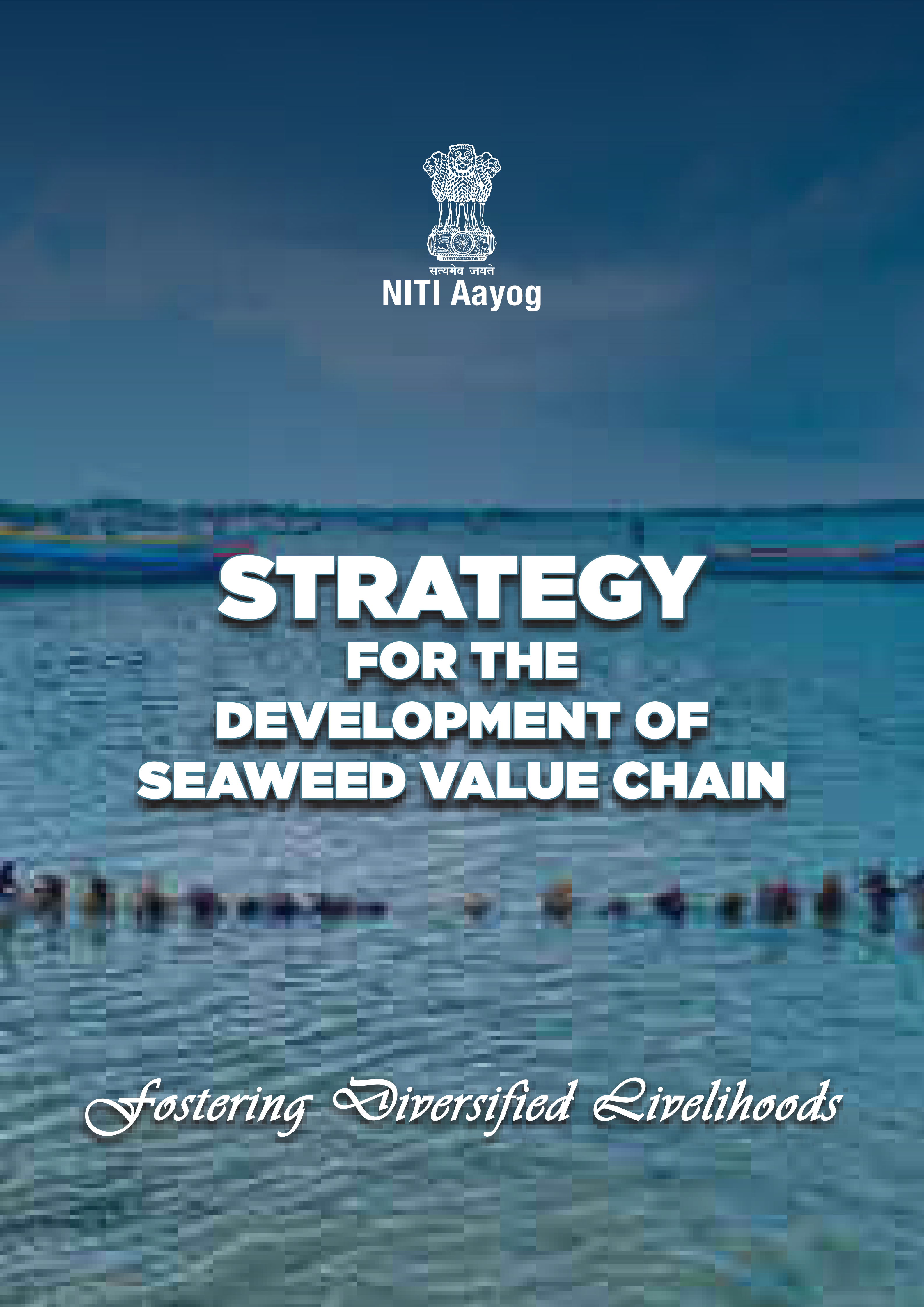
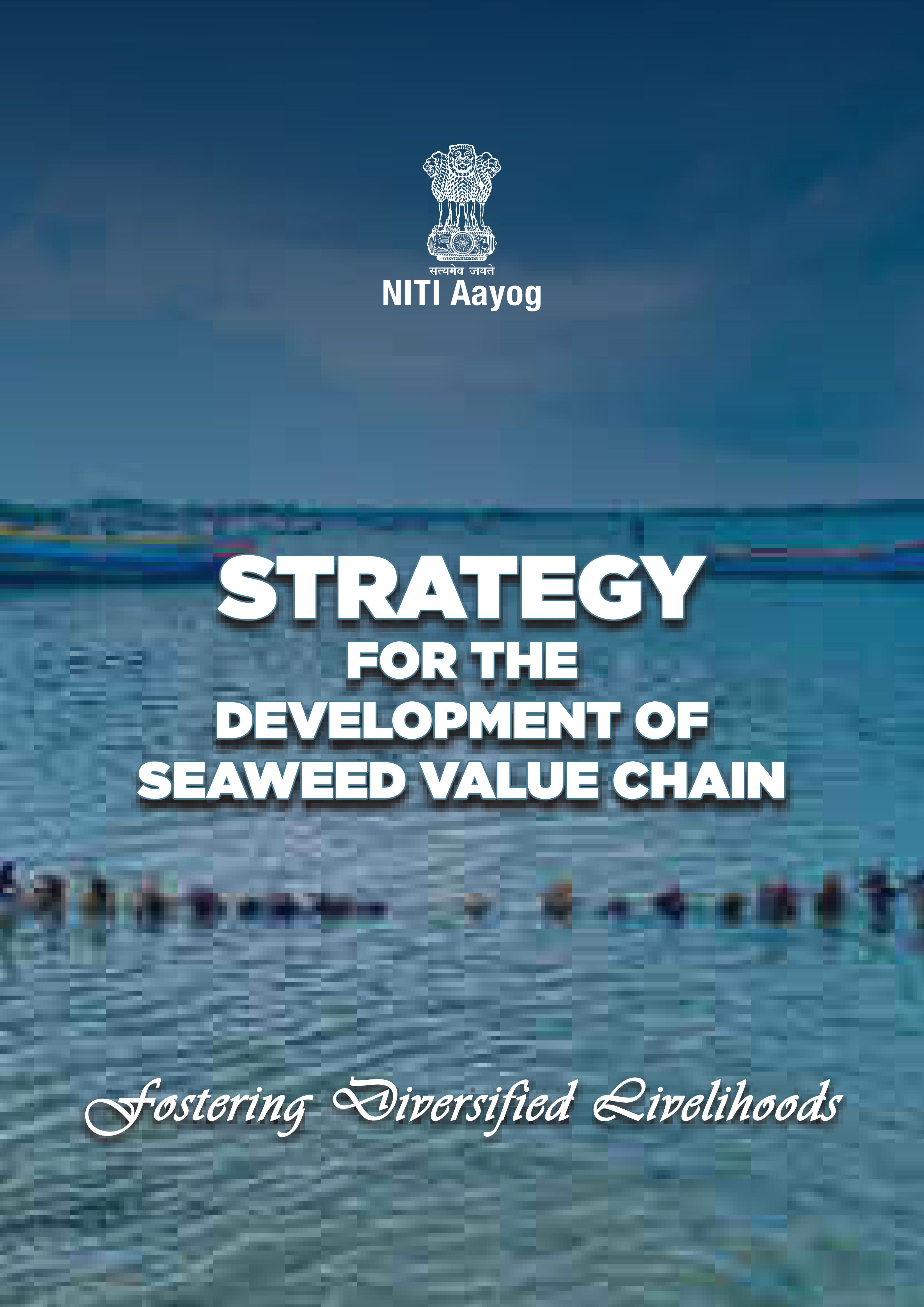


सत्यमेव जयते

NITI Aayog

STRATEGY FOR THE DEVELOPMENT OF SEAWEED VALUE CHAIN

Fostering Diversified Livelihoods



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Fostering Diversified Livelihoods

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Strategy For The Development Of Seaweed Value Chain

Fostering Diversified Livelihoods

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LIST OF ABBREVIATIONS AND ACRONYMS

SHORT FORM	FULL FORM
ASC/MSC	The Aquaculture Stewardship Council / Marine Stewardship Council
ATC	Alkali - Treated Cottonii
ATCC	Alkali - Treated Cottonii Chips
BFAR	Bureau of Fisheries and Aquatic Resources
BOD	Biochemical Oxygen Demand
CDSCO	Central Drugs Standard Control Organization
CMFRI	Central Marine Fisheries Research Institute
CMSNBE	Cooperative Managed Seaweeds Nursery Business Enterprise
COD	Chemical Oxygen Demand
CRZ	Coastal Regulation Zone
CSIR-CSMCRI	Council of Scientific & Industrial Research- Central Salt and Marine Chemicals Research Institute
DARE	Department of Agricultural Research and Education
DENR	Department of Environment and Natural Resources
DST	Department of Science & Technology
DSWD	Department of Social Welfare and Development
DTI	Department of Trade and Industry
EEZ	Exclusive Economic Zone
ESA	Ecologically Sensitive Area
f, d, s	f, fresh; d, dried; s, salted
FAO	Food and Agriculture Organization
FOB	Fixed Off Bottom
GEF	Global Environment Fund
GIS	Geographic Information System
GoMBR	Gulf of Mannar Marine Biosphere Reserve
GSSI	The Global Seafood Sustainability Initiative
ICAR	Indian Council of Agricultural Research

SHORT FORM	FULL FORM
IMTA	Integrated Multi-trophic Aquaculture
KCC	Kisan Credit Cards
KSWE	Kappaphycus seaweed extract
MoA&FW	Ministry of Agriculture and Farmers Welfare
MoBEF	Ministry of Blue Economy and Fisheries
MoMAF	Ministry of Marine Affairs and Fisheries
MPEDA	Marine Products Export Development Authority
MUZE	Multi Stream Zero Effluent
NAAS	National Academy of Agricultural Sciences
NCDC	National Cooperative Development Corporation
NCSCM	National Centre for Sustainable Coastal Management
NICRA	National Innovations in Climate Resilient Agriculture
NIOT	National Institute of Ocean Technology
PM-FBY	Pradhan Mantri Fasal Bima Yojana
PM-KISAN	Pradhan Mantri Kisan Samman Nidhi
PPP	Public-Private Partnership
PSL	Priority Sector Lending
PUFA	Polyunsaturated Fatty Acids
RC	Carrageenan refined
RDS	Raw Dried Seaweed
RFS	Raw Fresh Seaweeds
SDGs	Sustainable Development Goals
SFD	Social Fund for Development
SFSP	Seaweed Farmer Service Platform
SIAP	Seaweeds Industry Association of the Philippines
SOFIA	State of World Fisheries and Aquaculture
SRC	Semi-Refined Carrageenan
SRC	Semi-Refined Carrageenan
TNC	The Nature Conservancy
WWF	World-Wide Fund for Nature

EXECUTIVE SUMMARY

Numerous types of marine plants and macroalgae that thrive in rivers, lakes, and other bodies of water are together referred to as "seaweed". Over ten thousand seaweed species are found all over the world and can be broadly classified into three groups: green *(Chlorophyta)*, brown *(Phaeophyta)*, and red *(Rhodophyta)* seaweeds. Seaweeds are prized commercially for their bioactive metabolites, manure, and fodder, as well as for their cell wall polysaccharides, which include agar, algin, and carrageenan. They are used in the food, pharmaceutical, cosmetic, and mining industries for a wide range of commercial purposes. Apart from their usage as raw materials in the extraction of marine chemicals and bioactive compounds, some species of seaweed are also becoming more and more important as nutritious foods for human consumption.

India is a fortunate nation with an Exclusive Economic Zone (EEZ) spanning more than 2 million square kilometers and an enormous 8,118-kilometer coastline, supporting the livelihoods of about 4 million people. Thus, the need for augmenting the fishermen's income will never be an overstatement. Seaweed farming is a solution that can offer a sustainable and profitable alternative for economic stability and growth by reducing reliance on traditional fishing and diversifying coastal communities' livelihoods. Under optimal conditions, the net revenue from one hectare (400 rafts) of dry weight might reach up to ₹13,28,000/- per year. India at 33,345 tonnes wet weight of seaweeds per year produces less than 1 percent of global seaweed production. The total global exports of seaweed and seaweed-based hydrocolloids amount to USD 2.65 billion across 98 countries. Few countries dominate the trade balance viz. China, Indonesia, Philippines, Republic of Korea, Malaysia.Internationally, the trade of seaweed and its products is on the rise and can be good for the forex accounts of India. Besides this economic imperative, seaweed has ecological and nutritional imperatives as well. It has the potential to address the challenge of nutritional deficiency in India. Mariculture seaweed's estimated carbon sequestration rates amount to 57.64 metric tons of CO_2 per hectare per year, while pond-cultured seaweeds sequester 12.38 metric tons of CO_2 per hectare per year.

Seaweed has been in Indian waters since decades. However, certain challenges, such as lack of awareness, research and development, and the lack of a comprehensive policy framework, need to be addressed to develop the sector. This document presents a comprehensive framework addressing environmental concerns, laying out the economic feasibility, and identifying the potential sites that are conducive to the cultivation of seaweed. The methodology adopted for identifying these sites is most scientific, considering the factors conducive to the growth of seaweed as well as the ecological sensitivity of the areas. The document discusses methods and economics of on-shore and off-shore cultivation of prominent commercially significant species of seaweed, along with best practices of cultivation, governance, product development and harvesting followed globally.

The strategy is an outcome of rigorous stakeholder consultations wherein the reviews and comments of stakeholders were discussed and deliberated upon to finally bring it into this shape. It touches upon the entire value chain of the sector, from quality seed availability to different cultivation practices, processing technologies, marketing and exports of products, certification, regulatory mechanisms, and laws pertaining to environmental safeguards.

The inception of task on drafting this document happened with the conducting of rounds of consultative meetings with the stakeholders in the value chain of seaweed that included national level organizations viz. Council of Scientific & Industrial Research- Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Indian Council of Agricultural Research-Central Marine Fisheries Research Institute (ICAR-CMFRI), National Centre for Sustainable Coastal Management (NCSCM), National Institute of Ocean Technology (NIOT), Marine Products Export Development Authority

(MPEDA), Department of Agricultural Research and Education (DARE), key industries in the sector, coastal state and union territory governments, Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Union Ministry of Environment, Forests and Climate Change, researchers from universities as well as independent international experts in the sector. Multiple rounds of these consultations took place over a period of a year, during which deliberations were made to systematically study the value chain, its challenges, and curate a way forward for the seaweed vaue chain.

A detailed and conclusive report was submitted by ICAR-CMFRI (as nodal agency), jointly with CSIR-CSMCRI and NCSCM with the study of existing research in seaweed cultivation, with a scientific analysis based on data from global experiences. The inputs from the report are incorporated as part of this strategy. The report was drafted on the following pointers:

i. The impact of exotic species versus indigenous species of seaweed on biodiversity,

ii. The impact of cultivation of exotic and native species of seaweed on coral reef,

iii. Selection of commercially viableseaweed species taking into account itsecological neutrality.

The inception of seaweed value chain developmentrequires suitable sites across the coastline of India for the cultivation of seaweed be identified. Thereby a detailed report titled, "*Potential Areas for Seaweed Farming along the Indian Coast*" was jointly submitted by NCSCM, CSIR-CSMCRI and ICAR-CMFRI. A total of 333 sites were identified by ICAR-CMFRI, out of which trial and farming activities were carried out in 78 sites. A total of 51 sites were identified by CSIR-CSMCRI, out of which trial/farming activities are carried out at all the sites. The sites identified by ICAR-CMFRI and CSIR-CSMCRI were categorized into green zones (>1 km from CRZ-IA), amber zones (up to 1 km from CRZ-IA), and blue zones (within CRZ-IA and ESA), with 24,707 hectares identified as suitable for seaweed farming, including 3,999.37 hectares classified as green zones, 14,076.77 hectares as amber zones, and 6,631 hectares as blue zones. A GIS-based portal for viewing the mapped seaweed cultivation sites has been developed. Bringing 24,707 hectares under seaweed cultivation, nearly 7.51 lakh tonnes of *Kappaphycus alvarezii*or 28.1 lakh tonnes of *Gracilaria edulis* production is possible amounting to a revenue potential of over ₹ 5000 crores for either species.

Similarly, NIOT had submitted a detailed report to NITI Aayog, titled as "*Technical and Economic Feasibility of Offshore Farming of Seaweed in Indian EEZ.*" The inputs from the report are incorporated as part of this strategy. They include the estimation of area available for offshore farming, methodology for deployment, investment analysis and management practices for seaweed farm.

An expert committee chaired by the Hon'ble Member (S&T), NITI Aayog Dr. V K Saraswat was constituted to review this document in its draft form. The expert committee (Annexure-IV) included members from union ministries, research organizations, senior officers from the governments of the states and UTs, the Aqua Stewardship Council, key industries, etc. Inputs received were incorporated to bring this document into its current and final form. It was ensured that the process of stakeholder consultation was carried out at every step to develop a consensus.

Based on all above, recommendations are laid out at the end of this document to pave the way forward for holistic development of sector. Major recommendations laid out mainly correspond to the following domains:

(i) Regulatory and governance

a) Amendment in the Allocation of Business Rules, 1961 to include seaweed cultivation and its value chain under the allocation of business rules of the Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI. Similarly, Exports and certification of seaweed and its products be allocated to MPEDA.

b) Constitution of a National Steering Committee under the chairmanship of the Secretary, Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI for untapping the seaweed potential, and effectively managing associated environmental, economic, and interstate issues.

c) Constitution of national-level technical committee for the import of seaweed seeds and planting material under the Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI.

d) Inclusion of seaweed related credit in Priority Sector Lending (PSL) by RBI as seaweed is a tool to combat and deal with climate change.

e) The development of standards for various categories of seaweed products maybe done; edible products by FSSAI, pharmaceutical products by Central Drugs Standard Control Organization (CDSCO), biostimulants by the Ministry of Agriculture and Farmers Welfare (MoA&FW), animal feed by the Department of Animal Husbandary (MoFAH&D).

(ii) Social security and financial support

a) Comprehensive risk cover through insurance for crop, seaweed infrastructure and life of seaweed farmer maybe developed by the Department of Fisheries (GoI).

b) Financial support for seaweed cultivation maybe provided by broadening the ambit of PM-FBY, PM-KISAN and Kisan Credit Card (KCC).

c) Mobilization of seaweed farmers through SHGs, FFPOs, JLGs, etc. to strengthen their ability to access institutional credit facilities.

(iii) Incentivising investments and ease of doing business

a) Enhancing investment in processing and supply chain infrastructure in coastal regions through FDI and PPP.

b) Promoting ease of doing business through development of dynamic data portal and decision support tools with geo-tagging of all sites suitable for seaweed cultivation.

c) Development of market infrastructure and inclusion of seaweed and its products in e-NAM and agriculture mandis.

(iv) Infrastructure and institutions

a) Establishment of seed banks in all the maritime states and UTs to ensure the availability of quality seed material immediately after the end of monsoon.

b) Creation of logistics and primary processing centers at cluster level.

c) Creation of aggregation and marketing centers at district level with facilities for standardization and aggregation, storage, marketplaces and digital trade platforms.

d) Setting up of Centres of Excellence (CoE) for seaweed to support coastal states/UTs from capacity building of farmers, enterprenuers and startups, seed availability, multiplication, cultivation, harvesting, post-harvest handling, processing, marketing, domestic and international trading of seaweed as well as further research and development in the value chain.

(v) Skill development and research

a) Certificate and diploma courses through various national and state level organizations (public and private) for skill development, creating new sustainable opportunities and generate employment prospects.

b) Research for development of new seaweed-based bioethanol, animal fodder, pharmaceutical, neutraceutical products may be initiated by research organizations.

c) Study and framework on carbon credits from seaweed maybe initiated to incentivize and monetize the carbon credits so generated in seaweed cultivation.

If the recommendations in this strategy are implemented, it will certainly prove promising, which could reveal the new face of coastal India to the economy.

CHAPTER-I

THE IMPERATIVE TO SEAWEED DEVELOPMENT

1.1 Introduction

This strategy document presents a comprehensive framework that aims to capitalize on India's extensive coastline of 8,118 km and an Exclusive Economic Zone (EEZ) covering more than two million square kilometres, for the development of sustainable seaweed mariculture. It provides a strategic approach to leverage coastal resources, achieve economic viability, and address multiple Sustainable Development Goals (SDGs). The framework focuses on promoting food security, fostering innovation and infrastructure development, mitigating climate change, protecting marine ecosystems, and encouraging sustainable land use. The framework seeks to develop the seaweed value chain by addressing challenges and vulnerabilities, ensuring a prosperous and sustainable future.

1.2 Seaweed and its Significance

Numerous types of marine plants and macroalgae that thrive in rivers, lakes, and other bodies of water are together referred to as "seaweed". Over ten thousand seaweed species are found all over the world and can be broadly classified into three groups: green *(Chlorophyta)*, brown (*Phaeophyta*), and red (*Rhodophyta*) seaweeds. In addition to being rich in vitamins, minerals, and fibre, seaweed can also be rather appetizing. The Japanese have been encasing raw fish, sticky rice, and other items in a seaweed called nori for at least 1,500 years. A delicious sushi roll is the end product. Therefore, seaweed farming is the cultivation and harvesting of marine plants and algae in bodies of water.

Seaweeds are nutrient-rich, possess medicinal properties, including anti-inflammatory and anti-microbial effectsand have potential in cancer treatment. Seaweeds have wide-ranging applications in manufacturing, serving as effective binding agents in preparing commercial products such as toothpaste and fruit jelly, as well as popular softeners in organic cosmetics and skincare items. Seaweed farming has emerged as a pivotal industry, providing a sustainable and renewable source of these versatile marine plants and algae, supporting various sectors while meeting the increasing global demand for seaweed-based products.

Seaweeds are prized commercially for their bioactive metabolites, manure, and fodder, as well as for their cell wall polysaccharides, which include agar, algin, and carrageenan. They are used in the food, pharmaceutical, cosmetic, and mining industries for a wide range of commercial purposes. Apart from their usage as raw materials in the extraction of marine chemicals and bioactive compounds, some species of seaweed are also becoming more and more important as nutritious foods for human consumption. Seaweeds are an important source of crop bio-stimulants that can enhance agricultural crop productivity and quality, besides warding off. They also can be used to make animal feed additives.

1.3 Production – Global and Indian Scenario

Over the past five decades, global seaweed production has undergone a significant transformation and aquaculture has played a pivotal role. In 1969, wild collection and cultivation accounted for 50 percent of the world's 2.2 million tonnes of seaweed production. However, by 2019, while wild collection remained at 1.1 million tonnes, cultivation skyrocketed to 34.7 million tonnes, representing 97 percent of the total global seaweed production. This shift towards cultivation has led to a notable regional disparity, with Asia, particularly Eastern and South-eastern Asia, dominating global seaweed production by contributing 97.4 percent through cultivation (FAO, 2021). Conversely, the Americas and Europe lag, relying primarily on wild collection, which accounted for only 1.4 percent and 0.8 percent of total production, respectively. Africa and Oceania, despite their modest global shares, relied on cultivation as their primary source, contributing 81.3 percent and 85.3 percent in seaweed production, respectively. The seaweed industry has experienced remarkable growth and expanded beyond its traditional applications in the food and medicine sectors. The industry is projected to continue its growth trajectory, with a compound annual growth rate (CAGR) of 2.3 percent from 2022 to 2030.

In India, presently, nearly 33,345 tonnes wet weight of seaweeds per year is being harvested from natural seaweed beds (species of *Sargassum, Turbinaria*, *Gracilaria* and *Gelidiella*) by 5,000 families in Tamil Nadu (FRAD, CMFRI, 2022). India, which has an annual revenue of about ₹ 200 crores, provides less than 1 percent of the world's seaweed production. Among the global seaweed production through farming, *Kappaphycus alvarezii* and *Eucheuma denticulatum* contribute to 27.8 percent of the total production (FAO, 2022).

1.4 Exports and Imports

The global trade in seaweed can be seen as trade of seaweed and seaweed-based processed products. Global trade in seaweed has seen significant expansion, with an annual valuation ofUSD 6 billion, primarily driven by the food sector, contributing 85 percent to the industry's overall value. In 2021, the commercial seaweed market reached a noteworthy milestone with a valuation of USD 9.9 billion. Few countries dominate the trade balance *viz*. China, Indonesia, Philippines, Republic of Korea, Malaysia etc.

1.4.1 Exports

The total global exports of seaweed and seaweed-based hydrocolloids amount to USD 2.65 billion across 98 countries. This breaks down to roughly USD 909 million of seaweeds and another USD 1.74 billion of seaweed-based hydrocolloids. This is well elaborated by the United Nations Comtrade database (2021) (Figure 1).

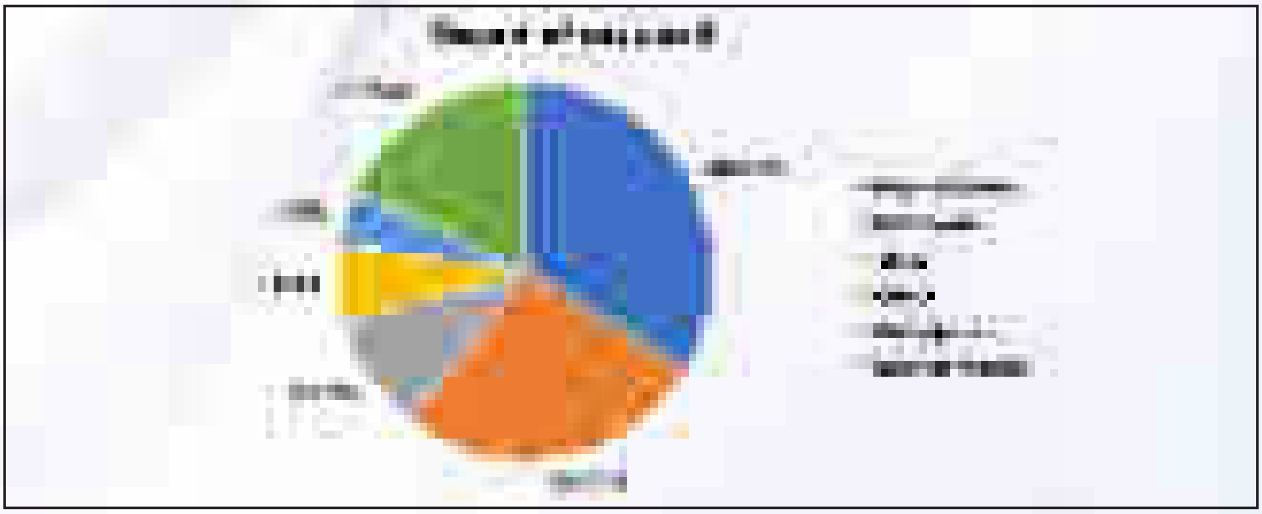


Figure 1. Export of seaweed, 2019

Source: United Nations Comtrade database (2021)

The Republic of Korea tops the exports of seaweed with a share of over 30 percent, whereas the top share for seaweed-based hydrocolloids is bagged by China with roughly the same share (Figure 2).

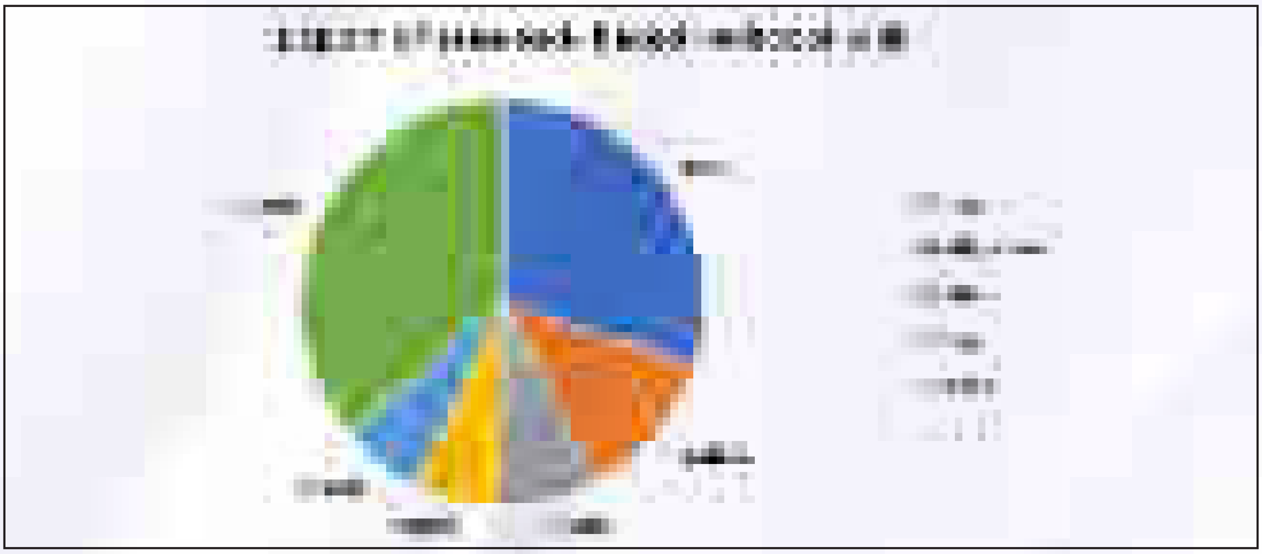


Figure 2. Export of seaweed-based hydrocolloids, 2019

Source: United Nations Comtrade database (2021)

1.4.2 Imports

The UN Comtrade database (2021) lays out that 128 countries import seaweed and seaweed-based hydrocolloids valued at nearly USD 2.9 billion. Out of these, USD 1.26 billion come from seaweed and the rest from seaweed-based hydrocolloids. Similar to exports, the import profile of the globe is also dominated by a few countries (Figure 3 and Figure 4).

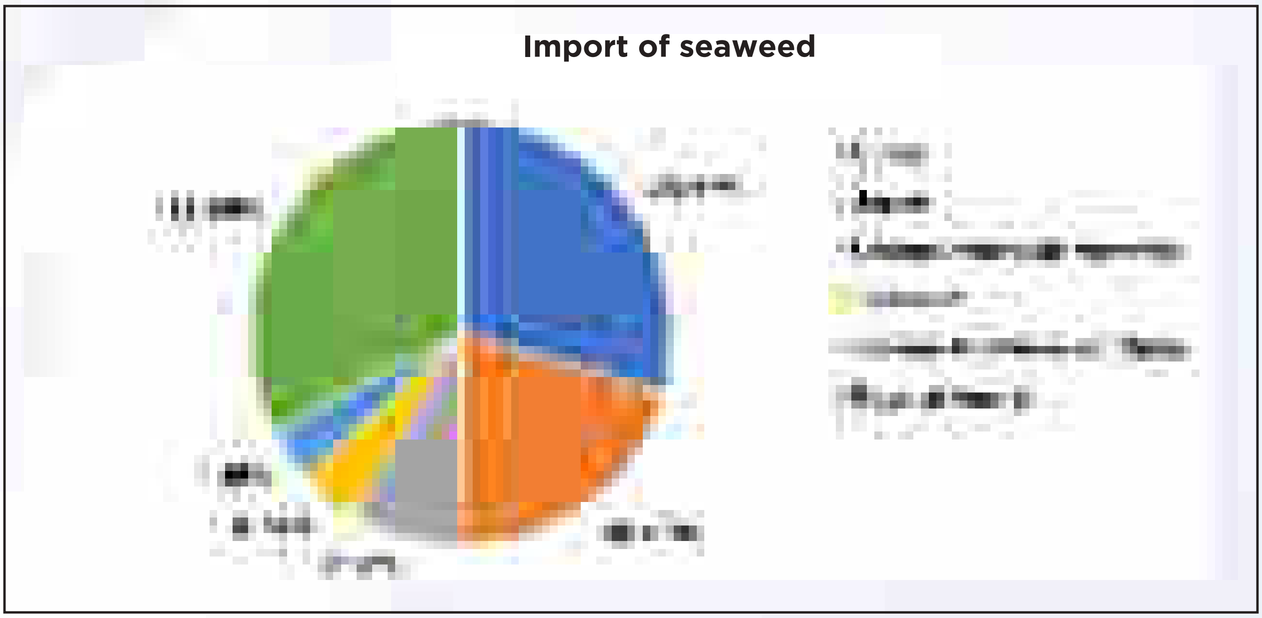


Figure 3. Import of seaweed, 2019

Source: United Nations Comtrade database (2021)

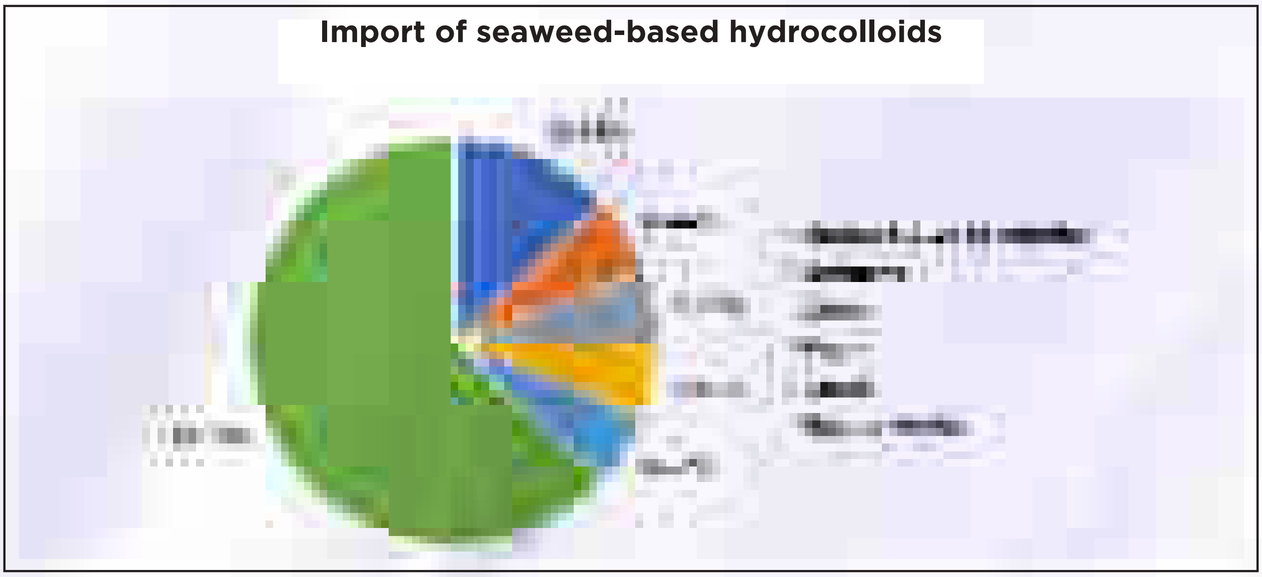


Figure 4. Import of seaweed-based hydrocolloids, 2019

Source: United Nations Comtrade database (2021)

1.5 The Need for a Targeted Strategy

It is already clear from the above figures that India stands very much under-tapped regarding seaweed production (less than one percent) and trade. Therefore, it's the need of the hour to have a targeted strategy for the development of the seaweed value chain in India. Coastal communities in India are currently grappling with the adverse impacts of climate change, including extreme temperatures, changing precipitation patterns, rising sea-levels, coastal flooding, erosion, and heightened risks of drought. These challenges have significantly affected the productivity of fisheries, coastal agriculture and aquaculture.

Besides, another major challenge is lack of quality seeds. The hurdles in importing germplasm and wet seed materials are among the major challenges in promoting seaweed cultivation. Continuous vegetative propagation using the existing seaweed strains of *Kappaphycus alvarezii* for decades has resulted in the loss of vigour of germplasm. Additionally, the asexual propagation has made the seedlings prone to environmental stress, disease, and epiphyses, leading to a decline in the yield of seaweed. The loss of vigour has resulted in a drastic reduction in yield, from 1:7 in previous years to 1:4 at present. In this regard, the potential states and UTs like Tamil Nadu, Andhra Pradesh, Maharashtra, Karnataka, Goa, and Dadra & Nagar Haveli and Daman & Diu have informed that an increase in seaweed production requires good-quality seaweed material to the seaweed farmers.

To address these pressing issues, it is essential to adopt unique, sustainable, and utilitarian practices and traditions that can bring about a substantial positive change in the well-being of coastal communities. In this context, the cultivation and value chain of seaweed emerges as a promising component that can significantly contribute to achieving socio-economic and ecological goals. There are economic as well as ecological imperatives that press for this need, which are discussed below.

1.5.1 Ecological Imperative: Enhancing Climate Change Resilience

Seaweed farming represents a climate-resilient form of aquaculture that offers numerous benefits. Seaweed cultivation is advantageous as it requires no land, freshwater, or fertilizers. It provides sustainable and diverse livelihood optionsalong with employment generation to coastal communities. Moreover, seaweed farming mitigates the adverse effects of oceanic eutrophication and acidification while promoting a healthy ecosystem by oxygenating seawater. Seaweed farming plays a role in carbon sequestration. They release carbon, which can be either buried in sediments or exported to the deep sea, effectively acting as a sink for CO_2. Mariculture seaweed's estimated carbon sequestration rates amount to 57.64 tonnes CO_2 per hectare per year, while pond-cultured seaweeds sequester 12.38 tonnes CO_2 per hectare per year. Globally, seaweed production reached 35.1 million tonnes of wet weight, with a first sale value estimated at 16.5 billion USD in 2022 (FAO, 2022). Seaweed cultivation demonstrates remarkable adaptability to changing environmental conditions, making it a resilient alternative for coastal communities contending with climate change impacts. Seaweeds can thrive in diverse temperatures and require minimal freshwater inputs, reducing the strain on limited freshwater resources.

Specifically, *K. alvarezii* has been estimated to sequester 19 kg of CO_2 per day per tonne of dry weight, or equivalently 760 kg of CO_2 per day per tonne of dry weight per hectare (Johnson et al., 2023a). Furthermore, seaweeds enhance water quality by effectively absorbing excess nutrients, thus improving marine environments. They also serve as essential habitats and protect a wide range of marine biodiversity, fostering the preservation of various species and their ecological interactions.

Besides, seaweed-based bio-stimulants have numerous applications in climate change. For instance, in plant and ratoon crops, the bio stimulant derived from *Kappaphycus* seaweed extract (KSWE) applied at 5 percent concentration increased cane productivity by 12.5 and 8 percent, respectively. When used at a 5 percent concentration, the KSWE can reduce greenhouse gas emissions by at least 2.06 kg CO_2 equivalents per tonne of cane produced (Singh et al., 2018). Additionally, it has been claimed that cattle greenhouse gas emissions can be decreased by using bio-stimulants derived from seaweed.

1.5.1 Economic Imperative

Seaweed cultivation diversifies marine production, doubles fish farmer's income, reduces reliance on traditional fishing, and diversifies coastal communities' livelihoods. Seaweed farming offers a sustainable and profitable alternative for economic stability and growth. For example, *Kappaphycus alvarezii* farming has crop duration of 45-60 days, allowing for multiple harvests per year. Farmers can make ₹ 16/-per kg of fresh seaweed and ₹ 70/-per kg of dried seaweed with an average dry weight of 10 percent. Under optimal conditions, the net revenue from one hectare (400 rafts) in dry weight might reach up to ₹ 13,28,000/- per year. A family of two persons can handle around 45 rafts, providing income opportunities.

Besides, seaweed and its products trade can also be good for India's forex accounts.Demand for seaweed-derived products, including biofuels, fertilizers, and food additives, presents income diversification and expansion opportunities.

1.5.2 Nutritional Imperative

Seaweeds, commonly called sea vegetables, are highly regarded for their nutritional value, and have gained popularity as a source of nutraceutical supplements due to their numerous health benefits. They provide vital minerals like calcium, phosphorus, sodium, and potassium along with a wide range of vitamins like A, B1, B12, C, D, E, niacin, folic acid, pantothenic acid, and riboflavin. They also contain essential amino acids that are needed for metabolism and general health. Seaweeds are particularly valuable as they provide approximately 54 trace elements crucial for the proper physiological functioning of the human body. These essential elements are present in colloidal, chelated, and balanced forms, ensuring their bioavailability. Seaweeds contain biologically active compounds like carotenoids, phlorotannin, fucoidan, and alginic acid, associated with preventive effects against various diseases, including inflammation, cancer, diabetes, arthritis, hypertension, and cardiovascular ailments. This has the potential to address the challenge of nutritional deficiency in India.

Thus, the strategy for seaweed cultivation is guided by the 3Es: Ecology, Economy, and Equity. It prioritizes ecological considerations to ensure the sustainable management of seaweed resources and protect marine ecosystems. Additionally, the strategy is focused on promoting economic development by creating avenues for seaweed farmers to generate higher incomes through market-oriented approaches. Finally, social equity should be a key objective, to provide equal opportunities and benefits for all stakeholders involved in seaweed cultivation, including coastal communities and marginalized groups. By incorporating these principles, the framework will foster the growth of seaweed cultivation while safeguarding the environment and promoting social and economic equity.

CHAPTER-II

ENVIRONMENTAL CONSIDERATIONS IN SEAWEED CULTIVATION

2.1 Background

India's primary seaweed cultivation methods involve vegetative propagation using fragments from mother plants ordifferent types of spores. Commercial seaweed farming in the country employs three techniques: floating bamboo rafts, lines, and tube nets. While *K. alvarezii* farming is predominantly carried out on the Tamil Nadu coast, experimental farming has been conducted in several other states and Union Territories. The introduction of *K. alvarezii* was initiated in 1984 when a fragment of the algae, then known as *K. striatum*, was brought from Japan. Seaweed cultivation in India has significant socio-economic implications, particularly for women in the Gulf of Mannar region. Agar and alginates industries, dependent on natural seaweed resources, have been traditionally important for livelihoods, with approximately 5,000 women relying on seaweed collection in this region. However, the rising economic value of *K. alvarezii* has led to an increase in its commercial cultivation.

2.2 Environmental Assessments Related to Seaweed Farming

2.2.1 Geography of the Environmental Study

Palk Bay

The Palk Bay (named after Robert Palk, Governor of Madras Presidency from 1755 to 1763) is the sea area, which is bounded on the north and west by the coastline of the State of Tamil Nadu in India, on the south by the Pamban Island of India, the Adam's or Rama Bridge (a chain of shoals) and Mannar island of Sri Lanka and on the east by the northeast coastline and the Jaffna peninsula of Sri Lanka. The Bay is 137 km long and 64-137 km wide. Although it is commonly referred to as Palk Bay, it is not typically a bay but a strait, thatconnects the Bay of Bengal to the northeast with the Gulf of Mannar to the south. The northern part of the Bay that opens to the Bay of Bengal is called the Palk Strait (Krishnan et al., 2016).

Gulf of Munnar

The Gulf of Mannar Marine Biosphere Reserve (GoMBR) was the first in South and Southeast Asia, running south from Rameswaram to Kanyakumari in Tamil Nadu, India, situated between Longitudes 78°08 E to 79°30 E and along Latitudes 8°35 N to 9°25 N. This Marine Biosphere Reserve encompasses a chain of 21 islands (two islands have sunk) and adjoining coral reefs off the coasts of the Ramanathapuram and the Tuticorin districts, forming the core zone, the Marine National Park. The surrounding seascape of the Marine National Park and a 10 km strip of the coastal landscape covering a total area of 10,500 square km, in the Ramanathapuram, Tuticorin, Tirunelveli and Kanyakumari Districts form the Gulf of Mannar Biosphere Reserve. The Gulf of Mannar has drawn the attention of conservationists even before the initiation of the Man and Biosphere program (MAB) by UNESCO in 1971. With its rich biodiversity of about 4223 species of various flora and fauna, part of this Gulf of Mannar was declared a Marine National Park in 1986 by the Government of Tamil Nadu and later as the first Marine Biosphere Reserve of India in 1989 by the Government of India. It has luxuriant growth of corals. The reefs are of narrow fringing types, located 150 to 300 m from islands and patch reefs rising from depths of 2 to 9 m and extending up to 2 km long, with a width of 50m. The Islands of GoM are divided into four groups: Mandapam, Keelakarai, Vembar and Thoothukkudi, considering the Islands' proximity to the respective locations(Figure 5).

Figure 5. Map showing the Palk Bay & Gulf of Mannar region

The Gulf of Mannar Biosphere Reserve is one of the major coral reef-forming regions along the mainland coast of India. The discontinuous barrier extends over 140 km from Tuticorin to Pamban, known as the "Mannar Barrier", which possesses a chain of 21 Islands along the length with fringing reefs around them. Diverse scientific organizations well studied the occurrence, species diversity and coral cover of Indian coral reefs. Still, the intervention of various threats on the reefs along the Gulf of Mannar, southeast coast, has been studied and reported. Institutes like NCSCM, ICAR-CMFRI, CSIR-CSMCRI, and other agencies have studied and documented the impact of seaweed cultivation on biodiversity.

2.2.2 *Kappaphycus alvarezii* Cultivation in Gulf of Mannar

(i) Studies by CSIR-CSMCRI

CSIR-CSMCRI conducted a research study from 2018 to 2019 to investigate the native diversity of seaweeds in the intertidal regions of 19 Islands in the Gulf of Mannar. The study was carried out in four monthly intervals and encompassed three seasons: the post-monsoon season (January - March), the summer season (April - June), and the monsoon season (South-West monsoon during July - September and North-East monsoon during October - December). The data collected during the study was divided into two categories based on the proximity to cultivation sites. The first category included islands located 2-8 km away from cultivation sites, while the second category consisted of islands located 30-70 km away. The analysis revealed the occurrence of 113 seaweed species near cultivation sites and 122 species far from cultivation sites. Interestingly, significant differences were observed only in terms of percentage cover ($F = 6.505$; $p = 0.013$) and species richness ($F = 10.312$; $p = 0.002$) between the two groups of islands.The Simpson diversity and Shannon Weaver indices, which are measures of species diversity, varied from 0.870 to 0.884 and 2.554 to 2.707, respectively. However, no significant differences were recorded between the two island groups regarding these diversity indices ($p > 0.05$).

The establishment of commercial cultivation of *Kappaphycus alvarezii* in the Gulf of Mannar Islands has no adverse effects on the native seaweed species (Veeragurunathanet al., 2021). The observed changes in diversity patterns can be attributed to spatial and temporal differences rather than being explicitly linked to commercial farming activities. The study provides evidence that the commercial cultivation of *K. alvarezii* does not negatively impact the diversity of native seaweed species in the Gulf of Mannar Islands.

A Bray-Curtis similarity index of 95 percent indicated the homogenous distribution of seaweed diversity. *Dictyota dichotoma*, *Halimeda gracilis*, *Padina pavonica*, *Sargassum polycystum*, and *Turbinaria ornata* were identified as the most commonly occurring species in both groups of islands. These results further reinforce the conclusion that the commercial farming of *K. alvarezii* does not affect the diversity of native seaweeds in the Gulf of Mannar Islands. Hence, the study unequivocally confirms that cultivating *K. alvarezii* for commercial purposes has no adverse impact on the native seaweed diversity in the Gulf of Mannar Islands (CSIR-CSMCRI). The change in diversity patterns is related to the spatial and temporal differences and thus could not be explicitly linked to commercial farming activities.

According to surveys conducted by the CSIR-CSMCRI, 137 seaweed species were recorded across 21 islands in the Gulf of Mannar. Among these, 48 species belonged to the green seaweed category, 48 species were red seaweeds, and 41 species were classified as brown seaweeds. The diversity indices indicated a high level of seaweed diversity in all the islands, except for Manaliputti Island, suggesting a healthy seaweed ecosystem. Krusadai Island stood out with a notably higher percentage of seaweed cover, reaching 84 percent. The islands of Vembar and Kilakkarai exhibited the highest recorded diversity compared to other island groups. Among the recorded species, *Halophila ovalis* was the only seagrass observed at Krusadai Island.

Dominant species of seaweed along Krusadai Island included *Halimeda gracilis*, *Caulerpa cupressoides, Hypnea valentiae, Lobophora variegata, Stoechospermum marigatum,* and *Gelidiella acerosa*. The study revealed that the diversity of green seaweeds was generally higher than that of red and brown seaweeds at all the locations investigated. The alga found on dead corals was observed to be in the vegetative stage, with no reproductive structures. In terms of genera, *Caulerpa* exhibited the highest number of species with a total of 18, followed by *Sargassum* with 14 species, *Dictyota*with 7 species, *Gracilaria* with 6 species, *Hypnea* with 6 species, and *Turbinaria* with 4 species.

CSIR-CSMCRI survey reports revealed that the seaweeds namely *Acanthophora spicifera*, *Boergessni aforebessii*, *Caulerpa peltata*, *C. racemosa*, *C. sertularioides*, *Chaetomorpha crassa*, *Dictyota dichotoma*, *Hypnea valentiae*, *Padina gymnospora*, *P. pavonica*, *P. tetrastromatica*, *Sargassum polycystum*, *S. tenerrimum*, *S. wightii*, *Turbinaria ornata* and *Ulva reticulata* are more dominant than *Kappaphycus alvarezii* in the Gulf of Mannar region (Mandal et al., 2010; Veeragurunathan et al., 2021). Diversity data was collected for islands located near cultivation sites (2-8 kilometers away) and those far from cultivation sites (30-70 kilometers away). The survey revealed 113 seaweed species near cultivation sites and 122 species far from cultivation sites. Notably, significant differences were observed only in percentage cover ($F = 6.505$; $p = 0.013$) and species richness ($F = 10.312$; $p = 0.002$) between the two groups of islands.

Although the occurrence of *K. alvarezii* in Indian waters has been a topic of debate, existing literature strongly supports its presence in India. The earliest recorded instance dates back to the nineteenth century (Silva et al., 1996), and subsequent reports have identified its occurrence in Port Okha (Krishnamurthy and Joshi, 1970, referred to as *Eucheuma spinosum*) and Red Skin Island in the Andaman Sea (Rao and Rao, 1999), as *Kappaphycus cottonii*).

Based on extensive peer-reviewed publications, *K. alvarezii* is considered native to Indian waters. There is no reported evidence of this species being invasive in any part of the world. The study by Conklin and Smith (2005) specifically investigated the potential invasion of *Kappaphycus* spp. on coral reefs in Kane'ohe Bay, Hawaii.It is important to note that the aforementioned study did not explicitly label *K. alvarezii* as an invasive species. While non-farmed populations of *K. alvarezii* have been reported near commercial sites in certain regions globally, and the occurrence of such populations in India should not be classified as an invasion. Therefore, it is essential to differentiate between the natural establishment of *K. alvarezii* populations and the invasive behaviour of certain species in different ecosystems.

(ii) Studies by ICAR-CMFRI

Recent studies conducted by ICAR-CMFRI focused on the distribution and diversity of marine algae in the Palk Bay and Gulf of Mannar region. The study was carried out between October and December 2021. ICAR-CMFRI examined five specific locations in the Gulf of Mannar *viz*. - Mandapam, Seeniappa Dargha, Krusadai Island, Nochyurani, and Puthumadam. The findings revealed the presence of 53 distinct species that belong to 28 genera. The dominant group was *Chlorophyta*, comprising 22 (41 percent) species, followed by *Rhodophyta* with 19 species (35 percent) and *Phaeophyta* with 12 species (22 percent). Notably, the highest species diversity was recorded at the Nochyurani station, with 32 species, followed closely by Puthumadam station with 31 species, Krusadai Island station with 30 species, and Mandapam station with 23 species. Conversely, the station at Seeniappa-Dargha exhibited the lowest seaweed diversity, with only 15 species identified. *Chlorophyta* displayed the greatest diversity among the selected stations in the Gulf of Mannar, with a total of 28 seaweed genera observed. Among these genera, *Caulerpa* (6 species) contributed the highest number of species, followed by *Gracilaria* (5 species) and *Halimenia* (4 species). Additionally, three species of seaweeds were observed from the genera *Padina*, *Sargassum, Hypnea,* and *Ulva*, while a single species was identified from the genera *Enteromorpha, Halimeda, Valonia, Valoniopsis, Lyngbya, Turbinaria, Stochospermum, Acanthophora, Amphiroa, Scinaia, Laurencia, Sarconima,* and *Portieria.*The field surveys conducted in the Gulf of Mannar region revealed that the seaweed species belonging to various genera exhibited varying levels of species abundance. At the Nochyurani station, the 32 seaweed species belonged to the genera *Caluerpa, Sargassum, Gelidiella, Enteromorpha, Valoniopsis, Padina, Lyngbya,* and *Stochospermum.* The seaweed species recorded at Puthumadam station (31 species) belonged to genera *Caluerpa, Sargassum, Dictyota, Chaetomorpha, Cladophora, Grateloupia, Enteromorpha, Valoniopsis, Padina,* and *Lyngbya*. The seaweed species recorded at Krusadai Island station (30 species) belonged to the genera *Halimeda, Caluerpa, Gracilaria, Lyngbya, Turbinaria, Hypnea, Lobophora, Scinaia, Laurencia, Sarconima, Sargassum, Portieria, Padina, Valonia, Ulva* and *Scinaia*. At the Mandapam station, 23 seaweed species identified belonged to the genera *Acanthophora, Caulerpa, Chaetomorpha, Cladophora, Dictyota, Gracilaria, Gratillobia, Halimenia, Hypnea, Lyngbya, Laurencia,* and *Padina,* while at Seniappa-Dharga station which registered, 15 seaweed species belonged to the genera *Acanthophora, Caulerpa, Chaetomorpha, Cladophora, Dictyota, Gracilaria, Halimenia, Hypnea, Lobophora, Lyngbya, Laurencia, Padina, Codium, Stochospermum* and *Turbinaria*. The Nochyurani station demonstrated the highest diversity of seaweeds from the *Chlorophyta* and *Rhodophyta* groups, while the Puthumadam station displayed the highest diversity of *Phaeophyta* seaweeds. During the surveys, the ICAR-CMFRI did not find any presence of *K. alvarezii* in the seaweed beds.

2.3 Studies Pertaining to Coral Reefs

A study by Kasinathan and Sandhya (2005) revealed that anthropogenic impacts such as sedimentation, illegal coral mining, fishing, and pollution pose increasing threats to the coral reefs in the Gulf of Mannar. The study highlighted the significant destruction of coral populations on the southern side of Pullivasal Island and the northern sides of Manauli and Hare Islands. Illegal coral mining emerged as the primary cause of reef disappearance in these areas, with observable bleaching phenomena in genera like *Montipora* and *Echinopora*. The ecological succession process observed in the aftermath of reef degradation showcased the dominance of echinoderms and seaweeds over the once-vibrant coral reefs of Pullivasal Island. Notably, prominent seaweed species such as *Sargassum* spp., *Caulerpa* spp., and *Turbinaria* spp. were found to be present on the dead corals. Additionally, excessive sedimentation was noted on some live coral patches, and extensive stretches of dead corals were observed in and around Manauli, Hare, and Appa islands.

During investigations on Manauli Island, the presence of black band disease affecting *Montipora* sp. of corals was noted. Black band disease is characterized by a distinct microbial assemblage forming a band that progressively moves across healthy coral colonies, actively causing the destruction of coral tissue and leaving behind the exposed coral skeleton. The phenomenon of coral-algal phase shift, observed in coral reefs, is attributed to a gradual increase in stress resulting from the depletion of herbivory (due to overfishing) or an elevation in nutrient levels (caused by pollution). In a study conducted by Sandhya et al. (2005), an average live coral cover of 54.9 percent was recorded, with a total of 35 species of hard corals identified along the transects. The study also documented an average bleached coral cover of 15.3 percent and a dead coral cover of 18.7 percent, resulting in an average Mortality Index of 0.22 for the reef. Among the coral species, *Acropora formosa* exhibited an "abundant" category, displaying the highest relative abundance percentage of 15.4 percent. However, the dominance of a single species was found to be absent.

(i) Studies by ICAR-CMFRI

According to ICAR-CMFRI (2016) findings, the Tuticorin Major Harbour reef was classified as "fair," as the linear scale of live coral cover measured 29.81 percent. Within the transect area, the relative abundance of live corals was primarily dominated by *Merulinidae* (74.22 percent), *Poritidae* (13.51 percent), *Dendrophyllidae* (11.85 percent), and *Acroporidae* (0.42 percent). The overall coral mortality index was determined as 0.7019, indicating an unhealthy state of the reef. Regarding specific coral families, Dendrophyllids were predominantly represented by *Turbinaria peltata*, while *Acropora muricata* and *Montipora digitata* were the dominant species among Acroporids. Merulinids were largely represented by *Goniastrea retiformis* and *Favites abdita*, whereas *Porites lutea* dominated among Poritids. Acroporids were the main component of dead corals, while Merulinids primarily dominated dead corals with algae.

Also, the ICAR-CMFRI, through its periodical survey and studies in the Gulf of Mannar and Palk Bay *viz*., biodiversity and benthic community structure of Velapertumuni Reef, Palk Bay, (Sukumaran et al., 2005), Krusadai Island, Gulf of Mannar (Sukumaran et al., 2008a), Kilakarai group of islands (Sukumaran et al., 2007) and Fringing Reef in Palk Bay (Sukumaran et al., 2008b) could not find any settlement of *K. alvarezii* in seaweed/coral beds.

(ii) Studies by NCSCM

Analysis of temporal change (2005 to 2014) in the extent of algae showed that all islands except Pullivasal and Poomarichan Islands recorded a significant increase in the extent of coverage of algae, primarily due to the extensive spread of native seaweeds *viz*., *Caulerpa* spp., *Ulva* spp., *Halimeda* spp. and *Turbinaria* spp. The reefs in Koswari and Van Islands were extensively covered by native seaweeds like *Halimeda gracilis* and *Caulerpa taxifolia* to the extent of 70-80 percent in specific.

NCSCM has conclusively reported that in the Gulf of Mannar survey, *K. alvarezii* was detected from Shingle and Krusadai islands, whereas no trace of the algae was found in Pullivasal and Poomarichan islands. In Mulli Island, *K. alvarezii* was found to be growing over the plate corals. The red alga was not found in any of the other islands other than the ones mentioned above. The presence of *K. alvarezii* in Shingle, Krusadai and Mulli, an island in the Keelakkarai Group of islands in GoM, was to the extent of 1.1, 0.572 and 0.00025 hectare, accounting for 2.12, 0.35 and 0.00022 percent of the total reef areas, respectively. In the study, colonies of *K. alvarezii* were recorded from the northern side of Shingle Island but not from the region previously reported by Edward and Bhatt (2012). The previously recorded region was found to be covered by various native seaweeds. In Krusadai Island, the *K. alvarezii* colonies were observed from all the previously recorded sites and the reef slope region of the Island, in the channel between Krusadai and the Rameswaram Island. *K. alvarezii* colonies were not recorded from the reefs of Pullivasal and Poomarichan during the current study, including the areas where they were reported earlier by Edward and Bhatt (2012). There were nine established algal colonies, with an average size of 29.936.47 cm, in the reefs of Mulli Island. Chandrasekaran et al. (2008) observed that the alga prefers the live corals as a substrate over the dead corals. In the study, it was observed that 68.57 percent of the branching corals with *K. alvarezii* were dead, implying that they are the most vulnerable life forms to the spread of this alga. The NCSCM came to the conclusion that the algal fragments from the site in Krusadai Island where experimental culture was conducted from 1990 to 2005 were the “primary source” of the spread of *K. alvarezii* in Krusadai Island based on published reports on the sequence of events related to *K. alvarezii* farming since its introduction in GoM. These pieces may have served as the “source” for additional southward dispersion along the island of Krusadai to the neighbouring islands of Pullivasal, Shingle, and Poomarichan. This red alga is said to be invasive, and its large-scale commercial cultivation site is thought to be a possible source (Ask et al., 2001). However, *K. alvarezii* has not spread over the corals/ coral reefs in Palk Bay, a region where the cultivation has been underway for over ten years, including areas predominantly occupied by the branching corals (Olaikuda region with *Acropora* spp.). This observation led NCSCM to conclude that the seaweed fragments from the farming sites in Palk Bay might not be the primary source for the reported *K. alvarezii* invasion in the Gulf of Mannar.

The published reports on the sequence of events related to *K. alvarezii* farming since its introduction in GoM led NCSCM to conclude that the ‘primary source’ of the spread of *K. alvarezii* in Krusadai Island was the algal fragments from the site in Krusadai island, where experimental culture was underway during 1990-2005. These fragments became the ‘source’ for further spreading southwards along the Island of Krusadai to the nearby islands of Shingle, Pullivasal and Poomarichan. Manual removal of *K. alvarezii* from corals poses the threat of secondary spreading (Conklin and Smith, 2005). The random and casual removal by untrained personnel could also result in the dispersal of vegetative fragments within and outside the a ected reef area, leading to the unintentional spread of the weed (Kamalakannan et al., 2014). The forest department has mediated concerted e orts to remove the algae from the infested areas manually. Unintentional or intentional human-mediated transfer might also be responsible for the introduction/spread of alga in the islands. Humans are considered important vectors for the spread of invasive species (Chivers and Leung, 2012). Mulli Island, in Keelakarai group of islands, which had established thalli of *K. alvarezii*, is located over 25 km away from Krusadai Island. However, the islands between Mulli and Krusadai, *viz*., Pullivasal, Poomarichan, Manoli, Manoliputti and Hare Islands, did not have the thalli of the invasive alga. The vegetative fragments of the alga cannot survive in deep water and will not be able to spread long distances or between islands (Russell, 1983; Smith et al., 2002). The sea around these Islands is more than 10 m deep and would limit the possibility of drift, settlement and spread of the alga. Thus, the presence of *K. alvarezii* in Mulli Island may not be attributed to the transport of fragments and their spread through water currents. The collection of seaweeds from the islands already invaded by the species and their transport through non-impacted islands could also spread this seaweed.

2.4 Global View

As per the global invasive species database, *Kappaphycus* spp.is (i) native of the Philippines (ii) alien and established in Indonesia (iii) alien and established in India. Cultivating native species does not pose a threat or attract any legal provisions. Exotic seaweed species can behave invasively if introduced to a new region having conducive biotic and abiotic conditions. Additionally, it must possess a number of properties to be classified as an invasive seaweed species. These traits are frequently opportunistic and include a quick rate of growth, a dynamic life cycle, and a high rate of recruitment, as well as physiology, size, and fitness. However, because of their complexity, the inherent mechanisms linked to the effectiveness of the biological invasion are still poorly understood. These factors make macroalgal marine invaders a hazard to estuarine and coastal ecosystems, especially when introduced in ecologically sensitive areas.

It may also be noted that *Kappaphycus* spp is reported as invasive in global data base and not *K. alvarezii* (Figure 6 and Figure 7). Given that several species of *Kappaphycus* arepresent across the globe, such generalized generic mention should not be taken as an alibi to mean *K. alvarezii*. Moreover, *K. alvarezii* has been cultivated in India for over 20 years and may not still be called an alien/exotic species. It may be noted that the green revolution was also based on crops that were non-native, but it favourably changed the agricultural scenario of India. Likewise, there are several instances where other crops were introduced in India and were farmed thereafter. *Kappaphycus alvarezii* which was introduced to the Indian coastal waters many years ago and has since been domesticated is considered ecologically safe.

Figure 6. GISD: India

Figure 7. GISD: Indonesia

2.5 Conclusive Summary of the Environmental Studies by Different Research Institutes

NCSCM, Chennai commented that the occurrence of *K. alvarezii* could also be attributed to human-mediated transfer in Mulli Island and their transport through non-impacted islands can cause secondary spread. The maximum spread of *K. alvarezii* (6 km) in the coral area was reported in Hawaii islands by alga spread over the reefs as far as 6 km after about 25 years of introduction (Rodgers and Cox, 1999) and 1 km distance in Fiji Islands (Ask et al., 2003). In India, particularly in Tamil Nadu, *K. alvarezii* did not reach the sporulation stage and never released spores. The life history of *K. alvarezii* is isomorphic, tri-phasic life cycle and needs all three phases, male, female and tetrasporphyte to complete the life history before they produce spores. Krishnan et al. (2021) reported that quantitative data pertaining to the affected parts of the reef by *K. alvarezii* and its spread in Mulli Island was negligible (0.00022 percent of reef area).

Surveys conducted by ICAR-CMFRI along the Indian coasts could not find any settlement of *K. alvarezii* in seaweed/coral beds. From the impact assessment of *K. alvarezii* cultivation on the marine environment being attempted since 1983 from the Hawaii Islands to the recent studies by CSIR-CSMCRI in Indian waters also could not observe the occurrence/establishment of non-farmed populations of *K. alvarezii* (Kaladharan et al., 2019).

Further, *K. alvarezii* reported areas other than Krusadai and Valai Island did not remain the same. After 13 years of *K. alvarezii* occurrence reports, most attachment/occurrence of *K. alvarezii* were not traced in adjacent islands, namely, Pullivasal and Poomarichan islands. Most of the published information on the occurrence of *K. alvarezii* in the Gulf of Mannar islands is through newspapers and non-peer-reviewed report/publications. In some studies, there is no technical information such as geographical co-ordinates, extent and areas of survey, quantity, etc., in their communications and have erroneous statistical interpretations.

Based on a conceptual model proposed by Colautti and MacIsaac (2004), it was concluded that the determinants, *viz*., propagule pressure, physiochemical requirements of the species and community interactions, act on exotic species to make them invasive. Therefore, it appears that the establishment of *K. alvarezii* at Krusadai Island is restricted at stage three (localized and numerically rare), as all the determinants, *viz*. seawater temperature, turbidity or seawater transparency, andpropagule pressure (due to high grazing pressure),are acting negatively. The observed occurrence of *K. alvarezii* on corals at Krusadai Island could merely be accidental, and its confinement over a relatively small area might be due to a combination of factors, particularly those mentioned above. The macro-algae forming dense beds in Palk Bay and the Gulf of Mannar were represented by *Halimeda* spp., *Caulerpa* spp., and *Ulva reticulate* spp.*K. alvarezii* was not found in any part of the reefs in Palk Bay, *viz*., Mandapam and Rameshwaram Island, despite 20 years of continued commercial cultivation.

The term invasive is gradation depending on human perception of the magnitude. The invasion process model depicts the discrete stages an invasive species passes through, which include transport, establishment, spread and impact (Julie et al., 2007). The overall analysis revealed that there are two schools of thoughts, one is *K. alvarezii*, is not in the spread/invasive stage in Palk Bay and the Gulf of Mannar region, it is merely an establishment in negligible areas. Whereas other thought it is in invasive stage and affects the sensitive benthic flora and fauna.

However, research institutes strictly discouragehuman-based activity in the core zone of the marine protected area and any ecologically sensitive areas as notified in the CRZ guidelines. *K. alvarezii* has been brought to India following proper quarantine protocols, has been cultivated in India for nearly 20 years, has now been naturalized, and thus may not still be called an alien/exotic species. The scenario of Indian agriculture has been favorably changed due to many such exotic crops that were brought and farmed thereafter. It may also be noted that *Kappaphycus* spp. is reported as invasive in the global data base and not *Kappaphycus alvarezii* in the Global Invasive species database. Given that several species of *Kappaphycus* are present across the globe, such generalized generic mention should not be taken as an alibi to mean *K. alvarezii* non-native crops. Likewise, there are several instances where other crops were introduced in India and were farmed thereafter.

CHAPTER-III

POTENTIAL AREAS FOR ONSHORE SEAWEED FARMING

3.1 Background

Seaweed farming holds significant commercial value due to its polysaccharides, bio-stimulants, and bioactive compounds, making it a valuable resource for various industries. To fully harness India's potential for seaweed farming, it is crucial to prioritize sustainable cultivation practices, technological advancements, and efficient utilization of the identified sites. The challenge lies in identifying suitable sites for seaweed farming. Research institutes conducted site selection surveys based on several criteria: proximity to the shoreline, intertidal and sub-tidal zones, previous farming activity, current and tidal exchange, wave action, water quality parameters, and absence of silt deposits and freshwater runoff. Additionally, sites were chosen to avoid hindering existing fishing and allied activities.Feasible locations for seaweed cultivation along the Indian coastline and an inventory of the possible areas that are not prone to environmental concerns of coral reef damage will be an integral component of seaweed value chain development in the country.

The sites identified by MoEF&CC-NCSCM, ICAR-CMFRI and CSIR-CSMCRI were categorized into green zones (>1 km from CRZ-IA), amber zones (up to 1 km from CRZ-IA), and blue zones (within CRZ-IA and ESA), with 24,707 hectares identified as suitable for seaweed farming, including 3,999.37 hectares classified as green zones, 14,076.77 hectares as amber zones, and 6,631 hectares as blue zones.

3.2 Methodology

The criteria for identifying the potential (onshore) seaweed farming siteshave been based on the suitability of the site for the cultivation of seaweed and the availability of the site free from any environmental concerns. The criteria adopted are given as follows:

i. Nearshore areas within 1000 m distance from the lowest low tide line.
ii. Intertidal and sub-tidal zones with a rocky or sandy bottom.
iii. Previous existence of seaweed farming activity.
iv. Seaweed collection from natural seaweed beds.
v. Sheltered areas with adequate current and tidal exchange.
vi. Areas with moderate wave action.
vii. Areas free from silt deposits.
viii. Optimum basic water quality parameters considered:
   - Salinity (28-38 ppt),
   - Sea surface temperature (26-31°C),
   - pH (6.5-8.5) and transparency (2-6 m),
   - Minimum water depth.
ix. Areas away from fishing harbour/landing centre.
x. No hindrance to existing fishing, fishing spaceand other allied activities.
xi. Accessibility for inputs, transportation, marketing, watch and ward.
xii. Areas away from freshwater runoff and domestic or agro-industrial effluents discharge.
xiii. Apart from these, cyclones effect (for example in state of Odisha) maybe taken into consideration.

MoEF&CC-NCSCM has completed the preparation of maps of potential seaweed cultivation sites along the entire coast of India based on the inputs provided by ICAR-CMFRI and CSIR-CSMCRI. MoEF&CC-NCSCM mapped all the sites provided by both institutions and has added value with the thematic layers for-

i. CRZ-IA areas,
ii. Areas at least 1km away from sensitive ecosystems,
iii. Shoreline change map,
iv. Structures on the coast and
v. Village boundary.

On a precautionary note, an Ecologically Sensitive Area (ESA) has been incorporated into the identified sites. Based on the presence and the vicinity of CRZ-IA, the potential seaweed farming sites were categorized into three Zones:

a. **Green zones**: sites located > 1 km from CRZ-IA. These sites are suitable for farming as they are more than 1 km away from sensitive ecosystems.
b. **Amber Zones**: sites located from the seaward side of CRZ-IA up to 1 km. These are locations with sensitive ecosystems close to the CRZ-IA area. Caution should be exercised while undertaking farming of seaweeds.
c. **Blue Zones**: Sites within CRZ-IA- ESA.

3.3. Output

A total of 333 sites were identified by ICAR-CMFRI, out of which trial / farming activities had beencarried out in 78 sites. A total of 51 sites were identified by CSIR-CSMCRI, out of which trial / farming activities are carried out in all the sites. It maybe noted here that the sites and area identified below is not exhaustive. Potential sites and area have been identified statewise/union territorywise (Table 1).

Table 1. Potential area for seaweed farming[1]

State / Union Territory	ICAR-CMFRI		CSIR-CSMCRI	
	Area (In hectares)	No. of sites	Area (In hectares)	No. of sites
Andhra Pradesh	1332.00	37	23	3
Andaman & Nicobar Islands	-	-	16.5	7
Diu	404.47	2	-	-
Goa	119.19	4	8.754	3
Gujarat	10582.13	13	122	7
Karnataka	1273.38	11	6.67	3
Kerala	79.67	7	7.86	1
Lakshadweep	212.80	11	-	-
Maharashtra	2715.90	10	155.41	3
Odisha	1483.76	14	-	-
Puducherry	382.53	23	-	-
Tamil Nadu	5217.24	196	115	24
West Bengal	448.84	5	-	-
Total	**24,251.90**	**333**	**455.19**	**51**

[1] District-wise and site-wise details is enclosed in Annexure-II.

3.4 GIS Based Portal for the Mapped Seaweed Cultivation Sites

A GIS-based portal for viewing the mapped seaweed cultivation sites has been developed. It is possible to include or exclude one or more of the following layers on the portal for viewing. A screenshot of the layers provided is given below in Figure 8.

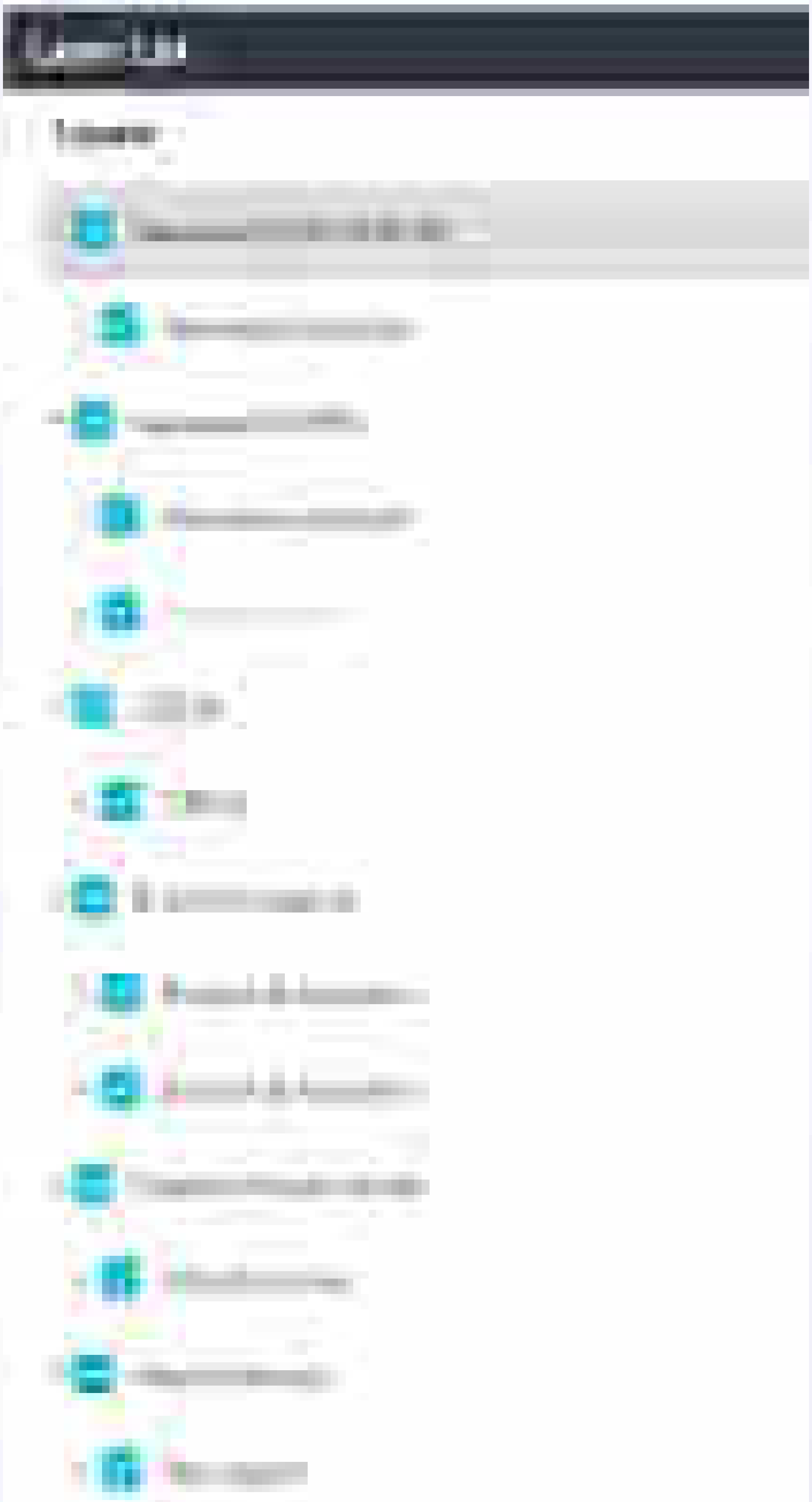


Figure 8. Screenshot of GIS-based portal showing layers incorporated

The portal could be accessed at the following link:

https://gisportal.ncscm.res.in/portal/apps/webappviewer/index.html?id=de0da170e52c44e996d-36f5cf5e1e0fa

The state wise potential area for seaweed farming is shown from Figures 9 to 20.

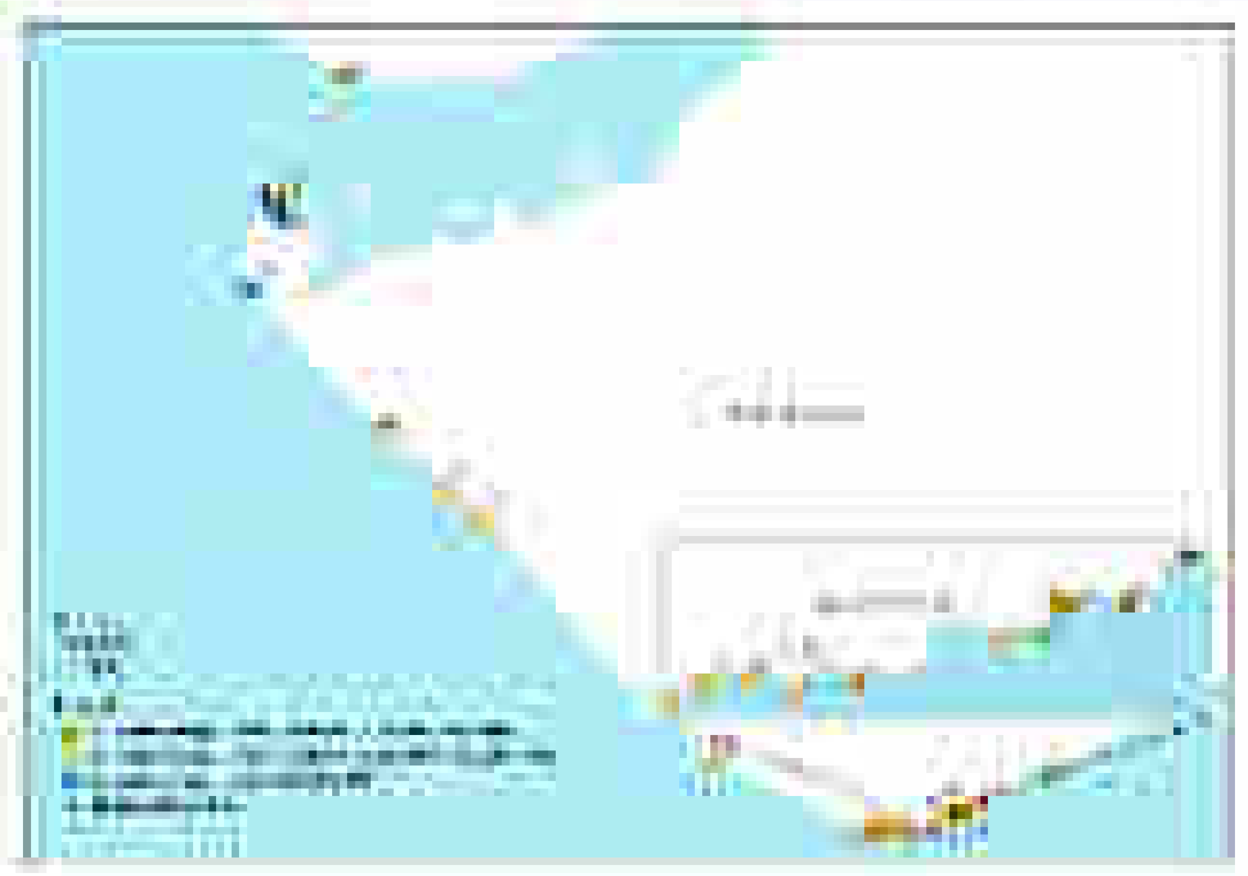


Figure 9. Potential area for seaweed farming in Gujarat & Diu

Figure 10. Potential area for seaweed farming in Maharashtra

Figure 11. Potential area for seaweed farming in Goa

Figure 12. Potential area for seaweed farming in Karnataka

Figure 13. Potential area for seaweed farming in Kerala

Figure 14. Potential area for seaweed farming in Lakshadweep

Figure 15. Potential area for seaweed farming in Tamil Nadu

Figure 16. Potential area for seaweed farming in Puducherry

Figure 17. Potential area for seaweed farming in Andhra Pradesh

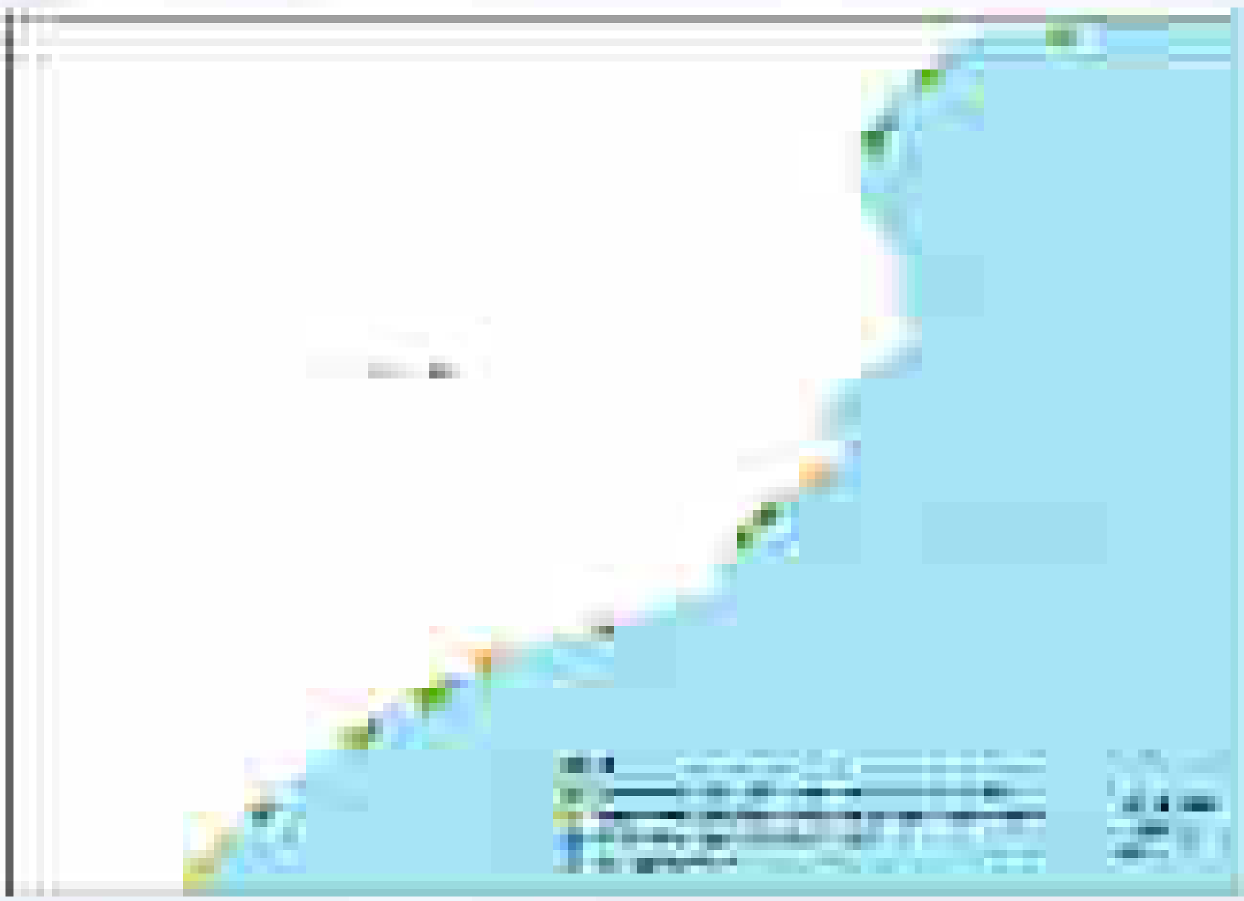


Figure 18. Potential area for seaweed farming in Odisha

Figure 19. Potential area for seaweed farming in West Bengal

Figure 20. Potential area for seaweed farming in Andaman & Nicobar Islands

CHAPTER-IV

TECHNICAL AND ECONOMIC FEASIBILITY OF ONSHORE SEAWEED FARMING

4.1 Introduction

The primary focus currently in India is cultivating *Kappaphycus alvarezii* (*K. alvarezii)*, a red algae species that produce carrageenan, a commercially important polysaccharide and bio-stimulant (Trivedi et al., 2023). While cultivation technologies for other seaweed species have been developed, *K. alvarezii* is favoured due to its higher yield and market price. However, the current dry seaweed production has declined from a peak yield of 1,500 tonnes to 400-500 tonnes per year. Efforts are underway to develop seed banks and quality planting material through tissue culture and improve genetic traits for enhanced farming. Various farming technologies have been developed, including floating rafts, net-tubes, long-lines, and cage-based integrated multi-trophic aquaculture systems.

In Lakshadweep, *Gracilaria edulis (G. edulis)* farming has been gaining momentum in recent years. Different seaweed species have different characteristics consequently other valuations in the market. Similarly, they have additional yield and harvesting cycles. Therefore, it becomes imperative to understand their economics before venturing into cultivation. In this chapter, we discuss in detail the economics of two important seaweed species namely K. *alvarezii* and *G. edulis* (Source: CSIR-CSMCRI and ICAR-CMFRI).

4.2 *Kappaphycus alvarezii*

One of the most significant commercial sources of carrageenans, which are gel-forming, viscosifying polysaccharides, is the red algae species *K. alvarezii*. This alga can grow up to 2 metres long and is green or yellow in colour. It grows quite quickly, doubling its biomass within 15 days of culture. Carrageenan is utilised as a gelling, thickening, and stabilising agent in a wide range of commercial applications, including frozen desserts, chocolate milk, cottage cheese, whipped cream, instant goods, yoghurt, jellies, pet foods, and sauces. Carrageenan is also employed in medicinal formulations, cosmetics, and industrial uses such as mining. CSIR-CSMCRI pioneered the cultivation of *K. alvarezii* in India, heralding an era of commercial seaweed farming in India.

Production has increased significantly from 21 tonnes (dry) in 2001 to 1490 tonnes (dry) in 2013, with a buying value ranging from ₹4.5 to ₹35 per kg (dry) besides 7,65,000 man-days of employment and an annual turnover of roughly ₹2 billion, India is quickly developing as a significant production centre in Southeast Asia for *K. alvarezii* production (Mantri et al., 2017). The socioeconomic benefits of using this seaweed are tremendous.

4.2.1 *Kappaphycus alvarezii* Farming Techniques

Along the Tamil Nadu coast, bamboo rafts and monoline seaweed farming techniques are widely used. In coastal states such as Andhra Pradesh and Gujarat, the tube-net technique is suitable. When the tube-net technique is combined with open sea cage farming, as in the case of Integrated Multi-Tropic Aquaculture (IMTA), seaweed grows at a faster rate than it does in a tube-net monoculture. Tube-net technique has overwhelmingly favourable socio-economic advantages as it incorporates the idea of resource integration and maximum utilization, benefitting fisher folks. Harvesting species such as *Eucheuma* spp., *Gracilaria* spp., *Kappaphycus* spp., *and Porphyra* spp. has been demonstrated to benefit diverse communities. The various seaweed farming techniques adopted in Tamil Nadu are shown in Figure 21.

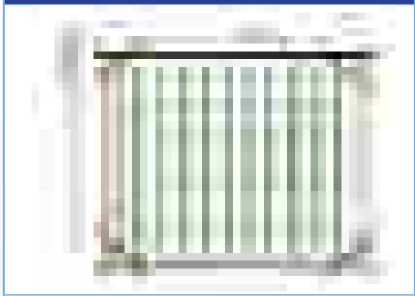
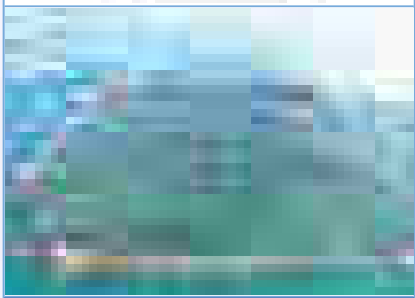
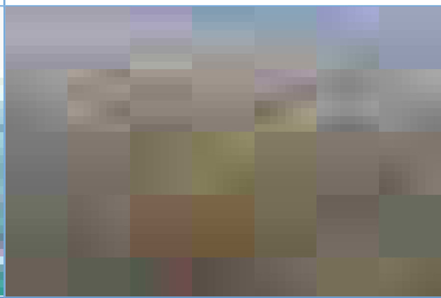
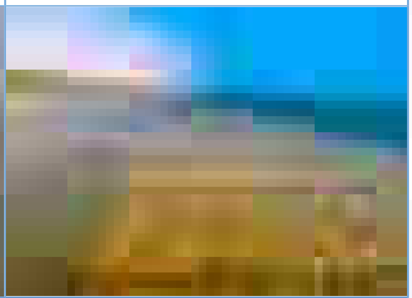
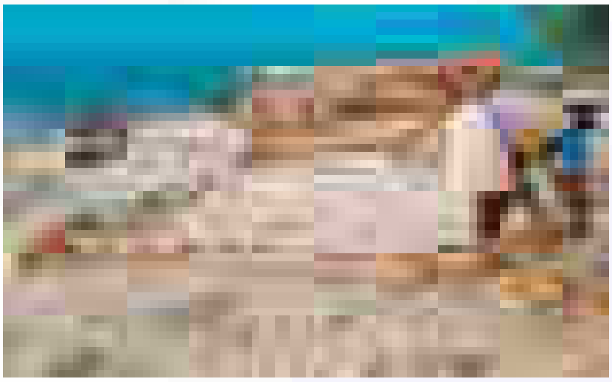
Bamboo Raft	Monoline	Tube-net
		
		
In calm and shallow places, the floating bamboo raft technique (12 feet x 12 feet bamboo poles) is ideal.	In moderate wave action, shallow depth, less presence of herbivorous fishes, the monoline technique is ideal.	The tube net technique is being adopted in places with higher wave actions.

Figure 21.Seaweed farming techniques in Tamil Nadu

4.2.2 Good Management Practices in Seaweed Farming

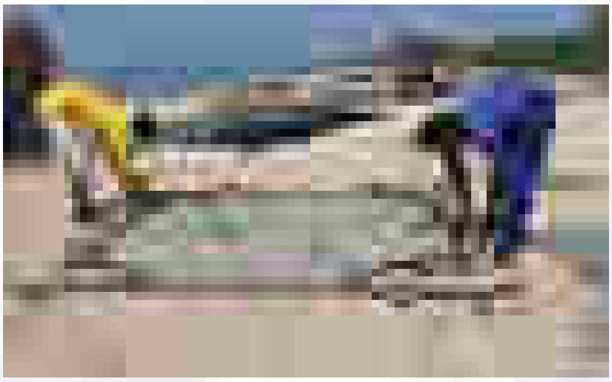
In order to maximise the productivity and production, ICAR-CMFRI and CSIR-CSMCRI have developed various good management practices for the different techniques of cultivation. They are elaborated below (Table 2 to 4).

Table 2. (a) Bamboo raft technique



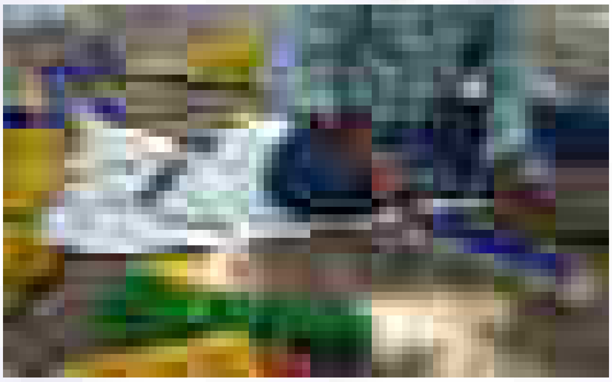
Hollow bamboo poles of 3-4" diameter for a 3.6 m x 3.6 m main frame and 1.2 m x 1.2 m diagonals must be chosen and attached using 4 mm rope.

Bamboos with natural holes, fissures, and soon must be rejected.



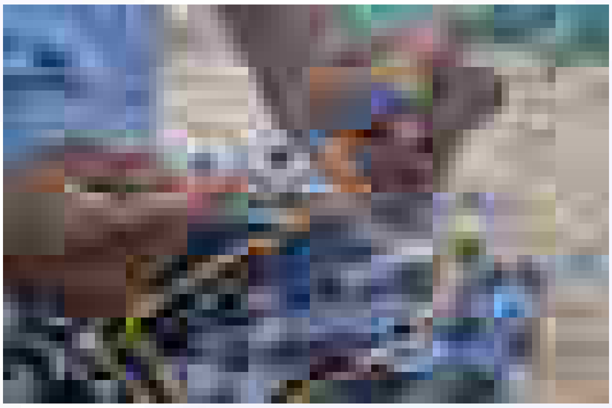
3 mm or 3.5 mm polypropylene twisted rope can be cut into 20 bits each ranging in length from 4.0 - 4.5 m for seeding.

HDPE fishing nets that have been damaged must be rejected.

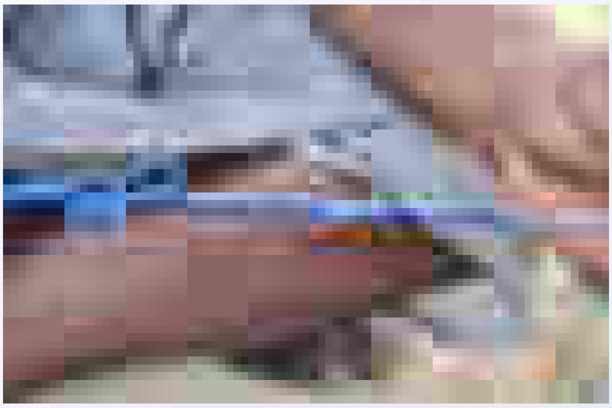


Cut the long braider into 20 pieces (for 20 plantation ropes) so that 400 pieces of HDPE braider with a length of 25 cm each can be made.

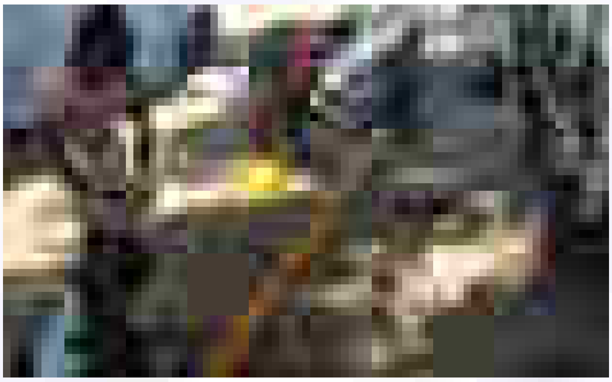
Damaged ropes have to be rejected.



Each braider should be twined at 15 cm intervals (on the 4.5 m length polypropylene twisted plantation rope). This allows 0.5 m on either side for fastening on the pole.

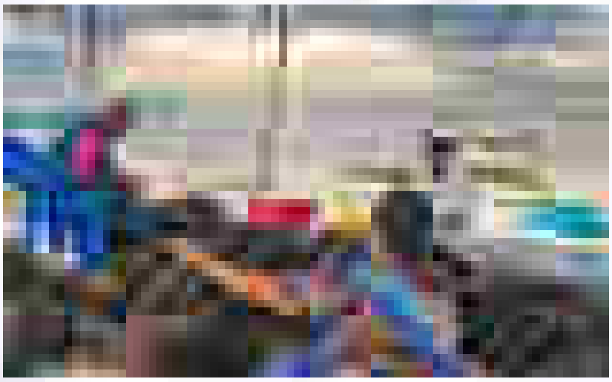


Damaged braiders have to be rejected.



To keep seaweeds from grazing, a used HDPE fishing net 4 m x 4 m must be fastened to the raft bottom using 2 mm rope.

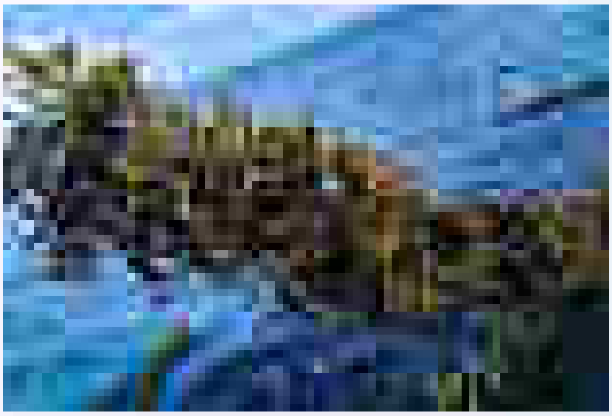
Unhealthy seeds should be rejected.



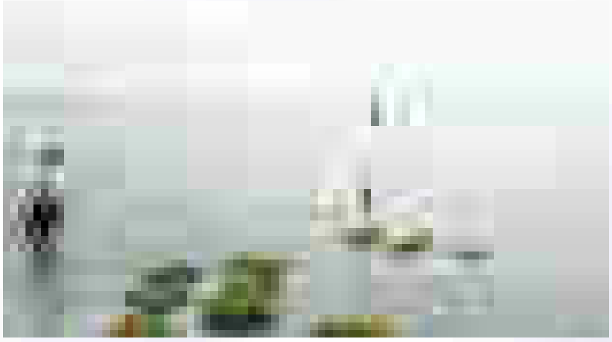
Seeding should be done on the beach or on land, ideally in the shade.

Seed material should not be placed in open places which are exposed to direct sunlight, rain, temperature, and humidity fluctuations. This would impact the quality of seed material.

A cluster of five rafts is connected by 6 mm rope. The cluster is positioned at near shore region having depth of 1.0 - 1.5 m. This is done using a 30 kg anchor tied with 12-14 mm rope.



400 rafts of 12 feet x 12 feet size are excellent forone hectare of land. This allows for adequate space between the rafts for proper seawater circulation, maintenance, and other farm operations.



Seedlings brought from other districts/ states should be placed in a clean net bag and stored at the bottom of the sea (1-2 m depth) for a few days before planting.

Total of 150-200 g of seaweed fragments are tied at 15 cm intervals throughout the length of the rope. A total of 20 seaweed fragments are linked together in a single rope, and 20 of these ropes are strung together in a raft. Seed needed for this is 60-80 kg.

Source: Johnson et al., 2023a

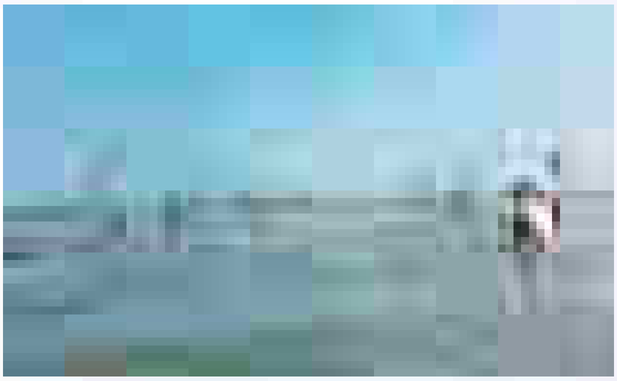
(b) Monoline technique

Based on the location, the dimensions of monoline units will vary. Procedure followed in Ramanathapuram district of Tamil Nadu is depicted below in Table 3.

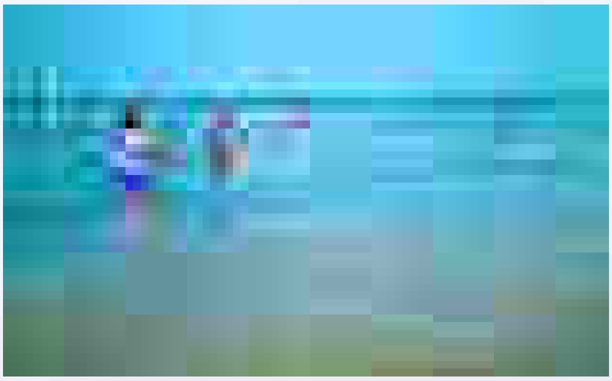
Table 3. (b) Monoline technique

Casuarina/eucalyptus poles of 3-4" diameter and 10 feet length, free of natural holes, fissures, and so on, should be chosen.

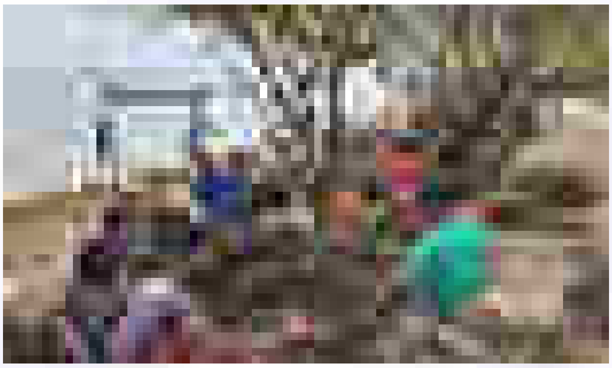
Poles with natural holes, fissures, and other damage should be refused.



Four casuarina poles of above dimensions are placed at 10-20 feet intervals in each corner for one unit.

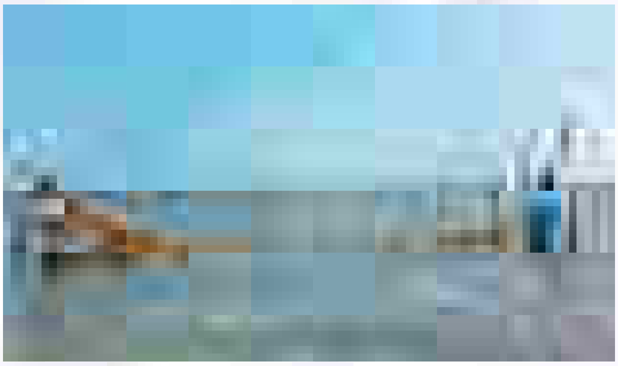


The seaweed seedling rope is linked on two sides with 6 mm rope.



Total of 150-200 g of seaweed fragments are tied at 15 cm intervals throughout the length of the rope (6.75 m).

Each rope has floats tied to it to increase its floatability.



The total seed consumption per monoline unit is 60-80 kg.

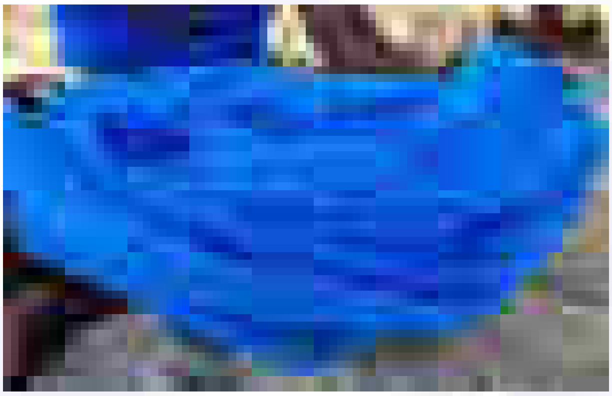
A single rope is made up of 40 seaweed bits.

The monoline is oriented parallel to the water movement or beach. This protects seaweeds and casuarina poles. It also reduces the attachment of floating debris.

One segment (120 feet long and 20 feet wide) equals ten monoline units (in terms of production, one monoline unit equals one raft).

Source: Johnson et al., 2023a

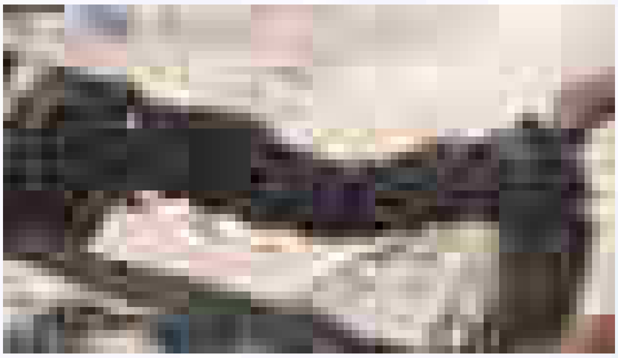
Table 4. (c) Tube net technique



Tube nets (25 m length, 10 cm diameter) can be produced from HDPE food grade nets (1.5 cm mesh size).

Damaged nets should be rejected.

The tube nets are held floating in the water column below the surface. Sufficient number and size of floats are placed at regular intervals. Anchor stones (about 30 kg) are used at each end to hold the tube nets steady in the water column; if required, additional anchors can be fixed in between.



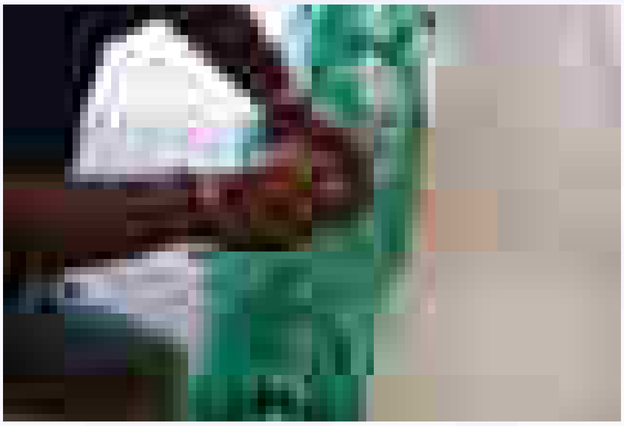
A 15 kg fresh weight seed material is put into the tubes using a 1.0 - 1.5 m long plastic pipe that acts as a funnel or hopper. For efficient seeding, the pipe diameter should be slightly smaller than that of the tube net. The plastic pipe is inserted into the tube net and the entire tube is pulled down, so that the mouth of the plastic pipe stands out of the tube. The tube net is carefully pushed down from the bottom of the plastic pipe, so that seedling material is placed into the tube sequentially, with no gaps between the seedlings. This technique is repeated until the entire tube net has been seeded with algal biomass. The tube nets are closed at both ends with rope to prevent material being lost.

(d) Sea cage-based tube net technique

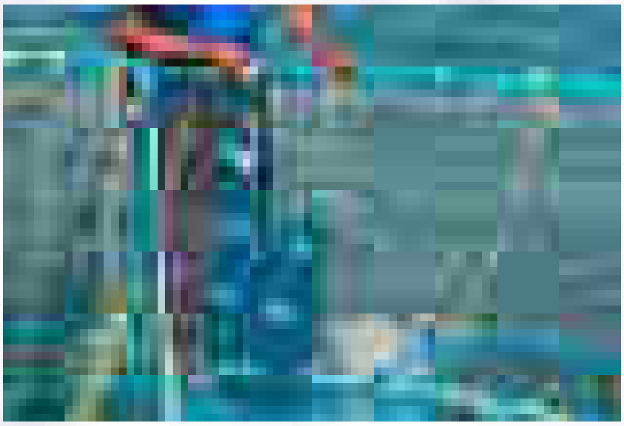
First activity involves site selection and installation of sea cage by stocking it up with marine finfish species. Preparation of the tube net for installing in the cage should be done using fishing nets of square mesh (10 mm) of 5 m length and 12-15 cm diameter. An average 1000 g of good quality seed material can be placed in each net-tube. PVC pipe cut-outs are placed at regularintervals of 45 cm for maintaining the firmnessof the tube net structure. The ends of the tube nets should be tied to the cage rings to hold the structure steady in thewater column. A total of 5 tube nets of 5 m length for one sea cage of diameter 6 m can be installed. The process is depicted in Table 5.

Table 5. Sea cage-based tube net technique

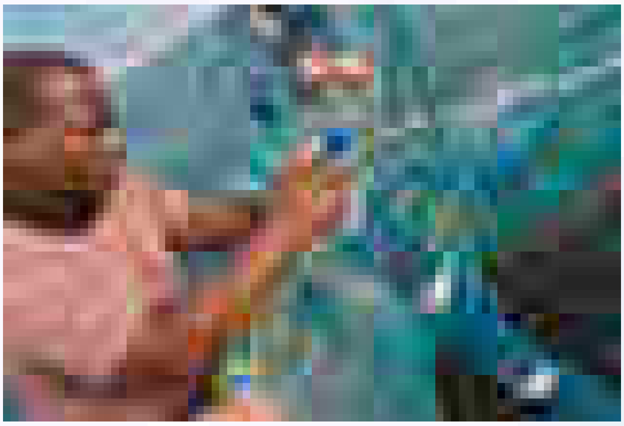
Selection of seaweed planting material.



Tube-net preparation in process.



Tube-net preparation in process.

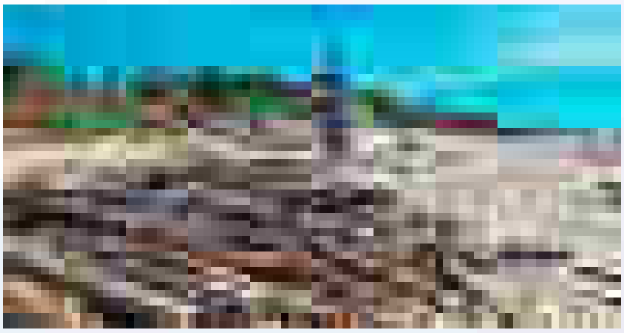


Tying of the ends of tube net to the cage ring.

4.2.3 Maintenance of Seaweed Farming

Maintenance plays a crucial role in ehancing productivity of seaweed farms. Adoption of best possible practices in maintenance (Figure 22) is crucial at every stage of the seaweed life cycle. The following practices for maintenance of seaweed farming are suggested.

- Seaweeds need a gentle care.
- Daily visit to the farm is necessary.
- Broken-off,missedseedlingsshouldbereplaced periodically.Sediments attached to the plants and ropes have to be removed regularly.
- Broken and drifted plants have to be removed periodically from the farming site.
- Damaged bamboo/casuarina poles have to be replaced periodically.
- After 1 - 2 years of culture period, the unusable bamboo poles, ropes, braiders, nets should be disposed properly. They should not be left in the sea or at the shore.



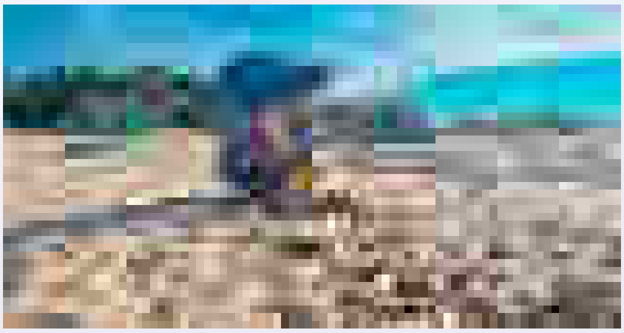


Figure 22. Maintenance of seaweed farming

Management of Disease

"Ice-ice" is the only disease reported in seaweed farming (Figure 23).It is caused probably due to abiotic stress like low salinity, high temperature and low light intensity.

Figure 23. Management of disease in seaweed farming

Management of Epiphytism

Epiphytism is the attachment of undesirable seaweeds to the cultured species which usually occur at theonset of monsoon brought by change in water temperature, trade wind and water current. The branches will show the symptoms of whitening and eventually disintegrate which may result in crop loss. If this is observed, entire crop has to be harvested and farming has to be restarted with new seedlings. The drifted seaweeds compete for space, nutrient and sunlight with the cultured species. Other seaweeds attached to the cultured species have to be removed periodically.

4.2.4 Postharvest Handling

Seaweeds are ready to be harvested in 45 days (Figure 24). To avoid contamination by sand/silt, collected seaweeds must be dried on raised drying platforms.Impurities such as stones, shells, and other foreign matter can be cleansed when drying. During rainy seasons, harvested and dried seaweeds must be covered with tarpaulin sheets. After drying, seaweeds can be put in sacks and stored in a clean, dry environment. Seaweeds (either dry or wet) are shipped to industries for commercial uses (Figure 25).

Figure 24. Harvesting of seaweed

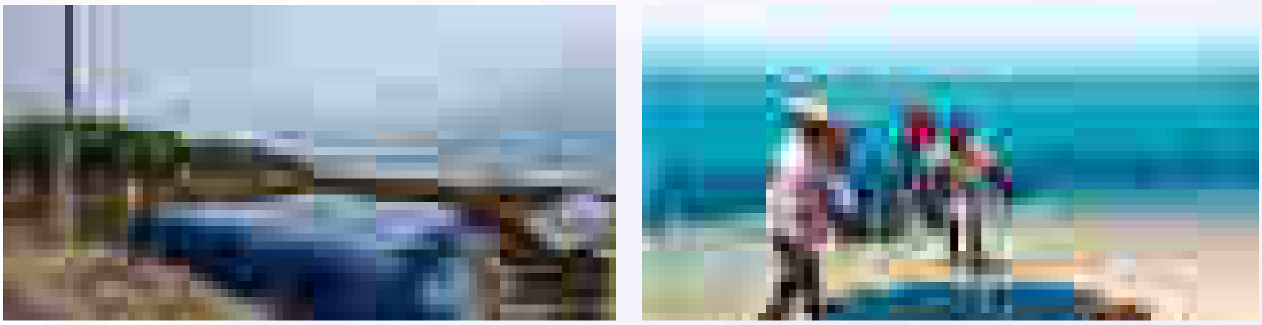


Figure 25. Postharvest handling of seaweed

4.3 *Gracilaria edulis*

Gracilaria edulis (G. edulis) is commonly used in the manufacturing of food-grade agar. To increase biomass production, *G. edulis* cultivation was carried out using floating raft technique (Figure 26). Research was conducted to study the seasonality of growth, growth rate differences in different locations, subtidal (off-shore) and intertidal (near-shore) cultivation, and the seasonal occurrence of epiphytes. January-February had the lowest biomass (1.50±0.1 kg fresh weight per m^2) and daily growth rate (DGR) (2.60±0.1 percent per day), which were substantially different ($P<0.001$) from other maximum growth periods. The biomass varied from 1.6 - 2.6 kg fresh weight per m^2. DGR (3.6-5.9 percent per day) was more at Ervadi but not substantially different ($P>0.05$). Cultivation in the subtidal zone produced considerably more biomass (12.50±0.9 kg fresh weight per m^2) and DGR (7.40±0.4 percent per day) than cultivation in the intertidal region (4.4±0.4 percent per day). *G. edulis* growth has been found to be hampered by epiphytes. In April and August, a maximum of 15 epiphytic algae were found, and a minimum of 7 in February. The results show that *G. edulis* can be successfully cultivated for 8 months of the year, with maximum growth rates from November to December (Ganesan et al., 2011). Cultivation in the subtidal zone, harvest after 60 days of growth, and weeding of epiphytic algae on a regular basis all boosted productivity. The ICAR-CMFRI has been conducting seaweed farming trials on several Lakshadweep islands from August, 2020 as part of the ICAR-sponsored National Innovations in Climate Resilient Agriculture (NICRA) project. The Lakshadweep administration chose bamboo, a natural material, for scaled-up demonstration farming of *G. edulis.*

Figure 26. G. edulis cultivation using bamboo raft technique

4.4 Economics of Cultivation: *K. alvarezii* v/s *G. edulis*

The crop life of *K. alvarezii* is 45-60 days, four to six crops or cycles (6 to 9 months) can be harvested annually. In 45 days, a 150 g seedling grows to 500 to 1000 g. Seed required for one raft (12 feetx 12 feet)and tubenet (25 m length) is 60 kg and 15 kg, respectively. The harvested seaweed has an average dry weight percentage of 10 percent. Farmers currently receive ₹ 16/- for fresh seaweed and ₹ 70/- for dried seaweed, respectively.

G.edulis farming takes 45 days to complete, five to six cycles (9 months) can be harvested annually. In 45 days, 50 g seedling can grow to 500 to 1500 g. Seed requirement for one raft (12 feet x 12 feet size) is 20 kg. The harvested seaweed has an average dry weight percentage of 15 percent. Farmers receive ₹ 20/- per kg of dried seaweed. The economics of *K. alvarezii* (Aquaculture 2022; 551: 737912) and *G. edulis* (Aquaculture International 2022; 30: 1505-1525) farming are compared below in the Table 6.

Table 6. Economics of *K. alvarezii* v/s *G. edulis* farming

S. No.	Components	*K. alvarezii*	*G. edulis*
1.	Gross seaweed production (wet weight in kg per raft per year)	1,000 kg	2,000 kg
2.	Number of crops per year	4	5
3.	Seaweed to be retained for usage as seed material in next year	240 kg	100 kg
4.	Net seaweed production (wet weight in kg per raft per year) (1 minus 3)	760 kg	1900 kg
5.	Dry weight proportion	10 percent of wet weight	15 percent of wet weight
6.	Weight of dry seaweed	76 kg	285 kg
7.	Price of dry seaweedweight per kg	₹ 70	₹ 20
8.	Total revenue generated per year per raft	₹ 5,320	₹ 5,700
9.	Annual total cost of production (including capital costs) per raft	₹ 2,000	₹ 2,578
10.	Net revenue per raft per year (8 minus 9)	₹ 3,320	₹ 3,122
11.	Total net revenue in dry weight per year	45 x ₹ 3,320 = ₹ 1,49,400/- (for 45 rafts)	25 x ₹ 3,122 = ₹ 78,050/- (for 25 rafts)
12.	**Net revenue from one hectare (400 rafts) in dry weight per year**	**₹ 13,28,000/-**	**₹ 12,48,000/-**

Source: ICAR-CMFRI

Native species (*Gracilaria*) are economically attractive, if biomass processed is used fordeveloping multiple products. The yield for *K. alvarezii, G. edulis* and *G. debilis* is 16.7-27.7, 3.75 and 7.5 kg per square metre of raft, respectively. Thus, it is apparent that the volume of the feedstock obtained per unit area, say one hectare is much higher for *K. alvarezii* than other species. Thus, economic feasibility is several folds high for *K. alvarezii*. The labour involved per unit area for both *K. alvarezii* and *Gracilaria* (agarophytes) is similar. Thus, if a higher price is offered to agarophyte seaweeds, it would make more people opt for it.

4.5 Cultivation of Other Seaweed Species

As discussed in the previous sections of this chapter, the production, profits, revenue and applications from seaweed differ significantly due to their characteristics. About 180 species ofGracilaria occur in the world, of which 32 species are reported from India. Among these, six species, namely *Gracilariacrassa, Gracilaria corticata, Gracilaria dura, Gracilaria edulis, Gracilaria fergusonii,* and *Gracilaria foliifera*, have the potential for agar production (Krishnamurthy, 1991). It becomes imperative to understand the significance of cultivating native promising seaweed species. They are discussed in brief below.

4.5.1 *Gracilaria dura*

Gracilaria dura (*G. dura)* has the potential to be a commercially viable source of agarose and agar in India. As a source of agarose with gel strength of 2200 g per cm^2, a gelling temperature of 30°C, and a sulphate concentration of 0.15 percent, *G. dura* is of great interest (Kavale et al., 2022). The west coast of India is the only area where *G. dura* is found. Experimental cultivation of *G. dura* was started along the southeast coast of India using tubenet, bottom-net, net-bag, net pouch (net techniques) and bamboo raft techniques (Figure 27). The tubenet technique produced the maximum biomass (1.764 kg fresh weight per m^2, DGR of 3.748 ± 0.91 percent), followed by the floating bamboo raft (1.05 kg fresh weight per m^2, DGR of 2.61 ± 0.45 percent) and bottom-net bag (0.904 kg fresh weight per m^2, DGR of 3.17 ± 1.71 percent) techniques (Veeragurunathan et al., 2015).

The net techniques had higherestimated revenues (USD 529 per month per hectare) than the other techniques studied, owing to the minimal manpower demand, ease of maintenance, reduced seedling loss, and rapid growth rate. The tube-net technique was recently used in an initial cultivation effort for *G. dura* along the Simar, Gujarat coast in northwest India. Seed material (10 kg fresh) was uniformly loaded in 25 m tubenets produced from fishing nets, sealed at both ends with polypropylene rope, and transplanted in rows to shallow coastal waters with anchor supports and floats. *G. dura* grew at a DGR of 2-3 percent, yielding 30-35 kg of fresh biomass in 40-45 days.

Figure 27: Different techniques of *G. dura* cultivation: (a, b) raft, (c, d) bottom-net bag, (e, f) HRT, (g, h) net-bag and (i, j) net-pouch; (a, c, e, g, i) with initial seedlings, (b, d, f, h, j) with fully grown plants before harvesting

4.5.2 *Gracilaria debilis*

Gracilaria debilis (*G. debilis)* is a commercially important red alga used in the manufacturing of medicinal agar. CSIR-CSMCRI cultivated *G. debilis* using floating bamboo raft technique along India's southeastern coast. Biomass yield, growth rate, and agar properties from each harvest, followed by bench-scale agar characterisation and economics was assessed (Figure 28). The first harvest (November-December) in both year-1 (11.02±2.08 kg fresh weight per m^2) and year-2 (7.17±3.95 kg fresh weight per m^2) yielded higher biomass and DGR (3.59±0.4 percent and 4.17±0.96 percent in year-1 and year-2, respectively).

During the monsoon season (July-August), biomass yield and DGR were at their lowest level. There was no discernible trend in the yield and gel strength of the extracted agar, which were 14-32.6 percent and 300-866 g per cm^2, respectively. This study confirmed that year-round production of *G. debilis* utilising the raft culture technique with six harvest cycles per year is achievable in Indian waters. A single operator's annual income was estimated to be USD 141, with a break-even point per acre achievable in 126 days (Veeragurunathan et al., 2019).

Figure 28. ***G. debilis*** **(two strains) cultivated using the bamboo raft technique.**

4.5.3 *Hypnea musciformis*

Hypnea musciformis (*H. musciformis)* is a native carrageenophyte that produces kappa-carrageenan. Natural beds of *H. musciformis* can be found along the shorelines of various islands in the Gulf of Mannar. Krusadai Island's lagoon waters were chosen for pilot-scale cultivation of *H. musciformis* using the monoline method. Actively growing apical sections of *H. musciformis* weighing 2-2.5 g (fresh weight) and measuring 5 cm in length were put between the braids of 20 m long coconut husk coir ropes. The ropes were secured to wooden pegs and buoyed by plastic floats. A total of 2000 m of coir ropes were seeded and planted in ten plots, each with ten ropes 20 m long. Hypnea was picked every 25 days till it reached a length of 30-35 cm. Thalli was trimmed, allowing fragments to sprout. Harvests ranged from 250 to 300 g fresh weight per metre of rope. A total biomass of 38-40 tonnes per hectare per year (fresh weight) was obtained from fifteen harvests every year (Ganesan et al., 2006).

4.5.4 *Gelidiella acerosa*

Gelidiella acerosa (G. acerosa) is the preferred source of raw material for the production of pharmaceutical and bacteriological grade agar with a gel strength varying from 850 to 2200 g per cm^2 (Ganesan et al., 2015). Indian agar processors produce an average of 100 tonnes of pharmacological-grade agar from *G. acerosa*. Long-line ropes, single rope floating, coral stone culture, and concrete stonewere some of the techniques initially used. They resulted in low biomass yields and were difficult to manage in terms of planting, monitoring and harvest practices. Therefore, it became necessary to develop improved techniques that could yield higher biomass with easier cultivation operations. The bamboo raft technique successfully used for the commercial cultivation of *K. alvarezii* was adopted for *G. acerosa,* yielding significantly higher harvested biomass than previous techniques. The bottom culture technique was developed to enhance the bamboo raft method by tying approximately 2 g of seedlings to nylon thread, which was wound around the stones (15-70 cm^2 area and 100-200 g weight) and hung 5 cm below the polypropylene ropes (3 mm diameter) (Ganesan et al., 2009) (Figure 29).

The polypropylene ropes were tied across the 1.5 m x 1.5 m bamboo frames. The algal thalli were oriented upwards by the dangling ropes. Ten polypropylene ropes per square raft (2 m x 2 m) were used to link eight infected stones to each rope. Each raft received 160 g fresh biomass, which equated to 71 g fresh weight per m^2. Harvesting included cutting erect thalli while leaving the basal sections on the stones to grow further. The stone-modified raft technique resulted in three harvests per year, with each harvest yielding 8-15 kg fresh weight per raft (Ganesan et al., 2011).

Figure 29. Bottom culture method using a cement block technique.

4.5.5 *Sarconema filiforme*

Sarconema filiforme (S. filiforme) is primarily utilised in the manufacture of carrageenan. For the first time, the CSIR-CSMCRI reported suceessful cultivation of the red alga *S. filiforme* and carrageenan content harvest at a 25-day growth period using floating rafts along the southeast coastof India (Figure 30) (Ganesan et al., 2014).

During the study, maximum biomass density (2.28±0.03 kg fresh weight per m^2) and DGR (11.63±0.06 percent) were observed from August-September each year, and these values were significantly different. Harvesting at the end of the 25-day culture period resulted in the maximum biomass (4.24±0.95 kg fresh weight per m^2). In contrast, plants harvested after 20 days had a greater DGR (13.20±0.20 percent), which was significantly different from plants harvested after 30 days. Biomass density (2.22-6.46 kg fresh weight per m^2) and DGR (5.0-10.91 percent) was significantly higher at Ervadi than at Thonithurai ($P<0.001$). A presence of hybrid lambda and iota carrageenan was observed using physico-chemical, infrared, and nuclear magnetic resonance spectral studies of extracted carrageenan. The farmed material produced more carrageenan than the wild stock of *S. filiforme* from Indian rivers.

Figure 30. ***S. filiforme*** **cultivation (a) seeded on rafts, and (b) ready for harvest**

4.5.6 *Gelidium pusillum*

Gelidium pusillum (G. pusillum) is mostly utilised in the preparation of agar. Three types of techniques were used to cultivate *G. pusillum* for increasing biomass output and generating agar with high gel strengthon the southeast coast of India. The net bag technique produced highest biomass yield (0.465 kg fresh weight per m^2) while the net pouch technique produced the lowest biomass yield (0.144 kg fresh weight per m^2). Similarly, the DGR in the net bag technique (1.05 percent) was higher than in the raft (0.679 percent) and net pouch (0.56 percent). Furthermore, the net bag technique yielded the highest quality agar (high gel strength: 2100 gper cm^2 in 1.5 percent gel; gelling temperature: 35°C; ash content: ≤ 1 percent; sulphate content: 0.34 percent), which is critical for better quality agar applications. *G. pusillum* cultivation techniques are depicted which is primarily employed in the manufacturing of agar (Veeragurunathan et al., 2018) (Figure 31).

Figure 31. ***G. pusillum*** **cultivation using different techniques**

Besides this, the basic production data including market value and infrastructure cost of different agarophytes is given in Annexure-I.

4.6 Integrated Multi-Trophic Aquaculture

The ICAR-CMFRI has developed and standardised systems for seed production and open sea cage farming of marine finfish and shellfish. As sea cage farming expands,the organic and inorganic load in the water is expected to increase, which can lead to illnesses. Bio-mitigation and improved biomass production can be done by merging together distinct groups of aquatic species with diverse feeding patterns. This is called as Integrated Multi-Trophic Aquaculture (IMTA), and it has recently attracted global attention. Successful trials wereconducted by integrating seaweed with sea cage farming of marine finfishes/shellfishes (Figure 32) in Tamil Nadu, Gujarat, and Andhra Pradesh. This has also resulted in increased seaweed production with fish, which has helped fishers' livelihoods, and contributed to earn more carbon credits.

IMTA was demonstrated during 2014-17 at Munaikadu, Palk Bay (Tamil Nadu). A total of 16 bamboo rafts (12 feetx 12 feet) containing 60 kg seaweed in each raft was integrated for four cycles (45 days per cycle) alongside one of the cobia farming cages. The rafts were positioned in a semi-circular pattern, 15 feet away from the cage to allow the seaweed to absorb the dissolved inorganic and organic nutrient wastes that travel along the water current from the cage. A total of 20 cages of 6 m diameter can be connected with 320 bamboo rafts (12 feet x12 feet) @ 16 bamboo rafts per cage in one hectare of space.

Seaweed rafts connected with cobia farming cages had a higher average production of 390 kg per raft through IMTA, while non-integrated rafts had a yield of 250 kg per raft. The integration with cobia cage farming resulted in an enhanced output of 140 kg of seaweed per raft (56 percent additional yield). The integration of seaweed rafts with cobia cages resulted in an increased net income of ₹ 62,720/-.

Carbon dioxide (CO_2) sequestration rate (per unit mass of *K. alvarezii* seaweed per day per 16 rafts per 4 crops) in the integrated and non-integrated rafts was equal to 47.4 kg and 30.4 kg CO_2 per day per tonne of dry weight, respectively. As a result, merging 16 seaweed rafts (4 cycles) with one cobia farming cage (per crop) resulted in an additional 17.0 kg CO_2per day per tonne of dry weight credit (55 percent sequestration rate).

ICAR-CMFRI has developed IMTA technology for commercial cultivation of *G. edulis*, *G. acerosa* and *Ulva lactuca*.

Figure 32. Aerial view of IMTA

POLICY FOR THE DEVELOPMENT OF SEAWEED VALUE CHAIN

CHAPTER-V

TECHNICAL AND ECONOMIC FEASIBILITY OF OFFSHORE SEAWEED FARMING

5.1 Background

The techniques for seaweed cultivation were initially developed in China during the 1950s, using line and rope culture methods for brown seaweeds. Ideally, coastal areas with minimal silt and turbidity, optimal salinity and temperature conditions, are suitable for cultivation. Rope methods are suitable for areas with low wave action, while tube net methods are preferable in areas with moderate wave action. The use for tube nets offers multiple support points for seaweed in rough water and thus minimizes biomass loss during rough conditions. The farm structure needs to be rope based anchored rather than bamboo rafts. National Institute of Ocean Technology- Atal Centre for Ocean Science and Technology for Islands (NIOT-ACOSTI), in collaboration with CSMCRI and A&N Fisheries Dept., has initiated large-scale seaweed cultivation in the Andaman region in offshore conditions. India should deploy offshore seaweed cultivation into its waters.

5.2 Estimation of Suitable Area for Seaweed Farming in Indian EEZ

Geospatial analysis was carried out utilizing 5 critical parameters (water depth, sea surface current, wave height, cost, distance) and 5 essential parameters (sea surface temperature, salinity, dissolved oxygen, nitrate, and phosphate. The essential environmental parameters required for cultivating seaweed were converted into thematic layers using Geographical Information System (GIS) tool. Weights of relative importance were assigned to each layer and integrated through overlay analysis to develop a final model. NIOT estimated area suitable for seaweed farming as 14259 km^2 in the water depth of 1 to 5 m for traditional scale farming, 100426 km^2 in the water depth of 5 to 25 m for community-scale farming and 94825 km^2 in the depth of 25 to 50 m for industrial scale farming.

5.3 Model for Large-scale Offshore Seaweed Farming

To address the need for a more robust culture system to overcome the challenges confronted in offshore environments, NIOT is being involved in demonstrating seaweed culture in rafts, tube nets, and monoline systems in A&N Islands. NIOT has proposed a culture model with a suitable mooring pattern for rough sea conditions.

5.3.1 Seaweed Farming Grid and Mooring Components

The major components of the seaweed grid system are HDPE pipes and grid buoys (Figure 33). The floating HDPE pipes and buoys are filled with styrofoam to retain the buoyancy and ingression of the water in the event of a minor crack. The mooring components are important parts of the seaweed grid system, which provide stability for positioning the grid systems to withstand the open sea conditions. The proposed culture plan has 10 grids of dimensions 120 m x 110 m (Figure 34 and 35). Each grid contains 18 rafts,each holding 8 tube nets (each 100 m in length) with a 10 cm diameter (mesh size 3.5 cm) (Figure 36).


HDPE pipes


Grid mooring buoy

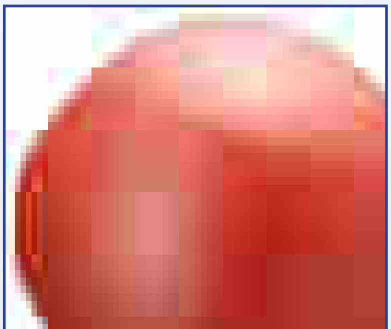

Raft rope buoy

Figure 33. HDPE pipes, grid mooring buoy, raft rope buoy

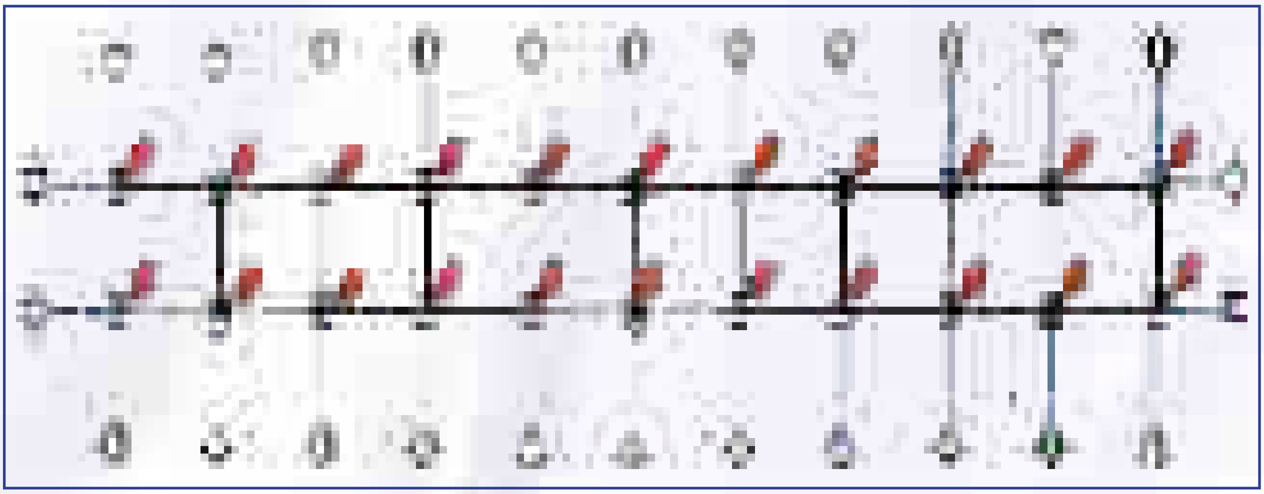


Figure 34. Schematic mooring pattern of 10 grids for open sea seaweed cultivation

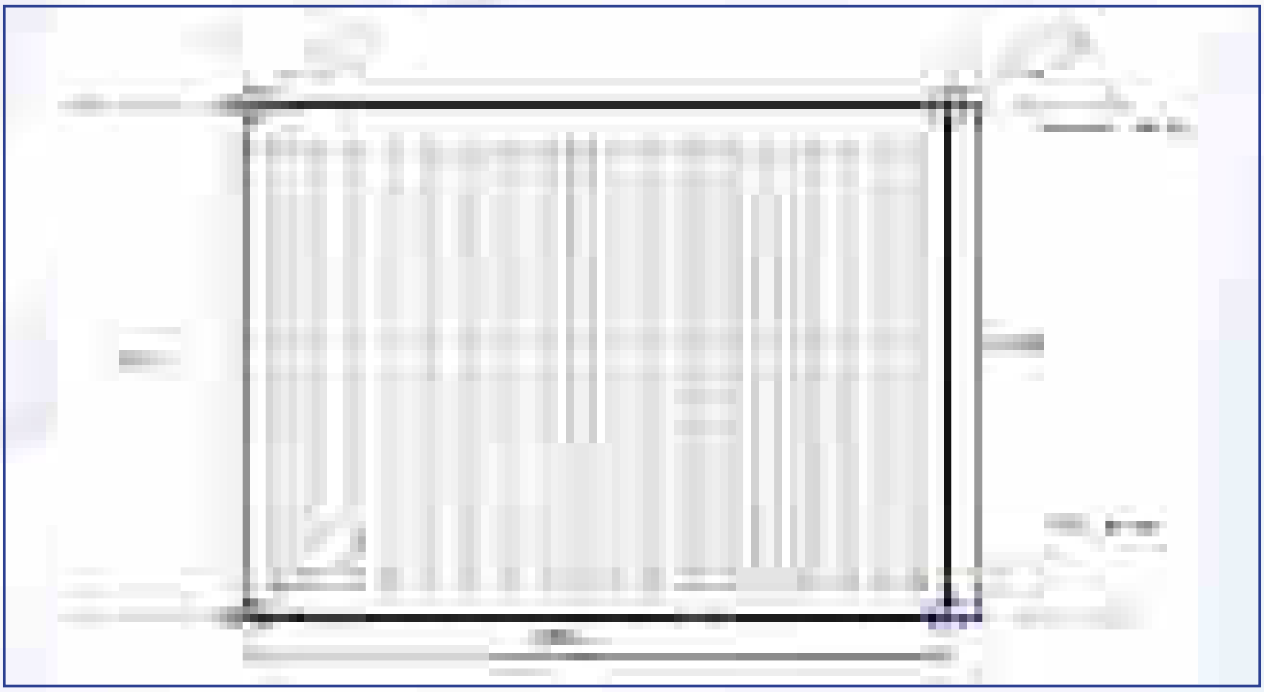


Figure 35. General layout of the grid (120 m x 110 m) for seaweed cultivation

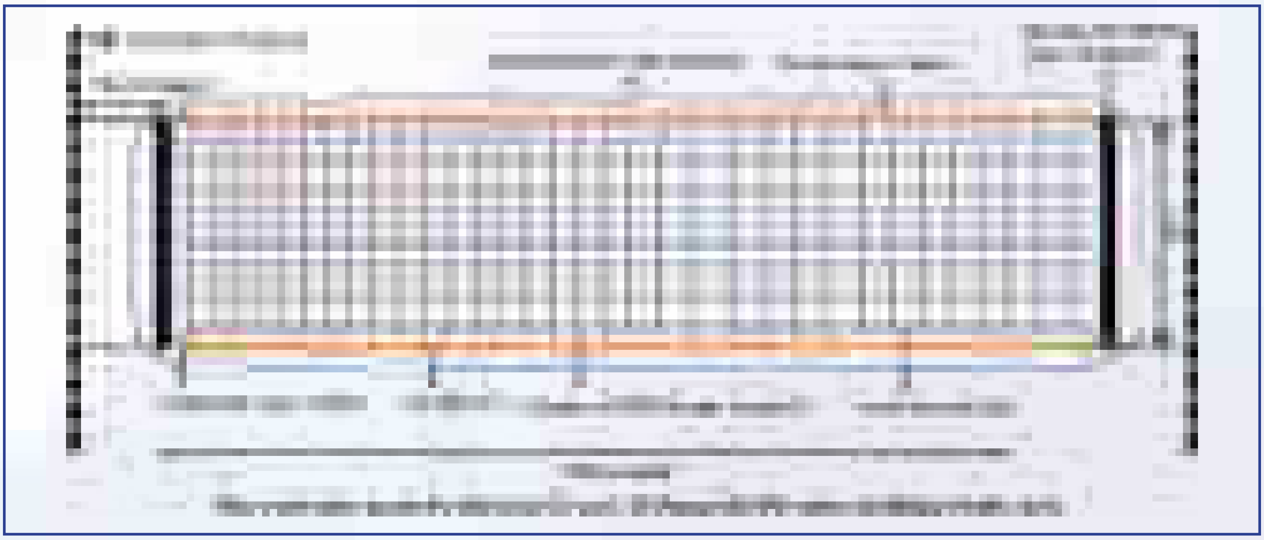


Figure 36. Overview of one raft with 8 tube nets

Nets made up of HDPE of 1.5 mm thickness with varied mesh sizes of 3.5 cm may be utilized for the culture of seaweeds to reduce the grazing by herbivores fishes. The non-metallic mooring components comprise various sizes of polypropylene ropes used for primary head ropes, grid ropes and anchor ropes (Table 7 and Figure 37).

Table 7. Specifications of rope and its breaking strength

S. No.	Specifications of rope	Min. breaking strength (tonne)
1.	Head rope: polypropylene diameter 14 mm (3 strands); 11.1 m per kg	3.0
2.	Grid rope: polypropylene diameter 44 mm (8 strands); 1.13m per kg	24.6
3.	Anchor rope: polypropylene diameter 48 mm (8 strands); 0.96 m per kg	28.6

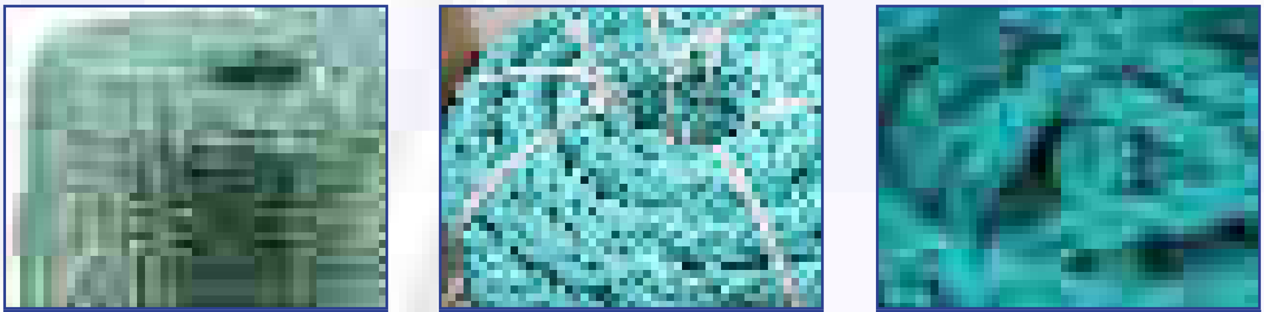


Figure 37. Ropes for anchor, grid and head for the raft

The metallic mooring components comprises MS Anchor (Samson Type), studded chains, collectors, shackles, thimbles (Figure 38). The MS anchor can be fabricated locally close to the deployment, and all other metallic components are available at the local market of major cities of India. The detailed specifications of mooring metallic components are also given (Table 8).

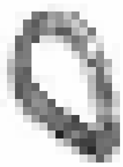
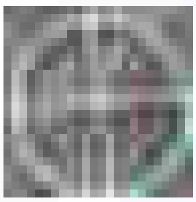
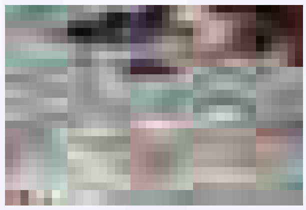
				
Omega shackle	**Thimble**	**Collector ring**	**Studded chain**	**MS Anchor (Samson Type)**

Figure 38. Metallic mooring components of a grid

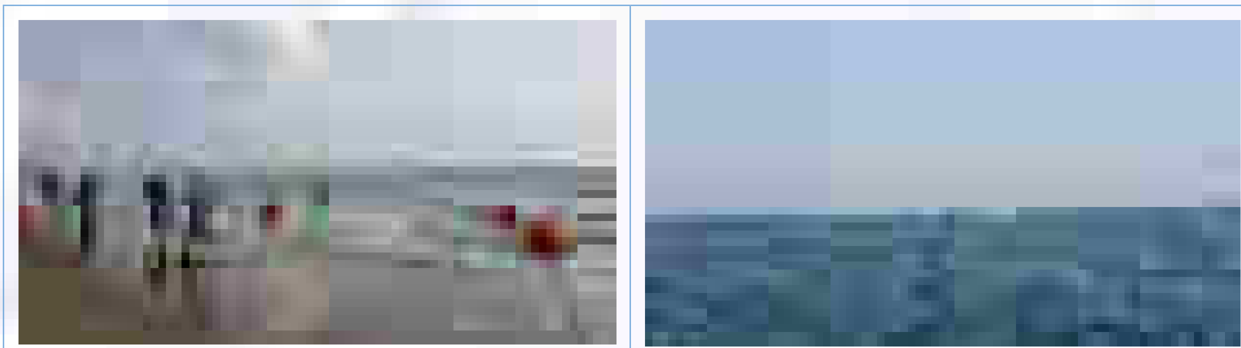
Table 8. Specification of mooring metallic components

S. No.	Component	Specification
1.	Anchor (Samson Type)	MS, weight 250 kg;thickness 25 mm diameter; detachable balancing rod length of 2 m (weight 20 kg)
2.	Studded chain	Grade-U2/ U3; ISO-1704; 32 mm; break load capacity - 58.3 tonnes; 22 kg per meter
3.	Collector ring	MS, 40 mm thickness; 60 cm inner diameter; weight-25 kg; sand blasted; hot dip galvanizes; break load capacity-89.6 tonne
4.	Bow shackle	Size-1.5 inch; break load capacity - 17 tonne; weight - 9.5 kg, forged alloy; anchor shackle with bolt and SS pin
5.	Thimble	Weight: 1.7-2.0 kg; hot dip galvanized; heavy duty stub-end reinforced; suitable for 44 mm pp rope

5.3.2 Grid Fabrication and Deployment

The grid fabrication shall be carried out on the beaches of the proposed deployment sites. The mooring grid preparation procedure is as follows-

- A grid buoy (330 L buoyancy) is connected to all collector rings using a 48 mm PP rope (8 strands, breaking load 28.6 tonnes), enabling to position of the grid at the desired depth of 10 m (the length of the anchor rope will vary according to the depth of the site) (Figure 39). The mooring grids are dragged from the beach to the pre-selected deployment location using a country boat and mechanized trawlers. The 120 m x 110 m subsurface grid will be positioned with multipoint point mooring by connecting all peripheral collector rings to the anchor system (MS 250 kg, with 5 m stud link chain 32 mm thickness, and D shackle 32 mm thickness). Using a mechanised trawler, the anchor ropes are tensioned to stretch the grid to a desired shape.
- Each grid contains 18 rafts,each raft holding 8 tube nets (each 100 m length) with a 10 cm diameter (mesh size 3.5 cm). Each raft is connected with the head rope (14 mm T) of a raft.
- Each raft protects culture tubes from seaweed-browsing fishes with the help of an anti-browsing net (3.5 cm mesh size and 1.5 mm T) by connecting to the raft's peripheral rope (12 mm T).



(a) Preparation and moving of mooring grid | **(b) Positioning of mooring grid**

Figure 39. Mobilization and positioning of mooring grid

5.3.3 Seaweed Planting Material

The availability of a local species of commercially important seaweed seed is one of the major bottlenecks in the large-scale expansion of the seaweed culture in India. Research institutes such as ICAR-CMFRI and CSIR-CSMCRI have developed lab technologies for seaweed seed production. The source and rate for few species of seaweed seed is given below (Table 9). Although the technology is available for several commercially important seaweed species, the consistent production of many seaweed seeds is limited to *Kappaphycus* sp. *and Gracilaria species.*

Planting material has to be either procured from a seed bank or harvested through the wild collection. The seaweed materials may be preserved using following methods (i) tank filled with seawater having provision for aerator (land-based system), (ii) tube net or raft method, (iii) small cage submerged in sea water, (iv) storage in gunny bags, covering during sunny days, followed by frequent spraying of seawater onto it. Proper aeration and humidity should be ensured.

Table 9. Source and rate of the seaweed seed

S. No.	Name of the seaweed species	Wild collection	Seed rate, ₹ per kg	Market value, ₹ per kg
1.	*K. alvarezii*	No	14.00	110.00
2.	*G. edulis*	Yes	5.00	40.00
3.	*G. dura*	Yes	-	-
4.	*G. salicornia*	Yes	-	-

Source: NIOT

5.3.4 Disease Management

Regular observation of seaweed is highly important. Less growth, change in color, and shedding of leaves are initial signs of the disease and parasite infection. Generally, infectious diseases are caused by viruses, bacteria, fungi and parasites. During *Kappaphycus* sp. cultivation, seaweed is prone to ice-ice disease and epiphytic filamentous algae. In the case of *Gracilaria* sp., red rot, white spot, green spot, white blight, rotten thallus syndrome, diatom blooms, twisted frond, blister, and pin- hole diseases frequently happened in seaweed cultivation conditions in Asia (Ward et al., 2019). Different acid treatment strategies for a few seconds are often used to control the spread of disease and pest outbreaks in seaweed aquaculture. Other methods, such as repositioning cultivation ropes to expose to sunlight and favorable salinity, may reduce the disease's spread. Currently, pest epiphytes are removed by hand.

5.3.5 Harvesting and Marketing

The grown seaweeds in the tube nets may be removed entirely by using twin hull Catamaran type boat with the harvesting machine. The seaweed grown in the raft grid can be harvested by lifting a tube net and collecting it appropriately. The seaweed has to be harvested in the early hours of the day and kept for sun drying for some time to remove the water. Periodical and partial harvesting can also be planned based on market demand.

5.4 Economic Feasibility Study

The proposed seaweed cultivation in the open sea method requires grid and mooring components. Expenditure such as grid components, grid fabrication, culture operation, boat hiring, seeding, harvesting machine, water monitoring equipment and labour wages need to be accounted for (Table 10 and 11). The pricing has been calculated based on the present market rates.

Table 10. Cost of components required for grid (120 m × 110 m)

S.No	Particulars	Unit	Qty./ grid	Unit cost (₹)	Cost/ grid (₹)	Cost / 10 grid (₹)
1	Primary cylindrical float (HDPE, ⌀ 200 mm, 6 mm, PN6) (18 x 2)	Nos.	36	5700	205200	2052000
2	Secondary cylindrical float(HDPE, ⌀ 110 mm, 6 mm, PN 6) (33 x18)	Nos.	594	2100	1247400	12474000
3	Anchor Samson Type (MS, 250 kg)	Nos.	2.6	25000	65000	650000
4	Anchor chain studded (MS 36 mm, 3 m)	Nos.	2.6	9000	23400	234000
5	D and Bow shackle (MS 38 mm)	Nos.	5.2	2200	11440	114400
6	Thimble for anchor rope (48 mm)	Nos.	2.6	2200	5720	57200
7	Grid Buoy (HDPE, 330 LTR)	Nos.	2.2	30000	66000	660000
8	Seeding, harvesting machine	Nos.	1	2500000	250000	2500000
9	Katamaran (barge) to mount seeding, harvesting machine	Nos.	1	1000000	100000	1000000
	Depreciation for 90 cultures (15 years x 6 cycles) ₹				**19,74,160**	**1,76,89,600**
10	Anchor rope (52 mm, 24.8 T)	Kg.	75	180	13500	135000
11	Collector ring (MS ⌀ 600 mm, 40 mm)	Nos.	2.2	6000	13200	132000
12	Grid buoy rope (PP 44 mm, 24T)	Kg.	14	180	2520	25200
13	Grid rope 44 mm (PP 44 mm, 24T)	Kg.	464	180	83520	835200
14	Head rope to raft -from the grid to raft (PP 14 mm, 3 T)	Kg.	52	180	9360	93600
15	Head rope for anti-browsing net (PP 12 mm, 2.2 T)	Kg.	140	180	25200	252000
16	Supporting rope (PP 6 mm, 0.6T)	Kg.	20	180	3600	36000
17	Net and tube preparation (mesh 3.5 cm & 1 mm T)	Kg.	510	500	255000	2550000
18	Anti-browsing net (HDPE, 35 mm mesh, 1.5 mm thickness)	Kg.	750	500	375000	3750000
20	Peripheral raft buoy (Doughnut shape 1.5 litre capacity)	Nos.	1188	120	142560	1425600
21	Tarpaulin sheet (200 gsm 50 feet x 50 feet)	Nos.	5	15000	75000	750000
22	Snorkel set with fin for raft observation	Nos.	20	5000	100000	1000000
23	Miscellaneous for stitching ropeand needles	Nos.	1	20000	20000	200000
	Depreciation for 30 cultures (5 years x 6 cycles)				**11,18,460**	**1,11,84,600**

During grid preparation, the following expenditure is needed to be spent on hiring manpower and boat for preparation, mobilization, and deployment of grid and rafts.

Table 11. Labour charges for grid preparation (120 m × 110 m)

S. No	Particulars	Unit	Req. Qty.	Unit cost (₹)	Cost per grid (₹)	Cost per 10 grid (₹)
1	Labour charge for unloading from truck	Nos.	10	1000	10000	100000
2	Hiring of crane for unloading anchor and ropes	Nos.	1	5000	5000	50000
3	Watch and ward charges	Nos.	20	500	10000	50000
4	Hiring of trawlers for grid deployment	Nos.	1	25000	25000	250000
5	Hiring of beach landing craft	Nos.	5	3000	15000	150000
6	Hiring of skilled labor during grid and raft deployment	Nos.	20	1000	20000	200000
7	Hiring of labour for tube and anti-browsing net fabrication (8L/Dx18Rx2G)	Nos.	100	1000	100000	1000000
Total					**1,85,000**	**18,00,000**

The operational cost includes the expenditure on procurement of seaweeds planting material, transportation, hiring of labour and boat for daily maintenance, storeroom and expenditures on harvest (Table 12).

Table 12. Operational cost for grid (120 m × 110 m)

S. No	Particulars	Unit	Qty.	Unit cost (₹)	Cost/grid (₹)	Cost /10 grid (₹)
1	Seaweed planting material (30 kg x 8 tube net x 18 rafts)	kg	4320	14	60480	604800
2	Labour for daily maintenance (4 labour x 45 days)	Nos.	180	500	90000	900000
3	Boat for maintenance (hiring charges)	Nos.	45	1500	67500	675000
4	Supervisor (1 supervisor for 2 grid and for 45days @₹800/ day)	Nos.	0.5	36000	18000	180000
5	Hiring of storeroom₹ 5000/ month	Nos.	1	10000	10000	100000
6	Harvest boat	Nos.	12	3000	36000	360000
7	Labour for drying and packing	Nos.	30	800	24000	240000
Total					**3,05,980**	**30,59,800**

The cost-benefit analysis for initiating culture is calculated using the standard formula for the deployment of the raft grid system. The capital investment in the raft grid system will last for about 8 years and expenditure will further reduce if the number of rafts is increased at the same location due to the reduction of anchors and other related mooring components. In the case, entrepreneurs use their boats and security, the operational cost will be less, and the profit margin will increase proportionally. The revenue and profit estimate for 10 grids (120 m x 110 m) for *K. alvarezii* is given in the Table 13.

Table 13. Revenue and profit estimate for 10 grids (120 m x 110 m) using *K. alvarezii*

S. No.	Particulars	Grid (₹)	6 cultures/year (₹)	30 cultures/5 yrs (₹)	10 grids/5 yrs (₹)
	Capital investment				
1	Cost of grid mooring components	19,74,160			1,97,41,600
2	Cost for grid fabrication	1,85,000			18,50,000
3	Cost of raft net and rope components	11,18,460			1,11,84,600
	Total	**32,77,620**			**3,27,76,200**
	Operational cost				
4	Seeding, maintenance and harvest	3,05,980	18,35,880	91,79,400	91,79,4000
	Economics of the culture operation (*K. alvarezii*)				
5	Gross income (25920 kg- fresh/grid/culture) (5184 kg dry @₹ 110/ kg) (1+2)	5,70,240	34,21,440	1,71,07,200	17,10,72,000
6	Income after deduction of operation cost (5-4)	2,64,260	1585560	79,27,800	7,92,78,000
7	Depreciation cost of grid & mooring and fabrication for 90 cultures (15 years x 6 cycles)	23,991	1,43,944	7,19,720	71,97,200
8	Depreciation for rope &net components for 30 cultures (5 years x 6 cycles)	37,282	2,23,692	11,18,460	111,84,600
Net income (6 - 7 + 8)		**2,02,987**	**12,17,924**	**60,89,620**	**6,08,96,200**

CHAPTER-VI

PROCESSING TECHNOLOGIES FOR SEAWEED

6.1 Introduction

The most widely cultivated tropical red seaweeds are of the genera *Kappaphycus, Eucheuma, and Gracilaria.* They are used as raw materials for hydrocolloid manufacturing. Marine hydrocolloid applications have manifested market growth at of 2 percent per annum over the past two decades (Suryanarayan et al., 2018). As the industry evolves,technology has evolved from conventional single stream processing to Multi-Stream Zero-Effluent (MUZE) processing to produce plant bio-stimulant products from seaweeds.

6.2 Comparison Between Single Stream and MUZE Processing

The traditional approach to extracting hydrocolloids from red seaweed has led to the waste of non-hydrocolloid components. However, with the growing adoption of MUZE processing, tropical red seaweed biomass is now being utilized to produce a diverse array of products, minimising waste. A comparative discussion between the conventional single stream processing approach and MUZE processing is given below (Figure 40).

Both single-stream and MUZE processing methods involve starting with fresh seaweed. However, in single-stream processing, the seaweeds are typically dried in sunlight, packed, and transported to remote factories for additional processing. On the other hand, MUZE processing begins near the farm sites, where live seaweeds undergo initial processing stages, thus facilitating value addition in proximity to the farming communities.

In the single-stream processing method, the initial step involves cooking the raw, dried seaweeds in an alkali solution. This is followed by a series of processes that include recovery and dehydration. Refined hydrocolloids are typically dissolved, clarified, and extracted by precipitating them in alcohol or potassium prior to drying. Semi-refined hydrocolloids, on the other hand, are maintained in a gel-like state throughout the processing and are dried after undergoing a washing step. Once the hydrocolloids are produced through single-stream processing, they are milled into powder form and then blended into ingredient solutions to create final products. In MUZE processing, the initial step typically involves extracting juice from seaweed and separating it from the seaweed pulp. This is achieved using equipment commonly found in the fruit and vegetable juice industries. The extracted juice is often concentrated under reduced pressure to minimize the transportation of low-solids liquid and to preserve the bioactive components present. Additionally, the juice may undergo fractionation to recover specific bioactive components like growth promoters and phycobiliproteins. The remaining pulp can be further processed, either in a wet or dry state, to produce hydrocolloids or other products such as ingredients for animal feed, employing various methods. Both the juice and pulp can then undergo a wide range of additional processing options. For instance, the juice, which is abundant in potassium compounds, can serve as a plant bio-stimulant or source for potash fertilizer.

In single-stream processing, water vapor is produced along with other solid wastes and liquid effluents. A significant amount of freshwater is often consumed throughout the processing in production of semi-refined carrageenan (SRC), which is the most widely produced carrageenan variant. The production of each tonne of SRC can generate several tonnes of alkaline wastewater with high chloride content, as well as high levels of biological oxygen demand (BOD) and chemical oxygen demand (COD). Waste solids arising from the clarification process of both wastewater and refined carrageenan leadto substantial production of waste filter cake. However, in a well-designed MUZE processing system, the primary waste generated is typically water vapor, which is expelled during the liquid concentration and drying stages. The freshwater obtained during the juice concentration process can be recycled back into the processing system or can be marketed and sold as a separate product.

MUZE processing for red seaweeds yields intermediate products in the form of juice and dried pulp. These products serve as the foundation for subsequent processing, yielding a diverse range of final products. These include hydrocolloids, food and feed ingredients, agricultural bio-stimulants, renewable chemicals, biofuels, and as a by-product of juice concentration, freshwater is also generated.

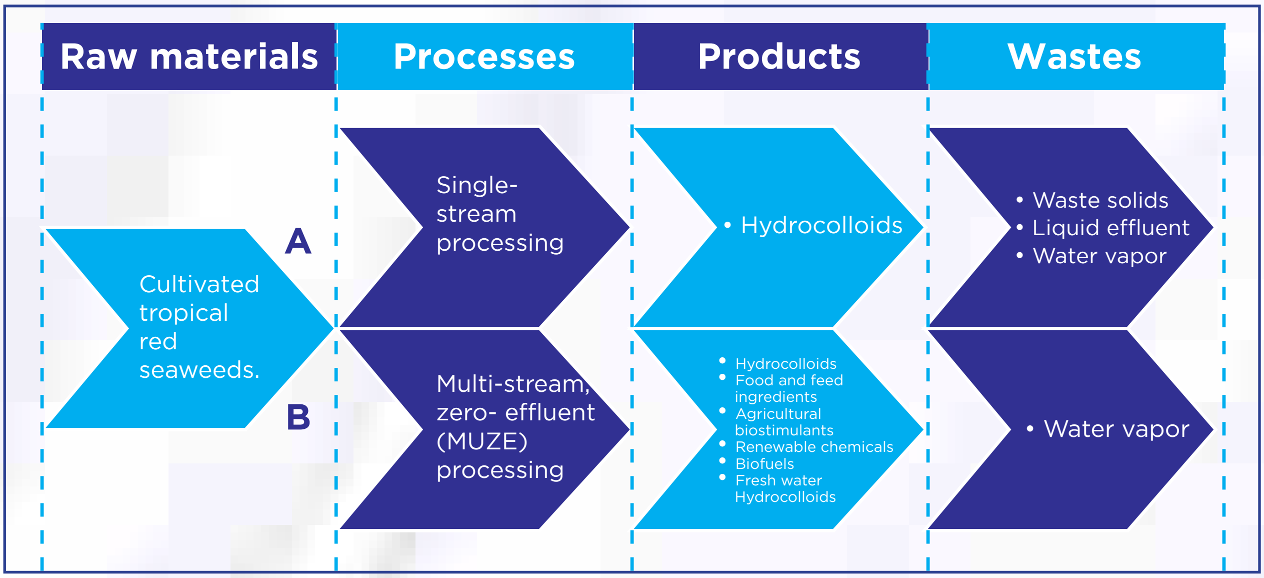


Figure 40. Comparison between conventional single-stream processing and MUZE processing for tropical red seaweed processing.

6.3 MUZE Products from Seaweeds

6.3.1 Sea Vegetables as Human Food

Seaweeds have been consumed by coastal communities since pre-historic times. In Japan and China, seaweed has been consumed as food since the fourth century and the sixth century, respectively (McHugh, 2003). Seaweeds are used in the traditional Japanese cuisine "shojin ryori" for flavour and it is also used as seasoning condiments in a variety of dishes (Tsuji, 1980; Fujii, 2005). Kombu, wakame and nori accounted for more than 10 percent of the Japanese seaweed diet until recently (Griffin, 2015). Seaweeds are also consumed traditionally in many Asian countries like Indonesia, the Philippines, South Korea, North Korea, and Malaysia (Ganesan et al., 2019). Recently, the consumption of seaweeds has gained wide attention in the Americas and Europe due to their functional properties and introduction of Asian cuisine (Bocanegra et al., 2009). In India, direct consumption of seaweed in scarce. However, *Gracilaria* and *Acanthophora spp.* are used in preparing porridge in Kerala and Tamil Nadu (Dhargakar, 2014). Juice of *Ulva* species is used In India for preparing *Halva* in southern parts of Tamil Nadu (Subba Rao et al., 2009, 2016). Seaweeds are considered as a food supplement for the 21st century due to the presence of bioactive compounds, macro and micro-nutrients in them.

Hydrocolloids derived from tropical red seaweeds have established themselves as essential food ingredients in global markets. Multiple companies across different countries globally produce liquid and solid seaweed-based soil and water conditioners (SWC) for agricultural purposes. SWCs have various benefits on both plants and animals (Table 14). The agricultural SWC market holds significant potential for the utilization of extracts from tropical red seaweeds. The majority of SWC products are manufactured using cold-water (CW) brown seaweeds (*Phaeophyta*) found in temperate zones. These brown seaweeds include kelp genera such as *Laminaria, Saccharina, Ecklonia* and *Durvillea,* as well as rockweed genera like *Ascophyllum and Fucus*. These species have long been utilized as animal feed additives, dating back many decades.

Table 14. SWC benefits

Benefits on	Productivity, quality and quantity	Diseases, parasites and pest control
Plants	1. Increase in productivity. 2. Improved seed germination 3. Early flowering and fruiting 4. Enhanced macronutrient uptake. 5. Improved appearance, nutritional quality, and uniformity. 6. Increased shelf life of harvestable material (e.g., fruits and seeds)	1. Enhanced disease, insect, and pest resistance. 2. Improved vigor, root development, and chlorophyll synthesis. 3. Adjuvant action in pesticide formulations. 4. Alleviation of bacterial and fungal infections / infestations.
Animals	1. Enhanced weight gains. 2. Improved milk production (mammals) and egg production (poultry). 3. Improved fat deposition, carcass quality, and shelf life	1. Improved gastrointestinal health associated with favorable changes in gastrointestinal flora. 2. Increased disease resistance. 3. Reduced microbial shedding during shipment and slaughter.
Both plants and animals	1. Reduced mortality. 2. Retarded senescence. 3. Increased fecundity. 4. Healthy and robust appearance.	1. Upregulation of immune system genes. 2. Suppression of pathogen biofilm production and quorum sensing. 3. Increased resistance to abiotic stress (e.g., temperature and salinity). 4. Benefits on symbiotic, symbiotic and prebiotic microflora.

6.3.2 Nutraceuticals

Seaweeds are gaining enormous attention in the nutraceutical industries due to their protective capabilities against various chronic diseases. The nutraceuticals market in India has been growing at a compounded annual growth rate of 20 percent for the past three years (ICAR-CMFRI, 2022), especially in the segments of functional food products, antioxidants, and immunity boosters. By the end of 2025, the Indian nutraceutical market is projected to have grown from an estimated USD 4 billion to USD 18 billion (Yadav & Mehta Malik, 2020). With increasing health awareness and the shift towards preventative health care, this segment can prove promising for seaweed processing in India. Recent efforts by the government in the regulatory protocols on nutraceutical products have resulted in the rapid growth of this segment.

Nutraceuticals have also been defined as "concentrated, isolated, or purified" pharmacologically bioactive molecules. Nutraceuticals portray a distinctive intersection of pharmaceutical and food products and will continue to have great attraction because they are naturally derived concentrated pharmacologically active compound(s), and therefore are intended to function as "natural drugs". Nutraceuticals are clearly not drugs. Unlike synthetic drugs, they are potential pharmacologically active substances which are derived from natural sources and concentrated by using green extractionorpurification techniques. The purification process eliminates the unnecessary components in the products and increases the quantities of the intended pharmacophore(s), which are specifically active against particular diseases. This apparently leads to greater pharmacological activities of nutraceutical products. Over the last few years, the use of seaweeds for the development of nutraceutical products has attracted interest from the pharmaceutical industries. Seaweeds are often termed as the "wonder herbs of the ocean" on account of their potential pharmaceutical properties. Evaluation of target biological activities against different lifestyle and metabolic disease models is done by ICAR-CMFRI. It has made a library of such molecules with bioactive potential with therapeutic properties.Various seaweed-based nutraceutical products developed by ICAR-CMFRI are as follows:

a. Anti-diabetic nutraceutical to combat type-2 diabetes
b. Anti-arthritic nutraceutical joint pain/arthritis
c. Anti-hypercholesterolemic nutraceutical to combat dyslipidemia
d. Anti-hypothyroidism nutraceutical to combat hypothyroid disorder
e. Anti-hypertensive nutraceutical to combat hypertension
f. Anti-osteoporotic nutraceutical to combat osteoporosis
g. Nutraceutical to improve innate immune system
h. Nutraceutical to combat non-alcoholic fatty liver disease
i. Extract to boost immunity and combating post-covid symptoms

6.3.3 Cosmetics

Seaweeds are often used as ingredients in the production of cosmetics. They are used either as additives (contributing to the organoleptic properties), or for stabilization and preservation of the products or as active ingredients (that fulfil the cosmetic function and activity) (Bedoux et al., 2014). The bioactive compounds present in seaweed whichcan be used as active ingredients in cosmetic products arephenolic compounds, polysaccharides, pigments, Polyunsaturated fatty acids (PUFA), sterols, proteins, etc., (Pereira, 2018; Salehi et al., 2019). Seaweeds are also a major source of vitamins (A, B, C, D, and E) which are extensively used in skincare products (Jesumani et al., 2019).

Phlorotannins, the most important phenolic compound, is well known for its anti-melanogenesis and anti-ageing properties (Norzagaray-Valenzuela et al., 2017). Polysaccharides are used in cosmetics as a gelling agent, viscosity adjuster, thickener, and emulsifier. Polysaccharideshydrate the skin and potentially protect it from wrinkles (Kanlayavattanakul and Lourith, 2014). The natural pigments found in seaweeds have attracted attention of cosmetologists. Xanthophyll is used as a colour source for the cosmetics (Mathew and Ravishankar, 2022). Since seaweed contains a large number of different fatty acids, it provides a promising source of raw PUFAs for cosmetics production (Khotimchenko et al., 2002). Several fatty acids restore the permeability barrier and prevent scaly dermatitis and skin dehydration (Servel et al., 1994). Some of the PUFAs, such as linoleic acid and arachidonic acid are necessary for growth and protection of the skin (Mansour et al., 1999). It was also suggested that a lack of these fatty acids leads to cutaneous problems such as alopecia, peeling of the epidermis and eczema. Seaweeds have amino acids, such as alanine, proline, arginine, serine, histidine, and tyrosine. *Palmaria* and *Porphyra* have the maximum amount of arginine, which is considered a natural moisturizing factor that can be used in cosmetic products (Jesumani et al., 2019).

6.3.4 Bio-stimulants for Agriculture

The sap derived from fresh *K. alvarezii* as well as *G. edulis* are effective biostimulants. Multi-crop trials by CSIR-CSMCRI in collaboration with 43 state agricultural universities and ICAR institutes revealed that the bio-stimulant usage level of 2-15 percent resulted in an increased crop production by 37 percent (Mantri et al., 2022; Bhushan et al., 2023) (Figure 41 and 42). Pan-India trials also reveal that *Kappaphycus*bio-stimulant improves the yield of pulses and oilseeds. Especially for soyabean and blackgram, the yield increased by over 20 percent.

Studies at molecular level through transcriptome analysis of roots and shoots of maize indicate that it is capable of ameliorating soil moisture-stress (Suryanarayan et al., 2018). It can also reduce the diminution in crop yield under stress (Trivedi et al., 2018a, 2018b, 2022a). Itstimulates soil microbes, thus enhancing mineral cycling of soil nutrients and making them more available to plants (Trivedi et al., 2022b). The soil microbes under moisture stress conditions were found to be maintained at par in normal irrigated conditions when *Kapppahycus* sap was applied. Studies show that *G. edulis* and *K. alvarezii* are effective in reducing the usage of chemical fertilizers by at least 25 percent in crops (Singh et al., 2018, 2023).

The seaweed-bio-stimulants derived from *Kapppahycus* and *Sargassum* spp. were found to contain several bioactive compounds such as phytohormones (indole-acetic acid,cytokinins, gibberellins), macro and micronutrientswhich can show bioactivity at extremely lower concentrations (some at even nano-molar levels) (Vaghela et al., 2022, 2023a, b). It also contains quaternary ammonium compounds (e.g., glycine betaine, choline chloride)enabling plants to withstand abiotic stresses like drought. *Kappaphycus alvarezii* as well as *Sargassum* based bio-stimulants imparts tolerance to soil fungal pathogens, thus warding off biotic stress (Suryanarayan et al., 2018).

The seaweed-based bio-stimulants have an extremely low carbon footprintof 73 and 119 kg CO_2 equivalents per kiloliter of *G. edulis* and *K. alvarezii* based bio-stimulants, respectively (Ghosh et al., 2015; Anand et al., 2018). Unlike traditional commercial fertilizers such as urea, muriate of potash, and diammonium phosphate, which have high carbon footprints (3253, 1435, and 515 CO_2 equivalents per tonne respectively), the integration of seaweed-based bio-stimulants with(reduced) chemical fertilizer application in sugarcane and rice has conserved 12 and 35 kg CO_2 equivalents per tonne respectively (Ayyakkalai et al., 2024). This is promising in mitigating global climate change.

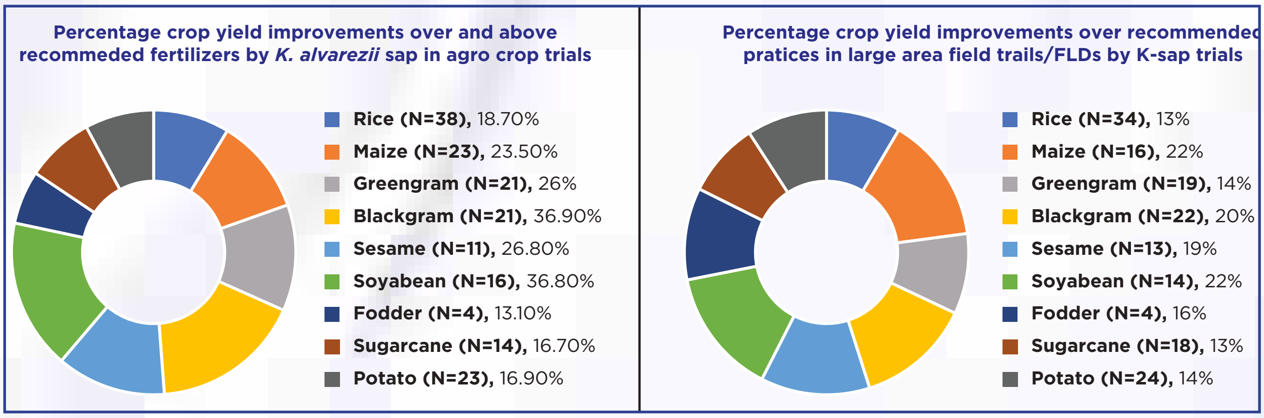


Figure 41. Percentage increase in yield of various crops by foliar application of *K.alvarezii* based bio-stimulant

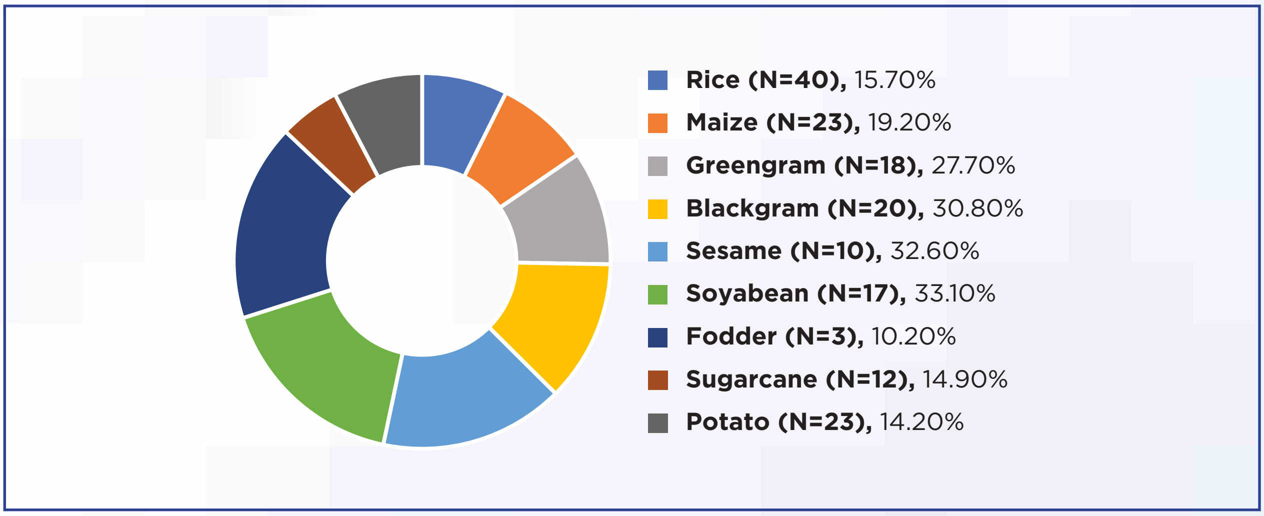


Figure 42. Percentage increase in yield of various crops by foliar application of *G. edulis* based bio-stimulant

6.3.5 Dairy and Animal Husbandry

Seaweeds are rich sources of choline, glycine, betaine, nutrients along with biologically active compounds such as fucoidan, betaine, and glucans which are known to enhance immunity in animals. Polyphenols in the seaweed exhibit antioxidant and Reactive Oxygen Species (ROS) scavenging activity. Seaweed formulations were developed to harness the active ingredients for improving productivity, improved rumen function, boost immunity, and all-around health of animals (cattle and poultry).

Livestock production, particularly ruminants, contributes to 7.1 gigatonnes CO_2 equivalents annually,accounting for approximately 14.5 percent of the global anthropogenic GHG emissions globally. Feed additives used in CH4 mitigation can either modify the rumen environment or directly inhibit methanogenesis resulting in lower enteric CH4 production. Some red seaweeds are anti-methanogenic, particularly the genus Asparagopsis, due to their capacity to synthesize and encapsulate halogenated CH4 analogues, such as bromoform and dibromochloromethane, within specialized gland cells as a natural defence mechanism. In a screening process, to identify CH4 reduction potential of select macroalgae in Australia, Asparagopsis taxiformis was demonstrated to be the most promising species with a 98.9 percent reduction of CH4 when applied at 17 percent OM in vitro (Roque et al., 2020).

CSIR-CSMCRI in collaboration with ICAR Institutes (IVRI, CARI, and NDRI) and CSIR-IITR, recently developed novel seaweed-based animal feed additive formulations to enhance productivity of animals, improving the quality of animal products and boosting immunity. The seaweed-based formulations were found to bestow the following properties:

a. Improved performance of poultry (especially breast) and cattle
b. Better immuno-responsiveness (cellular mediated and HA titre) in poultry and cattle
c. Gut health (microbial & structural) in poultry
d. Physio-biochemical characteristics of poultry meat
e. Higher egg production and advancement in egg- laying age
f. Higher calcium and iron content in milk
g. Better calcium retention leads to reduced chances of milk fever
h. Reduced methane emission and higher energy use efficiency in ruminants
i. Higher daily growth rate in cross bred calves

6.3.6 Food Packaging

Global plastic waste reached a staggering 29.1 million tons, with over 99 percent of this waste originating from petroleum-based plastics (Nandy et al., 2022). In view of this, the market value of biodegradable plastic materials has recently experienced significant growth. In 2021, the global market value of biodegradable plastics reached approximately USD 8 billion. Projections indicate that this value is expected to triple by 2026, reaching around USD 23.3 billion (Market Value of Biodegradable Plastics Worldwide, 2026).

Seaweed-based polysaccharides could be a potential solution to meet the high demand for renewable materials. These polysaccharides, sourced from marine environments, have garnered attention for their diverse applications in biopackaging, food, biomedical, and agriculture sectors. They possess advantageous properties such as strong gelling ability, recyclability, thermal stability, and non-toxicity. Seaweed polysaccharides can undergo degradation through both enzymatic and non-enzymatic processes. However, one of the key challenges in utilising biopolymers, including seaweed-based polysaccharides, for packaging purposes is their relatively limited mechanical strength and barrier properties compared to non-biodegradable alternatives. There are three types of seaweed polysaccharides viz. agar, alginate, and carrageenan. They are commonly used as film-forming materials as compared to other seaweed polysaccharides like lam- inarin, fucoidan, and funoran.

Polysaccharides such as alginate, carrageenan and agar isolated from seaweeds have been commonly used as precursors for edible film production (Mostafavi and Zaeim, 2020). The film-forming biopolymers derived from seaweeds are non-toxic, easily degradable and biocompatible and show high rigidity and low deformability (Doh, 2020). The bioplastic films from seaweed exhibit relatively low water vapour barrier properties and mechanical strength in comparison to conventional non-renewable polymers. Hence, seaweed is generally mixed with other components to improve the properties of seaweed films. The edible film from seaweeds can be used as sachets, pouches, wrappers, interleaves for seasoning cube and chocolates,frozen foods, etc. It can also be used as material for edible logo in bakery products. Edible film is also used in the pharmaceutical industry as functional strips. It can also be used in cosmetic and toiletries industries as a facial mask and bag for pre-portioned detergent (Siah et al., 2015).

Alginate-based, carrageenan/furcellaran based and agar-based edible films have various applications in food packaging. By varying the additional compounds added to them, their properties and applications can be found in Table 15.

Table 15. Seaweed polysaccharides based edible films and their applications in food packaging

S. No.	Additional components	Properties	Food applications
Primary material: Alginate-based edible films			
1	Alginates (food grade)	Improve the quality and increases the shelf-life of button mushroom	Button mushrooms
2	$CaCl_2$	Improved mechanical and water-resistant properties, decreased WVPT	-
3	Glycerol/sorbitol	Improves the mechanical properties	-
4	Potassium sorbate	Release the active substances	-
5	Sago starch, lemon grass oil and glycerol	Improved flexibility, tensile strength, and antimicrobial properties	-
6	Silver nanoparticles	Extend the shelf-life of fruits and vegetables	Carrot & pear
7	Silver-montmorillonite nanoparticles	Preserved the fresh-cut carrot from dehydration and microbial spoilage; extends the shelf-life	Fresh cut carrot
8	Gelatin	Retained the freshness of the fruit and also improved the appearance and attractiveness of the fruit	Apple
9	Acetylated monoglyceride	Decreases respiratory activities	Apple pieces
10	Chitosan, pullulan	Retained the quality and extended shelf-life.	Strawberry
11	Carrageenan	Higher tensile strength, elongation, and elasticity; lower water loss; maintained freshness and greenishness	Pear
12	Methylcellulose	Improved the shelf-life of fresh-cut	Peach
13	Galbanum gum/$CaCl_2$/ *Ziziphora persica*	Prevented microbial growth	Chicken fillet

S. No.	Additional components	Properties	Food applications
14	Wheyprotein/$CaCl_2$ (EC)/ lactoperoxidase enzyme whey proteinisolate/Ginger extract	Enhanced antimicrobial properties. Improved antimicrobial properties against *E. coli* and *S. aureus*.	Chicken thighs meat, cheese
15	Starch/Stearic acid/ tocopherols	Improved moisture barrier properties and decreased lipid oxidation	Ground beef Patties
16	Whey protein	Extend the shelf-life of fish	Kilka fish
Primary material: Carrageenan-based edible films			
1	Durian starch/carvacrol films	Antimicrobial activities against *S. aureus* bacteria	
2	Chitosan	Antimicrobial activities against *B. subtilis* and *B. cereus*, transparency	
3	Pectin/mica flakes	Improved barrier properties, hydrophobicity and WVP	
4	Arrowroot starch/iota carrageenan	Improved mechanical and barrier properties and extended the shelf-life of tomatoes	Cherry tomatoes
5	Arrowroot starch/iota carrageenan/Kyoho skin extract	Increased tensile strength, UV barrier ability and low water wettability. Acted as halochromic indicator for monitoring the freshness of the shrimp	Shrimp
6	Honey and bee pollen phenolic compounds	Increased physical properties, higher antibacterial and antioxidant properties on beef	Beef
7	Egg white protein	Improved mechanical properties and reduced WVPT and OP	Oil packaging
8	Palm oil	Extend the shelf-life of apple slices	Apple slices
Primary material: Furcellaran-based edible films			
1	Germinated fenugreek seeds	Enhanced antimicrobial properties and extended the shelf-life	Chicken breast
2	Chitosan/antimicrobial peptides	Improved antimicrobial properties	Smoked pork ham and pork loin
3	CMC/gelatin hydrolysate/ lingonberry extract	Improved antimicrobial and antioxidant properties, extended the shelf-life of cherry tomatoes	Cherry tomatoes
4	Soybean bran extract	Enhanced the thermal and antioxidant properties Extended the shelf-life of butter	Butter
5	Tea ground waste and CMC	Extended the shelf-life of salmon fillets	Salmon fillets
Primary material: Agar-based edible films			
1	Soy protein isolate	Improved water barrier properties	-
2	Silver nanoparticles	Improved hydrophobicity, thermal stability, antimicrobial and water barrier properties	-

S. No.	Additional components	Properties	Food applications
3	Titanium oxide	Improved tensile strength, water vapor and UV barrier properties	-
4	Green tea extract and probiotic strains	Extended shelf-life of fish and improved antimicrobial properties	Fish fillets
5	Gelatin, Cloisite Na and thymol	Acted against microbial growth	Chicken breast
6	Fish protein hydrolysate and clove essential oil	Inhibited the growth of H_2S-producing microbes	Flounder fillets
7	Alginate, collagen, silver nanoparticles and grapefruit seed extract	Inhibited the greening of potatoes	Potatoes
8	ZnO nanoparticles, cinnamon essential oil and nisin	Prevent the growth of microorganisms during the storage	Minced fish
9	k - carrageenan, konjac glucomannan blend and Cloisite 30B	Antimicrobial and antifogging properties	Spinach
10	ZnO nanoparticles	Extend the shelf-life or grapes	Green grapes

6.3.7 Biofuels

Seaweeds are potentially significant future sources of sustainable biofuels. Seaweeds fall under third-generation feedstock category. They are advantageous due to high carbohydrate content, absence or low lignin content, higher photosynthetic efficiency than terrestrial biomass. Their potential biomass yield per unit area is often higher than that of terrestrial plants, does not directly compete with human food supply, does not compete for arable land, does not require freshwater, does not require fertilizer, and the potential to obtain high-added value products alongside.

Due to higher carbohydrate content, green seaweeds such as *Ulva lactuca* and *Enteromorpha intestinalis* are considered as viable feedstocks for the production of bioethanol. The carbohydrates are converted to bioethanol by appropriate microorganisms such as yeast or bacteria (Ramachandra and Hebbale, 2020). The techniques or pathways used generally in the fermentation of seaweed are separate hydrolysis, fermentation and simultaneous saccharification and fermentation (Offei et al., 2018). The yield of bioethanol in red algae varies from 4-43 percent (Andhikawati et al., 2020).

To prepare for fermentation, the seaweed biomass undergoes a process where SWC juice is extracted, and the remaining pulp is subjected to saccharification. This saccharification step involves treating the pulp with 0.9 N sulfuric acid at a temperature of 100°C. At a bench scale of 16 kg, this process yields approximately 30 percent in terms of saccharification. Next, the hydrolysate resulting from saccharification is neutralized using lime and undergoes desalination through electrodialysis. After this preparation, the hydrolysate is ready for fermentation in the presence of *Saccharomyces cerevisiae*, a type of yeast commonly used in ethanol production. During fermentation, about 80 percent of the reducing sugars present in the hydrolysate are converted into ethanol. The ethanol produced through this process has been successfully utilized as fuel for a petrol vehicle. Furthermore, additional fermentation trials using marine yeast called *Candida* sp. have demonstrated its ability to function in high-salinity conditions and produce ethanol without requiring a desalting process.

A combination of heterogeneous catalysed hydrolysis and *Saccharomyces cerevisiae* fermentation can be employed to produce bioethanol from *Kappaphycus* biomass, specifically from a species known as *Eucheuma cottonii*. Their focus was on utilization of macroalgal biomass as an alternative source to lignocellulosic materials for bioethanol production. Fermentation of the hydrolysate produced 0.33 grams per grams of bioethanol yield with an effciency of 65 percent (Tan et al.,2013).

6.3.8 Medical Textiles

Natural fibres, especially polysaccharides, are a promising material for producing wound dressing products. Products based on alginate, a linear unbranched polysaccharide extracted from brown seaweed, are currently the most popular dressing products used in wound management since it has numerous advantages over traditional cotton-based products. The bandages based on alginate endow easy solubility and reduced wound curing rate than cellulose-based bandages. Alginate is reported to have a high absorbency of exudates. It has gel-forming property. When alginate dressing comes into contact with the wound exudates, it absorbs the exudates and provides a desirable wound moist environment and allows the adequate exchange of water vapour and oxygen which is crucial for wound healing. The gelling property of alginate also aids in painless removal of dressings. Alginate can absorb fluid 15 to 20 times its weight; hence alginate dressings can be used for moderate to heavy exudates (Qin, 2008).

CHAPTER-VII

LEADING THE WAY THROUGH GLOBAL BEST PRACTICES

7.1 Best Practices in Governance Models: The Success of Indonesia

Indonesia is a major producer of seaweed, particularly *Gracilaria, Kappaphycus* and *Eucheuma*. To reap long-term benefits from seaweed cultivation in Indonesia, the necessary support was given through policies, research, and value chain diversification. The change in the policy and governance model adopted by Indonesia increased their productivity through quality assurance.The Ministry of Marine Affairs and Fisheries (MoMAF), Indonesia recognized their vast potential for mariculture development and nominated seaweed as one of its top three priority commodities for aquaculture development from 2021 to 2024. The plan was to expand seaweed farming in eastern Indonesia. The various governance models of the carrageenan seaweed supply chain include direct, modular, market, and relational models. During the "direct governance" period, the "big three" transnational firms of Marine, Colloids, Auby, and CP controlled the purchasing of seaweed. The second phase of "modular governance" took place when suppliers started to play a bigger role in the supply chain. The third stage of "market governance" began when it became impossible to integrate and defend farming as it expanded throughout Indonesia.

In 2008, seaweed farming supported an estimated 20,000 part-time farming families with an average annual income of USD 5,000. By 2017, it rose to 267,800 people in their seaweed industry, according to MoMAF. By 2018, 346,320 marine aquaculture producers were active in the country.In 2017, there were sixteen carrageenan processors in Indonesia, all of which were domestically operated.

7.1.1 Governance

a) PERPRES (Peraturan Presiden, Presidential Regulation) no. 33/2019: Road map of seaweed industry

- Provision of high-quality seaweed seeds derived from tissue culture and non-tissue culture nurseries/seaweed gardens
- Facilitating labor/manpower implementation in the seaweed development region for cultivation and post-harvest.
- Support for the provision of cultivation and post-harvest seaweed facilities and infrastructure in the cultivation development area
- Facilitating access to funding for micro and small-scale agricultural enterprises and seaweed processing industries through groups/cooperatives.

b) Law no. 7/2016: Protection and empowerment of fishermen, fish farmers and salt farmers

- Legal guarantee to protect and to empower small-scale fishery communities (0.5-5 hectare) to overcome problems, including threats of disease, contamination, brood stock, seeds, feed and fertilizers, conflicts of coastal land use / land status (land tenure), climate change and also problems of facilities and infrastructure, marketing of products and access to finance.

c) **Law no. 1/2014: Management of coastal areas and small islands (amendment to law No. 27/2007)**

This law ensures the state's jurisdiction and duty for coastal zone and small island management in the form of control over third parties (individual or private) via a licencing mechanism. Giving approval to other parties does not diminish the state's right to formulate policies, make plans, carry out administration, manage, and supervise.

Provides rights to communities including customary law community units as well as traditional rights in the principle of the unitary state of the Republic of Indonesia.

d) **Law no. 23/2014: Local government**

Authority of the provincial government to manage marine natural resources except oil and natural gas. Administratively, the province has the authority to manage the sea to 12 nautical mile limit. However, the limitation of 12 nautical miles does not apply for small-scale fishermen to fishing activities.

e) **Law no. 45/2009: Fishery (amendment to law no. 31/2004)**

Includes several areas, such as financing and capital assistance for smallholder fishermen and aquaculture farmers, education and training for improving the skills of fishermen and farmers, development of joint business groups and cooperatives, empowerment of women, and facilitation of partnerships between fishermen and small-scale fish farmers with other stakeholders in the industry & allows small-scale fishermen and aquaculture farmers to carry out their activities in all Indonesian fisheries management areas and to prioritize activities in conservation areas within sustainable fisheries zones, subject to applicable regulations.

7.1.2 Quality Assurance through Certification

A focus was given to quality assurance and certification systems. Purchasers of seaweed had the option of seeking sustainable or organic certification. A buyer can choose from a variety of sustainable seaweed certification programs. This was done by adoption of various standards for seaweed quality assurance which are described as follows:

i. **The Global Seafood Sustainability Initiative** (GSSI) employed guidance from the Food and Agriculture Organization (FAO) to benchmark and acknowledge sustainability certification schemes.

ii. **The Friend of the Sea-Seaweed Standard** delineates specifications for management systems, legal compliance, environmental impact assessments, social responsibility, and traceability. This standard pertains to both farmed and wild seaweed and is especially pertinent to the environmental and social concerns present in Indonesia.

iii. **The Assure Quality Standard** required a sustainable management plan, biomass estimation, seaweed production records, and recycling of gear.

7.2 Best Practices in Cooperative Modelling and Product Diversification: Lessons from Philippines

Philippines is a major player in the seaweed industry, ranking third behind China and Indonesia. Seaweed industry contributes 60 to 70 percent to theireconomy. Seaweed cultivation is taken up as family business by those located in economically impoverished regions. It supports approximately one million people and over 1,70,950 jobs in allied fields. Seaweed farming techniques in the Philippines range from traditional fixed off-bottom (FOB) method to more sophisticated installations such as hanging long lines, single raft longlines, multiple rafts longline, and spider web approaches, offering flexibility and potential for expansion with varying levels of investment and durability. Seaweed was processed and sold in various forms such as raw fresh seaweed, seaweed chips, seaweed noodles, raw dried seaweed, and carrageenan, which were used in industrial applications. The raw fresh seaweed was the most basic form, while seaweed chips and noodles were popular value-added products. Raw dried seaweed was dried after harvesting, and Carrageenan was extracted from it to produce semi-refined or refined products. Additionally, seaweed was also used as an ingredient in animal feed and fertilizers for crops. The National Seaweed Technology Development Centre achieved significant growth in vegetables by using seaweed drippings and dried seaweed as fertilizers.

7.2.1 BFAR's Cooperative Model

Bureau of Fisheries and Aquatic Resources (BFAR) has launched a system with 10 seaweed farmer cooperatives in the provinces of Palawan, Albay, Sorsogon, Bohol, Dinagat Province, and Surigao del Sur to build and run seaweed nurseries as a business. Cooperative Managed Seaweeds Nursery Business Enterprise (CMSNBE) is the name of the prototype project. Cooperative revenues are distributed to shareholders, farmers, and the community, encouraging inclusion and shared prosperity. BFAR was to identify the top 20 seaweed producing municipalities in the country and form sustainable cooperatives to execute the Pareto Principle, which is widely applied in corporate business and even government today. The following assistance was extended to them until they were able to operate independently:

- Development of human resources through training in governance and business management, which was provided by accreditedtraining institutions.
- Financial support (this is the incubation stage) for the cooperatives to execute their strategic plans.
- Establishing a cooperative consortium from among the BFAR partner cooperatives and providing necessary operational support. Support was also provided to engage in missionary seaweeds that could be proessed into products like food, fertiliser, and feeds with the goal of achieving national food security.
- Establishment of partnerships between cooperative consortium and organisations or companies that allowed creating and developing goods made from seaweeds for use as food, fertiliser, and feeds.
- BFAR connected the cooperatives and provided finance from the Land Bank of the Philippines (till three years or when the cooperative becomes a sustainable business enterprise being able to obtain conventional bank financing).
- Supported the establishment of seaweed farms in offshore areas for carbon capture and reducing eutrophication of marine waters.
- Established a link between the cooperatives and the MLGUs (Municipal Local Government Units) to allocate 50 hectares or more in the municipal waters for the establishment of cooperative farms.

7.2.2 Government Policies, Strategies and Programs

The government of Phillipines focussed on adoption of targeted policies for various stakeholders in the value chain so as to ensure success (Table 16).

Table 16. Government policies, strategies & programs of Philippines

Objectives/ Targets	Strategies / Policies / Programs	Issues / Constraints being addressed	Key result Areas
Increase seaweed production by 2 percent per year for five years (2022-2026).	1) In conjunction with the commercial sector, improve and maintain existing BFAR Seaweed Culture Laboratories (SCL). 2) Establishment of a cutting-edge seaweed culture laboratory	1) Current cultivars having low productivity and production. 2) Insufficient availability of seaweed propagules in the off-season and the destruction of seaweed farms as a result of unfavourable weather conditions.	BFAR SCLs have been improved/ maintained in conjunction with the business sector. Created a cutting-edge facility.
	Establishment of a satellite seaweed land-based nursery/seedling bank (seaweed phonics) in collaboration with cooperatives (Sorsogon, Bohol, and Hinatuan) and the private sector.	1) Inadequate supply of good quality seaweed propagules. 2) Low productivity and production of present cultivars.	Established satellite seaweed land-based nursery/ seedling bank (seaweed phonics) in partnership with cooperatives and in collaboration with the private sector.
	Seaweed nurseries are being established and maintained in conjunction with the private sector, BFAR management and cooperative management.	1) Inadequate supply of good quality seaweed propagules. 2) Low productivity and production of present cultivars. 3) Limited drying facilities inconsistent quality of dried seaweed.	1) Established and maintained BFAR/ cooperatives managed seaweed nurseries. 2) Provided propagules. 3) Provided hanging type solar dryers.
Provide access to financial resources to farmers (credit support)	1) Examine possible credit programs for seaweed farmers. 2) Seminars are used to disseminate information about available credit programs for seaweed farmers. 3) Recommend to ACPC that the Central Bank designate significant seaweed producing areas as Micro-Financing Organizations (MFO).	Lack of capital and access to financial resources	Capital provided to seaweed farmers
	1) Conduct a financial literacy orientation seminar for seaweed farmers. 2) Reproduction of educational and informational materials. 3) Assist with the preparation of documentary needs and processes.	Lack of information on available loan assistance from financing institutions	Created awareness on available loans from financing institutions.
	1) Making payment arrangements. 2) Create non-collateral, easy-to-repay loans for seaweed farmers. 3) Conduct scientific study on appropriate loan terms, interest rates, and repayment plans, as well as the viability of the unique loan programme.	Created awareness/ consciousness on the importance of financial management.	Microfinancing made available to seaweed farmers in major seaweed producing regions.

Objectives/ Targets	Strategies / Policies / Programs	Issues / Constraints being addressed	Key result Areas
Improve linkages of seaweed farmers to major local markets	1) Intensify the organisation of Seaweed farmers into a cooperative in order to meet the demands of seaweed processors. 2) Formation offederations from the seaweed cooperatives.	1) Presence of several 'tiers' in the trading chain. 2) Presence of 'fly-by-night' traders.	1) Layers of traders were minimized. 2) Fly-by-night traders controlled
	Organization of convention, symposium.	1) There is no direct connection between farmers and processors. 2) Poor or unsatisfactory business or collaboration with seaweed farmers.	1) Farmers and buyers/processors had direct communication. 2) Enhanced business partnerships with farmers.
	1) Meet investors, particularly for the recently developed seaweed applications that have a market. 2) Providing warehouse to cooperatives.	1) Low adherence to the demands and criteria of the market. 2) Few facilities for drying and storing. 3) The dried seaweed's quality is uneven and subpar. 4) Seaweed growers' meagre earnings. 5) Absence of storage to group their produce.	1) Improved market demand for seaweed products (RDS). 2) Secure cooperatives market through a Memorandum of Understanding with direct buyers. 3) Farmers saved a large amount of RDS. 4) Higher volume, higher RDS pricing, better income, and improved/ maintained RDS quality.

Objectives/ Targets	Strategies / Policies / Programs	Issues / Constraints being addressed	Key result Areas
Capacitate seaweed farmers and farmer's organization	1) Regular attendance oftrainers' and fisherfolks' trainings/seminars/ workshops 2) Training for seaweed production and processing -NC II	1) Noncompliance with biosecurity and appropriate farming practices. 2) Exposure to seasonal weather disruptions and the effects of climate change. 3) Seaweed pests and illnesses (ice-ice) are common. 4) In field farming, indiscriminate, improper application, and discharge of artificial fertilizer.	Trainers and farmers followed GAqP, PNS on seaweed production and processing, which reduced the impact of CC and the incidence of pests, epiphytes, ice-ice, and improper use of chemical fertilizer.
	Establishment of training and assessment centers for seaweed production - NC II and Seaweed processing- NC II in Luzon, Visayas, and Mindanao under the agriculture career system	1) Increasing competition from other seaweed producers. 2) In terms of market potential for carrageenan seaweed, competition with other countries exists, dwindling pool of qualified technical specialists.	1) Farmers' competitiveness in comparison to other countries. 2) Exposure to advanced technology countries.
	1) Students will be able to attend training and assessments thanks to a TESDA scholarship. 2) Graduates having a National Certificate II will be used as resource individuals by BFAR during trainings. They will also be given the tools and supplies they need to start their own business.	Encourage young generations to work in the seaweed sector.	1) Additional knowledge/ technology was acquired. 2) Networking with local and international institutions has been established.
	Cross-country/regional visits to successful seaweed areas/farmers, as well as knowledge and best practices exchange	Collaboration on funding and grants with international institutions and agencies e.g., GCRF-UKRI, WWF-GEF.	Access to the knowledge of farmers who are experts in seaweed technology.
	Collaboration and networking with the national and international seaweed community and those working on the conservation of marine resources.	Declining pool of competent technical experts.	

Objectives/ Targets	Strategies / Policies / Programs	Issues / Constraints being addressed	Key result Areas
Promote community-based value-added products and fresh seaweeds for food and nutrition security	1) Supply of processing equipment, materials, and tools 2) Product development, production, and marketing of seaweed-based products 3) Technical support with seaweed-based product packaging and labelling	1) Inadequate understanding of the developmental elements of seaweed processing. 2) Technical instruction and assistance have a limited reach and quality.	1) Beneficiaries identified. 2) Beneficiaries (coops) were trained. 3) Provided start-up processing equipment/ materials/tools. 4) Commercialized seaweed-based products
	1) Product marketing 2) Participation in trade shows 3) Connect to the market by hosting an annual inventors-investors forum.	Limited promotion of seaweed products.	1) Technical support in the packaging and labelling of seaweed-based goods. 2) Participation in trade shows. 3) Creation of forum for inventors.
	1) Establishment & operation of VLSPFCarrageenan, agar, alginate, and other phycocolloids extraction 2) Monitoring and evaluation of the processing facilities' status	Limited technical staff to work on seaweed applications.	1) Established and running VLSPF. 2) Status of processing facilities was monitored and appraised.
	1) Development of new seaweed application (R&D) 2) Examination of the generated products 3) Transfer of technology 4) Production and dissemination of IEC materials for developed products	1) Carrageenan R&D as an organic food additive has a limited budget. 2) Alternative uses for seaweeds in feeds and fertilizers. 3) Promotion of new seaweed products is limited.	1) New seaweed applications created. 2) IEC materials about the items developed were created and distributed carts for seaweed products.

7.2.3 Product Diversification and Linkages

Key enablers along the various seaweeds value chains include national agencies such as DA-BFAR, DTI, Department of Science and Technology (DOST), Department of Social Welfare and Development (DSWD), Department of Environment and Natural Resources (DENR), the local government units, SIAP, NGOs, SUCs. The entire ecosystem of the country targetedly focused on inclusion of all stakeholders in value chain and orient them with mutual, backward and forward linkages so as to serve the different forms of seaweed sold in the market viz. raw fresh seaweed, raw dried seaweed and semi-refined and refined carrageenan.

The most basic form of seaweed, i.e. raw fresh seaweed value chain (Figure 43) was linked to its key stakeholders viz. the BFAR, farmers, traders, seedlings contractors, etc.

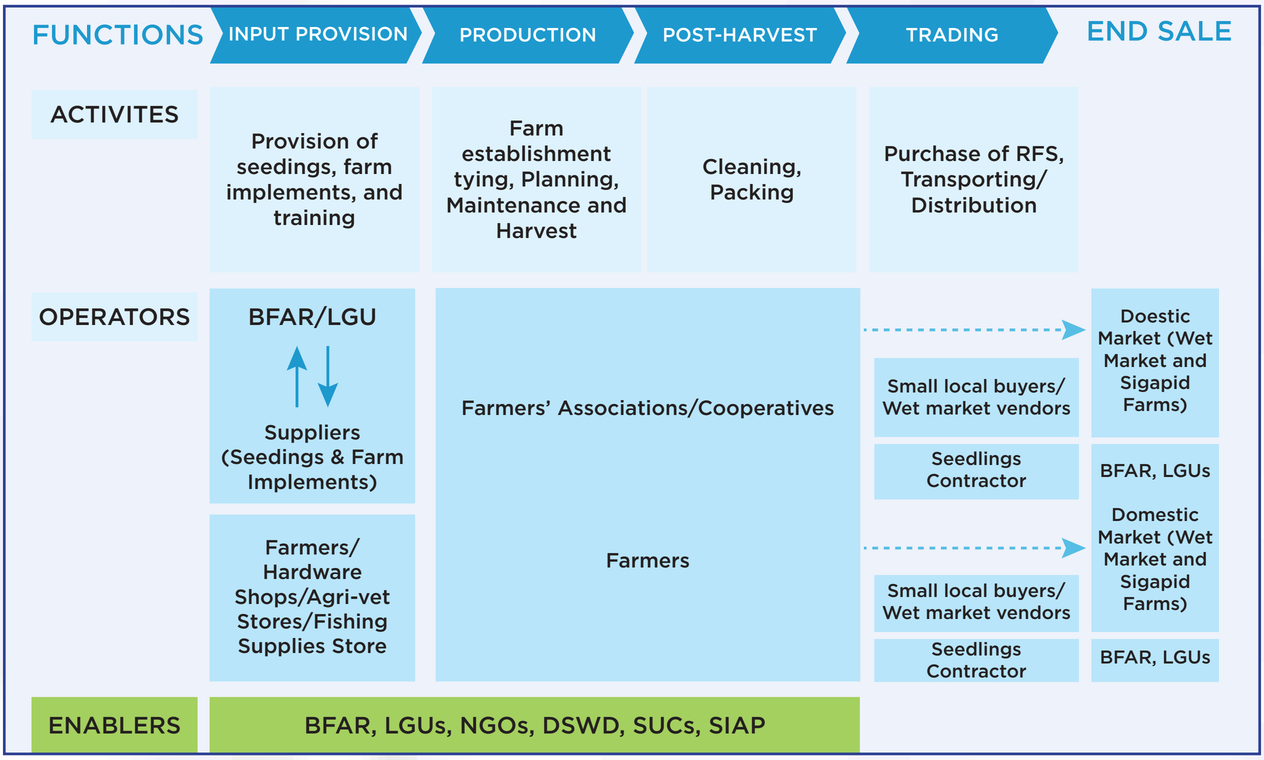


Figure 43. Value chain map of raw fresh seaweeds

The raw dried seaweed value chain map (Figure 44) is divided into four key sections: Input provision, production, post-harvest, and trading. In the RFS value chain, the activities in the input provision and production phases of the chain are identical. Yet, the post-harvest and trading segments engage in other crucial activities. The traders' collection of dried seaweeds is largely sourced from foreign nations. Despite the availability of significantly less expensive Indonesian seaweeds, Philippine RDS continues to be the chosen seaweed by other nations because of its quality. BFAR offices that require dried seaweed for their livelihood projects are currently receiving a small quantity of supplies.

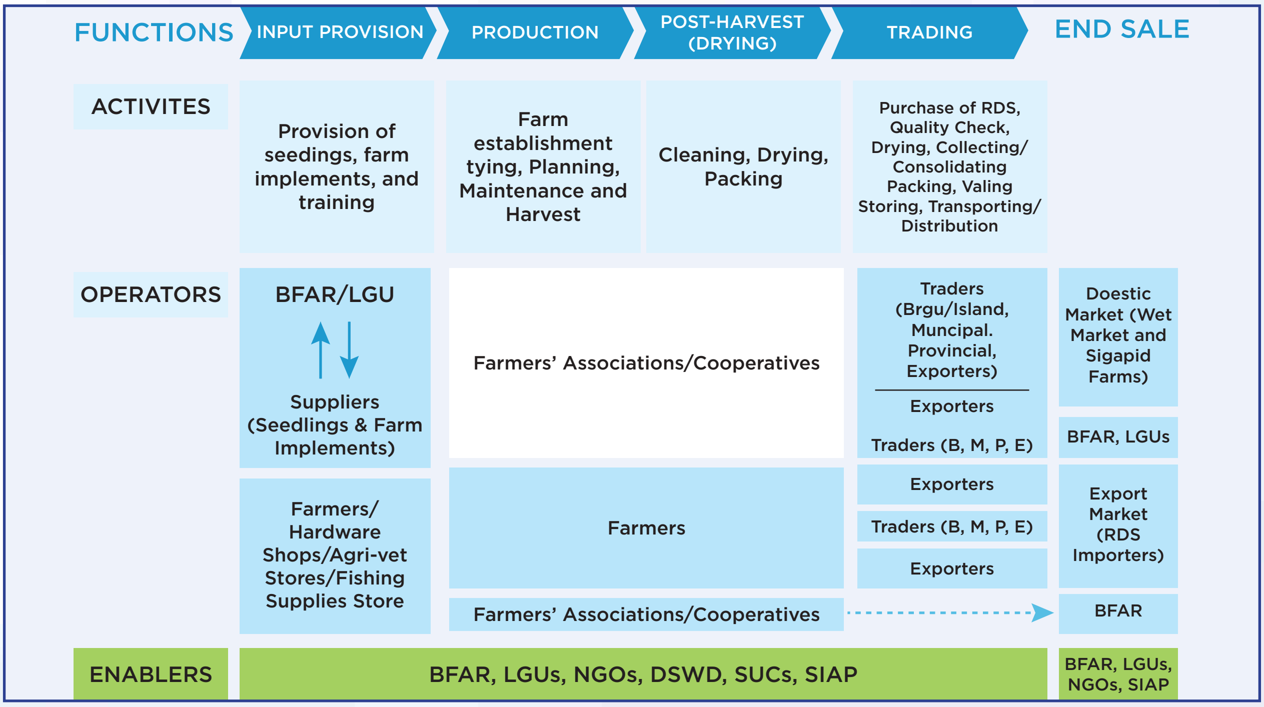


Figure 44. Value chain map of raw dried seaweeds

The manufacturing of semi-refined (SRC) and refined carrageenan is thought to involve a longer value chain map (Figure 45) as a result of the conversion of dried seaweeds to carrageenan (RC). The RDS value chain is most similar to the four segments. The extended marketing and processing activities of the chain include additional duties such as the procurement, quality inspection, and management of dried seaweeds, the conversion of dried seaweeds into carrageenan, packaging, distribution, and marketing of carrageenan. Despite the fact that the majority of the country's carrageenan is exported, the domestic market, particularly the food processing sector, benefits from its production.

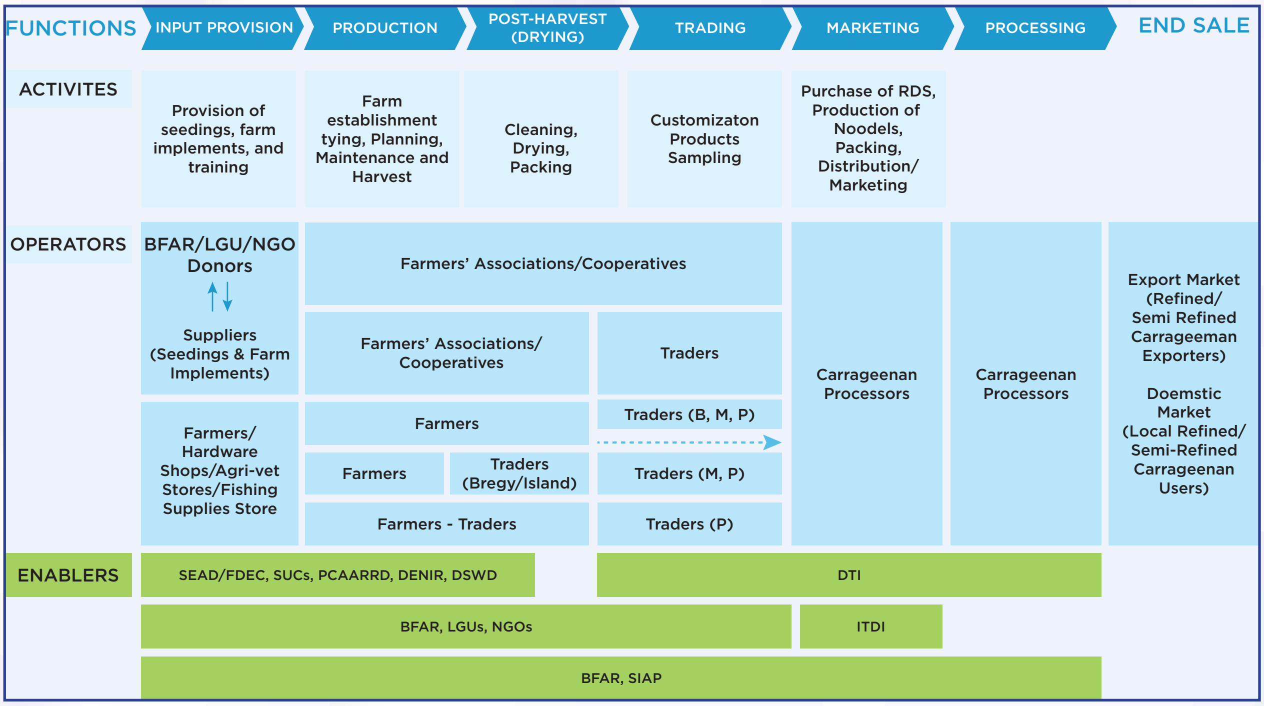


Figure 45. Value Chain map of semi-refined and refined carrageenan

7.3 Best Practices in Cluster Development and Standardization of Farms: Lessons from Africa

Seaweed production in Africa is concentrated in Tanzania's Zanzibar, Madagascar, and South Africa. Tanzania has 30,000 farmers, mainly women, cultivating *Eucheuma* and *Kappaphycus* species using off-bottom farming methods. Climate change and low gate prices were just two of the sector's concerns, but seaweed farmers in Tanzania have demonstrated how the industry may flourish in a relatively short amount of time to become one of the main producers outside of Asia.

The main species farmed are the *Eucheuma species, E. denticulatum, K. striatus and K. alvarezii,* varieties of which were imported from the Philippines in 1989. Whereas production of *E. denticulatum* is above 100,000 tonnes (fresh weight), the production from the genus *Kappaphycus* was less than tonnes (fresh weight). Seaweed production in Tanzania has increased rapidly since the start of the industry in 1989, particularly in Zanzibar, which comprises two islands, Pemba and Unguja. Production increased from 8,080 tonnes in 1989 to a maximum production of 1,76,000 tonnes recorded in 2016.

7.3.1 The Seaweed Cluster Initiative

The Seaweed Cluster Initiative (Seaweed CI) aimed to increase seaweed production in the country by modifying farming techniques and adding value to the produced seaweed. The following were the key strategies adopted to achieve this goal:

1. **Addressing the problem of *cottonii* dying-off**: Solving the problem of dying-off of *Cottonii*, a high-priced seaweed species raised the income of farmers.
2. **Adding value to seaweed**: Incentives were provided for semi-processing and full processingto make seaweed products. These fetched higher prices than bulk-unprocessed seaweed.
3. **Farming new seaweed species**: The Seaweed CI aimed to incentivize farmers to farm new seaweed species that added income to their farming activities.
4. **Standardisation of farms**: By standardising farms, more space was used within the same farming areas, thus increasing production per unit area. This reduced wastage of space.

Seaweed CI implemented a standardisation strategy (Figure 46) for seaweed farms to increase farming area and reduce seaweed breakage due to strong winds. It involves placing farms facing the same direction instead of different directions used by the farmers. The standardisation process will omit unnecessary spaces that are unused between farms thus increasing the farming area. This approach also reduced the breakage of seaweed due to strong winds, which improved seaweed production.

Figure 46. Current placement of farms and what the CI is doing to standardize the farms.

The seaweed cluster initiative has also been instrumental in devising small group product development strategies. Several initiatives have involved seaweed farmers in value-adding initiatives. For example, the Seaweed Centre Company Ltd., located in Paje village on the East Coast of Zanziba was built through collaboration between Chalmers University of Entrepreneurship in Sweden, Seaweed Cluster initiative, and Zanzibar Adventure School. The Centre has a soap factory, shop for selling seaweed value-added products, a kitchen for cooking seaweed food, a roof top meeting and "restaurant" facility. They produced food products such as seaweed cake, juice, cookies, jams and seaweed salad, as well as seaweed soaps blended with neem, moringa extracts, lime (citrus) & clove. The Centre also conducts Seaweed Farming Tour where visitors are taken through the process of farming and adding value to seaweed. Paje Seaweed Centre Company Ltd. works with the women NGO (Paje Seaweed Centre Society) who make the seaweed products includes seaweed soaps, body creams, spa scrubs, and foods. The key takeaways from this are:

- Utilize conventional (old) technology to create semi-refined iota carrageenan (SRC-I) in carrageenan (SRC-I) from raw, dried seaweed (RDS) in Zanzibar-based production facilities.
- Employ newly developing multi-stream, zero-effluent (MUZE) technology to start processing live, fresh seaweed (FS) to create SRC-I as well as agricultural nutrient products and various other products that may be made possible by evolving biotechnology.

7.4 Best Practices in Energy Production from Seaweed: Lessons from Japan

The Ocean Sunrise Project is a ground-breaking initiative in Japan aimed at harnessing the immense potential of the country's exclusive economic zone (EEZ) and maritime belts, which rank among the worlds largest. By focusing on the production of bioethanol from *Sargassum horneri* seaweed, this project presents an opportunity for Japan to explore sustainable energy options. Recognizing the pressing issue of global warming, the project alignes with international frameworks such as the Kyoto Protocol. While traditional biofuel production has relied heavily on food crops such as maize and sugarcane, concerns about food costs and limited scalability have emerged. The Ocean Sunrise Project highlights the need to explore alternative biofuel sources. Seaweed, with its comparable bioenergy production to terrestrial plants, presents a viable solution as an energy crop that can generate substantial amounts of alternative fuel without compromising food supplies.

7.4.1 Project Image of Bioethanol Production

The Ocean Sunrise Project aimed to produce 5 million kiloliters of bioethanol by farming 150 million tonnes of *Sargassum fulvellum*, using less than 1 percent of Japan's economic zone of 4.48 million square km. By expanding this production to the three largest oceans, about 1 billion kiloliters of bioethanol can be produced. However, such large-scale seaweed farming required deep water farming technology, and demonstrations are needed to gradually develop farming and harvesting technology at various water depths. The project's mid to long-term goal is to achieve these objectives, which can contribute to solving global environmental and energy issues while utilizing unused spaces in the world's oceans.

The Ocean Sunrise Project involves the use of water as its primary material flow, with seaweed accounting for 90 percent of the 150 million tonnes of annual production. The fermentation and distillation process consumes the remaining 10 percent. Any water left in the seaweed after natural drying, fermentation, and distillation is returned to the ocean. During the fermentation and distillation processes, 58 percent of the consumed seaweed substances are converted into bioethanol through the fiber, alginate, and mannitol processes, while the remaining 42 percent is composed of organic components, nutritive salt and ash and will be used efficiently as cattle feed or fertilizer.

To address the issues related to facility and maintenance costs, the Ocean Sunrise Project plans to use a soft facility structure consisting of ropes and nets for seaweed farming. This system will be implemented in coastal zones with water depths of 500 meters or less and offshore zones with water depths ranging from 500 to 3,000 meters. In coastal zones, seaweed farming technologies such as kelp (*Laminaria*) and wakame (*Undaria pinnatifida*) will be adapted, where seeds will be planted and grown on ropes laid at the water surface. Harvesting methods using reaping vessels or laver farming technology are being considered. The target cost for seaweed production is 1,000 yen per 1 tonne of wet weight.

For offshore zones, the project envisions using sea kite farming, utilising ocean currents. The sea kites will be configured with a triangular shape of 1.5 km in length and 1.0 km in width, similar to trawl nets. Equipment made of canvas configured like otter boards of trawl nets will be placed onto sea kites, and their spread-out position will be maintained by the power of ocean currents. Single point mooring, based on deep water mooring technology, will be used. Seaweed production per facility is estimated at 60,000 to 190,000 tonnes annually.

For the Ocean Sunrise Project, a water bag transport method was implemented in order to reduce transportation and land storage expenses. A system like this would use the water bag transportation method for moving enormous amounts of water. Water bags are being investigated as a substitute facility for fermenters in addition to being used to store seaweed in ports and on the ocean.

Alginate, mannitol, and fiber found in seaweed are converted into ethanol, butanol, etc. to create seaweed biofuel. The effectiveness of the fermentation system that is built is crucial in various production processes. The RITE (Research Institute of Innovative Technologies for the Environment) system, which combines alginate glycation with extremely efficient fermentation technologies, is one example of a technological advancement that the Ocean Sunrise Project is seeking.

7.5.2 Comparison of Ethanol Production Rate

According to contained component estimates, seaweed may produce about 27 kg, or 34 litres, of ethanol for every tonne of raw material. Similarly, the findings in the Table 17 reflect a comparative analysis of estimated ethanol generation from land crops and seaweed. While having a lower production rate than land crops, seaweed have high-water content. Due to high productivity per area, ethanol generation potential is significant and equivalent to that of sugarcane.

Table 17. Ethanol production from major land crops and seaweed

Raw material	Moisture in raw material (%)	Carbohydrates, etc. (subject to fermentation) (%)	Ethanol Production per 1 tonne of raw material	
			(kg/tonne)	(l/tonne)
Corn	14.5	70.6	360.8	462.6
Barley	14.0	76.2	389.5	499.3
Wheat	10.0	75.2	384.4	492.8
Rice	15.5	73.8	377.2	483.6
Sweet potato	66.1	31.5	161.0	206.4
Potato	79.8	17.6	90.0	115.3
Sugarcane	60.0	15.0	76.7	98.3
Seaweed (*Sargassum horneri*)	90.0	5.8	29.6	38.0

Source: Aizawa et al., 2007

Seaweed contains different components subject to fermentation (alginates, etc.) than that of land crops (starches, glucose) and thus there is a difference in production coefficient.The overall energy balance is thought to be almost equivalent to that of bioethanol made from land crops. However, during the refining process via distillation, energy consumption is high, and it is estimated that production is possible with input energy at 70 percent of the calorific power of ethanol. To improve energy efficiency, new technologies such as membrane dehydration are desired. Using membrane dehydration, it is estimated that production is possible with input energy at 55 percent of the calorific power of ethanol. Figure 47 depicts the resource consumption in ethanol production equivalent to 1 kg of oil-based gasoline. Bioethanol production from seaweed could be a potential game-changer for the Indian seaweed industry.

Figure 47. Resource consumption in ethanol production equivalent to 1 kg of gasoline (oil based)

7.5 Best Practices in Processing of Seaweed to Culinaries: Lessons from South Korea

South Korea is a significant global player in the seaweed industry, with an impressive annual seaweed harvest of 1,761,526 tonnes in 2017 worth USD 864,409 thousand. In 2018, Korea exported 42,033 metric tonnes of seaweed worth USD 601,006 thousand, while importing 14,341 metric tonnes valued at USD 28,161 thousand. *Pyropia*, known locally as "Gim," is the most valuable seaweed species, contributing to 71 percent of the total output value. The most commonly produced seaweed species were *Undariapinnatifida*, *Saccharinajaponica*, and *Pyropia* spp. *Pyropia* was the most exported species, while *Cottoni* and *Spinosum* were the mostly imported one.Korea's prowess in seaweed farming makes it a net exporter of seaweed, both in terms of quantity and value.While Koreans have a long history of consuming seaweed as food, there is now a qualitative shift in the consumption patterns of seaweed-based products. People are increasingly turning to seaweed as a functional health food, beauty product, and biotherapeutic. This shift towards more diverse and sophisticated applications of seaweed-based products highlights the growing importance of seaweed beyond traditional cuisine. Since the 1980s, numerous seaweed food products have been developed, including machine dried *Pyropia*, toasted *Pyropia*, salted or sliced *Undaria,* sun-dried *Undaria*, and seasoned *Saccharina* jam. Currently, there is a wide range of packaged goods and processed fast foods available.

Pyropia is typically mechanically processed into dried sheets, and almost all obtained *Pyropia* undergoes this processing method. In terms of *Undaria*, there has been a shift in output from salted to dried one due to a decline in the export of salted *Undaria* to Japan. Dried *Undaria* is widely used in various processed foods, snacks, and wellness items in Korea. Boiled and sun-dried *S. fusiforme* is also a significant commercially important export to Japan. In recent years, *U. prolifera* has been processed into salt and oil after being dried in sheets, similar to *Pyropia*.

7.5.1 The Golden Seed Project of South Korea

Pyropia spp. is the most important seaweed species in South Korea and breeding efforts are focused on developing temperature-resistant, fast-growing cultivars that are high in desirable secondary metabolites and disease-resistant. *Undaria pinnatifida* is widely cultivated in Korea and serves as a fresh feed for abalone. The cultivation area for *S. japonica* has increased by 671 percent between 2001 and 2015 to meet the growing demand for kelp feed from abalone producers. The kelp farming sector has expanded rapidly, driven by advancements in seedling and rearing technology. The Korean government established the "Golden Seed Project" to support the creation of seaweed cultivars.

To regulate human health and lifestyle, seanol (sea polyphenol) is derived from *E. cava* and sold as cosmetics, medical food, and other products. A significant industry in Korea for many years, agar-agar extraction from *Gelidium* has constantly been a top export product. However, as a result of the majority of the processing facilities moving overseas, the agar processing business has experienced a substantial downturn. There are currently only a few agar processing facilities left, and agar-agar exports make up only about USD 3 million in annual exports. In addition to its use in food, kelp is increasingly being used in health supplements such pills, extracts, jelly, and powder. In some areas, local governments have developed thalassotherapy utilizing seaweed. Some of the culinaries processed out of seaweed in South Korea are depicted in Figure 48.

Figure 48. Seaweed processing and products of South Korea. (a) Processing of *Pyropia* to dried sheets (21 cm × 19 cm in size, 2.5 g-wet weight). (b) Sun-dried *Undaria pinnatifida*. (c) Sun-dried *Sargassum fusiforme*. (d) Sun-dried *Saccharina japonica* waiting for the auction. (e) Sun-dried *Ulva prolifera*. (f) Fried with oil and salt of *Pyropia*. (g) Various products of *Pyropia*. (h) Snacks and instant salads of seaweeds. (i) Seaweed cosmetics

7.5.2 Learnings from South Korea

The development of seaweed cultivation technology, which has prioritised reducing labour and pursuing the efficient use of technology, large-scale farming, development of automated harvesting and processing technologies, and increasing productivity through better varieties and culture techniques, is the cause of this growth. The developments of indoor culture systems support the industry's competitiveness and allow seaweeds to be produced year-round in order to compete with terrestrial vegetables. By placing such systems close to markets, it is possible to satisfy customer demand for fresh goods while reducing the carbon emissions caused by shipping such goods from far-off ports. The Korean seaweed industry grows in response to the needs of environmentally and health-conscious consumers with more certifications. The world's first Aquaculture Stewardship Council-Marine Stewardship Council (ASC-MSC) certification was obtained by a seaweed company (The Haedam Co. farm) in Korea in 2019, and as the Korean seaweed indurstry grows in response to the needs of environmentally and health-conscious consumers, more certifications are anticipated in the future.

CHAPTER-VIII

RECOMMENDATIONS & WAY FORWARD

Considering the status of seaweed value chain in India, it requires multi-stakeholder, multilevel and inter-ministrial convergence, collaboration, and co-ordination. To fulfill the goal of increasing the allied sector's share of GVA in agriculture from 7.28 percent in 2018-19 to approximately 9 percent by 2024-25 and in order to maximize the realization of potential of seaweed value chain, recommendations are laid out below.

8.1 Regulatory and Governance

i. Amendment in the Allocation of Business Rules, 1961

The Allocation of Business Rules, 1961 may be suitably amended to explicitly allocate the responsibility for seaweed value chain development to the appropriate department, ministry, or agency.The "seaweed" and any other aquatic life are included under the term 'fish' which has been defined under the Maritime Zones of India (Regulation of Fishing by Foreign Vessels) Act, 1981 [clause 2(b)]. Besides, the global status of' seaweed production' has always been published as part of The State of World Fisheries and Aquaculture (SOFIA), which is the flagship publication of the FAO by its Fisheries and Aquaculture Department.

Accordingly, seaweed cultivation and its value chain should be included under the allocation of business rules of the Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI, which would help in undertaking delegated responsibilities in a more focused manner.

ii. Exports and certification of seaweed and its products

The exports of seaweed may be allocated to MPEDA under the Ministry of Commerce &Industry, GoI by suitably amending the Allocation of Business Rules, 1961. MPEDA and the National Cooperative Development Corporation (NCDC) may undertake the sale and export of seaweed and its products through the existing network of FPOs, FFPOs, SHGs, etc. MPEDA may be designated to oversee the certification process of seaweed and its products. International harmonization should be made to align certification programs and standards. This can facilitate the global trade of certified seaweed products and prevent market barriers due to varying certification requirements. MPEDA may establish the certification protocols and processes. Afterwards, it may be handed over to an independent third-party certification organization to run the certification system.

iii. Constitution of a National Steering Committee

A national steering committee under the chairmanship of the Secretary, Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI, comprising representation from the coastal states and union territories, can be constituted for untapping the seaweed potential, and effectively managing associated environmental, economic, and interstate issues. The steering committee may comprise representation from CSIR-CSMCRI, ICAR-CMFRI, MPEDA, etc.

iv. Constitution of Technical Committee for the import of seaweed seeds and planting material

Lack of quality seeds and hurdles in importing germplasm and wet seed materials are among the major challenges in promoting seaweed cultivation.The authority for providing permission for the import of live seaweed material to India for research purposes currently deals with the Directorate of Plant Protection, Quarantine, and Storage under the Ministry of Agriculture and Farmers Welfare. As per Plant Quarantine Order 2003 (Schedule VII-Plant and Planting Materials), only "dried seaweeds" such as-*Chondrus* spp./ *Ecklonia rnaxima, Eucheuma* spp./*Gelidiurn* spp./ *Gelidiella* spp./ *Gracilaria* spp./ *Kappaphycus* spp./ *Pteroclodia* spp. are allowed to be imported for human consumption. The commodities under 'Schedule VII, including seaweed, are permissible on the basis of a phytosanitary certificate issued by the exporting country, and the inspection is conducted by the inspection authority. In order to obtain proper permission to import live seaweed material from abroad, the

Plat Quarantine (PQ) Form No. 23 & 24 issued by the Plant Protection Adviser, Directorate of Plant Protection, Quarantine & Storage (DPPQ&S), GoI has to be duly filled in and furnished to the above department so as to give appropriate clearance for the import of explants or tissue culture-raised plantlets (for research purposes).

A national-level technical committee for the import of seaweed seeds and planting material may be constituted under the Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI. The technical committee may use a mechanism for seaweed, similar to the indenting system used for crop seeds. The committee shall comprise representation from the following organizations:

- Directorate of Plant Protection, Quarantine, and Storage (DPPQ&S)
- Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI
- Department of Agriculture & Farmers Welfare
- The Indian Council of Agriculture Research (ICAR)

v. Priority Sector Lending for seaweed

The Reserve Bank of India may consider including credit related to seaweed in the list of priority sector lending (PSL) of banks, as seaweed is a tool to combat and deal with climate change.

vi. Guidelines for the regulation of seaweed-based products

The certification system for seaweed-based products maybe developed by the regulatory and certifying authority pertaining to the product category. For example, certification for pharmaceutical products maybe developed by Central Drugs Standard Control Organization (CDSCO), for biostimulants by the Ministry of Agriculture and Farmers Welfare (MoA&FW), for animal feed by the Department of Animal Husbandary (MoFAH&D).

Standards on edible seaweed products would typically incorporate establishing maximum limits for contaminants, including heavy metals and toxins. They also encompass the formulation of guidelines for labeling and packaging, along with specific prerequisites for production and processing methods. Furthermore, permissible additives and preservatives are defined within these standards to ensure product safety and quality. Such standards may be developed and notified by the FSSAI. FSSAI should harmonize Indian Standards for use of seaweed products in line with the CODEX standards.

vii. Import and quarantine system

A defined process for the import and quarantine of different seaweed strains should be notified. Research institutions responsible for the process of acclimatization, assessment, and final clearance should also be notified. This would increase growing options for cultivators and get them away from monoculture while increasing income opportunities.

8.2 Social Security and Financial Support

i. Comprehensive risk cover through insurance

To mitigate the risks posed by weather events such as excess rains, cyclones, high tides, etc., risk cover is essential for seaweed farming. The insurance scheme may be finalized in consultation with the insurance companies. The insurance may cover crop insurance, life-insurance of the seaweed farmer, insurance for capital infrastructure relating to seaweed cultivation and processing. The Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI may lead this in the interest of farmers.

ii. Financial support for seaweed cultivation

The scope of the PM-KISAN scheme may be broadened to include seaweed farmers, and similar input support may be provided to them under the scheme. The appropriate guidelines for the same may be formulated by the Ministry of Agriculture & Farmers Welfare (MoA&FW). Similarly, the scope of the PMFBY scheme may be broadened to cover seaweed farmers under its ambit. The appropriate guidelines for the same may be formulated by the MoA&FW.

iii. Improved access to institutional credit for seaweed farmers

In order to provide institutional credit to seaweed farmers, the following is recommended:

1. Covering all seaweed farmers under Kisan Credit Cards (KCC) and enabling access to institutional credit.
2. Promote a large number of joint liability groups (JLGs) for group financing, which will enhance the access of small and marginal farmers to institutional credit.
3. Mobilize farmers through self-help groups (SHGs), commodity interest groups (CIGs), and fish farmer producer organizations (FFPOs) and strengthen their ability to access credit facilities from banks and cooperatives.
4. As recommended earlier, the Reserve Bank of India may consider including credit related to seaweed in the list of PSL of banks, as seaweed is a tool to combat and deal with climate change. This will make available more and easy institutional credit for seaweed farmers.

8.3 Incentivising Investments and Ease of Doing Business

i. Enhancing investment in coastal regions

Recognizing the significant link between agricultural and allied sector growth and gross capital formation (GCF), increasing investments in the seaweed sector through both the public and private / corporate sectors is crucial. The Ministry may take enabling measures for the corporate sector and young entrepreneurs to take advantage of various reforms introduced in the sectors of marketing, foreign direct investment (FDI), input management, initiatives like Stand-up India, Start-up India, and infrastructure-promoting initiatives.

ii. PPP partnership

The importance of investment in supply chain infrastructure and integrated processing is critical for the creation of market opportunities for seaweed farmers. The Public-Private Partnership (PPP) mode may be adopted for the creation of such infrastructure. PPP mode may also be deployed to support the development and implementation of certification programs. This can provide financial assistance, technical expertise, and research support to certification bodies, seaweed producers, and processors.

iii. Ease of doing business

The Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI should establish guidelines for seaweed cultivation activities such as site selection, infrastructure development, and monitoring.

iv. Development of dynamic data portal and decision support tools

A portal may be developed with geo-tagging of all sites suitable for seaweed cultivation. The portal should have multiple users so that state governments, union governments, research organizations, farmers, universities, etc. may have access to the data required. It should identify seaweed clusters, such that respective state governments and universities should be able to utilize it for the formulation of cluster development plans for seaweed.

v. Inclusion of seaweed and its products in e-NAM and agriculture mandis

e-NAM and state agriculture mandis may be amended to have a separate category of seaweed and seaweed-related products for their trade and sale. PPP mode for sale-side intervention may also be explored.

vi. Scaling up of Seaweed Farmer Service Platform (SFSP)

The 'Seaweed Farmer Service Platform' (SFSP) may be scaled upwhich can serve as a central repository in the data ecosystem to enable data-based decision-making.

vii. Use of remote sensing data

Real remote sensing-based metrological monitoring systems can be leveraged to provide customized short-, medium-, and long-term meteorological forecasts to farmers. This will enable farmers to make the right decisions at the right time to reduce losses and improve yields.

8.4 Infrastructure and Institutions

i. Establishment of seed banks

Seed banks should be established by the research institutions, agriculture, and fisheries universities, as well as FFPOs in all the maritime states and UTs to ensure the availability of quality seed material immediately after the end of monsoon.

ii. Leveraging FFPO's for infrastructure development and economies of scale

FFPOs can be instrumental in the cultivation and utilization of seaweed through enhanced production, infrastructure development, market linkages, marketing support, and financial inclusion. FFPOs can play a vital role in helping farmers economies of scale. The Department, through the Small Farmers Agri-Business Consortium (MoA&FW), KVKs, agriculture and fisheries universities (both public and private) may incentivize the formation of FFPOs catering to seaweed.

iii. Creation of logistics and processing centers at cluster level

In order to facilitate primary processing of seaweed at cluster level, logistics and processing centers may be created to provide access to basic logistics such as warehouses (both dry and wet), transport (dry and reefer), pack houses, cleaning, grading, packaging facilities, etc.

iv. Creation of aggregation and marketing centers at district level

These centers can serve as hubs where primary processed seaweed produce is brought for standardization and aggregation, enabling efficient transactions.

1. Standardization and aggregation*:* The centres will ensure that the seaweed products meet specified quality standards and are properly processed. Standardized and aggregated seaweed can be transported from these centres to export, whole-sale, or retail markets for further distribution.
2. Upgraded storage facilities and promote using the eNWR (electronic negotiable warehouse receipt) system to streamline storage, trading, and collateralization of seaweed products.
3. Marketplaces and Digital Trade Platforms*:* They can also function as marketplaces where farmers can directly sell their seaweed produce.These centres can be integrated into digital trade platforms like eNAM (National Agriculture Market) to facilitate online trading, price discovery, and transparent transactions. Integrating with eNAM will give farmers access to a broader market and enhance price competitiveness.

viii. Creation of Indian Seaweed Cluster Initiative (ISCI):

The Indian Seaweed Cluster Initiative (ISCI) may be created to develop value-added products from seaweed, focusing on small-scale farmers and processors, particularly women, in coastal states.

ix. Centre of Excellence for Seaweed

Centres of Excellence (CoE) may be established in every coastal state and union territory for holistic development and support of seaweed. The state department of fisheries in collaboration with MPEDA-RGCA, NaCSA, research institutions, Fisheries and Agriculture Universities may submit proposals for the establishment of CoE to the Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GoI. The CoE will facilitate research, development, training, and collaboration to establish a thriving, environmentally conscious seaweed industry. The CoE shall be setup within the following broad framework (Table 18).

Table 18. Components and tentative budget for the proposed CoE for seaweed

S. No.	Components	Tenative Budget (₹crores)
1.	**Seed Bank** Inshore facility for seaweed tissue culture, spore culture, indoor/outdoor nursery, outdoor seaweed seed reserves with essential scientific manpower	4.5
2.	**Seaweed Research and Demonstration Farms** Inshore and offshore demonstration farms in identified atolls	2.0
3.	**Aquatic Environment Monitoring and Disease Management** NABL laboratory with essential equipment for chemical/physical/biological quality of water and soil and a disease diagnostic & quarantine centre.	2.8
4.	**International Collaborations with Academia and the Industry** Knowledge and skill transfer by visiting experts and visits by in-house scientists to other centres of excellence around the globe in seaweed to develop a sound, inclusive seaweed enterprise in the islands	3.5
5.	**Product Development and Incubation** Infrastructure and facilities for the development of processing technology of seaweed, product development, testing, and the incubation of entrepreneurs.	3.2
6.	**Training and skill development** Infrastructure and skills for on-the-job training for farmers and processors, and support for postgraduate research on seaweed by the universities.	2.0
7.	**Cost of civil works and land acquisition**	2.0
	Total	**20**

1. The CoE shall develop models and practices for the onshore/inland cultivation of seaweed, cultivation of seaweed in creeks. It shall make an estimate of the total land possible to be brought under inland seaweed cultivation in the state or union territory. For example, the state of Goa has nearly 17,000 hectares of Khazan land, which may be utilized for the inland cultivation of seaweed.
2. The CoE shall be a nodal point for identification of other seaweed species, which could be specific to the state or union territory besides the ones mentioned in the document. The CoE shall provide support to the state or union territory for entire value chain, from seed availability, multiplication, cultivation, harvesting, post-harvest handling, and processing, marketing, and domestic and international trading of seaweed.

3. The CoE will focus on optimizing cultivation techniques, promoting the growth of potential seaweed species, and establishing a seed bank for their preservation. By leveraging advanced technologies such as tissue culture and spore culture, the CoE will facilitate the production of high-quality seaweed seedlings for farmers.
4. The CoE will prioritize research and development efforts to enhance the value of seaweed products. This includes exploring innovative applications in sectors such as food, feed, biofuels, pharmaceuticals, cosmetics, and fertilizers.Through collaboration with academia and industry experts, the CoE will develop cutting-edge technologies, refine processing techniques, and promote the creation of value-added products having high market demand.
5. Recognizing the importance of knowledge and skill enhancement, the CoE will provide comprehensive training programs for farmers, processors, and entrepreneurs. This training will cover various aspects of seaweed farming, processing techniques, quality control, and product development. By equipping stakeholders with the necessary expertise, the centre aims to empower and actively participate in the seaweed industry and enhance its income opportunities.
6. International collaborations with leading academic institutions and industry experts will be a key focus of the CoE. The centre shall aim to stay at the forefront of seaweed research and development through knowledge and skill transfer, facilitated by visits from global experts and exchanges of in-house scientists.
7. At present, *Kappaphycus* is the single dominant species being cultured on a commercial scale. Commercial-scale culture of the native seaweed species like *Gracilaria, Gelidiella, Porphyra, Asparagopsis, Ulva, Enteromorpha, Monostroma, Sargassum* has also to be promoted by CoE for better growth rate and biochemical production.
8. The CoE may identify industrial-scale offshore farming. Sea leasing policies must be framed with due consideration to the concerns of national security in the seas.
9. The CoE will develop machinery for seeding, maintenance, harvesting, and processing to support large-scale coastal as well as offshore farming.
10. A facility for the culture of small branches of potential seaweed speciesshould be established to develop fast and stress tolerant strains. Gene bank should be created to generate DNA fingerprinting (RAPD) of different strains of potential seaweed species, as these will serve as a basis for genetic classification and identification of the cultivars for biodiversity conservation and protection from bio piracy. Similarly, tissue culture laboratory should be established at the CoE which shall provide and store high yielding elite commercial strains/germplasm or seedlings of seaweed.
11. Referral laboratories should be established at district level for quality assurance and management of seaweed and their products. The CoE shall oversee the regional referral laboratories.
12. The CoE will provide state-of-the-art infrastructure and incubation facilities to facilitate product development and entrepreneurial ventures. This will enable entrepreneurs to test and refine their seaweed-based products, access necessary equipment, and receive guidance from industry experts. By nurturing innovation and supporting the growth of small businesses, the centre will drive economic diversification and create a conducive environment for entrepreneurship.
13. The sites and areas identified by CSIR-CSMCRI and ICAR-CMFRI are not exhaustive. The CoE shall identify more sites and areas suitable for the cultivation of seaweed in the respective state or union territory in consultation with the local research organizations, agriculture and fisheries universities, and their respective state or union territory governments, following the norms and appropriate environmental safeguards in identifying the sites. It shall take due care that the sites identified should not be ecologically sensitive and should not coincide with

turtle nesting grounds, crocodile habitat, or other relevant factors. Suitable human-animal conflict mitigation measures should be considered with proper technological innovations by the CoE.

14. The CoE shall, at the state level, create a map for the allocation of sea space, wherein seaweed clusters are identified for the development of the required infrastructure.
15. Creation of Seaweed Service Centres (SSCs) may be created under theCoE in the identified clusters mandated to provide all inputs available under various government programs under different sectors as a '**Single Window Service'**.

x. Incentives to islands

Considering the remoteness and inadequacy of the basic facilities in the outer islands (A&N Islands, Lakshadweep), incentives in the form of subsidies are to be extended for plant machinery, generators, and POL to the entrepreneurs for setting up seaweed processing units for them. Further, freight subsidies are to be included for the transportation of finished or semi-processed seaweed and its produce to the mainland by local entrepreneurs.

8.5 Skill Development and Research

i. Certificate and diploma courses for skill development

This comprehensive program aims to thoroughly understand the entire seaweed cultivation process, including harvesting and post-harvest management. By offering these courses, the seaweed industry and individuals can gain the essential expertise required to engage in seaweed cultivation effectively and maximize its potential for enhancing livelihoods. These courses enable technically skilled farmers to do seaweed farming, creating new sustainable opportunities and generating employment prospects. The said training may be offered by agriculture and/or fisheries universities, MPEDA-RGCA, various ICAR institutes etc.

ii. Product development from seaweed

Bio-stimulants used in agriculture derived from seaweeds have demonstrated an increase in crop production about 20-35% and can help in reducing chemical fertilizer consumption to the tune of 25% without impacting the final yield of the farmers. Aligned research institutions (public and private) may conceive research programs for the development of seaweed-based bioethanol,animal fodder, pharmaceuticals, neutraceuticals, etc.

iii. Development of production technology

The research institutions under ICAR and CSIR may initiate research on key environmental, social, and economic aspects of seaweed cultivation, such as responsible harvesting practices, water quality management, ecosystem protection, labour practices, and waste management.

iv. Study and framework on carbon credits from seaweed

To accelerate the growth of the carbon credit sector and foster a robust industry, it is crucial to prioritize opportunities and incorporate seaweed within the national and international carbon credit frameworks and trading markets. The Union Ministry of Fisheries may initiate a study through research institutions on opportunities through carbon credits from seaweed. It may develop a framework for the estimation and trading of carbon credits from seaweed. This step will align with India's commitment to achieving net zero carbon emissions.

v. Realignment of research organizations and academic institutions

The objectives of research organizations such as ICAR-CMFRI, CSIR-CSMCRI, state and national-level agricultural and fisheries universities, private universities, the Department of Science and Technology, the National Institute of Oceanography (NIO), the National Institute of Ocean

Technology (NIOT), and other institutions involved in fisheries and seaweed may be made more explicit to cover seaweed value chain development under its ambit.

vi. Incentives and recognition

The Union Ministry of Fisheries may look into possibilities of recognition of seaweed and its products for GI tag. Similarly, it may initiate research on the access to preferential markets, eco-branding opportunities, encouraging greater adoption of certified seaweed products.

vii. Research on climate climate-resilient seaweed varieties

The research institutions (both public and private) may initiate and conduct research for the development of climate resilient seaweed varieties and a strengthened seed value chain system for mitigating risks and ensuring successful seaweed cultivation in coastal areas. Seaweed varieties that resistant to biotic and abiotic stresses, and collaborations between institutions, farmers, and the private sector are essential

ANNEXURES

Annexure-I: Basic Production Data Including Market Value and Infrastructure Cost of Different Agarophytes

The analysis is done at the rate of 1 tonne per day (1 TPD) and 5 tonnes per day (5 TPD) dry biomass with low and high range yield scenario.

Table 19. Basic production data including market value and infrastructure cost of different agarophytes

Parameters	*G. acerosa* (*Ganesan et al., 2009*)				*G. debilis* (*Veeragurunathan et al., 2019*)				*G. dura* (*Veeragurunathan et al., 2015b*)				*G. edulis* Ganesan et al., 2011a			
	1 TPD		5 TPD		1 TPD		5 TPD		1 TPD		5 TPD		1TPD		5 TPD	
	Yield scenario				Yield scenario				Yield scenario				Yield scenario			
	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range
Seed biomass (kg) raft^{-1}	0.5	0.5	0.5	0.5	3	3	3	3	1	1	1	1	1	1	1	1
Yield (kg) raft^{-1} @ 90 days *Ge. acerosa* @ 45 days *G. debilis, G. dura, G. edulis*	5	6	5	6	14	43	14	43	2	10	2	10	6	28	6	28
Yield after deducting seed material for subsequent crop raft^{-1} (kg)	4.5	5.5	4.5	5.5	11	40	11	40	1	9	1	9	5	27	5	27
Dry to fresh weight ratio (Water content)	4	4	4	4	8	8	8	8	7	7	7	7	10	10	10	10
Dry weight (kg)	1.12	1.38	1.12	1.38	1.38	5	1.38	5	0.14	1.29	0.14	1.29	0.5	2.7	0.5	2.7
Number of rafts required for @ 1 TPD or @ 5 TPD	889	727	4,444	3,636	727	200	3,636	1,000	7,000	778	35,000	3,889	2,000	370	10,000	1,852
Number of people required for seeding @ 2 rafts day^{-1} person^{-1}	444	364	2,222	1,818	364	100	1,818	500	3,500	389	17,500	1,944	1,000	185	5,000	926

Parameters	*G. acerosa* (*Ganesan et al., 2009*)				*G. debilis* (*Veeragurunathan et al., 2019*)				*G. dura* (*Veeragurunathan et al., 2015b*)				*G. edulis* Ganesan et al., 2011a			
	1 TPD		5 TPD		1 TPD		5 TPD		1 TPD		5 TPD		1TPD		5 TPD	
	Yield scenario				Yield scenario				Yield scenario				Yield scenario			
	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range
Number of rafts growth cycle^{-1} @ 90 days *Ge. acerosa* @ 45 days *G. debilis, G. dura, G. edulis*	80,000	65,455	4,00,000	3,27,273	32,727	9,000	1,63,636	45,000	3,15,000	35,000	15,75,000	1,75,000	90,000	16,667	4,50,000	83,333
Area required (ha)	32	26.18	160	130.90	13.09	3.6	65.45	18	126	14	630	70	36	6.667	180	33.33
Total days of farming year^{-1} @ 3 harvests of 90 days for *Ge. acerosa* @ 6 harvests of 45 days for *G. debilis* and *G. edulis* @ 5 harvests of 45 days for *G. dura*	270	270	270	270	270	270	270	270	225	225	225	225	270	270	270	270
Total days of obtaining harvest	180	180	180	180	225	225	225	225	180	180	180	180	225	225	225	225
Total produce year^{-1} (tons)	180	180	900	900	225	225	1125	1125	180	180	900	900	225	225	1125	1125

Parameters	*G. acerosa* (*Ganesan et al., 2009*)				*G. debilis* (*Veeragurunathan et al., 2019*)				*G. dura* (*Veeragurunathan et al., 2015b*)				*G. edulis* Ganesan et al., 2011a			
	1 TPD		5 TPD		1 TPD		5 TPD		1 TPD		5 TPD		1TPD		5 TPD	
	Yield scenario				Yield scenario				Yield scenario				Yield scenario			
	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range	Low Range	High Range
Market value of biomass tons^{-1} as prevailing rates (Million USD) @ USD 1603 for *Ge. acerosa,* @ USD 601 for *G. debilis* @ USD 534 for *G. edulis* and @ USD 1336 for *G. dura*	0.29	0.29	1.44	1.44	0.14	0.14	0.68	0.68	0.24	0.24	1.20	1.20	0.12	0.12	0.60	0.60
Infrastructure cost (Million USD) @ USD 8.016 raft^{-1}	0.64	0.52	3.21	2.62	0.26	0.07	1.31	0.36	2.52	0.28	12.65	1.40	0.72	0.13	3.61	0.69
Total investment (Million USD) @ 50% subsidy from Fisheries Department Government of Tamil Nadu	0.32	0.26	1.60	1.31	0.13	0.04	0.66	0.18	1.26	0.14	6.30	0.70	0.36	0.07	1.80	0.34

Annexure-II: List of Sites for Seaweed Cultivation

Table 20. List of sites/locations identified by ICAR-CMFRI

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
1	Fraserhanj (Bakkhali)	West Bengal	South 24 Parganas	99.76	88.275441	21.527064	2767.64
2	Sagar Island Systems	West Bengal	South 24 Parganas	124.70	88.081361	21.585523	4924.96
3	Sundarban Dhanchi Forest	West Bengal	South 24 Parganas	94.72	88.43875	21.577823	0.00
4	Mandarmani	West Bengal	Purba Mednipur	69.79	87.736616	21.608956	7122.11
5	Shankarpur	West Bengal	Purba Mednipur	59.87	87.634498	21.593063	6203.91
6	TN NA1 28 Cuddalore M	Tamil Nadu	Cuddalore	20.86	79.785874	11.723963	252.03
7	TN NA1 28 Cuddalore M	Tamil Nadu	Cuddalore	36.54	79.784645	11.714561	198.43
8	TN NA1 28 Kudikadu	Tamil Nadu	Cuddalore	52.33	79.776866	11.679383	287.39
9	TN NA1 28 Tiyagavalli	Tamil Nadu	Cuddalore	26.19	79.76598	11.636834	196.18
10	TN NA1 28 Tiyagavalli	Tamil Nadu	Cuddalore	52.26	79.764695	11.618647	245.01
11	TN NA1 28 Kayalpattu	Tamil Nadu	Cuddalore	36.59	79.760594	11.585995	200.58
12	TN NA1 28 Andar Mullipalayam	Tamil Nadu	Cuddalore	26.14	79.760031	11.575109	181.69
13	TN NA1 28 Silambimangalam	Tamil Nadu	Cuddalore	52.19	79.763132	11.551198	175.43
14	TN NA1 28 Bommaryarpalayam	Tamil Nadu	Villupuram	26.27	79.853373	11.990061	466.99
15	TN NA1 28 Kunimedu	Tamil Nadu	Villupuram	52.42	79.894983	12.073823	182.62
16	TN NA1 28 Anumandai	Tamil Nadu	Villupuram	47.21	79.923603	12.118473	193.53
17	TN NA1 28 Marakkanam TP	Tamil Nadu	Villupuram	21.04	79.963504	12.181346	161.58
18	TN NA1 28 Panaiyur	Tamil Nadu	Chengalpattu	26.34	80.02537	12.284704	123.82
19	TN NA1 28 Paramankeni	Tamil Nadu	Chengalpattu	26.34	80.069672	12.348372	36.73
20	TN NA1 28 Kadalur	Tamil Nadu	Chengalpattu	26.24	80.149071	12.45101	696.48
21	TN NA1 28 Kadalur	Tamil Nadu	Chengalpattu	34.70	80.14226	12.439111	129.01
22	TN NA1 28 Mamallapuram	Tamil Nadu	Chengalpattu	36.82	80.212103	12.650188	329.34

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
23	TN NA1 28 Nemmeli	Tamil Nadu	Chengalpattu	31.70	80.234552	12.713968	286.26
24	TN NA1 28 Thiruvidanthai	Tamil Nadu	Chengalpattu	21.16	80.243072	12.740335	942.09
25	TN NA1 28 Kovalam	Tamil Nadu	Chengalpattu	52.79	80.258521	12.785208	1282.78
26	TN NA1 28 Uthandi	Tamil Nadu	Chengalpattu	31.64	80.25307	12.862499	185.59
27	TN NA1 28 Kalanji	Tamil Nadu	Thiruvallur	21.18	80.34462	13.332358	1423.26
28	TN NA1 28 Pulicat	Tamil Nadu	Thiruvallur	26.51	80.33115	13.422613	0.00
29	Chilka lake Arakuda (Near Bar mouth	Odisha	Puri	49.85	85.551923	19.667565	1730.78
30	Satpada	Odisha	Puri	130.03	85.515158	19.647266	1805.50
31	Ramchandi Muhanan near Chandrabhaga	Odisha	Puri	49.84	86.062779	19.849116	230.61
32	Baliharichandi area	Odisha	Puri	6.20	85.701197	19.749574	323.55
33	Puruna bandha area	Odisha	Ganjam	149.83	85.005333	19.316333	1256.27
34	Ramayapatnam	Odisha	Ganjam	150.04	84.810332	19.137565	507.14
35	Kalijai area	Odisha	Puri	199.75	85.298177	19.534246	1744.72
36	Gopalpur Open sea	Odisha	Ganjam	99.73	84.880493	19.221232	728.97
37	Balaramgadi to Mahi sahi area	Odisha	Baleshwar	100.05	87.050819	21.427848	1980.49
38	Balarampur Panchubisha to Januka	Odisha	Baleshwar	149.55	86.887383	21.245999	2583.77
39	Kirtania to Talasari	Odisha	Baleshwar	99.73	87.45732	21.539461	4882.12
40	Jatadhari Muhana Gadakujanga	Odisha	Jagatsinghpur	149.59	86.557625	20.176867	1851.57
41	Sea Near Neheru Banglow	Odisha	Jagatsinghpur	49.79	86.709269	20.281619	338.83
42	Gada Harishpur	Odisha	Jagatsinghpur	99.79	86.496361	20.098284	1830.53
43	M1 644 Nagaon to Revdanda	Maharashtra	Raigarh	642.42	72.897551	18.577683	745.56
44	M1 644 Maneri - Suveri	Maharashtra	Raigarh	548.88	72.930644	18.25977	372.91
45	M1 644 Harnai -Murud	Maharashtra	Ratnagiri	343.66	73.104847	17.779467	462.39

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
46	M1 644 Adoor	Maharashtra	Ratnagiri	150.03	73.179797	17.41756	403.00
47	M1 644 Ganapatipule -Bhandarpulee	Maharashtra	Ratnagiri	129.60	73.266609	17.129693	815.97
48	M1 644 Rameshwar	Maharashtra	Sindhudurg	94.71	73.312246	16.547225	227.84
49	M1 644 Mithmumbari	Maharashtra	Sindhudurg	149.19	73.381804	16.34743	390.58
50	M1 644 Kolamb	Maharashtra	Sindhudurg	184.30	73.457128	16.072239	0.00
51	M1 644 Medha-Mayana-Khavana	Maharashtra	Sindhudurg	198.75	73.54967	15.925445	270.12
52	M1 644 Navabag to Varachemad	Maharashtra	Sindhudurg	274.35	73.62862	15.835689	96.81
53	LD1 17.5	Lakshadweep	Agatti	17.48	72.161847	10.848441	0.00
54	LD1 17.5	Lakshadweep	Amini	1.50	72.720202	11.130597	5346.31
55	LD1 17.5	Lakshadweep	Androth	0.50	73.682308	10.818396	0.00
56	LD1 17.5	Lakshadweep	Bitra	46.14	72.310946	10.956464	0.00
57	LD1 17.5	Lakshadweep	Bangaram	45.48	72.167837	11.592596	0.00
58	LD1 17.5	Lakshadweep	Chetlath	1.60	72.70423	11.690572	0.00
59	LD1 17.5	Lakshadweep	Kiltan	37.40	72.754158	11.195694	0.00
60	LD1 17.5	Lakshadweep	Kadmath	25.47	73.630655	10.100661	0.00
61	LD1 17.5	Lakshadweep	Kavaratti	5.00	72.619299	10.555205	0.00
62	LD1 17.5	Lakshadweep	Kiltan	1.79	73.002653	11.475348	0.00
63	LD1 17.5	Lakshadweep	Minicoy	30.44	73.050472	8.318637	0.00
64	KL1 10 Vizhinjam	Kerala	Thiruvananthapuram	10.04	76.960752	8.3832	14329.36
65	KL1 10	Kerala	Kollam	19.89	76.605104	8.915685	234.10
66	KL1 10 Elathur	Kerala	Kozhikode	1.02	75.731039	11.334715	1421.87
67	KL1 10 Elathur	Kerala	Kozhikode	6.97	75.739164	11.321399	1256.20
68	KL1 10 Thikkodi	Kerala	Kozhikode	19.87	75.61346	11.478311	87.77

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
69	KL1 10 Padana	Kerala	Kasargod	4.99	75.122272	12.207132	216.05
70	KL1 10 Pallikara	Kerala	Kasargod	16.89	75.026971	12.390098	226.52
71	GJ1 1500 Bhada -Kathada	Gujarat	Kachchh	1495.18	69.247683	22.821562	155.09
72	GJ1 1500Adatra - Arambhada CT	Gujarat	Devubhumi Dwaraka	1993.43	69.01457	22.454508	0.00
73	GJ1 1500 Dwaraka - Baradia	Gujarat	Devubhumi Dwaraka	1992.90	68.963783	22.219649	0.00
74	GJ1 750 Kuchhidi - Zaver	Gujarat	Porbandar	747.63	69.554424	21.652101	248.85
75	GJ1 750 Ratanpar - Oddar	Gujarat	Porbandar	747.68	69.659213	21.568188	253.29
76	GJ1 1500 Jafrabad	Gujarat	Amreli	614.30	71.367356	20.846351	1080.11
77	GJ1 1500 Velan	Gujarat	Gir Somanath	299.32	70.845229	20.698345	128.77
78	GJ1 1500 Velan	Gujarat	Gir Somanath	199.86	70.87087	20.701652	95.62
79	GJ1 1500 Velan	Gujarat	Gir Somanath	199.05	70.824978	20.68888	289.54
80	GJ1 1500 Navapara to Lati	Gujarat	Gir Somanath	1993.91	70.366473	20.897111	37.95
81	D1 200 Rajput Rajpara	Gujarat	Gir Somnath	199.09	71.091122	20.747713	359.12
82	D1 200 Navabandar	Gujarat	Gir Somnath	49.85	71.045366	20.724319	597.37
83	D1 200 Navabandar	Gujarat	Gir Somnath	49.93	71.070542	20.729372	1324.52
84	D1 200	Diu	Diu	299.68	70.948539	20.698228	466.31
85	D1 200	Diu	Diu	104.80	70.903466	20.692255	991.18
86	AP1 40 Vishakapattinam	Andhra Pradesh	Vishakapattnam	44.25	83.322967	17.703905	6153.44
87	AP1 40 Vishakapattinam	Andhra Pradesh	Vishakapattnam	38.70	83.343406	17.716436	4135.76
88	AP1 40 Chinagadila	Andhra Pradesh	Vishakapattnam	55.29	83.357513	17.744738	800.07
89	AP1 40 Kapuluppada	Andhra Pradesh	Vishakapattnam	27.65	83.421942	17.819844	2659.10
90	AP1 40 Bheemunipatnam	Andhra Pradesh	Vishakapattnam	55.31	83.461474	17.888973	273.40
91	AP1 40 Kapuluppada	Andhra Pradesh	Vishakapattnam	38.81	83.417656	17.811185	1664.35
92	AP1 40 Chepaluppada	Andhra Pradesh	Vishakapattnam	27.63	83.417359	17.8408	2831.02

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
93	AP1 40 Yendada	Andhra Pradesh	Vishakapattnam	55.24	83.374501	17.760982	1198.48
94	AP1 40 Cheepurupalle E	Andhra Pradesh	Vishakapattnam	27.60	83.095487	17.531039	544.29
95	AP1 40 Pudimadaka	Andhra Pradesh	Vishakapattnam	55.09	83.010056	17.488369	748.97
96	AP1 40 Vakapadu	Andhra Pradesh	Vishakapattnam	49.60	82.861223	17.406064	1155.56
97	AP1 40 Rambili	Andhra Pradesh	Vishakapattnam	22.08	82.936143	17.440693	5146.63
98	AP1 40 Gudepuvalasa	Andhra Pradesh	Vizianagaram	27.79	83.566799	17.988173	3148.35
99	AP1 40 Kancheru	Andhra Pradesh	Vizianagaram	27.72	83.553061	17.966652	6026.25
100	AP1 40 Kancheru	Andhra Pradesh	Vizianagaram	27.70	83.560498	17.974638	4806.14
101	AP1 40 Yendada	Andhra Pradesh	Vishakapattnam	36.51	83.367222	17.756524	696.44
102	AP1 40 Narayanagajapathirajapu	Andhra Pradesh	Srikakulam	38.76	83.687724	18.08451	1038.77
103	AP1 40 Baruvapeta	Andhra Pradesh	Srikakulam	29.96	84.599545	18.875957	465.29
104	AP1 40 Rushikudda	Andhra Pradesh	Srikakulam	19.98	84.636769	18.912866	623.35
105	AP1 40 Uppada	Andhra Pradesh	East Godavari	27.48	82.343334	17.072427	1538.88
106	AP1 40 Ponnada	Andhra Pradesh	East Godavari	38.44	82.400853	17.127127	607.17
107	AP1 40 Kona	Andhra Pradesh	East Godavari	33.05	82.537531	17.235612	4802.05
108	AP1 40	Andhra Pradesh	East Godavari	27.33	82.369033	16.941444	308.43
109	AP1 40 aAmaravalli	Andhra Pradesh	East Godavari	38.41	82.366812	17.095041	750.04
110	AP1 40 Kona	Andhra Pradesh	East Godavari	54.93	82.498713	17.20844	663.54
111	AP1 40 Kona	Andhra Pradesh	East Godavari	27.55	82.484485	17.200018	540.91
112	AP1 40 Kandikuppa	Andhra Pradesh	East Godavari	27.23	82.229292	16.525096	1127.10
113	AP1 40 Vemuladeevi	Andhra Pradesh	West Godavari	54.47	81.673942	16.320581	1478.55
114	AP1 40 Perupalem	Andhra Pradesh	West Godavari	54.38	81.600486	16.328539	4305.74
115	AP1 40 Nidamarru	Andhra Pradesh	Krishna	54.37	81.415938	16.333558	1208.33
116	AP1 40 Chinagollapalem	Andhra Pradesh	Krishna	27.24	81.50245	16.341633	3656.50

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
117	AP1 40	Andhra Pradesh	Krishna	32.48	81.025491	15.845619	857.14
118	AP1 40 Etha Mukkala	Andhra Pradesh	Prakasam	26.90	80.131021	15.366913	2275.73
119	AP1 40 Pakala	Andhra Pradesh	Prakasam	26.95	80.09104	15.244544	502.63
120	AP1 40 Karedu	Andhra Pradesh	Prakasam	27.00	80.06948	15.13412	858.87
121	AP1 40 Mypadu	Andhra Pradesh	Prakasam	21.41	80.186521	14.505034	537.19
122	AP1 40 Venkanapalem	Andhra Pradesh	P S Nellore	26.71	80.181079	14.441574	4359.07
123	Thengapattinam	Tamil Nadu	Kanniyakumari	30.10	77.176675	8.227595	14319.60
124	Colachel	Tamil Nadu	Kanniyakumari	30.05	77.261892	8.167649	11333.50
125	Kadiapattinam	Tamil Nadu	Kanniyakumari	30.03	77.301395	8.138461	6164.98
126	Muttom	Tamil Nadu	Kanniyakumari	70.85	77.319946	8.120413	2944.86
127	Pillaithoppu	Tamil Nadu	Kanniyakumari	20.05	77.340682	8.122818	1354.67
128	Periyakaadu	Tamil Nadu	Kanniyakumari	30.00	77.398194	8.105935	132.57
129	Kovalam	Tamil Nadu	Kanniyakumari	20.17	77.519697	8.080737	225.98
130	Kanyakumari	Tamil Nadu	Kanniyakumari	39.99	77.560749	8.088564	659.97
131	Chinnamuttom	Tamil Nadu	Kanniyakumari	30.30	77.566291	8.097698	770.01
132	Arockiyapuram	Tamil Nadu	Kanniyakumari	50.62	77.560562	8.110241	118.76
133	Periyathalai	Tamil Nadu	Thoothukudi	36.17	78.03171	8.3571	191.36
134	Manapad	Tamil Nadu	Thoothukudi	67.52	78.065572	8.376584	151.81
135	Kulasekarapattinam	Tamil Nadu	Thoothukudi	41.49	78.061432	8.396893	1045.10
136	Alanthalai	Tamil Nadu	Thoothukudi	81.60	78.076038	8.429717	138.02
137	Amali nagar	Tamil Nadu	Thoothukudi	31.14	78.12676	8.488738	112.19
138	Veerapandiyapattinam	Tamil Nadu	Thoothukudi	62.57	78.127766	8.510081	380.63
139	Kayalpattinam	Tamil Nadu	Thoothukudi	82.89	78.136906	8.567774	606.10
140	Punnakayal	Tamil Nadu	Thoothukudi	25.88	78.130225	8.613056	135.05

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141	Palayakayal	Tamil Nadu	Thoothukudi	52.86	78.14164	8.692885	719.44
142	Mullakadu	Tamil Nadu	Thoothukudi	92.56	78.163227	8.73019	152.38
143	Tuticorin harbour Point	Tamil Nadu	Thoothukudi	83.22	78.20375	8.769394	2106.47
144	Mottaigopuram	Tamil Nadu	Thoothukudi	41.76	78.168814	8.84794	0.00
145	Vellapatti	Tamil Nadu	Thoothukudi	61.96	78.170097	8.864128	0.00
146	Tharuvaikulam	Tamil Nadu	Thoothukudi	71.99	78.181989	8.89623	0.00
147	Pattinamathur	Tamil Nadu	Thoothukudi	82.48	78.196379	8.937305	0.00
148	Sippikulam	Tamil Nadu	Thoothukudi	78.04	78.238781	8.982049	0.00
149	Keezhavaippar	Tamil Nadu	Thoothukudi	61.75	78.266848	9.001255	0.00
150	Periyasamypuram	Tamil Nadu	Thoothukudi	51.60	78.338265	9.051045	103.96
151	Vembar	Tamil Nadu	Thoothukudi	82.53	78.379587	9.08598	36.32
152	Thomaiyarpuram	Tamil Nadu	Kanniyakumari	10.09	77.584515	8.138298	2111.24
153	Kootapuli	Tamil Nadu	Tirunelveli	10.83	77.606342	8.146832	78.23
154	Perumanal 1	Tamil Nadu	Tirunelveli	6.38	77.642839	8.156861	759.48
155	Perumanal 2	Tamil Nadu	Tirunelveli	8.98	77.652348	8.158025	102.53
156	Kuthenkuli	Tamil Nadu	Tirunelveli	15.31	77.682391	8.159584	2403.07
157	Idinthakarai	Tamil Nadu	Tirunelveli	15.93	77.756616	8.184407	137.28
158	Uvari	Tamil Nadu	Tirunelveli	20.28	77.789921	8.22491	1185.12
159	Koduthalai	Tamil Nadu	Tirunelveli	15.99	77.826105	8.24684	165.00
160	Kootapanai	Tamil Nadu	Tirunelveli	15.49	77.865602	8.260584	328.67
161	Periyathalai	Tamil Nadu	Tirunelveli	35.25	77.928576	8.297195	158.90
162	Kunthukal	Tamil Nadu	Ramanthapuram	20.64	79.219351	9.265974	0.00
163	Mandapam	Tamil Nadu	Ramanthapuram	18.53	79.143608	9.273803	817.60
164	Vedalai 1	Tamil Nadu	Ramanthapuram	17.48	79.114593	9.265965	0.00

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165	Vedalai 2	Tamil Nadu	Ramanthapuram	13.33	79.088406	9.259691	1893.56
166	Seeniappa Darga	Tamil Nadu	Ramanthapuram	24.78	79.071047	9.260204	400.72
167	Nochioorani	Tamil Nadu	Ramanthapuram	19.55	79.035589	9.266062	291.85
168	Manankudi	Tamil Nadu	Ramanthapuram	16.44	79.015654	9.269665	211.86
169	Pudumadam	Tamil Nadu	Ramanthapuram	25.70	78.995954	9.271877	30.91
170	Valangapuri	Tamil Nadu	Ramanthapuram	12.90	78.976933	9.27295	31.52
171	Vellarioodai	Tamil Nadu	Ramanthapuram	15.40	78.958111	9.271694	150.59
172	Thalai Thoppu	Tamil Nadu	Ramanthapuram	20.61	78.945298	9.269764	31.31
173	Inthira Nagar	Tamil Nadu	Ramanthapuram	12.35	78.923995	9.263862	0.00
174	Munthal (Periyapattinam)	Tamil Nadu	Ramanthapuram	13.37	78.914343	9.25462	0.00
175	Pudhukudiyiruppu (Periyapattinam)	Tamil Nadu	Ramanthapuram	10.30	78.904297	9.250122	0.00
176	Thoppuvalasai	Tamil Nadu	Ramanthapuram	15.41	78.892417	9.252997	0.00
177	Velayuthapuram	Tamil Nadu	Ramanthapuram	13.89	78.880579	9.255234	0.00
178	Kalimankundu	Tamil Nadu	Ramanthapuram	10.38	78.869974	9.25414	0.00
179	Sethukarai	Tamil Nadu	Ramanthapuram	8.74	78.844784	9.24775	0.00
180	Kanjirangudi (Pakkirappa Dargha)	Tamil Nadu	Ramanthapuram	14.44	78.828127	9.241488	0.00
181	Sengalaneerodai	Tamil Nadu	Ramanthapuram	25.81	78.8103	9.236075	0.00
182	Keelakarai	Tamil Nadu	Ramanthapuram	22.73	78.774584	9.222756	0.00
183	Bharathinagar	Tamil Nadu	Ramanthapuram	25.75	78.75706	9.215627	0.00
184	Mangaleswari Nagar	Tamil Nadu	Ramanthapuram	28.90	78.740102	9.211334	0.00
185	Earanthurai	Tamil Nadu	Ramanthapuram	26.80	78.728024	9.207908	0.00
186	Erwadi	Tamil Nadu	Ramanthapuram	19.03	78.720788	9.19519	0.00
187	Sadaimuniyanvalasai	Tamil Nadu	Ramanthapuram	16.51	78.713431	9.190104	7.66
188	P.M. Valasai	Tamil Nadu	Ramanthapuram	37.04	78.696114	9.192665	909.41

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189	Adancheri	Tamil Nadu	Ramanthapuram	28.77	78.678534	9.194827	43.09
190	Valinokkam	Tamil Nadu	Ramanthapuram	90.57	78.627216	9.152083	66.86
191	Keelamundhal	Tamil Nadu	Ramanthapuram	31.92	78.584632	9.134889	29.59
192	Melamundhal	Tamil Nadu	Ramanthapuram	31.95	78.563848	9.134072	214.15
193	Mariyur	Tamil Nadu	Ramanthapuram	30.38	78.53221	9.135388	185.08
194	Oppilan	Tamil Nadu	Ramanthapuram	30.33	78.498317	9.130957	798.99
195	Mookaiyur	Tamil Nadu	Ramanthapuram	30.86	78.471578	9.126272	80.22
196	Naripaiyur	Tamil Nadu	Ramanthapuram	24.68	78.428612	9.11687	2179.42
197	Kannirajapuram	Tamil Nadu	Ramanthapuram	29.32	78.404973	9.10601	1681.64
198	Rochma Nagar	Tamil Nadu	Ramanthapuram	36.99	78.393837	9.09769	363.97
199	Dhanushkodi	Tamil Nadu	Ramanthapuram	92.84	79.394168	9.205266	0.00
200	Sangumal	Tamil Nadu	Ramanthapuram	25.70	79.328878	9.298257	0.00
201	Olaikuda	Tamil Nadu	Ramanthapuram	36.01	79.332719	9.312429	0.00
202	Mangadu	Tamil Nadu	Ramanthapuram	22.70	79.320247	9.32604	0.00
203	Sambai	Tamil Nadu	Ramanthapuram	30.68	79.309757	9.328654	0.00
204	Vadakadu	Tamil Nadu	Ramanthapuram	30.87	79.300869	9.325106	0.00
205	Pillaikulam	Tamil Nadu	Ramanthapuram	26.86	79.289549	9.31897	0.00
206	Ariyankundu	Tamil Nadu	Ramanthapuram	23.77	79.273493	9.303895	171.86
207	Villoondi	Tamil Nadu	Ramanthapuram	26.74	79.267697	9.295688	19.14
208	Manthoppu	Tamil Nadu	Ramanthapuram	14.51	79.257981	9.292897	0.00
209	Victoria Nagar	Tamil Nadu	Ramanthapuram	9.80	79.245609	9.292782	0.00
210	Naalupanai	Tamil Nadu	Ramanthapuram	15.46	79.237583	9.293244	0.00
211	Akkalmadam	Tamil Nadu	Ramanthapuram	20.67	79.228247	9.292745	0.00
212	Pamban	Tamil Nadu	Ramanthapuram	8.24	79.219021	9.290659	0.00

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213	Thonithurai	Tamil Nadu	Ramanthapuram	14.46	79.182379	9.283844	0.00
214	Meenavar colony	Tamil Nadu	Ramanthapuram	6.19	79.175275	9.285083	0.00
215	T. Nagar	Tamil Nadu	Ramanthapuram	15.41	79.141301	9.292391	0.00
216	Munaikadu	Tamil Nadu	Ramanthapuram	41.26	79.133084	9.290157	0.00
217	Umayalpuram	Tamil Nadu	Ramanthapuram	39.10	79.120605	9.289511	0.00
218	Vedalai	Tamil Nadu	Ramanthapuram	24.82	79.09612	9.292139	0.00
219	Pillaimadam	Tamil Nadu	Ramanthapuram	22.69	79.078595	9.29746	0.00
220	Pirappanvalasai	Tamil Nadu	Ramanthapuram	16.42	79.056685	9.305274	0.00
221	Irumeni	Tamil Nadu	Ramanthapuram	16.46	79.034064	9.319663	0.00
222	Uchipuli	Tamil Nadu	Ramanthapuram	20.56	79.011143	9.337312	0.00
223	Attrangarai	Tamil Nadu	Ramanthapuram	15.79	78.991957	9.353179	0.00
224	Alakankulam	Tamil Nadu	Ramanthapuram	16.34	78.979743	9.364193	0.00
225	Panaikulam	Tamil Nadu	Ramanthapuram	16.52	78.964427	9.380283	0.00
226	Puduvalasai	Tamil Nadu	Ramanthapuram	19.53	78.95253	9.393193	0.00
227	Athiyuthu	Tamil Nadu	Ramanthapuram	15.50	78.94307	9.404081	0.00
228	Palanivalasai	Tamil Nadu	Ramanthapuram	9.27	78.932768	9.416178	0.00
229	Mudiveeranpattinam	Tamil Nadu	Ramanthapuram	27.87	78.911718	9.449242	0.00
230	Devipattinam	Tamil Nadu	Ramanthapuram	2.11	78.898754	9.488682	18.09
231	Thiruppalaikudi	Tamil Nadu	Ramanthapuram	8.26	78.91967	9.537252	55.70
232	Karankadu	Tamil Nadu	Ramanthapuram	8.77	78.967178	9.64712	0.00
233	Mullimunai	Tamil Nadu	Ramanthapuram	9.31	78.969549	9.651434	0.00
234	Puthupattinam 1	Tamil Nadu	Ramanthapuram	5.21	78.974794	9.674123	0.00
235	Puthupattinam 2	Tamil Nadu	Ramanthapuram	7.25	78.979868	9.685547	0.00
236	Veerasangili madam	Tamil Nadu	Ramanthapuram	23.74	78.984404	9.691991	0.00

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
237	Soliyakudi 1	Tamil Nadu	Ramanthapuram	8.30	78.99082	9.701959	0.00
238	Soliyakudi 2	Tamil Nadu	Ramanthapuram	7.22	79.002233	9.715295	0.00
239	Nambuthalai	Tamil Nadu	Ramanthapuram	7.74	79.014758	9.729375	0.00
240	Thondi	Tamil Nadu	Ramanthapuram	10.86	79.030531	9.752423	0.00
241	M.R. Pattinam	Tamil Nadu	Ramanthapuram	12.47	79.035843	9.759624	0.00
242	P.V. Pattinam	Tamil Nadu	Ramanthapuram	10.11	79.041585	9.765044	0.00
243	Narenthal	Tamil Nadu	Ramanthapuram	13.50	79.055201	9.771427	0.00
244	Vattanam	Tamil Nadu	Ramanthapuram	20.64	79.065266	9.785148	0.00
245	Dhamothirapattinam	Tamil Nadu	Ramanthapuram	14.47	79.075107	9.796561	0.00
246	Pasipattinam	Tamil Nadu	Ramanthapuram	12.45	79.080111	9.802255	0.00
247	Theerthandadhanam	Tamil Nadu	Ramanthapuram	8.27	79.093142	9.828469	0.00
248	S.P Pattinam	Tamil Nadu	Ramanthapuram	15.52	79.101309	9.833809	0.00
249	Muthukuda	Tamil Nadu	Pudukottai	7.43	79.120355	9.876761	0.00
250	Arasanagaripattinam1	Tamil Nadu	Pudukottai	5.19	79.125327	9.886777	0.00
251	Arasanagaripattinam2	Tamil Nadu	Pudukottai	30.95	79.132595	9.897023	0.00
252	Mimisal	Tamil Nadu	Pudukottai	22.81	79.151318	9.915665	0.00
253	Gopalapattinam 1	Tamil Nadu	Pudukottai	8.31	79.153463	9.925178	0.00
254	Gopalapattinam 2	Tamil Nadu	Pudukottai	7.28	79.155267	9.931338	0.00
255	Palakkudi	Tamil Nadu	Pudukottai	19.14	79.171442	9.946305	0.00
256	Kallivayal	Tamil Nadu	Pudukottai	18.15	79.177672	9.952028	0.00
257	Jegathapattinam	Tamil Nadu	Pudukottai	10.72	79.192101	9.966871	0.00
258	Kottaipattinam 1	Tamil Nadu	Pudukottai	7.75	79.200259	9.974685	0.00
259	Kottaipattinam 2	Tamil Nadu	Pudukottai	8.29	79.207149	9.984702	0.00
260	Odavimadam	Tamil Nadu	Pudukottai	17.12	79.210725	9.988118	0.00

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
261	Pudukkudi	Tamil Nadu	Pudukottai	14.53	79.223365	10.002896	0.00
262	Aathipattinam	Tamil Nadu	Pudukottai	12.84	79.228994	10.008418	0.00
263	Ammapattinam	Tamil Nadu	Pudukottai	14.52	79.235004	10.015356	0.00
264	Avudaiyarpattinam	Tamil Nadu	Pudukottai	19.70	79.240389	10.019779	0.00
265	Sangupattinam	Tamil Nadu	Pudukottai	5.69	79.253775	10.031577	0.00
266	Kodiyakkarai	Tamil Nadu	Pudukottai	23.86	79.261639	10.03489	0.00
267	Muthurajapuram	Tamil Nadu	Pudukottai	22.83	79.260779	10.043199	0.00
268	Seetharamanpattinam	Tamil Nadu	Pudukottai	10.44	79.236263	10.077614	0.00
269	Krishnajipattinam	Tamil Nadu	Pudukottai	12.45	79.229007	10.093547	0.00
270	P.R. Pattinam	Tamil Nadu	Pudukottai	10.68	79.228325	10.101594	0.00
271	Ganeshapuram	Tamil Nadu	Thanjavur	7.35	79.230987	10.136893	0.00
272	Somanathanpattinam	Tamil Nadu	Thanjavur	7.76	79.241403	10.161357	0.00
273	Mandhiripattinam	Tamil Nadu	Thanjavur	9.32	79.240784	10.171134	0.00
274	Senthalaipattinam	Tamil Nadu	Thanjavur	14.44	79.256123	10.190606	0.00
275	Adaikathevan	Tamil Nadu	Thanjavur	8.79	79.266845	10.200752	0.00
276	Karankuda	Tamil Nadu	Thanjavur	9.60	79.272147	10.2371	0.00
277	Sethubavachathiram	Tamil Nadu	Thanjavur	12.47	79.288472	10.253317	0.00
278	Pillayarthidal	Tamil Nadu	Thanjavur	17.64	79.295645	10.259743	0.00
279	Manora	Tamil Nadu	Thanjavur	10.85	79.301467	10.264025	0.00
280	Chinnamanai	Tamil Nadu	Thanjavur	2.28	79.311261	10.269225	0.00
281	Mallipattinam	Tamil Nadu	Thanjavur	4.24	79.313838	10.271802	0.00
282	Mallipattinam 2	Tamil Nadu	Thanjavur	16.47	79.326831	10.281261	0.00
283	Pudhupattinam	Tamil Nadu	Thanjavur	27.01	79.338652	10.285552	0.00
284	Kollukadu	Tamil Nadu	Thanjavur	35.19	79.358326	10.289055	0.00

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
285	Athiramapattinam	Tamil Nadu	Thanjavur	75.68	79.385866	10.312359	0.00
286	Thondiyakadu Lagoon	Tamil Nadu	Tiruvarur	104.04	79.573807	10.33266	0.00
287	Maniyantheevu	Tamil Nadu	Nagapattinam	28.99	79.874015	10.365397	2073.98
288	Arcottuthurai 1	Tamil Nadu	Nagapattinam	10.45	79.871645	10.380691	2354.64
289	Arcottuthurai 2	Tamil Nadu	Nagapattinam	31.19	79.868939	10.405044	198.66
290	Periyakuthagai	Tamil Nadu	Nagapattinam	55.99	79.866314	10.43065	138.35
291	Pushpavanam	Tamil Nadu	Nagapattinam	76.76	79.864871	10.468282	281.48
292	Naluvethapathy	Tamil Nadu	Nagapattinam	20.75	79.864068	10.486239	1363.95
293	Vizhunthamavadi	Tamil Nadu	Nagapattinam	18.69	79.857745	10.587638	243.02
294	Kameswaram	Tamil Nadu	Nagapattinam	13.52	79.855357	10.622519	105.10
295	Sammanthan Pettai	Tamil Nadu	Nagapattinam	3.12	79.851227	10.7906	2889.44
296	Pillaichavadi	Puducherry	Puducherry	21.05	79.859838	12.008683	385.59
297	Kanagachettykulam	Puducherry	Puducherry	1.07	79.872901	12.037803	4355.47
298	Solai Nagar	Puducherry	Puducherry	21.03	79.841577	11.95445	4219.91
299	Vaithikuppam	Puducherry	Puducherry	21.04	79.839842	11.947252	3429.50
300	Kurusukuppam	Puducherry	Puducherry	20.97	79.838573	11.938706	2478.55
301	Vambakeerapalayam	Puducherry	Puducherry	52.37	79.836267	11.925094	720.47
302	Veerampattinam	Puducherry	Puducherry	21.01	79.830478	11.898209	388.12
303	Chinna Veerampattinam	Puducherry	Puducherry	62.82	79.828038	11.88635	37.20
304	Pudukuppam	Puducherry	Puducherry	52.45	79.822467	11.869483	108.79
305	Nallavadu	Puducherry	Puducherry	41.86	79.8143	11.850116	89.75
306	Pannaithittu	Puducherry	Puducherry	10.46	79.807594	11.830239	90.52
307	Narambai	Puducherry	Puducherry	20.91	79.803604	11.816448	77.41
308	Moorthikuppam	Puducherry	Puducherry	21.00	79.798921	11.793909	474.93

S. No.	Site name / Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
309	Dhandebag-Kangiguda Island, Karwar	Karnataka	Uttar Kannanda	100.12	74.093036	14.890487	1628.08
310	Baval-Kanga Island, Karwar	Karnataka	Uttar Kannanda	10.98	74.103786	14.866643	659.28
311	Harwada, Ankola	Karnataka	Uttar Kannanda	71.77	74.256179	14.722096	290.28
312	Belikeri, Ankola	Karnataka	Uttar Kannanda	134.48	74.271157	14.68881	255.22
313	Gabit Keni, Ankola	Karnataka	Uttar Kannanda	7.02	74.275679	14.662826	558.86
314	Belambar, Ankola	Karnataka	Uttar Kannanda	243.17	74.27567	14.643358	798.30
315	Haldipur-Horbhag, Honnavar	Karnataka	Uttar Kannanda	410.81	74.399953	14.359216	208.20
316	Manki 1, Honnavar	Karnataka	Uttar Kannanda	49.80	74.472985	14.149463	254.81
317	Manki 2, Honnavar	Karnataka	Uttar Kannanda	93.62	74.468889	14.172933	518.53
318	Navayatkeri, Murudeshwara (North)	Karnataka	Uttar Kannanda	51.84	74.460284	14.192737	68.63
319	Huddi Point South Bhatkal-Shiroor (North)	Karnataka	Uttar Kannanda	99.78	74.56806	13.935105	1642.76
320	G2 63	Goa	North Goa	62.84	73.797949	15.468678	29474.02
321	G2 63	Goa	North Goa	7.47	73.869158	15.429757	36956.80
322	G2 63	Goa	South Goa	3.99	73.800861	15.392393	38589.86
323	G2 63	Goa	South Goa	44.88	74.036559	14.977085	12859.45
			Total area	**24237.40**			

Table 21. List of sites/locations identified by CSIR-CSMCRI

S. No.	Site name/ Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
1	Muttom	Tamil Nadu	Kanniyakumari	4.50	77.311546	8.126126	5285.86
2	Chinnamuttom	Tamil Nadu	Kanniyakumari	4.50	77.559842	8.090057	1289.31
3	Leepuram	Tamil Nadu	Kanniyakumari	3.50	77.558923	8.114749	585.83
4	Arockiapuram	Tamil Nadu	Kanniyakumari	3.50	77.56182	8.121499	511.78
5	Kuthankuzhi	Tamil Nadu	Tirunelveli	3.50	77.783976	8.213375	3178.88
6	Punnakayal	Tamil Nadu	Thoothukudi	4.50	78.130839	8.633573	447.49
7	Pullavali	Tamil Nadu	Thoothukudi	5.50	78.137032	8.685768	955.36
8	Mullaikadu	Tamil Nadu	Thoothukudi	8.50	78.15856	8.725967	865.72
9	Muthiapuram	Tamil Nadu	Thoothukudi	7.50	78.176103	8.746424	1456.92
10	Sambai	Tamil Nadu	Ramanathapuram	8.50	79.313483	9.328353	40.79
11	Mangadu	Tamil Nadu	Ramanathapuram	10.50	79.324063	9.323519	37.03
12	Mandapam	Tamil Nadu	Ramanathapuram	7.50	79.183921	9.283029	71.84
13	Karangadu	Tamil Nadu	Ramanathapuram	2.50	78.966112	9.646359	85.87
14	Pudupatinum	Tamil Nadu	Ramanathapuram	2.50	78.976951	9.67994	0.00
15	Soliyakudi	Tamil Nadu	Ramanathapuram	7.50	79.002859	9.715597	39.35
16	Nambuthalai	Tamil Nadu	Ramanathapuram	1.50	79.005458	9.717941	0.00
17	M.R.Pattinum	Tamil Nadu	Ramanathapuram	3.50	79.038726	9.763516	0.00
18	Jagathapattinum	Tamil Nadu	Pudukottai	5.50	79.188138	9.964441	20.68
19	Kottaipattinam	Tamil Nadu	Pudukottai	5.50	79.206169	9.984383	75.70
20	Odavimadam	Tamil Nadu	Pudukottai	4.00	79.209519	9.988407	0.00
21	Adiakkadevan	Tamil Nadu	Thanjavur	5.50	79.263562	10.195113	23.05
22	Sethubavachatram	Tamil Nadu	Thanjavur	1.50	79.283954	10.249517	20.30
23	Manora	Tamil Nadu	Thanjavur	2.00	79.302813	10.265212	3.63
24	Kovilpathu	Tamil Nadu	Nagappattinum	1.50	79.859699	10.54761	3437.91
25	Mypadu	Andhra Pradesh	Nellore	10.00	80.10901	14.301	2358.78
26	Mangamaripeta	Andhra Pradesh	Visakhapatnam	8.00	83.41678	17.82498	3113.61
27	Suryalanka	Andhra Pradesh	Guntur	5.00	80.5338	15.8487	14.30
28	Fish Landing Centre Jetty	Andaman & Nicobar Islands	North & Middle Andaman	1.00	92.908406	12.909713	0.00

S. No.	Site name/ Location	State	District	Area (ha)	Longitude	Latitude	Distance from CRZ-IA (m)
29	Aves Island	Andaman & Nicobar Islands	North & Middle Andaman administrative	5.00	92.932366	12.918892	0.00
30	German Jetty	Andaman & Nicobar Islands	North & Middle Andaman	1.00	92.9011	12.923709	0.00
31	Sound island	Andaman & Nicobar Islands	North & Middle Andaman Administrative	5.00	92.972036	12.939918	0.00
32	LTC Jetty	Andaman & Nicobar Islands	North & Middle Andaman	0.50	93.035889	13.279566	0.00
33	Ariel Bay lighthouse	Andaman & Nicobar Islands	North & Middle Andaman	1.00	93.028233	13.281681	0.00
34	Durgapur	Andaman & Nicobar Islands	North & Middle Andaman	3.00	93.03813	13.280065	0.00
35	Madvad	Gujarat	Junagadh	25.00	70.8434	20.69462	1381.53
36	Kalapan	Gujarat	Gir Somanath	3.00	71.0793	20.75065	1064.66
37	Simar	Gujarat	Gir-Somanath	40.00	71.13	20.75	937.42
38	Rajapara	Gujarat	Gir-Somanath	40.00	71.17	20.78	1753.39
39	Miyani	Gujarat	Porbandar	4.00	69.3796	21.83466	926.60
40	Mithapur	Gujarat	Dwarka	5.00	69.055366	22.422181	0.00
41	Ohka	Gujarat	Dwarka	5.00	69.063698	22.47651	199.14
42	Burondi	Maharashtra	Ratnagiri	84.07	73.13182	17.70594	6900
43	Kolthare	Maharashtra	Ratnagiri	67.34	73.13378	17.64408	262
44	Mochemad	Maharashtra	Sindhudurg	4.00	73.6495	15.8041	232
45	Hawaii	Goa	North Goa	3.06	73.8063	15.4548	> 5000
46	Cacra	Goa	North Goa	3.05	74.8345	15.4516	4600
47	Bogmalo	Goa	South Goa	2.65	73.8338	15.3695	> 5000
48	Bawal	Karnataka	Karwar	3.17	74.106897	14.870783	892
49	Maravanthe	Karnataka	Udupi	2.00	74.642231	13.704816	> 5000
50	Benegere	Karnataka	Udupi	1.50	74.653597	13.664521	> 5000
51	Puthanthod	Kerala	Ernakulam	7.86	76.2629	9.8695	330
			Total	**455.19**			

Annexure-III: Laws Pertaining to Coral Reef Protection

India

1. In India, the primary law protecting wildlife, including marine wildlife, is the Wildlife (Protection) Act, 1972 (WLPA) and further amendments in 2022. It prohibits hunting animals listed in its schedulesand regulates trade in such animals and their parts. It also provides for the declaration of protected areas where human activities are restricted. Two approaches i.e. (i) banning hunting of and regulating trade in species by listing them in the schedules, and (ii) designating protected areas.

2. Corals are included in Schedule-I list of the Wild Life Protection Act, 1972 and further amendments in 2022 and have included all the hard coral in the Schedule List of WLPA of 1972, which explicitly outlaws coral mining and trade in India.

3. Environment Protection Act, 1986 (EPA) confers exclusive jurisdiction to the Central Government to preserve and protect the marine environment and to prevent and control marine pollution.

4. Coastal Regulation Zone Notification (CRZ) 2019 under the EPA explicitly notifies the Ecologically Sensitive Areas (CRZ 1A) in which corals and the associated biodiversity of reefs are to be conserved.

5. Marine Protected Areas (MPA): to preserve certain areas of the nation's waters, including areas with coral reefs.

Indonesia

1. Designation and management of Marine Protected Areas (MPA) in Indonesia was authorized by Ministerial declaration in 1990.

2. Management and responsibility for marine areas has been in the hands of the Department of Forestry, specifically the Directorate General of Forest Protection and Nature Conservation (PHPA). Four different types of MPA in Indonesia are recognized: (i) National Parks (ii) Strict Nature Reserves (iii) Wildlife Reserves (iv) Nature Protection Park.

Philippines

1. *Kappaphycus alvarezii* is a marine red macroalga with a native range confined to shallow-reef areas of the Sulu archipelago, Philippines. The marine habitats of the Philippines are recognized to be some of the most biodiverse systems globally yet only 1.7 percent of its seas are designated as marine protected areas (MPA) with varying levels of implementation. Many of these MPA were established based on local-scale conservation and fisheries objectives without considering larger-scale ecological connections (Pata and Yñiguez, 2021). There is no clear definition of coral reefs under the Philippine law. It continues to follow the definition according to the Presidential Proclamation 2146 Series (1981) as it does not categorize them as environmentally critical. Introduction of Exotic Species is considered unlawful into Marine National Parks (MNP) only whereas, it is not so in the reef areas outside the MPAs. It is approved based on the Environmental Impact Assessment (EIA) studies which categorizes the project as (i) Category A to D, (ii) proclaiming certain areas and types of projects as environmentally critical and (iii) within the scope of the EIA system established under presidential decree no. 1586.

2. In addition, under Section 91, it shall be unlawful for any person or corporation to gather, possess, sell or export ordinary precious and semi-precious corals, whether raw or in processed form, except for scientific and research purposes.

Annexure-IV: Expert Committee Office Memorandum

File No. Q-11050/3/2023-AGRICULTURE

NITI (National Institution for Transforming India) Aayog

(Agriculture & Allied Sectors Vertical)

NITI Aayog, Sansad Marg New Delhi – 110001

Date: 11th July 2023

OFFICE MEMORANDUM

Subject: Constitution of Expert Committee to review the Draft Policy on "Seaweed Value Chain Development in India" and draft curricula of certificate courses on seaweed cultivation -reg.

It has been decided with approval of the competent authority to set up an Expert Committee on the subject cited above with the following composition and ToRs.

2. The composition of the Expert Committee is as under:

1.	Dr. V.K. Saraswat, Hon'ble Member (S&T), NITI Aayog	Chairman
2.	Dr. J.K. Jena, Deputy Director General (Fisheries), ICAR	Co-Chairman
3.	Prof. Himanshu A. Pandya, Professor & Former VC, Gujarat University	Co-Chairman
4.	Ms. Neetu Kumari Prasad, Jt. Secretary, Dept. of Fisheries,	Member
5.	Shri Tanmay Kumar, Additional Secretary, MoEFCC	Member
6.	Shri. Dodda Venkata Swamy, Chairman, MPEDA	Member
7.	Dr. A. Gopalkrishnan, Director, ICAR-CMFRI	Member
8.	Dr. Kannan Srinivasan, Director, CSIR-CSMCRI	Member
9.	Dr. Dharani G, Scientist E, National Institute of Ocean Technology (NIOT)	Member
10.	Shri Rajesh Kumar, Additional Chief Secretary (Fisheries), Govt. of Maharashtra	Member
11.	Shri A. K. Rakesh, Additional Chief Secretary, Govt. of Gujarat	Member
12.	Ms. Salma K Fahim, Principal Secretary (Fisheries), Govt. of Karnataka	Member
13.	Shri. K S Srinivas, Principal Secretary (Fisheries), Govt. of Kerala	Member
14.	Shri Mangat Ram Sharma, Addl. Chief Secretary (Fisheries), Govt. of Tamil Nadu	Member
15.	Sri Gopal Krishna Dwivedi, Principal Secretary (Fisheries), Govt. of Andhra Pradesh	Member
16.	Shri Suresh Kumar Vashishth, Principal Secretary (Fisheries), Govt. of Odisha	Member
17.	Shri. Santhosh Kumar Reddy V, Secretary (Fisheries), Govt. of Lakshadweep	Member
18.	Ms. Nandini Paliwal, Secretary (Fisheries), Govt. of Andaman & Nicobar	Member
19.	Shri Shivkumar Suryanarayanan, Managing Director and Co-Founder, Sea6 Energy Pvt. Ltd.	Member
20.	Shri Ashwin Shroff, Executive Chairman, Excel Industries Pvt. Ltd.	Member
21.	Patricia Bianchi, Seaweed Account Manager, Aqua Stewardship Council	Member
22.	Dr. Neelam Patel, Senior Adviser (Agri), NITI Aayog	Member Secretary

3. The Terms of Reference (ToR) of the Expert Committee will be as follows:

   I. To review the draft policy on the development of seaweed value chain in India.

   II. To draft roadmap for the development of entire seaweed value chain -on-shore and off-shore.

   III. To develop any other necessary components for the policy framework of the seaweed value chain that may be required.

4. The Expert Committee may examine and address any other issues which are important though not specifically spelt out in the ToR. The Expert Committee may devise its own procedures for conducting its business / meetings / field visits / constitution of sub-groups, etc.

2. The Chairman of the Expert Committee may co-opt any other official / non-official expert / representative of any organization as a member(s), if required.

3. The Expert Committee will review the draft policy and curricula and finalize it within 60 days of its constitution.

4. Mr. Paremal Banafarr, Young Professional, W018, Fifth Floor, NITI Aayog, New Delhi, Telephone- 011-2304 2203 (L) - e-mail: paremal.banafarr@nic.in will be the nodal officer for this committee in NITI Aayog. Any further queries / correspondence in this regard may be made with him and the Member Secretary of the Committee.

Paremal Banafarr
Agriculture & Allied Sectors Vertical
NITI Aayog
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Distribution:

Chairman and all Members of Expert Committee

CEO, NITI Aayog

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