metabolism**:** The microbiome plays a key role in nutrient uptake and the breakdown of complex carbohydrates (e.g., agarase and carrageenase activity).

Marine Biotechnological potentials /applications:

The seaweed microbiome forms an important source of enzymes (agarase, carrageenase) and bioactive substances, including antimicrobial compounds with antibiotic potential. The symbiosis is essential, where the seaweed provides a nutrient-rich surface (exudates) for microbial colonization. In turn, the microbiome regulates crucial developmental stages, such as spore settlement in green seaweeds and carpospore liberation in red seaweeds. The microbes that facilitate growth, nutrient cycling and defence also offer candidates with high potential for biotechnological applications, such as bioethanol production, bioprospecting for novel bioactive compounds and agricultural fertilisers (McKenna *et al*., 2025).

In this regard, the metagenome-assembled genomes of seaweed holobionts by Weigel Brooke *et al*. (2022) could be considered a novel study. This genome was used to report the discovery of novel enzymes and pathways, including the degradation of halogenated compounds (Lavecchia *et al*., 2024), nutrient cycling (Weigel Brooke *et al*., 2022), and the production of plant growth regulators (Wang *et al*., 2022). Further research in SAMS is expected to lead to higher yields or the creation of tailored biomass by optimising the three-way interaction between seaweed genotype, its environment, and microbiome, as indicated by Li *et al*. (2023) and Simon *et al.* (2022), or through improved microbiome design (Wichard, 2023).

Conclusions:

Today, one of the thrust areas in marine biotechnology research is bioprospecting for novel bioactive compounds from marine resources. With the advent of new technologies, it is possible to conduct in-depth studies of the seaweed microbiome and to produce novel metabolites with sensational bioactivity profiles for the welfare of mankind.

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SEAWEED DIVERSITY, CULTIVATION AND ITS UTILIZATION IN INDIA: A WAY FORWARD TO BLUE ECONOMY

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Abstract

Seaweeds represent a potential bioresource with significant ecological, economic, and biotechnological relevance, positioning them as key resources to strengthen India's blue economy. Seaweeds are categorized according to their pigment composition as *Rhodophyta*, *Phaeophyta* and *Chlorophyta*. They are abundantly distributed along coastal regions owing to favorable environmental conditions. They are rich in diverse biochemical compounds which underpin their wide range of industrial applications and are increasingly recognized as valuable resources for promoting environmental sustainability, enhancing food security, and providing hydrocolloid for nutraceuticals and functional food applications. Cultivation practices encompass clonal vegetative propagation and non-clonal seedling-based systems implemented through floating raft, tube-net, off-bottom monoline, and long-line methods. Biotechnological advances embracing tissue culture, protoplast fusion, hybridization, mutagenesis, molecular characterization, and cryopreservation offer tools for genetic enhancement, disease resistance, and sustainable biomass production. Collectively, sustainable cultivation practices, value-chain diversification, biotechnology integration,

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and effective disease mitigation can strengthen seaweed aquaculture as a climate-resilient and economically viable component of India's blue economy framework.

Keywords: Cultivation, polysaccharides, bio stimulant, pharmaceuticals, biotechnology, diseases

Introduction

Seaweeds, also known as marine macroalgae, are multicellular, photosynthetic eukaryotic organisms widely cultivated and harvested worldwide for food, animal feed, fertilizers, and industrial applications including pharmaceuticals, cosmetics, and phycocolloid production (McHugh 2003). They are rich in proteins, carbohydrates, vitamins, minerals, trace elements such as Fe, I, Zn, Ca, Mg and antioxidants, highlighting their nutritional and therapeutic value (Corino et al. 2019; Øverland et al. 2019). Seaweeds are reservoirs of structurally diverse bioactive metabolites, notably pigments, fatty acids, sterols, proteins, lipids, fibers, and polysaccharides which exhibits broad-spectrum biological activities, including antioxidant, antiviral, anticoagulant, anticancer, immunomodulatory, and anti-inflammatory effects, highlighting their relevance in pharmaceutical, nutraceutical, and functional food development.

Additionally, seaweed-derived hydrocolloids contribute to food and industrial sectors, whereas bio-stimulant formulations enhance crop productivity, nutrient-use efficiency, and abiotic stress tolerance supporting climate-resilient agriculture. Seaweeds are taxonomically classified based on pigmentation into three main groups: *Rhodophyta* (red), *Phaeophyta* (brown), and *Chlorophyta* (green). Globally, more than 164,000 algal species have been estimated, of which approximately 9,800 are seaweeds, and only about 0.17% have been domesticated for commercial exploitation (Duarte et al. 2007). Globally, red algae account for more than 60% of the 30 million tons of seaweed produced annually (FAO 2018). Over 200 seaweed species supporting an international market valued at over USD $ 6.2 billion primarily through phycocolloids such as algins, agars, and carrageenans (Zemke-White and Ohno 1999). Seaweeds also play a crucial ecological role by contributing to marine primary production and providing habitat for nearshore benthic communities (Mann 1973).

A record 130.9 million tonnes of aquaculture were produced worldwide in

2022, including 36.5 million tonnes fr.wt of algae (worth USD 17 billion) that includes both seaweed and microalgae. Remarkably, increase in seaweed production worldwide since 2000, reaching over 38 million tonnes fr.wt in 2022. Of this, 30 - 38% accounts human consumption (FAO 2024). There are about 600 different types of seaweed used for food globally. however, brown seaweed is the most popular, followed by red and green seaweed (Leandro et al. 2020).

As the world's population grows, seaweed farming has become a viable way to fulfil the growing need for food and resources (Jagtap et al. 2022). Global seaweed production mostly comes from the five major continents, with Asia accounting for 97.38% of total production. China ranks first in seaweed production (56.82%), followed by Indonesia (28.6%), South Korea (5.09%), Philippines (4.19%), North Korea (1.6%), North America (1.36%), Japan (1.15%), Malaysia (0.53%), and Mexico (0.02%) (Zhang et al. 2022). The Andaman and Nicobar Islands, Lakshadweep, Tamil Nadu, and the Gulf of Mannar have the most diversity of seaweeds and diversified marine flora among India's 7,500 km of coastline (Jaikumar et al. 2024). aquaculture has played a major role in the more than threefold

India's tropical and subtropical coastal waters are home to major groups like *Chlorophyceae*, *Phaeophyceae*, and *Rhodophyceae* (Mantri et al. 2019) as well as economically significant genera like *Ulva lactuca*, *Kappaphycus alvarezii*, *Sargassum*, *Turbinaria*, *Gracilaria*, and *Gelidiella* spp. Because of its uses in food, agriculture, biofuels, nutraceuticals, and pharmaceuticals, India's seaweed business is increasing quickly in response to rising worldwide demand. This underscores the need of comprehending the variety, distribution, and economic worth of seaweeds along the Indian coast (Ganesan et al. 2019). Seaweeds are primarily found along marine coastlines in intertidal and subtidal zones. Environmental factors such as water temperature, light availability, salinity, nutrients, and substrate type affect the distribution of seaweeds (Kaliaperumal et al. 1995). Seaweeds are mostly found in coastal areas like Mumbai, Ratnagiri, Goa, Tamil Nadu, and Chilika in Odisha, as well as rocky shorelines like the Gulf of Kutch, Gulf of Mannar, Andaman and Nicobar Islands, and Lakshadweep (Satheesh and Wesley 2012; Manikandan and Vivek2024; Sahoo 2010; Chennuri etal.2019).

Various methods are practiced globally to cultivate seaweeds such as fixed off-bottom, raft method, single rope floating technique, monoline method, longline method, tube net method, and net bag method (Behera et al. 2022). This article aims to comprehensively elucidate the diversity of seaweeds, cultivation strategies, utilization patterns, therapeutic potential, and emerging biotechnological interventions.

Seaweed diversity along Indian coast

India (08.04–37.06 N and 68.07–97.25 E), a tropical South Asian country has a stretch of about 11,098 km coastline with 2.35 million km^2 Exclusive Economic Zone (EEZ) and nine maritime states like Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Orissa, Andaman and Nicobar, Lakshadweep Islands (Sharma et al. 2019). There are 844 species of seaweeds reported, including 434, 194, and 216 species of red, brown, and green seaweeds, respectively (Oza and Zaidi 2001). Among the seaweed species, 14.8% are endemic. Of these 16.82% are Rhodophyta, 16.75% are Phaeophyta, and 9.25% are Chlorophyta. The states of Tamil Nadu and Gujarat comprises of 366 seaweed species, which together make almost half of India's total seaweed diversity (Jha et al. 2009). From five seasonal surveys conducted in the Gulf of Mannar Marine Biosphere Reserve, 137 seaweed species from 32 families and 17 genera were identified. Brown algae (41 species) came in second, followed by green and red algae (48 species each). The monsoon and post-monsoon seasons had greater species richness than the summer months. The genus *Caulerpa* was the most diverse (18 species), followed by *Sargassum* (14 species), *Dictyota* (8 species), *Gracilaria* (6 species), *Turbinaria* (4 species), and *Hypnea* (6 species) (Veeragurunathan *et al*., 2022).

Stations	Chlorophyta	Phaeophyta	Rhodophyta	Total	References
	Species	Species	Species	Species	
Maharashtra	17	14	22	53	Balakrishnan and Sivaleela, 2022
Goa	16	13	20	49	Balakrishnan and Sivaleela, 2022
Gujarat	55	36	109	200	Jha *et al*. 2009
Lakshadweep Islands	33	10	39	82	CSMCRI Survey conducted during 1977 to 1979
Andhra pradesh	12	6	16	38	Sowjanya and Sekhar 2015
Karwar Bay, Karnataka	13	10	9	32	Naik *et al*. 2015
Gulf of Mannar, Tamil Nadu	80	56	146	282	Manikandan and Vivek, 2024
Kerala	14	9	19	42	Yadav *et al*. 2015
Andaman and Nicobar Islands	79	58	107	244	Karthick *et al*. 2021

Table 1. Seaweed diversity along Indian coast.

Seaweed cultivation methods

In our country, seaweed cultivation is mainly done by adopting traditional methods. From an agronomic point of view, there are two types seaweed cultivation: clonal and non-clonal. Clonal seaweeds have the ability to propagate from their fragments when attached to ropes and nets in marine water. After each harvesting, small fragments of seaweeds are allowed to remain attached to nets from which thalli will get regenerated in the next growing season. Non-clonal seaweed cultivation is a multistep method that includes a spore-based culture technique requiring the rearing of seedlings and their installation on ropes for cultivation. Seaweed cultivation has been introduced as an alternative source of income in many low-income coastal countries that lack fishing resources, which empowers women and reduces poverty (Mantri *et al*., 2017; Sievanen *et al*. 2005). Notably, eucheumatoid seaweed farming has raised the socioeconomic standing of coastal communities where there are few other options for a living, such as overexploitation that depletes or diminishes marine resources (Valderama, 2012).

The most promising cultivable species in India is *K. alvarezii*, which is measurably grown in six coastal districts in Tamil Nadu (Cuddalore, Thanajvur, Pudukottai, Ramanathapuram, Thoothukudi, and Kanyakumari). Commercial activities began in Gujarat in 2003 and are currently expanding (Mantri *et al*., 2017). Several cultivated species, including *G. edulis* (Meenakshisundaram *et al*. 2009; Mantri *et al*. 2020), *Gracillaria dura* (Mantri *et al*. 2020; Veeragurunathan *et al*. 2015), Gelidiella acerosa (Meenakshisundaram *et al*. 2009; Ganesan *et al*. 2015), and *Gracilaria debilis* (Veeragurunathan *et al*. 2016; Veeragurunathan *et al*. 2019). *Acanthophora. spicifera*, *Enteromorpha flexuosa and K. alvarezii* can be successfully grown in long-line ropes and nets. The tube-net method, which is efficient and cost-effective, has been reported in various studies (Reis *et al*., 2015; Mantri *et al*., 2017). The experimental cultivation of *G. dura* has been attempted along the south-eastern coast of India using net, pouch, bottom-net bag, hanging rope, and raft techniques, as well as a raft method along the Gujarat coast (Mantri *et al*., 2009; Veeragurunathan *et al*., 2015). According to Naik *et al*. (2010), offshore seaweed cultivation will address problems associated with biofuels and help fill the gap in farmland and address food shortages.

Sl. No.	Cultivation method	Advantages
1	**Floating bamboo raft (Fig.1-2)**	Provides favourable environmental conditions, economic, eco-friendly, as well as user-friendly method
2	**Tube net (Fig.3)**	Lower risks to weather conditions, uniform growth rate, useful in deep water with minimum infrastructure
3	**Off-bottom mono line**	Easy to handle, particularly walking of farmers during low tides, low cost for implementation
4	**PVC pipe raft**	Easy to float, easy to handle
5	**Cage systems**	Varieties of cages are possible, advantageous to tackle the epiphytes, and sustain in the bad weather conditions
6	**Multiple raft long line**	Useful for large-scale production, more economic and user-friendly

Table 2. Seaweed cultivation methods and its advantages.

Fig.1. Raft with Gracilaria debilis cultivation

Fig.2 Raft with Gracilaria edulis cultivation

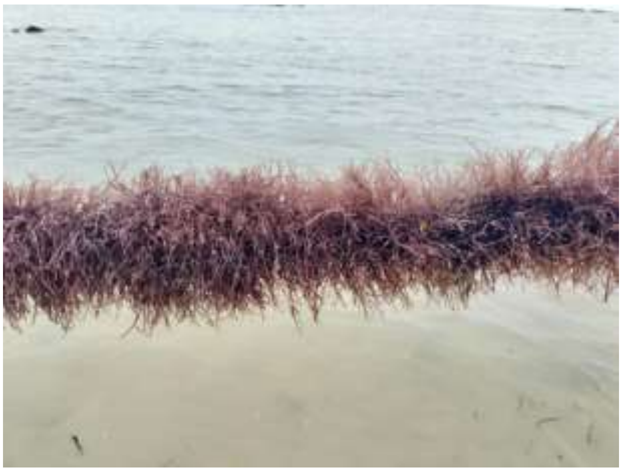

Fig.3 Fully grown tube net of G. edulis

Colour strains of seaweeds

Colour mutants have been extensively used in genetic and physiological studies of red algae. Their primary value lies in facilitating the detection of fertilization events and in distinguishing between sexual and asexual reproductive processes (van der Meer *et al*., 1986). Despite clear phenotypic and physiological differences among colour strains, many studies assessing the biological properties of *K. alvarezii* have been conducted using mixed populations or without clearly identifying the strain under investigation. This lack of strain specificity limits the interpretation of biological and biochemical data. Since each colour strain or morphotype may possess distinct chemical composition and functional properties, strain-specific evaluation is necessary to fully exploit their biological potential and improve their utilisation in cultivation and industrial applications.

Along the southeastern coast of Tamil Nadu, India, both red and green colour variant strains of *G. debilis* and *G. edulis* have been reported (Veeragurunathan *et al*., 2016; 2019). Classic red strains of red algae are characterized by intense pigmentation primarily due to the dominance of phycoerythrins, whereas brown colour strains arise from the presence of additional pigments such as fucoxanthin.

A comparative study evaluating red and green colour strains of *G. debilis* and *G. edulis* (Fig.4-7) demonstrated clear differences in growth and biomass production. The red strains consistently outperformed the green strains in both species. The red strain of *G. debilis* achieved the highest biomass yield, reaching 12.46 ± 1.24 kg fr. wt m^{-2}, while *G. edulis* recorded a maximum yield of 5.49 ± 0.26 kg fr. wt m^{-2}. Daily growth rates were also higher in red strains, with values reaching 5.82 ± 0.57% day^{-1}, whereas *G. debilis* recorded a maximum of 5.42 ± 1.73% day^{-1}. These results indicate that red strains possess superior growth potential and are therefore more suitable for large-scale cultivation (Veeragurunathan et al. 2016). The cultivation performance of three colour strains, such as red, green, and brown, of *K.* alvarezii is being investigated (Veeragurunathan *et al,* unpublished data)

Fig.4. Green strain of G.debilis

Fig.5 Red strain of G.debilis

Fig.6.Green strain of G.edulis

Fig.7.Red srain of G.edulis

Seaweed Utilization

Seaweeds are increasingly recognized as important marine resources due to their expanding role in global mariculture, food systems, and industrial applications. Beyond their traditional use as food and sources of hydrocolloids, seaweeds contain a wide range of bioactive compounds, including polysaccharides, phenolics, peptides, fatty acids, and carotenoids, which exhibit significant biological and functional properties. The growing demand for natural and sustainable bioresources has intensified research on seaweed-derived compounds for applications in nutraceutical, pharmaceutical, and functional product development.

Bioactive Compounds in Seaweeds

Seaweeds synthesize a diverse range of primary and secondary metabolites with significant functional and biological properties. Many of these compounds are produced in response to environmental stressors such as variations in temperature, salinity, nutrient availability, ultraviolet radiation and pollution. Major bioactive constituents identified in seaweeds include polysaccharides, peptides, polyunsaturated fatty acids (PUFAs), phenolic compounds, sterols, carotenoids, terpenes, acetogenins, alkaloids, and other secondary metabolites

(Balboa *et al.* 2013; Yu *et al.* 2014; Chakraborty and Joseph 2016; Chakraborty *et al.* 2018).

Seaweed Polysaccharides

Seaweed polysaccharides are high molecular weight macromolecules found in marine algae that serve as structural materials and energy suppliers (Schuerch, 1986). Seaweed polysaccharides such as agar, agarose, alginic acid, carrageenan, ulvans, and fucoidans are exploited for various commercial applications. These algal polysaccharides serve as tools for therapeutic and industrial applications including nutraceuticals, pharmaceuticals, cosmeceuticals, and functional foods (Chudasama *et al*., 2021).

In red seaweeds, the principal structural polysaccharides are sulfated galactans, including agar, agarose, and carrageenan. Certain red algal species also contain sulfated mannans or neutral xylans as structural components (Usov, 2011). Brown seaweeds predominantly contain laminarin, alginate, and fucoidan, whereas green seaweeds are characterized by the presence of ulvans, galactans, and arabinogalactans (Popper *et al.* 2011; Dobrinčić *et al.* 2020). Sulfated polysaccharides derived from seaweeds have been extensively investigated due to their biological activities, including anticoagulant, antiviral, antioxidant, antitumor, immunomodulatory, anti-hyperlipidemic, and hepatoprotective properties (Wang *et al.* 2014). Seaweed polysaccharides were tested for the synthesis of agar aldehyde (Aald) mediated solid silver nanocomposite (Aald–AgNPs), which exhibited excellent anticancer and antibacterial activity (Kholiya *et al.* 2020).

Seaweed bio stimulants

Bio-stimulants are defined as materials of biological origin or living microorganisms that, when applied to plants through soil or foliar routes, activate intrinsic physiological mechanisms that enhance nutrient uptake and utilization, promote growth, and improve tolerance to biotic and abiotic stresses, irrespective of their nutrient content (Ali et al. 2021). Among the various bio-stimulant categories, seaweed-derived bio-stimulants have received increasing attention as sustainable alternatives to conventional agrochemicals due to their multifunctional role in improving crop productivity while reducing environmental impact (Shukla et al. 2021; Franzoni et al. 2022).

Seaweed-derived biostimulants contain a broad range of bioactive compounds, including polysaccharides, phytohormones (auxins, cytokinins, and gibberellins), betaines, amino acids, phenolics, vitamins, and other secondary metabolites that collectively regulate key physiological and biochemical processes in plants (Mucjan *et al*. 2011; Shukla *et al*. 2021; Franzoni *et al.* 2022). These compounds stimulate root and shoot development, enhance nutrient uptake efficiency, improve photosynthetic performance through increased chlorophyll synthesis and leaf area expansion, and modulate endogenous hormonal signalling pathways, thereby supporting biomass accumulation and yield formation (Shukla *et al*. 2021; Franzoni *et al.* 2022).

Seaweed extracts derived from *Ascophyllum nodosum, K. alvarezii,* and *G. edulis* have been extensively investigated for their biostimulant activity. Extracts of *K. alvarezii* contain quaternary ammonium compounds and other metabolites that contribute to multiple physiological functions, particularly enhancing plant resilience under drought stress conditions (Chaudhary *et al*. 2023). The application of K. alvarezii seaweed extract and other seaweed-based biostimulants has been shown to improve nutrient uptake, photosynthetic efficiency, endogenous hormone regulation, and the activation of metabolic and defence-related pathways, resulting in improved plant growth and stress tolerance (Gopalakrishnan *et al*. 2024).

In addition to direct effects on plant physiology, seaweed-based biostimulants influence soil health and microbial dynamics. Extracts derived from *A. nodosum* and *K. alvarezii*, applied as foliar sprays or soil drenches, have been reported to enhance soil microbial diversity and improve soil biochemical and physicochemical properties, thereby indirectly supporting nutrient availability and plant growth (Trivedi *et al*. 2021; Gopalakrishnan *et al*. 2025).

At the molecular level, foliar application of *A. nodosum* extract (ANE) significantly enhanced crop yield under open-field conditions, primarily through increased fruit number per plant, with additional contributions from improved fruit size and weight (Staykov *et al*. 2025). Metabolomic and transcriptomic analyses revealed that ANE modulated primary metabolism by enhancing sugar accumulation, amino acid synthesis, nitrogen assimilation, and osmoprotectant production, thereby supporting fruit set and development. Differential expression of genes related to carbohydrate metabolism, cell wall modification, oxidative stress response, and nutrient transport indicated a metabolic priming effect that promotes efficient resource allocation and long-term resilience (Staykov *et al*. 2025). Large-scale field trials further demonstrated yield enhancement and significant reductions in carbon footprint, confirming the agronomic and environmental benefits of seaweed-based biostimulants (Sharma *et al*. 2017).

Therapeutic activities of seaweeds

Seaweeds, a renewable natural resource, found abundantly along the Indian coast, have shown to provide a rich source of natural bioactive compounds with antidiabetic, hepatoprotective, antiviral, antifungal, antibacterial, antioxidant, anti-inflammatory, antihypercholesterolemia, hypolipidemic and antineoplastic properties (Sharma *et al*., 2019). *Padina boergesenii*, a brown alga found in the Gulf of Mannar, on the southeast coast of Tamil Nadu, India, exhibited antidiabetic, antioxidant, hepatoprotective, chemopreventive, and herbivory effects (Senthilkumar *et al*. 2014). Janarthanan *et al*. (2012) screened *Sargassum wightii* (Brown Algae), *Chaetomorpha linum* (Green Algae), and Padina gymnospora (Light Brown Algae) for antibacterial activity and found that the acetone extracts of all three marine algae showed higher inhibitory activity against gram-positive and gram-negative human pathogenic bacteria. Anantharaman *et al*. (2011) reported in vitro antioxidant activities of *Halimeda tuna*, *Turbinaria conoides*, and *Gracilaria foliifera* collected from the South East Coast of India. Manilal *et al*. (2009) observed the cytotoxic potential of the red alga *Laurencia brandenii* in a brine shrimp cytotoxicity and hatchability assay using Artemia salina from the Kollam, Kerala, area on the southwest coast of India. The methanolic extract of *Gracilaria edulis* and *Sargassum polycystum* from the Mandapam coast, Gulf of Mannar, Tamil Nadu was evaluated to evaluate the antidiabetic activity of marine species in STZ-induced diabetic rats and resulted positively and also reported a significant increase in beta cell density, indicating the property of insulin secretagogue activity (Koneri *et al*. 2018). Anticonvulsant activity was found in *Sargassum ilicifolium* and *K. alvarezii* from the intertidal rocky shore of Bhatkarwada, Ratnagiri (Yende *et al*. 2018). Rebecca *et al*. (2012) reported antibacterial activity of *S. ilicifolium* and *K. alvarezii* against Escherichia coli, Salmonella sp., and

Klebsiella sp. collected from different coastal regions of Rameshwaram. *Gracilaria corticata* exhibited anti-oxidant properties (Movahedinia *et al*., 2014), anti-cholesterolemic and anti-tumour activity (Dist *et al.,* 2013) and hepatoprotective activity (Sampathkumar *et al.,* 2008). In a study by Rout *et al.* (2015) using the aqueous extract of G. corticata in diabetic rats, a decrease in blood glucose and glycosylated haemoglobin levels was observed. *Ulva fasciata* showed antidiabetic activity due to its underlying antioxidant, hypoglycemic, and alpha-amylase-inhibiting properties, as reported by Mohapatra *et al*. in 2016. Kumar *et al.* (2015) reported in vitro antioxidant and antimutagenic efficacy in *Acanthophora specifera*. *Gelidiella acerosa* collected from Tamil Nadu exhibited anticholinesterase (AChE), and butyrylcholinesterase (BuChE) activities. The inhibition of acetylcholinesterase (AChE) enzyme, which catalyzes the breakdown of ACh, aids in the symptomatic treatment of Alzheimer's disease (Syad *et al*. 2012). Palanisamy et al. in 2017 reported antioxidant and anticancer activities of fucoidan extracted from *S. polycystum*. Immunomodulatory activity has been reported in fucoidan *extracted from S. wightii* and *Undaria pinnatifida.* Broad-spectrum antioxidant, anticancer, and antidiabetic activities have been reported for carrageenan from *K. alvarezii*, *Portieria hornemannii*, *Spyridia hypnoides*, *Asparagopsis taxiformis*, *Centroceras clavulatum*, and *Padina pavonica* (Suganya *et al.* 2016; Abirami and Kowsalya 2013; Arunkumar *et al*. 2021). Additionally, carrageenan from *Hypnea valentiae* displayed antimicrobial, antioxidant, and anticoagulant properties (Palani *et al*. 2022). Senthilkumar et al. 2016 reported anticancer activity in *Codium decorticatum*. Indumathi and Mehta (2016) reported anticoagulant activity in peptides from *Porphyra yezoensis*. Collectively, these multifunctional bioactivities highlight seaweeds as promising natural resources for pharmaceutical, nutraceutical, and functional food development, warranting further investigation into structure–activity relationships, bioavailability, and clinical validation.

Seaweed Biotechnology

Repeated vegetative propagation reduces genetic diversity, leading to slower growth, lower phycocolloid yield and quality, and greater disease susceptibility (Hurtado *et al*. 2003). Therefore, periodic replacement of propagules with genetically diverse stocks such as different strains, colours, and morphotypes is necessary to sustain agronomic performance. The development and selection of improved strains can further enhance bioactive compound production and increase yields in commercial seaweed cultivation.

Biotechnological tools are crucial for enhancing aquaculture production worldwide. Advances such as tissue culture, mutation and selective breeding, and genetic engineering can improve yield, stress tolerance, and biochemical traits. Marine biotechnology methods including micropropagation, protoplast fusion, hybridization, gene transfer, grafting, parthenocarpy, chimerism, and chemical induction have gained strong interest for developing fast-growing, high-yield, disease-free strains with improved quality. Protoplasts are valuable tools for genetic manipulation, hybridization, and polysaccharide synthesis. In seaweeds, protoplast production is mainly used to select and propagate improved strains for breeding and cultivation. Protoplasts have been used for studying foreign gene expression in *Porphyra* and *Ulva*. Isolated protoplasts are also used in various studies on membrane function, cell structure, and the biochemical synthesis of cell walls. There are more than 90 seaweed species from which successful protoplast isolation and regeneration have been reported (Reddy *et al*. 2008). The first report of successful protoplast isolation using the enzymatic method was in green seaweed *Enteromorpha intestinalis* (presently known as *Ulva intestinalis*) by Millner *et al.* (1979).

Grafting is a simple, low-cost vegetative propagation technique that improves seaweed biomass yield, growth, and phycocolloid quality, while enhancing tolerance to environmental stresses such as grazing, strong waves, currents, wind variation, and temperature changes (Sahu *et al*. 2010). Grafting effects on growth and carrageenan quality were evaluated in different colour strains of *K. alvarezii* from India. Ungrafted plants showed κ-carrageenan gel strength of 270–350 g cm^{-2}, whereas grafted plants reached 330–690 g cm^{-2} (Sahu *et al*. 2011). Parthenogenetic spore germination in *Ulva* spp. has been reported, in which single cells differentiate into reproductive cells that release multiple spores (Cheney *et al*. 1986). Unfertilized male and female gametes can also develop parthenocarpically into male and female plants, respectively (Balar and Mantri 2019).

Seaweed tissue culture is a key tool for micropropagation and high-yield strain selection. In vitro clonal propagation enables rapid mass production and supports sustainable supply of commercially valuable biomass (Reddy *et al*. 2008; Baweja *et al*. 2009). Tissue culture studies have been reported in 4 green, 51 red, and 33 brown algae; however, successful regeneration remains limited, with complete plant regeneration achieved in only 21 red and 17 brown species out of 87 tested (Veeragurunathan *et al*. 2023). Natural selection and conventional breeding have been the primary approaches for developing high-yield, disease-resistant varieties. However, farmed species increasingly require biotechnological tools, particularly to control reproduction in non-clonal species. Standardizing high-throughput sequencing methods such as metagenomics, 16S metabarcoding, and transcriptomics is essential for developing effective disease monitoring and mitigation strategies in commercial farming.

Seaweed diseases

Diseases of seaweed represent a significant challenge to the sustainability of tropical and temperate seaweed farming. They pose a barrier to the development of seaweed-based blue economy initiatives. Ice-ice disease is a well-known and serious seaweed disease affecting *Kappaphycus* species of eucheumatoid seaweeds, which are major global sources of κ-carrageenan used in food, industrial, and pharmaceutical applications (Doty 1975; Largo 2002). Ice-ice disease is characterized by thallus bleaching, whitening, hardening, and eventual branch breakage, thereby triggering severe ice-ice outbreaks (Trono and Ohno 1989). For instance, *Kappaphycus spp*. have been reported primarily during the summer and monsoon seasons in countries such as China, India, the Philippines, and Zanzibar. These are commonly associated with elevated temperatures, high epiphytic infestation, and other environmental stressors. The occurrence and severity of ice-ice disease vary widely, ranging from moderate to high levels (22-40%), with extreme cases resulting in near-total crop loss (Pang *et al*. 2015; Tisera and Naguit 2009; Arasamuthu and Patterson 2018; Largo *et al*. 2020).

Monsoon-related environmental conditions such as high temperature, rapid shifts in salinity, diminished levels of light, and low nutrient availability, contributed to the sudden mass mortality of *K. alvarezii* in the Ramanathapuram district of India during August - September 2013, resulting from the near-total loss of the entire seaweed crop in this area. The clustering of cultivation rafts, as well as prolonged submersion of the rafts during low tides in

Palk Bay further exacerbated the incidence of ice-ice disease (Mantri *et al*. 2024; Kaladharan *et al*. 2014, 2019; Arasamuthu and Patterson 2018).

Conclusion

Seaweed is an important marine resource with a variety of ecological, nutritional, and industrial uses. The global demand for seaweeds has increased significantly over the past two decades due to their expanding applications in food, hydrocolloids, pharmaceuticals, cosmetics, agriculture, and bioenergy sectors. Moreover, it benefits the coastal communities as a promising livelihood opportunity. The seaweed industry needs innovative, efficient cultivation techniques to meet global demand. A comprehensive understanding of their cultivation practices, applications and constraints is needed in advancing and reinforcing the blue economy. For strengthening the blue economy through seaweeds, steps including finding suitable seaweed species for large-scale commercial cultivation, offshore and large-scale cultivation technologies, genetic improvement, disease management, sustainable harvesting policies and biorefinery-based value addition should be implemented. Overall, seaweeds represent a low-input, high-output marine resource capable of simultaneously supporting economic development, providing steady income and alternative livelihood to the coastal fishermen community, environmental sustainability, and social equity, making them central to future blue economy strategies.

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FARMING OF SEAWEEDS AND SUSTAINABLE LIVELIHOOD DEVELOPMENT IN THE INDIAN CONTEXT

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Abstract

Seaweeds are increasingly in demand as they are a potent marine bioresource in several sectors, from Agriculture to wastewater treatment. Even though there was a great demand for its biomass, which accounts for about 11 Lakhs, whereas their production was only about 74000 tonnes. This huge gap has led several institutions to raise awareness and disseminate seaweed farming technology to aqua farmers and fisherwomen. Since the cultivation of seaweeds is simple and unique, the technique of seaweed farming can be cultivated by fisherfolk women and interested men. As these working models were carried out by several women's self-help groups, additional income can be generated and guaranteed within the fisherwomen's community. The farming techniques were easy to understand and reliable to practice. The most important cultivated species in India are *Kappaphycus* and *Gracilaria edulis*. The predominant methods include the Raft culture method, Monoline and Tube net method, which make them easily adaptable, and the practice of culturing makes them most sustainable for livelihood development. In India, there are several hotspots for culturing economically important seaweeds on both the east and west coasts. Tamil Nadu, Gujarat, Lakshadweep and Andaman are the highest producers of seaweeds in India. Hence, the demand for seaweed biomass paves the way for sustainable

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seaweed culture through a self-help group model, particularly among women in India.

Keywords: Seaweeds, Macroalgae, Raft culture, Monoline and Tubenet culture.

1. Introduction

1.1. Importance of seaweeds

Seaweeds are marine macroalgae that grow enormously in coastal and shallow ocean waters. Unlike other terrestrial crops they do not require freshwater, fertile soil or chemical fertilizers for their growth. They utilized dissolved nutrients and sunlight directly from seawater, making them one of the sustainable bioresources available. Seaweed operates as a large carbon sink, generating up to 50% of Earth's oxygen while providing habitats for marine life. In recent years, seaweeds have gained global recognition not only as a food source but also as a raw material for industries such as agriculture, medicine, cosmetics, and biodegradable plastics. Seaweeds are divided into three main classifications: green algae (Chlorophyta), brown algae (Phaeophyta), and red algae (Rhodophyta). Many economically valuable *Gracilaria* species, such as *Kappaphycus alvarezii,* are grown for their hydrocolloid abundances. These seaweeds are extracted to produce agar, alginate, and carrageenan, all of which are utilized as stabilizers and gelling agents in the food, healthcare, skincare, and biotechnology sectors. In addition to its industrial value, seaweed has potential nutritional benefits. They are rich in essential minerals such as calcium, iodine and iron as well as vitamins, proteins and dietary fibres. As a result, seaweed-based products are becoming increasingly popular as nutraceutical ingredients in Indian markets. Seaweeds contribute to the balance of marine ecosystems by limiting eutrophication and mitigating coastal pollution. Seaweeds are so important because they provide a combination of environmental, nutritional, and economic benefits. The Indian government has made seaweed cultivation a priority through initiatives such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY). These initiatives aim to improve seaweed habitats, processing facilities, and training programs in order to strengthen the entire value chain.

1.2. Need for seaweed farming

In India's "Blue Economy”, seaweed farming is rapidly becoming a ground-breaking, sustainable industry. India, which has a 11,098-kilometre coastline, has tremendous potential for this industry, which is increasingly recognised for its contributions to traditional livelihoods, environmental preservation, and food safety. However, the increasing industrial demand cannot be met solely by natural collection. Overuse of natural beds can disturb marine ecosystems and reduce biodiversity. Therefore, scientific and sustainable farming practices are essential. India currently imports a huge number of seaweed-based products. Import dependency can be reduced and self-sufficiency promoted by increasing domestic production. Seaweed farming also helps with socioeconomic problems in coastal areas. Fishing villages sometimes suffer from seasonal unemployment due to fishing bans and unpredictable weather. Seaweed cultivation provides an alternative and supplementary revenue stream, particularly for women and marginalized communities.

1.3 Self-Help Group Model in Coastal Villages

A successful model of community-driven seaweed farming has emerged in Ramanathapuram district, also known as Ramnad, Tamil Nadu, India. The shallow coastal waters in the area are ideal for growing species like *Kappaphycus alvarezii*. Local communities were taught scientific farming methods through collaborative efforts by research institutions such as the Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar, Gujarat. The vast majority of seaweed farmers in Ramanathapuram are women who operate in Self-Help Groups (SHGs). In addition to sharing responsibility for seeding, maintenance, harvesting, and drying, these organizations combine their funds to buy ropes, floats, and plants. The SHG model promotes cooperation, thrift, and profit-sharing. With multiple harvests each year, one raft unit can generate 150-200 kg (wet weight) per cycle, providing women farmers with a consistent source of supplementary income. In Ramnad district's coastal settlements, the SHGs concept has considerably increased women's empowerment, enhanced household earnings, and fostered societal progress. This community-driven initiative clearly demonstrates how coordinated group participation and scientific backing can transform marine resources into opportunities.

Women Self-Help Group members involved in seaweed farming training

2.1. Types of Cultivation, Yield and Economics

With a short cycle, seaweed cultivation is inexpensive and perfect for small-scale fishermen, allowing for several harvests annually. Typical techniques used are as follows:

1. **Floating raft method:**

It is a widely followed method. Seaweed fragments are attached to ropes suspended from bamboo or PVC rafts anchored in shallow waters.

Cultivation period: 45–60 days

Average yield: 150–260 kg wet weight per raft per cycle

Economics: Initial investment is moderate which includes cost of raft materials and seedlings, but returns are steady due to multiple harvest cycles.

1. **Monoline method:**

Long, sturdy ropes that are strung between bamboo or wooden poles are used to tie seedlings. Seaweed fragments are tied at regular intervals. This method is easy to manage and ideal for beginners. It is suitable for shallow waters.

Cultivation period: 45–60 days

Average yield: 60-80 kg. Slightly less than the raft approach, but affordable.

Economics: Lower initial investment compared to the raft method

2. **Tube net method:**

This technique, commonly used for species such as *Gracilaria* and *Kappaphycus*, involves placing seed material into tubular nets, which are then connected to bamboo rafts for marine culture.

Cultivation period: 30–45 days

Average yield: 200-260 kg per bamboo raft (4 tube-net per unit). Stable and consistent due to protection from grazing.

Economics: High initial investment cost but provides a sustainable income for small-scale coastal communities.

Advantages of Tube net method:

The tube net method has gained attention due to its several practical advantages:

- Increased yield and Productivity: Provides a 50% larger yield, allowing for improved growth rates and higher density planting compared to traditional off-bottom or monoline methods.
- Reduced Fragment Loss: During waves or currents, seedlings stay firmly contained, minimizing separation.
- Uniform Growth of seaweed: The enclosed space promotes uniform growth and lessens the likelihood of mechanical harm.
- Protection from Grazing: The mesh structure protects seaweed fragments from herbivorous fishes and other marine organisms.
- Faster Seeding and Minimized Labour: Takes significantly less time for seeding and harvesting, reducing labour work.
- Weather resistant: Seaweed can endure strong currents and harsh seas better than floating rafts because of its structural design, which reduces drag.

Conclusion

In India, seaweed farming is a profitable and sustainable marine industry with great potential for the development of coastal folk livelihoods. Seaweeds play a crucial role in socioeconomic, environmental, and nutritional aspects, as well as in their industrial uses. To protect natural marine habitats and meet growing industrial demand, careful cultivation is necessary. The success of the Self-Help Group model in the Ramanad district highlights how community involvement, especially from women, can turn seaweed farming into a reliable source of income. The tube net approach offers better protection, a higher survival rate, and more consistent yields than other growth techniques. Seaweed farming can significantly boost India's blue economy, empower coastal communities, and promote environmental sustainability, provided for by ongoing government support, technological progress, and added value.

FUNCTIONAL DIVERSITY OF SEAWEEDS AND ITS IMPLICATIONS FOR BLUE ECONOMY SUSTAINABILITY

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Seaweed is a plant-like aquatic organism grows at the bottom of ocean depths as well as being cultivated to great extent in farms of aquaculture globally (Msuya et al. 2022). Over 50,000 species of seaweeds were there from 132 countries globally (Froehlich et al. 2019). Seaweeds include red brown, and green algae that synthesize a diverse group of bioactive compounds as well as structural molecules such as lipids, proteins and carbohydrates which could be applied for several purposes in cosmetics, agriculture, pharmaceutical and biotechnology (Ren et al., 2022). Seaweeds are also excellent resources for various bioactive compounds like polyphenols, polysaccharides, sterols and sulphated polysaccharides (Muthukumar et al., 2020), which have been implicated with antioxidant, anti-inflammatory, anticancer, and antidiabetic effects (Peñalver et al., 2020). They also include valuable Fatty acids, such as eicosapentaenoic acid and docosahexaenoic, as well as various secondary metabolites with nutritional and medicinal purposes (Pradhan et al., 2021). Apart from their health benefits to human, seaweeds have a high commercial value as they are popular for food processing, cosmetic purposes, agriculture and filature establishment among many other applications that lead to sustainable industrial development (Twigg et al., 2024; Shafie et al., 2022).

Dr. Joseph Selvin is the Professor in the Dept. Department of Microbiology, School of Life Sciences, Pondicherry University. His research is very unique in India, which was focused on "microbiome biology of marine sponges and corals". He has skill and expertise in the field of Microbiome Biology, Microbial Genomics and Bioprospecting

Microbial communities comprising bacteria, archaea, fungi, microalgae, protozoa and viruses are associated with the surfaces and tissue of seaweeds. While most of these microorganisms have been shown to promote host growth and stress tolerance, certain types may exert negative effects and lead to seaweed disease (Van Der Loos et al., 2019). Seaweed–microbe interactions are key regulators of seaweed growth, stability and the marine environment in which they occur. Such knowledge may be utilized to control harmful algal proliferation and inform sustainable aquaculture of seaweed through higher biomass yields (Lutzu et al., 2018). Seaweeds act as ecosystem engineers, having a major impact on primary production and providing both food and shelter to marine organisms. In combination with their epiphytic bacteria, they add up to one functional entity that results in growth promotion, health, resistance and stress adaptation (Schmidt et al., 2020). Some seaweed-associated microbial strains could promote the stress tolerance of seaweeds and contribute to the bioremediation processes of these natural contaminants such as hydrocarbons and chemical fertilizers (Ren et al., 2022).

Anthropological activities have discharge pollutants into marine system and among them, plastics, micro/nano-plastics and heavy metals are of concern because they act in combination producing harmful effects to living organisms (Khalid et al., 2021). In spite of an increasing interest on microplastic pollution in marine ecosystems, the entries and effects of it in macroalgae, particularly seaweeds are poorly understood. The retention of microplastic in seaweeds is influenced by algal morphologies, plastic polymer properties and the ambient environment (Li et al., 2021). The ecological implications of microplastics in seaweeds are intricate. Possible damaging effects (on seaweed physiology) of microplastics can be seen in the growth inhibition of *Gracilaria*, while other species such as *Chaetomorpha linum* appear to remove microplastic from the water column (Xiao et al., 2024). Meanwhile, organisms such as *Sargassum* can help microplastic to transit the marine food web, intensifying bioaccumulation hazard. Manufacture of edible seaweeds can exacerbate contamination, with dried varieties such as *Pyropia* found to be heavily laden with microplastics (Rimmer et al., 2024). Microplastic early detection has been based largely on visual examination, which is cheap but not reliable for particles less than 1 mm. Recent developments cover microscopical, fluorescence-related techniques, chemical cleavage and separation, thermal analysis and vibrational spectroscopy for polymer identification. Analysis can be size- and composition-selective with methods such as FTIR and Raman spectroscopy, whereas morphological or chemical information using electron microscopy or surface analytical techniques respectively are possible. Combination of various analytical methods is necessary for the accurate identification and characterization of microplastics in environmental samples (Harini et al., 2025). Seaweed serves as sinks and transfer agents of microplastics, with contamination determined by species traits, environmental exposure and the post-harvest process. Aquatic heavy metal pollution is one of the most serious environmental problems in current time due to industrialization, urbanization and also climate change (Saravanan et al., 2024). Pb, Cd, Zn, Mn, Cu, Tl as well as some other scattered metals (Cr, Tl, Co, Ni and As) are common in coastal sediments (Li et al., 2021). Heavy metals are bioaccumulated in marine food webs, reaching toxic concentrations in higher terrestrial organisms such as humans. They are toxic significant threat to ecosystem health, as well as being the cause of several human diseases (Ray et al., 2024; Mitra et al., 2022), hence it is critical to characterise them in aquatic systems subjected to current industrial and climate stresses. Heavy metal transfer from rivers to the coastal region is an environmental risk, but it also shows that seaweed species possess the capacity for pollutant uptake.

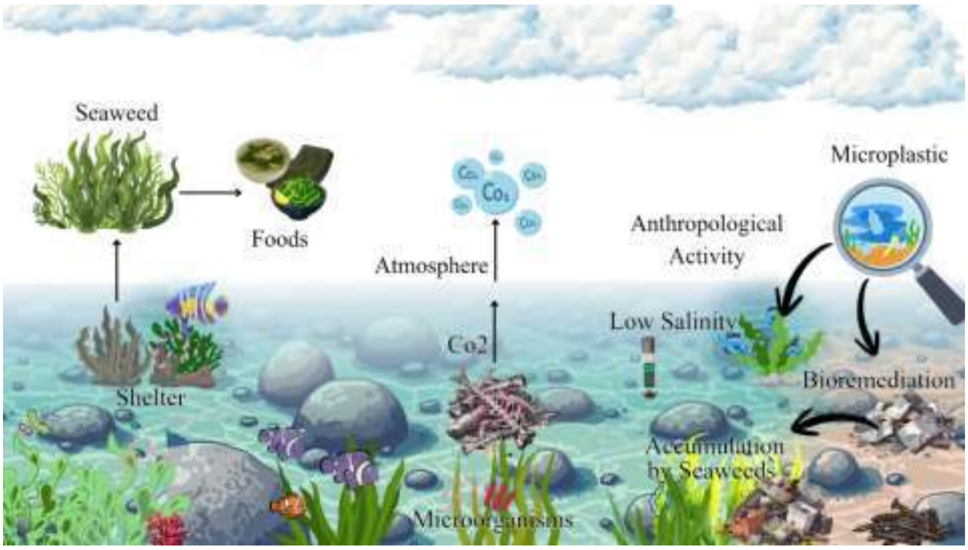

Figure 1 Schematic representation of ecological roles of seaweeds in coastal marine ecosystems.

Severe weather has impact on seaweeds, which are important socially, economically, and ecologically across the globe. Socially, seaweeds are part of human diet and contribute to food security and contain cultural values in many Asian countries where there is a tradition of consuming edible species (nori) (Sultana et al., 2022). Economically, seaweed farming is a source of income and economic development for local communities and regional economies through countries such as China, Indonesia and Philippines, where species like *Kappaphycusalvarezii* are propagated on the large scale for industrial purposes like carrageenan production (Behera et al., 2022). Ecologically, seaweeds serve as the foundation for coastal ecosystems, are involved in nutrient cycling and in some cases help bioremediate such as bioaccumulation of lead (II), copper (II) removal from surrounding waters (Oh et al., 2012).

Recent studies have shown that the response of seaweed to salinity alterations is species-specific and has a great effect on heavy metal uptake. The effect of elevated salinity on arsenic uptake in Sargassum and the influence of reduced salinity on copper accumulation in Ascophyllum nodosum and *Fucus vesiculosus* have been demonstrated. Similarly, *Ulva lactuca* has been reported to take up higher amounts of a number of metals (cadmium, chromium, selenium and zinc) at low salinities. These findings emphasize the contribution of salinity to control metal availability in seawater (Datta et al., 2024; Wang et al., 1999).

Algal biomass production is a fast-growing industry in the blue economy because of its potential to capture carbon, contribute to renewable energy, improve food and nutritional security, assist waste water treatment, and provide employment. The growing seaweed market also supported the concept of 'sustainable resources' for blue and circular economy practices, whereas algal biorefinery could serve as a sustainable avenue for carbon sequestration and value-added product generation (Ismail et al., 2025). Like metals, oil and biofuels, algal bioactive molecules are the vital non-biological building blocks of the blue economy (choudhary et al., 2021). Seaweeds are key features of both temperate to polar marine coastal ecosystems, contributing to primary production, biodiversity and ecosystem functioning. By providing oxygen and serving as crucial food sources, they support marine food webs and mediate carbon, nitrogen, phosphorus and other element cycles (Lotze et al., 2019). Seaweed canopies shield marine life from high light and predatory pressures, and influence local environmental conditions such as flow rate and sediment resuspension. They will also help reduce wave energy and reinforce sediment stability by attenuating underwater waves which led in reduction coastal erosion. These functions can harbor fundamental ecosystem services, including carbon storage, climate regulation, control of nutrient dynamics, and binding up toxic substances like heavy metals. Furthermore, seaweeds are a valuable feedstock for marine herbivores and which are consumed by humans and livestock providing economic value as well as human health benefits. Marine algae can be helpful in areas such as aquaculture, biotechnology, renewable energy for sustainable development and job creation in support of the blue circular economy (Minicante et al., 2022). Even though algae are an efficient metal sequesters, the details on the mechanism of it as well as the species-level understanding are still not studied fully. Most studies are focussed on heavy metal accumulation and microbial functions in seaweeds that have addressed a specific species or local environmental conditions. The mechanisms involved in it are largely unknown as related to systematic taxa and climate-related stressors, emphasizing the need for more comprehensive integrative studies in relation with sustainable blue economy pathways.

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7	Ayana Surendran	Dept of FST, FOST
8	Ashly Augustine	Dept of Marine Biosciences, FOST
9	Nisha Alex	Dept of Marine Biosciences, FOST
10	Fathima Muhammed	Dept of Marine Biosciences, FOST

XVI. CULTURAL EVENTS COMMITTEE

1	Dr.Rahul Krishnan	Asst.Professor (Chairperson)
2	Dr.Shyla G	Asst.Professor(Convenor)
3	Ms. Arya P	Asst.Professor
4	Ms.Praveena P	Research Scholar
5	Adarsh Jayath AB	Research Scholar
6	Benny Akash J	MSc 2024
7	Meera Raju	MSc 2024
8	Ankith	BFSc 2024

XVII. PRESS AND PUBLICITY COMMITTEE

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2	Dr. Nevin KG	Asst. Professor (Convenor)
3	Dr.Prabhakaran MP	Asst. Professor
4	Rejish Kumar VJ	Asst.Professor, Aquaculture
5	Mohammed Nadhim Ansari	PhD Scholar
6	Melbinlal	PhD Scholar
7	Gokula Krishna	FRM Student
8	Meryl Mary Mathews	FRM Student
9	Praveen Joseph	Computer Assistant

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1	Dr. Subhash Chandran	Controller of Examinations (Chairperson)
2	Dr. Rejish Kumar VJ	Asst. Professor (Convenor)
3	Mr. Sanjay Balachandran	PhD Scholar
4	Mr. Naveen Nivas	PhD Scholar
5	Mr. Abhay Krishna	MFSc, Aquaculture
6	Abhijai S	MFSc, Aquaculture

XIX. NATIONAL SEMINAR COMMITTEE

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2	Dr. Abhilash Sasidharan	Asst. Professor (Convenor)
3	Dr.Ravi Sharadbhai Baraiya	Guest Faculty
4	Roopa Rajan	Guest Faculty
5	Fathima Ashraf	Research Scholar
6	Neha P Nair	Research Scholar
7	Akshara Pratheep	Research Scholar
8	Ahana Vijayan	Research Scholar

XX. BUSINESS MEET COMMITTEE

1	Dr. Anoop K K,	Asst Professor (Chairperson)
2	Dr. Abish B	Asst Professor(Convenor)
3	Rakesh Gopal	MBA Third Semester
4	Santhimol TA	MBA Third Semester
5	Amala Cleferd	MBA Third Semester
6	Amitha K	MBA Third Semester
7	Haneena AK	MBA Third Semester
8	Irfan A	MBA Third Semester
9	Karthik AM	MBA Third Semester
10	Sajith K Saji	MBA Third Semester
11	Sanith Babu	MBA Third Semester
12	Swagath Santhosh	MBA Third Semester
13	Vaishnavi LS	MBA Third Semester
14	Amal	MSc Atmospheric Science First Semester
15	Jaseel	Atmospheric Science First Semester
16	Ramis	Atmospheric Science First Semester
17	Manimekhala	Atmospheric Science First Semester

XXI. EXPO-EXHIBITION COMMITTEE

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2	Dr. Chiranjiv Pradhan	Asst.Professor(Convenor)
3	Dr.Arun S	Asst. Professor
4	Dr.Jayalakshmi KJ	Asst. Professor
5	Mr.Saneer NS	Extension Staff
6	Mr.Renjith R	Extension Staff
7	Mr.Navas	Farm Labourer
8	Mr.Iqbal	Farm Labourer

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2	Ms.Sethulakshmi CS	Asst.Professor (Convenor)
3	Ms.Mary Helena S	MFSc, FRM, 2024 Batch
4	Ms.Haritha MS	MFSc, FRM, 2024 Batch
5	Ms.Anagha SR	MFSc, FRM, 2024 Batch
6	Ms.Himavarsha	MFSc, FRM, 2024 Batch
7	Ms.Sindhu Madhavi	MFSc, FRM, 2024 Batch
8	Ms.Chitralekha	MFSc, FRM, 2024 Batch
9	Pamisetty Kalyan	MFSc, FRM, 2024 Batch

XXIII. COMPENDIUM COMMITTEE

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2	Dr. Rejish Kumar VJ	Asst. Professor (Convenor)
3	Ms.Judith Das	Asst. Professor
4	Ms.Sweta Das	Post Doctoral Fellow
5	Naveen Nivas	Post Doctoral Fellow
6	Sreena Raj	Guest Faculty, FOST
7	Neema Job	Centre for Bioactive Compounds, FOST
8	Sreelekshmi PU	Centre for Bioactive Compounds, FOST

KUFOS

The Kerala University of Fisheries and Ocean Studies (KUFOS), established on November 20, 2010, is India's first university dedicated to fisheries and ocean studies. KUFOS serves as a hub for advanced education in fisheries, ocean sciences, and related fields, with a mission to develop skilled manpower and promote systematic research, capacity building and extension activities. The university operates from a 62-acre main campus at Panangad, on the outskirts of the city of Kochi, and has two additional campuses, a 50-acre brackish water and marine aquaculture research facility at Puduvype (Vypeen island, Kochi), and a College of Fisheries at Payyanur in Kannur District.

As a premier institution in Kerala for fisheries and ocean science-related disciplines, KUFOS has a long-term vision of becoming a globally recognized centre of excellence in fisheries, aquaculture, and ocean sciences by spearheading transformative education, cutting-edge research, and sustainable innovation that empowers communities and catalyses the blue economy.

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Regional Centres
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KUFOS

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