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State Planning Commission

Tamil Nadu State Land Use Research Board

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Sustainable Seaweed Farming

in Tamil Nadu - Way Forward

"Sustainable Seaweed Farming in Tamil Nadu – Way Forward"

State Planning Commission

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Foreword

Seaweeds, often hailed as the wonders of the sea, are immensely valuable plants with a rich array of applications. Traditionally seaweed harvesting has been practised along the southeastern coast of Tamil Nadu, but the indiscriminate and disorganized harvesting practices have raised concerns in recent times. Seaweed cultivation has emerged as a promising venture, offering a lucrative opportunity in terms of technologies and also as alternate livelihood opportunity for the coastal communities.

Seaweed, not only serves as a vital source of raw material for various industries, including health foods, medicines, pharmaceuticals, textiles, fertilizers, and animal feed, but also presents an avenue for economic growth. However, the current availability of seaweeds falls short of meeting the raw material demands of seaweed industries.

Despite the presence of commercially important native species, the seaweed cultivation industry in the state heavily relies on certain exotic species. The primary challenge lies in the absence of commercially viable technologies for cultivating multiple native seaweed species. Storage limitations, financial constraints faced by seaweed farmers, climatic conditions, and marketing intricacies further compound the issues within this sector.

The Research and Development initiatives in the seaweed industry are still in their early stages, lacking a comprehensive policy to encourage and regulate seaweed cultivation. In light of these circumstances, a workshop held in January 2023 explored discussions on seaweed species diversification, the impact of seaweeds on biodiversity, seaweed culture in the ecosystem (particularly in Gulf of Mannar and Palk Bay), potential industrial opportunities, required infrastructure, and livelihood prospects. Valuable insights were provided by representatives from fisher communities actively engaged in seaweed collection during the workshop.

This report summarises the recommendations from experts, stakeholders, and fisher communities, aiming to guide and shape the future of the seaweed industry in Tamilnadu.

Vice Chairman,
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Executive Summary

Seaweed cultivation is an economically viable livelihood option for the coastal fishing community from various perspectives. Therefore, it is essential to explore all the scientific and economic aspects of seaweed cultivation so that a comprehensive policy and programmes can be evolved to facilitate the development of seaweed cultivation in Tamilnadu.

From this perspective, Tamil Nadu State Land Use Research Board, State Planning Commission in co-ordination with Dr. J. Jayalalithaa Fisheries University organized a workshop in January 2023 on "Sustainable Seaweed Farming in Tamil Nadu – Way Forward" by inviting various stakeholders, subject experts, and related institutions to discuss the different aspects of Seaweed cultivation and to get an insight on the best practices adopted in other states.

The topics covered are species diversification of seaweed, impact of seaweeds on biodiversity, impact of seaweed culture on the ecosystem, particularly in Gulf of Mannar and Palk Bay, potential industrial opportunities, infrastructure required and the livelihood opportunities. Apart from discussing the sustainable aspects of seaweed cultivation, the workshop also explored the different aspects such as the role of seaweed as a healthy food, and the industrial aspects of post-harvest seaweed processing. A total of 70 participants including a member from the host institute and State Planning Commission, State Fisheries Department, farmers and seaweed cultivators, fisherwomen, industry, forestry department and the scientific community attended and shared their views on the Technical Sessions.

The report on Seaweed Cultivation is a comprehensive and valuable resource for researchers, policymakers, marine conservationists, industry professionals, and stakeholders interested in understanding and harnessing the potential of seaweeds. It also provides information on initiatives taken to promote seaweed cultivation in Tamil Nadu.

Contents

1. Background

Seaweeds are an integral part of coastal ecosystems and offer invaluable ecosystem services supporting the life of many marine forms . The ecosystem services which provided from these seaweeds are of four major service clusters such as supporting, provisioning, regulating, and cultural. Some of them are soil formation, Erosion regulation, Environmental monitoring, Spiritual and religious service, Nutrient cycling, etc. The economic value of seaweeds significantly contributes to the sustainable development of rural coastal regions. Seaweeds are consumed as food in some Asian countries, but their utilization for production of phycocolloids is widespread across the globe, with an estimated value of more than one billion US$. In India, seaweeds have been utilized exclusively for the production of phycocolloids but recently they are used for the production of plant growth stimulants for agricultural applications. The domestic agar and alginate industry totally depends on the supplies from natural seaweed beds with some occasional imports. The recent success achieved in both upstream and downstream technologies in production and processing of seaweeds has boosted the prospects for commercialization of seaweed resources in the country (Source : Seaweed resources in India – current status of diversity and cultivation: prospects and challenges).

Seaweeds are macroscopic algae that grow in the marine and shallow coastal waters and brackish water habitats. Seaweeds (macro algae) are wonder plants of the sea, the new renewable source of food, energy, chemicals and medicines with manifold nutritional, industrial, biomedical, agriculture and personal care applications. Seaweeds are also termed as the 'Medical Food of the 21st Century' due to usage as laxatives, for making pharmaceutical capsules, in treatment of goitre, cancer, bone-replacement therapy and in cardiovascular surgeries.

About 844 species of seaweeds have been reported from Indian seas. Among them, 221 species are commercially important and abundant along the Tamil Nadu and Gujarat coasts and around Lakshadweep and Andaman & Nicobar Islands. Rich seaweed beds occur around Mumbai, Ratnagiri in Maharashtra, Goa, Karwar in Karnataka, Varkala, Vizhinjam in Kerala, Pulicat in Tamil Nadu & Andhra Pradesh and Chilka in Orissa. Seed stock of seaweeds is traditionally collected from natural waters along the southeastern coast of Tamil Nadu. But, continuous, indiscriminate, and unorganized harvesting has resulted in depletion of the natural resource.

Sustainable management of seaweed production and extraction is necessary to: maximise the potential of seaweeds; provide livelihood opportunities for coastal communities; supplement fishermen's income during fishing ban periods; meet the growing industrial demand for seaweed-derived Agar, Agarose, Carrageenan, and Alginates; produce large quantities of seed material for the commercialization of seaweed culture; and preserve natural resources. (Source : Seaweed Cultivation - Alternate Livelihood for Coastal; National Fisheries Development Board)

1.1. What are seaweeds?

Seaweeds are marine algae that grow primarily in the ocean and nearby salt waters. The plant-like seaweeds generally live attached to some hard substrata such as rocks, dead corals, etc. There are about 10,000 species of seaweed in the seas around the world (Guiry, 2014). Seaweeds are of different shapes, sizes, compositions and colours and occupy the intertidal, tidal and subtidal regions. As seaweeds are found everywhere in the sea, they are termed as 'weeds' They are regarded as a renewable resource for many bioactive natural products. Hence, there are claims to call them 'Sea-plant' or 'Sea-vegetable' considering their importance. While some seaweed species are attached to hard substrates like rocks, some species are attached to the sea bottom through root-like structures called holdfasts (Jane and Bradford 2006).

Being primitive plants, seaweeds do not have any true root, stem or leaves (Abdel-Kareem and ElSaied 2022). Some species of seaweeds even float on the seawater and can form single or multi-cellular colonies. Light and substrate are the primary requirements for seaweeds to grow in a marine environment, while floating seaweed species do not require even substrates. Seaweeds have primary importance in the development of submerged vegetation habitats in deep-sea, coastal and estuarine environments as they only require light and nutrients for growth and establishment (Cotas*et al.* 2023)

The body of seaweed is made up of the thallus, stipe, floats and holdfast (Figs. 1 and 2). The thallus is the large leaf-like structure of the organism. The stipe functions as the stem connecting thallus and holdfast. The holdfast is the root of the plant anchoring it to the substrate. The floats are air-filled structures that help the plant to be buoyant. The thallus and stipe are consistent across all types of seaweed. Some species of seaweed do not have floats and the free-floating species do not have holdfasts (Swanson 2018).

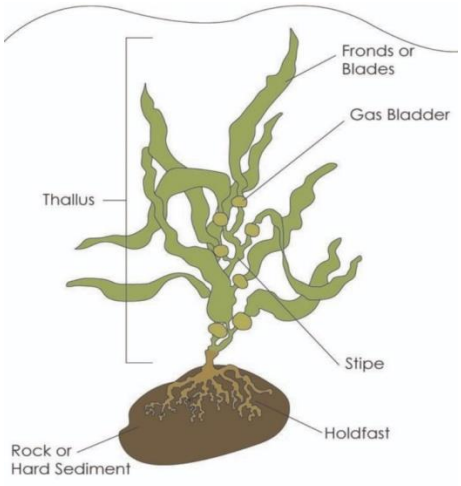


Fig. 1: Morphology of seaweed (Source: Swanson 2018)

Fig. 2: Underwater image of a luxuriant seaweed bed

1.2. Taxonomic Groups

Based on their pigment profile and morphological, anatomical and reproductive structures, seaweeds are categorized into three taxonomic groups namely Chlorophyceae (green algae), Phaeophyceae (brown algae), and Rhodophyceae (red algae) (Abdel-Kareem and ElSaied 2022). Apart from the varying pigment profile, these three groups differ significantly in several ultrastructural and biochemical features such as photosynthetic pigments, storage compounds, composition of cell walls, presence/absence of flagella, ultrastructure of mitosis, connections between adjacent cells, and the fine structure of the chloroplasts (http://www.seaweed.ie). According to AlgaeBase, there are about 11,000 species of seaweeds, of which 7,500 are red algae, 2,000 brown algae and 1,500 green algae (http://www.seaweed.ie). Presumably, there are more species of seaweeds than the recorded numbers in globally.

1.2.1. Green seaweeds (Chlorophyceae)

Green seaweeds (Chlorophyceae) are thought to be the ancestor of land plants (Fig. 3). They are characterized by presence of chlorophylls a and b are an important source of food for marine organisms as they produce starch (http://www.seaweed.ie). Examples of green seaweeds include *Codium, Ulva, Cladophora, Caulerpa* and *Chaetomorpha*.

Fig. 3: Green seaweed, Caulerpa sp.

1.2.2. Brown seaweeds (Phaeophyceae)

Brown seaweeds (Phaeophyceae) are dominant on rocky shores (Fig. 4) and ranges from olive green to brown colour primarily containing fucoxanthin are the main primary producers of prevailing ecosystems and hence support a wide range of organisms (http://www.seaweed.ie). Examples of brown seaweeds include *Sargassum, Turbinaria, Dictyota* and *Laminaria*.

Fig. 4: Brown seaweed -Sargassum sp.

1.2.3. Red seaweeds (Rhodophyceae)

The red colour of the red seaweeds (Rhodophyceae) is due to the presence of the pigments phycoerythrin and phycocyanin; this masks the other pigments (Fig. 5). They have filamentous or membranous fundamental form and store food as floridean starch. Red algae do not have flagella. Their morphology ranges being unicellular to complex parenchymatous and non-parenchymatous thallus (http://www.seaweed.ie). Examples of red seaweeds include *Gracilaria, Gelidiella, Porphyra* and *Kappaphycus.*

Fig. 5: Red seaweed, Kappaphycus alvarezii

1.3. Ecological importance of seaweeds

Seaweeds play critical roles in marine ecology supplying all categories of supporting services, which are presented in Table 1 and Fig 6. (Cotas *et al.* 2023). Large fleshy seaweed beds are equally important as forests on the surface. Seaweed beds are highly productive as they produce 1.5 g C m^{-2} h^{-1} by photosynthesis (Duarte and Chiscano 1999) and are considered as one of the principal and widespread productive coastal ecosystems (Cotas *et al.* 2023). Seaweeds produce food in the form of starch with the help of sunlight and release oxygen. The major portion of the carbon used by seaweeds for photosynthesis provides food to a wide range of marine organisms. Thousands of herbivorous species including commercially important fishes depend on seaweeds for food. It has been reported that grazing organisms consume about 34% of seaweed production and the detrital cycle absorbs around 38% of the carbon generated (Duarte and Chiscano 1999). Thus, the position of seaweeds in the marine food chain is critical due to their role in photosynthesis and primary production. Photosynthesis by seaweeds also helps in the production of atmospheric oxygen. Along with seagrasses and phytoplankton, seaweeds are responsible for 50 to 80% of the earth's atmospheric oxygen while only 28% of atmospheric oxygen is produced by rainforests (Cotas *et al.* 2023).

Table 1: Functions and supporting services of seaweeds
(Source: Cotaset al. 2023)

Ecosystem Service Category	Ecosystem Services Provided by Seaweeds	Examples of Benefits for Humans
Functions /Supporting services	Soil formation (sediment formation)	Increase environment quality for aquatic plants, increase in Seaweed primary productivity
	Photosynthesis	Production of oxygen and biomass
	Primary production	Biomass for higher trophic levels
	Production of oxygen	Providing suitable habitat for fish and other organisms used by humans
	Nutrient cycling	Preservation of ecosystem functioning; indirect benefits to food webs and water purification
	Water cycling	Influence seawater balance
	Provisioning of habitat	Conservation of biodiversity and biomass production of higher trophic levels (e.g., fish)

They absorb harmful materials such as heavy metals and chemical substances from the marine environment and balance the nutrients by producing oxygen through photosynthesis. Seaweeds help in cycling nitrogen, phosphorus, sulfur and iron (Wetzel 2001; Cotas *et al.*

2023). They work as a filter system of the marine environment. Seaweeds have a significant impact on nutrient cycling through a variety of physical, chemical and metabolic processes, as well as interactions with other species (Layton *et al.* 2020; Eger *et al.* 2020). Seaweeds along with sediment store nitrogen and phosphorus in aquatic ecosystems (Resende *et al.* 2021). On death, seaweeds release nutrients to the water through biomass decomposition and help in phytoplankton and periphyton primary production (Pawlik *et al.* 2016; Cotas *et al.* 2023). Due to their capability for accumulating metals, seaweeds are considered as natural metal biosorbents.

Seaweeds provide habitat to innumerable species of marine organisms and offer food, shelter, nursery and recruitment grounds to them (Hasselström *et al.* 2018). Many species of fish, crustaceans, mollusks and echinoderms have been reported to find shelter in seaweed beds. Hundreds of species of epibenthic organisms take refuge in seaweed beds and hence the biodiversity of seaweed habitats is very high. As seaweeds grow everywhere, they are home to several marine organisms in the seas around the world. Due to the provision of shelter to commercially important fin and shell fishes, seaweed beds are often fisheries hotspots (Theuerkauf *et al.* 2022; Cotas *et al.* 2023).

Climate change has affected all the living things on earth and is expected to cause more severe damages. Seaweeds contribute significantly to the annual biological reduction in CO_2 and the global carbon cycle (Turan and Neori 2010). By capturing 10% of global automobile emissions (equivalent to 175 million tons of carbon), seaweed beds play an important role in fighting climate change implications (Gallagher 2022). Though occupying a very little coastal region, seaweed beds are an important component of climate change adaptation and mitigation strategy (Cotas *et al.* 2023). Seaweed habitats have also been reported to mitigate the effects of global warming, acidification, and deoxygenation (Cotas *et al.* 2023). They also aid in preventing soil erosion by sediment trapping and thus maintain shorelines.

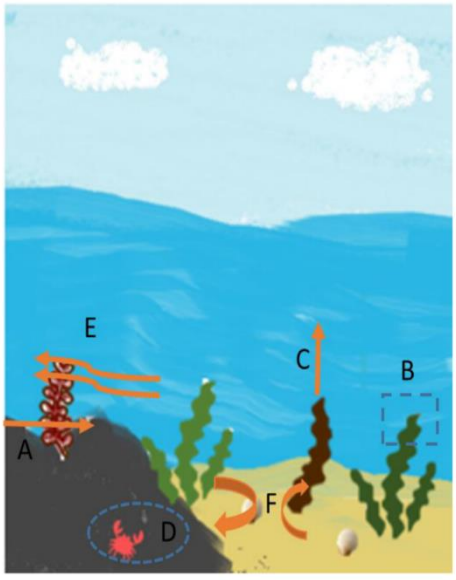


Figure 6: Schematic presentation of some of the ecological services of seaweeds:

(A) sediment formation (supporting services/function);

(B) biomass production (provisioning services);

(C) photosynthesis and production of oxygen (regulating services);

(D) provisioning of habitat (supporting services/function);

(E) erosion regulation (supporting services/function);

(F) nutrient cycling (supporting services/function).

(Source: Cotas*et al.* 2023)

1.4. Ecological roles of seaweed in coral reefs and seagrass habitats

Seaweeds are one of the key members of coral reef communities that play vital ecological functions such as stabilization of reef structure, production of tropical sands, nutrient retention and recycling, primary productivity and trophic support for reef organisms. Seaweeds in tropical reef ecosystems are responsible for a large amount of nutrient retention and recycling that contributes to the high level of primary productivity and trophic support to the incredible diversity of consumers (Fong and Paul 2011). Shallow water reef areas have higher rates of primary productivity than the surrounding oceanic water due to the presence of seaweeds (Fong and Paul 2011).

However, when the cover of seaweeds increases more than the coral cover, it becomes problematic for corals for it leads to benthic space competition. Increased covers of macroalgae in global reef areas have been reported to be due to the effects of climate change and human impacts (McManus and Polsenberg 2004). Mass coral bleaching events and consequent space competition from seaweeds have become a serious global issue affecting coral reefs, including the reefs of the Gulf of Mannar of Tamil Nadu, India (Edward *et al.,* 2018; Raj *et al.,* 2021).

Seaweeds play the same roles such as nutrient cycling, primary productivity and trophic support in the seagrass ecosystem, but it has been reported to cause more harm to seagrass beds by reducing light, taking space, taking dissolved oxygen, consuming nutrients, decomposing and causing sedimentation (Han and Liu 2014).

1.5. Commercial importance of seaweeds

1.5.1. Food industry

Many of the seaweed species are edible and have been taken as food by coastal communities all over the world since prehistoric times. In particular, in Asian countries, seaweeds are a common food and seaweed eating has expanded to Western countries. Seaweeds are popular in the food industry due to their rich nutritional values like dietary fibers, proteins, vitamins and minerals that are important for human beings. Seaweeds also contain bioactive substances like polysaccharides, polyphenols, phytochemicals and polyunsaturated fatty acids that can help deal with inflammation, cancer, oxidative stress, allergies, diabetes, thrombosis, obesity, hypertension, lipidemia and many degenerative diseases (Tanna and Mishra, 2019). The global population is increasing every day and there is not enough food for this ever-increasing population. To address this issue of food demand, many countries have started to explore alternative food sources including marine bio-resources (Choudhary*et al.* 2021). Seaweeds have been found to be a renewable food

source that can possibly provide for the increasing demand.

Edible seaweeds contain various bioactive compounds with potential health benefits. Seaweeds basically contain high proportions of polysaccharides along with various other potentially beneficial compounds such as good-quality protein and essential fatty acids, particularly long-chain n-3 polyunsaturated fatty acids (PUFAs) (Kılınç*et al.* 2013). Seaweed polysaccharides are used by the food industry as texture modifiers because of their high viscosity and gelling properties. The adding of seaweeds or their extracts to food products helps in reducing the utilization of chemical preservatives. Seaweeds are used in food processing and meat product formulations. In Asia seaweeds have been used for centuries in salads and soups, and as low-calorie dietetic foods (Kılınç *et al.* 2013). Some of the uses of seaweeds (Roohinejad *et al.* 2017) are as follows,

- Agar is used to prepare icings and bakery glazes
- Alginates are used in restructured meat, vegetable and meat products, ice creams and frozen and reduced fat products. They are also used as a coating film in microwave cooked chicken nuggets.
- Carrageenans are used as ingredient in ice cream, yoghurt, cheese and milk-based products and in bakery products like bread and as a coating film to extend the shelf-life of fresh chicken breast

Due to the high melting temperature and the ability to prevent crystallization of sugar, agar is widely used to prepare icings and bakery glazes. Alginates do not melt at high temperatures, and form cross linked gels and hence are used in many restructured meat and vegetable products and meat products. They are also used in ice creams and frozen and reduced fat products. Alginate is also used as a coating film in microwave cooked chicken nuggets to shorten cooking time. Carrageenans have gelling, emulsifying, thickening and stabilizing properties, and hence are widely used as ingredient in dairy products such as ice cream, yoghurt, cheese and milk-based products. Carrageenans are also used in bakery products such as bread and as a coating film to extend the shelf-life of fresh chicken breast (Roohinejad *et al.* 2017).

1.5.2. Animal feed/supplements

Seaweeds have traditionally been used as animal feed in the coastal areas. They can substitute the antibiotics in various animals as they are very rich in metabolites such as pigments, carotenoids, phlorotannins, polyunsaturated fatty acids, agar, alginate and carrageenan and minerals such as iodine, zinc, sodium, calcium, manganese, iron, and selenium. As animal feed, seaweeds are rich and sustainable sources of macronutrients and micronutrients. They have a relatively high protein quality compared to cereal and soy flour (Morais*et al.* 2020).

1.5.3. Biofuel

Fuel sources for the ever-increasing demand are rapidly decreasing due to the rapid urbanization and industrialization. Seaweeds are probably the most potential source of biomass for biofuels as they can be cultivated even in adverse conditions (Kumar *et al.* 2021). Biofuels derived from algae are considered as third generation fuels as they have the merits of rapid growth, high CO_2 capture, and ease of cultivation even in barren lands (Peter *et al.* 2021). It is being reported in the literature that seaweeds with 80%–90% water content are more suitable for anaerobic digestion and fermentation to produce biogas and bioethanol respectfully (Nagula *et al.* 2022).

1.5.4. Biofertilizer/growth stimulants

Recent studies reveal that seaweeds possess biostimulatory compounds such as various forms of carbohydrates, amino acids, small quantities of phytohormones, osmoprotectants and proteins. Due to the bioactive components and effects, the use of seaweed-based bioproducts has been increasing in crop production systems. Seaweeds have phytostimulatory properties that help in increased growth of important crops and high yield. Seaweeds also exhibit phytoelicitor activity that helps to evoke defence responses in plants to fight pests, diseases and abiotic stresses including drought, salinity and cold. They also evoke phytohormonal responses to regulate plant growth. Treatment by seaweed extracts also causes significant changes in the microbiome components of soil and aids in sustainable plant growth (Ali *et al.* 2021).

1.5.5. Nutraceuticals

Nutraceuticals are food or part of food that offer health benefits. Throughout human history, seaweeds have been used as food, folk remedies, dyes and mineral-rich fertilisers. Recent studies reveal that bioactive compounds from seaweed can play a major therapeutic role in disease prevention in humans. Polysaccharides, pigments, fatty acids, polyphenols and peptides derived from seaweeds have been proven to potentially contribute to functional food and nutraceutical development. These bioactive compounds are explored for such functional aspects as antioxidant, antibacterial, anticancer, antidiabetic, antitumor, antiviral, anti-inflammatory and anticoagulant properties, both in in-vitro and in-vivo model systems (Ganesan *et al.* 2019b). Many studies have demonstrated the health benefits of seaweed supplementation alongside a regular diet. Global epidemiological studies have shown that countries where seaweed is consumed on a regular basis have significantly fewer instances of obesity and dietary-related disease (Shannon and Abu-Ghannam 2019). Seaweed products have high contents of vitamin, fibre, minerals and omega-3-fatty acids and hence can provide high commercial scope (Ganesan *et al.* 2019b).

1.5.6. Cosmetics

Globally, the demand for skincare products with natural ingredients is rapidly increasing. Seaweeds have been proved to have potential skincare properties and hence seaweed-derived ingredients are commonly used in cosmetics, cosmeceutics and nutricosmetics (Jesumani*et al.* 2019). Bioactive compounds from seaweeds such as polyphenols, polysaccharides, proteins, peptides, amino acids, lipids, vitamins and minerals can be used as ingredients, additives and active agents in the formulation of skin care products (López-Hortaset al. 2021). Seaweed components are used in commercially available soaps, shampoos, sprays, hydrogels or creams, and also as suitable carrier systems or vesicles such as liposomes, nano/microparticles, emulsions, hydrogels, etc., (López-Hortas*et al.* 2021).

1.5.7. Other uses

Apart from the above-mentioned uses, seaweeds are used in several other industries. Bioplastics made of seaweeds are gaining popularity in recent years due to the problem of plastic pollution. Due to their biocompatibility, biodegradation, non-cytotoxicity and antimicrobial properties, biopolymers from seaweed are used in implantable materials, wound dressing, pill disintegrators, ligament and tendon tissue engineering and preparation of moulds in dentistry or bone fixation parts. Bioplastics made of seaweeds have also been reported to be comparatively more durable and resistant to microwave radiation but less brittle (Ditchburn and Carballeira 2019). Due to their resistance to microbes, seaweeds are potential antifouling compounds to be used in submerged marine structures (Ho*et al.* 2015). Seaweed-derived nanoparticles have also shown promising results in several biomedical and environmental functions and are to be explored further. Figure 7 showcases the several ecological benefits of seaweeds.

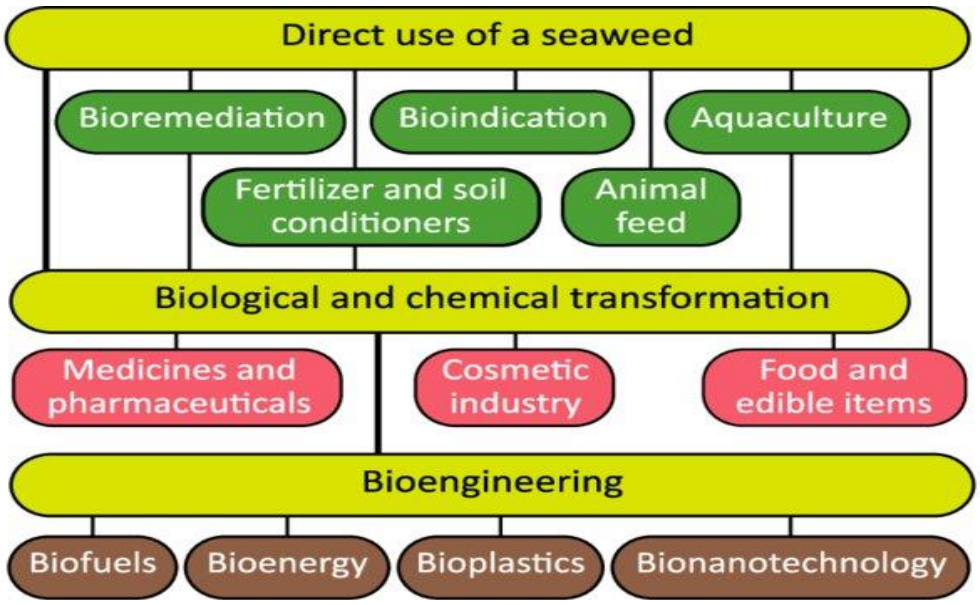


Fig. 7: Multiple uses of seaweeds (Source: Ditchburn and Carballeira 2019)

1.6. Seaweed distribution and status

1.6.1. Global scenario

Seaweeds are the largest and most productive underwater vegetated habitats on Earth. Seaweeds occur in all major oceanographic realms distributed from the poles to the tropics, with most of the records concentrated in temperate latitudes 40–60° (Pessarrodona*et al.* 2022). Seaweeds are distributed horizontally in different zonations viz. supra tidal, intertidal and subtidal regions of the seas and oceans. Green seaweeds are most commonly found in the intertidal zone and brown seaweeds inhabit the tidal or upper subtidal zones while red seaweeds grow in subtidal waters (Rao *et al.* 2018). The depth range for seaweeds is from the intertidal zone to the greatest depths (> 200 m) receiving enough light to support their growth (Duarte *et al.* 2022). Recent comprehensive estimates of global algal diversity report 72,500 taxa (Mantri*et al.* 2019).

1.6.2. Indian scenario

India has a long coastline of about 8,100 km with an Exclusive Economic Zone of 2.17 million km^2. The Indian coastline supports luxuriant growth of diverse seaweed populations (Fig. 8). A total of 844 seaweed species have been reported from India with a standing stock of 58,715 tonnes (Banerjee *et al.* 2020). It includes 216 species of Chlorophyta, 191 species of Pheophyta, 434 species of Rodophyta and 3 species of Xanthophyta (Temkar*et al.* 2018). The vast diversity of habitats, including estuarine mangrove vegetation, sandy beaches, rocky shores, deep tide pools, cliffs and caves, coral substrates and artificial offshore structures, provide ample support for diverse seaweed groups to thrive in intertidal and subtidal waters. India has reported the highest number of seaweed taxa compared to all the other nations bordering the Indian Ocean (Sahoo*et al.* 2001; Mantri*et al.* 2019a)

In India, macroalgae are found in plenty along the Tamil Nadu and Gujarat coasts, Lakshadweep archipelago, and Andaman & Nicobar Islands. Further, seaweed resources are abundant along the coasts of Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhinjam, and Pulicat in Tamil Nadu, Andhra Pradesh, and Chilka in Orissa. In India, Gujarat and Tamil Nadu coasts harbour the highest seaweed diversity (Ganesan*et al.* 2019a). In 1980–90, the Central Salt and Marine Chemicals Research Institute (CSMCRI) estimated the total standing stocks of seaweeds as 97,400 tonnes wet wt. from the coast of Tamil Nadu, 7,500 tonnes wet wt. from the coast of Andhra Pradesh and 19,345 tonnes wet wt. from the Lakshadweep Islands (Kaliaperumal and Kalimuthu 1997). It is also to be noted that most of the Indian coastal areas are not sufficiently covered to be in a position to compile comprehensive data on seaweed flora (Mantri*et al.* 2019a).

Fig. 8: Popular Seaweed locations in India(Jaikumaret al. 2023)

1.7. Seaweed cultivation

1.7.1 Global scenario

Global production of seaweed has been estimated at 32.4 million tonnes including both wild-collected and cultivated algae (FAO 2020). Out of the total global production, 97.1% is from cultivation (FAO 2020) and the rest is from wild collection. More than 200 seaweed species are traditionally harvested from the wild in 32 different countries (Mantri*et al.* 2019a). In the case of Asia, 99% of seaweed is cultivated and China ranks first in the world in terms of aquaculture production, accounting for 56.82% of global aquaculture followed by Indonesia with 28.6% (Zhang *et al.* 2022).

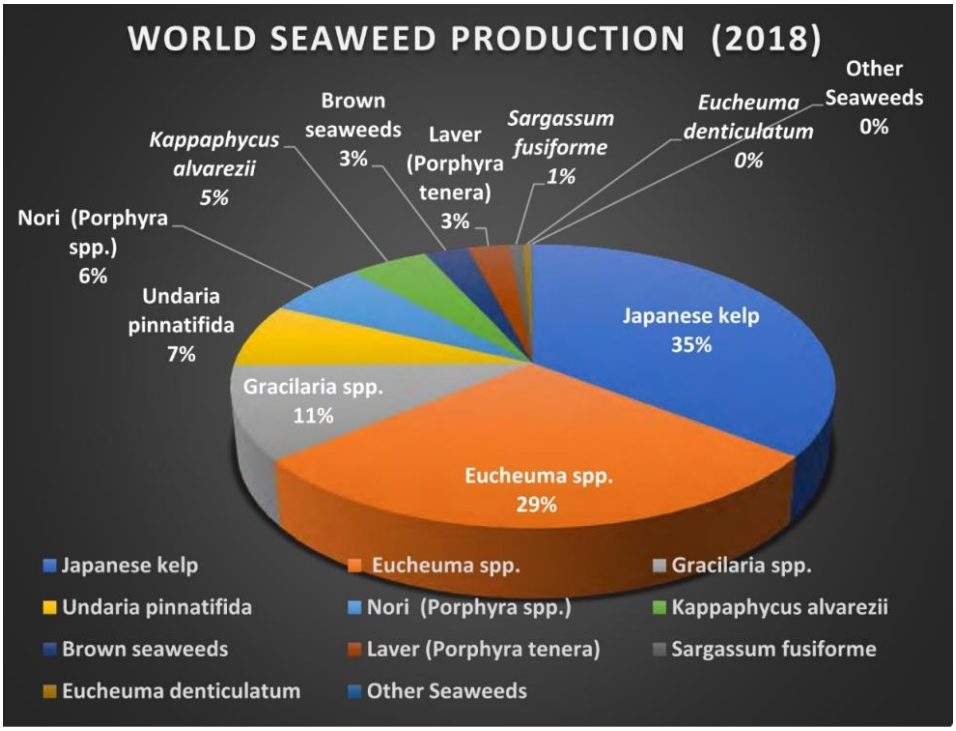


Fig. 9: Species-wise cultivation of seaweeds in the world
(Source: Department of Fisheries, Govt. of India, Presentation)

1.7.2. Indian scenario

India stands in 13th position in global seaweed production as the contribution of the Indian seaweed industry to global seaweed production accounts only for 5.3 tonnes (wet weight) (FAO 2020). Indian coastline harbors four million fishermen in 3,288 locations (Mantri*et al.* 2019a). There are 46 agar- and alginate-producing industries in India. Many small and medium-scale seaweed processing units are located in south India. In India, 193,834 km^2 of territorial waters are accessible to artisanal fishermen where commercial seaweed cultivation can be carried out. It is important to note that the demand for carrageenan is around 500 tonnes per year, for agar 400 tonnes per year, and for alginate 1,000-2,000 per year. But the production of carrageenan, agar and alginate in India is a mere 50-60, 150 and 250-600 tonnes per year respectively (Mantri*et al.* 2017, 2019b, 2020a). Though technologies have been developed for several species of agarophytes and alginophyes, the Indian seaweed industry predominantly depend on the exotic carrageenophyte*Kappaphycusalvarezii*. The agar and alginate industries have started to import from other countries due to the lack of production by the Indian seaweed industry. Indian seaweed industry is dependent on three basic cultivation techniques such as raft culture, monoline culture and tube net culture (Figs. 10-12).

Fig. 10: Raft culture

Fig. 11: Monoline culture

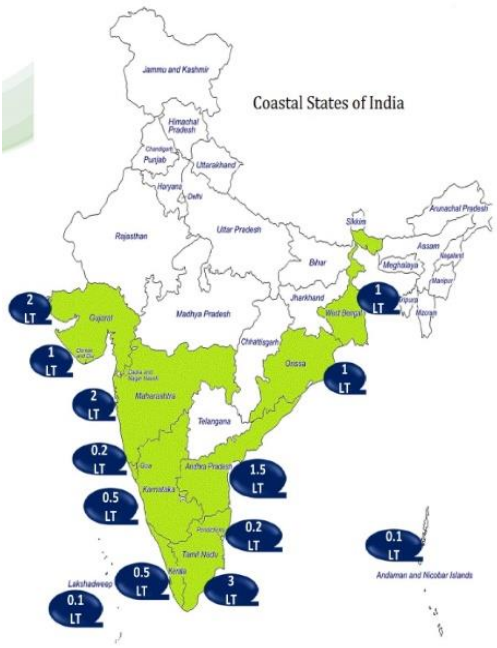
Fig. 12: Tube net culture (Source: Kavaleet al. 2021)

1.7.2.1. Pradhan Mantri Matsya Sampada Yojana

Under Pradhan Mantri Matsya Sampada Yojana, Rs.640 Cr has been allocated for Seaweed Cultivation and Value Chain Development in India (Fig. 13). The objectives of the projects are to enhance production and productivity in the seaweed aquaculture in the country for harnessing the potential of the coastal waters and reduce reliance on wild harvest; to improve the seaweed value chain and industrial product diversification to meet domestic demand and thus reduce dependence on imports; to promote seaweed cultivation as a viable and sustainable livelihood amongst rural communities, especially for women; and to establish an institutional mechanism in Research and Development in seaweed farming and value chain and mechanism for effective Transfer of Technology. The production target for the country from 2020-21 to 2024-25 is 11.2 lakh tonnes in wet weight from 13 states/union territories including Gujarat, Maharashtra, Goa, Kerala, Tamil Nadu, Andhra Pradesh,

Odisha, West Bengal, Karnataka, Puducherry, Lakshadweep, Andaman & Nicobar Islands, and Daman & Diu (Department of Fisheries, Govt. of India, Presentation).

State Wise Production Targets



Production target (Lakh ton) in wet Weight						
State	2020-21 (5%)	2021-22 (10%)	2022-23 (25%)	2023-24 (30%)	2024-25 (30%)	Total (100%)
Gujarat	0.1	0.2	0.5	0.6	0.6	**2**
Maharashtra	0.05	0.1	0.25	0.3	0.3	**1**
Goa	0.01	0.02	0.05	0.06	0.06	**0.2**
Kerala	0.025	0.05	0.125	0.15	0.15	**0.5**
Tamil Nadu	0.15	0.3	0.75	0.9	0.9	**3**
Andhra Pradesh	0.075	0.15	0.375	0.45	0.45	**1.5**
Odisha	0.05	0.1	0.25	0.3	0.3	**1**
West Bengal	0.05	0.1	0.25	0.3	0.3	**1**
Karnataka	0.025	0.05	0.125	0.15	0.15	**0.5**
Puducherry	0.01	0.02	0.05	0.06	0.06	**0.2**
Lakshadweep	0.005	0.01	0.025	0.03	0.03	**0.1**
Andaman & Nicobar Islands	0.005	0.01	0.025	0.03	0.03	**0.1**
Daman &Diu	0.005	0.01	0.025	0.03	0.03	**0.1**
Total	0.56	1.12	2.8	3.36	3.36	**11.2**

Fig. 13: State-wise seaweed production targets

(Source: Department of Fisheries, Govt. of India)

2. Present scenario of seaweed cultivation in Tamil Nadu

Tamil Nadu coast is one of the seaweed diversity hotspots of the country, especially in the Gulf of Mannar and Palk Bay. Seaweed standing stocks of Tamil Nadu coast have been estimated as 97,400 tonnes wet weight (Kaliaperumal and Kalimuthu 1997). A total of 282 seaweed species have been reported from Tamil Nadu and a total of 181 seaweed species have been reported from the Gulf of Mannar alone (Balaji*et al.* 2012). Among them, the macroalgal genera *Gracilaria, Gelidiella, Hypnea, Sarconema, Sargassum* and *Turbinaria* have been reported to be commercially important (Ganesan*et al.* 2019a). These genera can yield commercially important agar, alginate and carrageenan. Seaweed cultivation is an excellent alternative livelihood option to reduce fishing pressure along the Tamil Nadu coast.

The south coast of Tamil Nadu encompasses the Indian Ocean, Arabian Sea, and Bay of Bengal and there are distinct variations in the nature of sub stratum in the intertidal and subtidal regions. On the northern side, long and wide sandy beaches, flat rocks, boulders and stones in the lower and upper intertidal regions are available (Ganesan*et al.* 2019a). Species belonging to the genera *Ulva, Chaetomorpha, Bryopsis* and *Grateloupia* inhabit the rocks and boulders. Palk Bay is situated off the central Tamil Nadu coast bordering the Cauvery deltaic region, which is a muddy intertidal and subtidal coast due to the confluence of many rivers flowing to the sea (Ganesanet al. 2019a). Several species of agar-yielding Gracilariaare dominate in this region. The Gulf of Mannar, located in the southern part of Tamil Nadu, has the richest diversity of seaweeds due to the availability of dynamic ecosystems like coral reefs (Ganesan*et al.* 2019a). Commercially important *Sargassum, Acanthophora*, *Hypnea, Ulva, Gelidiella, Turbinaria*and*Sargassum* species are common in the Gulf of Mannar, especially around the 21 uninhabited islands (Ganesan*et al.* 2009a).

It has been reported that more than 1,500 households along the Tamil Nadu coast especially along the coasts of the Gulf of Mannar and Palk Bay are involved in seaweed cultivation and earn about US $300 per month (Ganesan*et al.* 2019a). *Kappaphycusalvarezii, Gracilariaedulis, Gelidiellaacerosa* and*Gracilaria dura* are the species reported to be cultivated in Tamil Nadu coast (Ganesan*et al.* 2019a). However, among these species, the cultivation of *K. alvarezii* which is an exotic species introduced in Tamil Nadu during 1990's, has become widespread in Tamil Nadu coast (Fig. 14). Despite the very long coastline and the rich occurrence of macroalgae resources, the Tamil Nadu still does not use advances in technologies for seaweed cultivation.

It has also been reported that 1,555 fishermen from 14 coastal villages in the Gulf of Mannar and 670 fishermen from 24 villages in the Palk Bay are involved in *native macroalga collection* (Ganesan*et al.* 2019a) (Fig. 15).

Fig. 14: Cultivation of Kappaphycusalvarezii Tamil Nadu

Fig. 15: Wild collection of Sargassum sp. in Tamil Nadu

2.1. Establishment of Multi-purpose Seaweed Park

Realizing the importance and potential of seaweed resources of the Tamil Nadu coast, recently, the Department of Fisheries and Fishermen Welfare, Govt. of Tamil Nadu announced the establishment of a multipurpose seaweed park in Tamil Nadu. The Tamil Nadu coast is the second longest in the country with 1,076 km where the seaweed park is planned along the coasts of the Gulf of Mannar and Palk Bay. Southern districts such as Nagapattinam, Thanjavur, Tiruvarur, Pudukottai and Ramanathapuram have been selected for seaweed farming. In, November 2023, an amount of Rs.127.72 crore has been allotted to establish the seaweed park in Tamil Nadu. In the total outlay of 127.72 crore, the share of the central Government is 75.15 crore, the share of the Tamil Nadu Government is 48.94 crore and the beneficiary share is 3.6 crore (Fig. 16) (Department of Fisheries and Fishermen Welfare 2021, Govt. of Tamil Nadu Presentation) Establishing a seaweed park is expected to provide livelihood options to thousands of people along the Tamil Nadu coast and reduce the pressure on fishing.

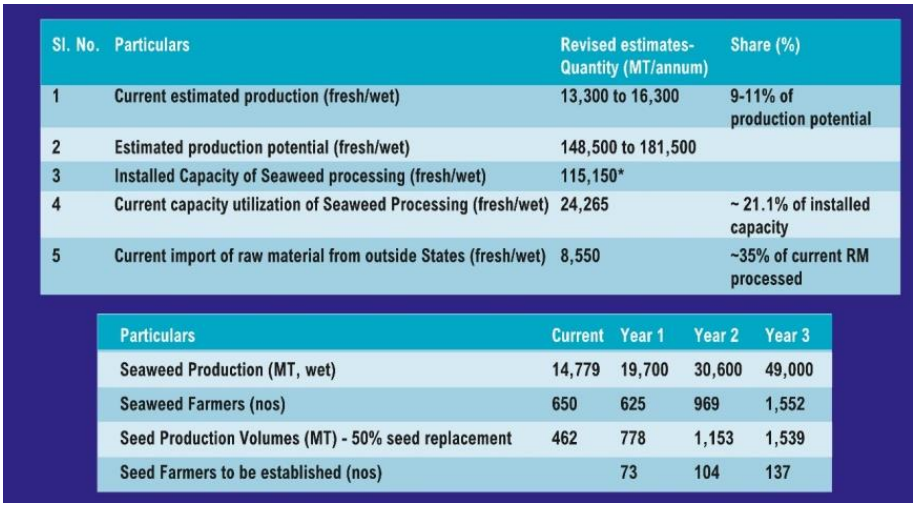
The Department of Fisheries and Fishermen Welfare, Govt. of Tamil Nadu has been promoting seaweed farming as a viable supplementary or alternative livelihood option even earlier. The department has distributed 15,360 seaweed rafts and monolines to 1,956 fisherwomen for seaweed farming. The present average annual seaweed production in Tamil Nadu is 10,000 tonnes/Annum (Wet weight).

The proposed park seeks to bring an advanced and sustainable technologies to enhance production and value-addition. Thereby creating employment opportunities to coastal fisher youth and fisherwomen, development of value-added seaweed products by encouraging private sector/entrepreneurs and supporting them to set up seaweed processing units in the

proposed seaweed park, exploration of untapped seaweed potential in the coastal districts of Tamil Nadu through scientific and traditional seaweed farming, development of R&D for production of quality seaweed and development of seaweed seed bank through Research Institutes, Universities, Private entrepreneurs and Fisheries Department (Department of Fisheries and Fishermen Welfare 2021, Govt. of Tamil Nadu Presentation). Figure 17 provides the details of targets envisaged for seaweed farming in Tamil Nadu.

Particulars	Total Program Cost	Central Govt. Share	State Govt. Share	Beneficiary Share
Hub-1 (Seaweed Production Park)				
Hub-2 (Seaweed Processing Park)				
Spoke level (Type 1)				
Spoke level (Type 2)	127.71	75.15	48.94	3.60
Seed importation and probagation				
FPO formation & funding support				
Seaweed farmer support raft				
Seaweed farmer support monoline				
Total Cost (in Crores)	127.71	75.15	48.94	3.60

Fig. 16: Estimated budget for the establishment of multi-purpose seaweed park in Tamil Nadu (Source: Department of Fisheries and Fishermen Welfare 2021, Govt. of Tamil Nadu)



Sl. No.	Particulars	Revised estimates-Quantity (MT/annum)	Share (%)
1	Current estimated production (fresh/wet)	13,300 to 16,300	9-11% of production potential
2	Estimated production potential (fresh/wet)	148,500 to 181,500	
3	Installed Capacity of Seaweed processing (fresh/wet)	115,150*	
4	Current capacity utilization of Seaweed Processing (fresh/wet)	24,265	~ 21.1% of installed capacity
5	Current import of raw material from outside States (fresh/wet)	8,550	~35% of current RM processed

Particulars	Current	Year 1	Year 2	Year 3
Seaweed Production (MT, wet)	14,779	19,700	30,600	49,000
Seaweed Farmers (nos)	650	625	969	1,552
Seed Production Volumes (MT) - 50% seed replacement	462	778	1,153	1,539
Seed Farmers to be established (nos)		73	104	137

Fig. 17: Targets envisaged for seaweed farming in Tamil Nadu (Department of Fisheries and Fishermen Welfare 2021, Govt. of Tamil Nadu Presentation)

The immediate focus of the establishment of a seaweed park is on increasing the production level to match the processing demand in a phased manner, upgrading village level infrastructure for drying, storage and accessibility and creation of necessary infrastructure. Medium to long term focus of the proposal is on increasing processing capacity in the subsequent phase through establishment of seaweed processing park, simultaneously working on increasing production and development of new product lines from seaweeds to

match increased processing capacity and creation of necessary infrastructure (Department of Fisheries and Fishermen Welfare 2021, Govt. of Tamil Nadu Presentation).

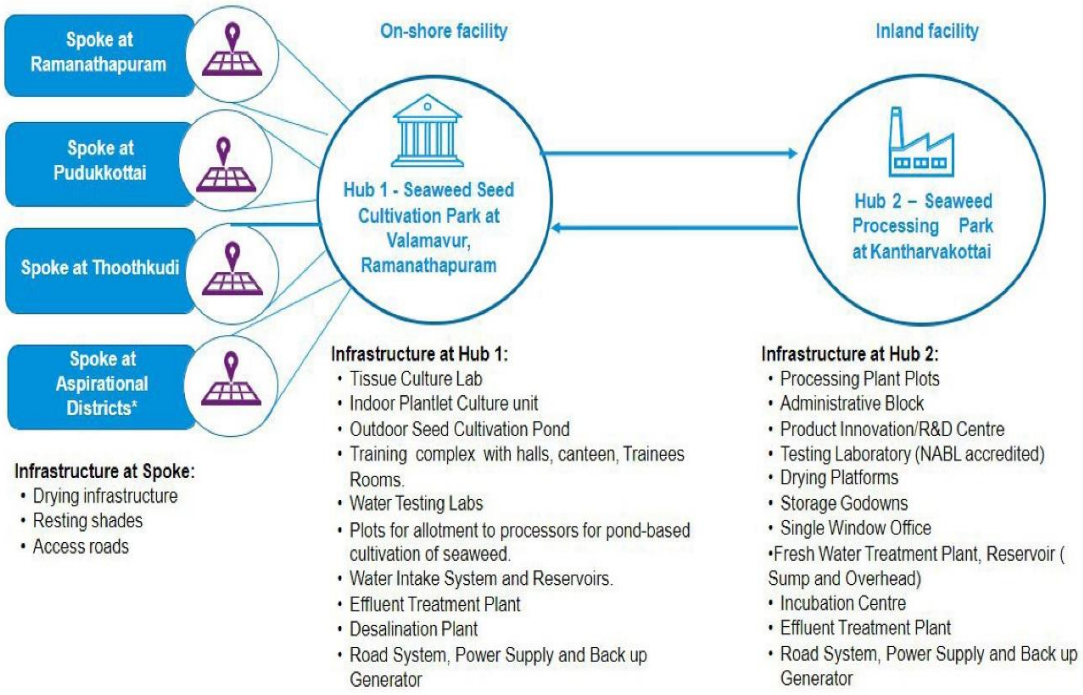


Fig. 18: Multipurpose Seaweed Park – Hub & Spoke model – Conceptual Framework of Integrated seaweed park (Department of Fisheries and Fishermen Welfare 2021, Govt. of Tamil Nadu Presentation)

In spite of developing a multipurpose seaweed park in Tamil Nadu, it is imperative to have a holistic approach to the promotion of the seaweed industry in Tamil Nadu for both cultivation and wild collection. The establishment, execution and monitoring of the seaweed park should be properly managed to avoid adverse effects. Hence, it is important to develop a comprehensive action plan with guidelines to make judicious utilization of seaweed resources and the environment, thereby maintaining an ecological balance for the sustainability of the seaweed industry.

3. Issues in seaweed cultivation

The seaweed industry has a huge potential in Tamil Nadu considering the resources and the demand. However, the seaweed industry has not taken off to compete in the global market even after several years of research and implementation. This is due to certain critical issues that need to be addressed effectively for better results. These issues range from the lack of baseline studies to several implementation issues as detailed below.

3.1. Baseline studies and data

Seaweeds are available from the intertidal regions to deeper waters along the Tamil Nadu coast. Research on seaweeds in Tamil Nadu has happened predominantly on shallow water seaweeds while deeper water seaweeds are not explored (Fig. 19). It is certain that the number of seaweed species available on the Tamil Nadu coast will increase significantly if proper underwater research is carried out in deeper waters. It is likely that more commercially important species and seeds for already known species can be availed from deeper waters. The stock assessment of seaweeds has not been carried out in detail for the Tamil Nadu coast. The baseline data on the status, distribution and standing stocks of seaweeds along the coast of Tamil Nadu is important and crucial for the establishment and sustainability of seaweed industry.

Fig. 19: Deepwater (20 m) luxuriant seaweed bed in the Gulf of Mannar

3.2. Technologies to cultivate multiple species

The primary issue in seaweed cultivation along the Tamil Nadu coast is the lack of commercially viable technologies to cultivate multiple native seaweed species. Though there are several commercially important native species, the seaweed cultivation industry in Tamil Nadu is depending on the exotic seaweed *K. alvarezii*. World Wildlife Fund (WWF) has given

a caution on its website that "WWF supports the production of local seaweed species wherever farming activities are taking place and encourages the development of new native species as seaweed farming expands worldwide as some seaweed species have turned invasive when grown outside their natural range, overgrowing coral reefs, and throwing off the balance of the local ecosystem (https://www.worldwildlife.org/industries/farmed-seaweed). Technologies to cultivate several commercially important native seaweed species have been reported to be experimentally successful (Ganesan*et al.* 2019a) (Table 2), but have not been promoted to be commercially viable along the Tamil Nadu coast.

Table 2: Experimentally successful technologies to cultivate commercially important native seaweed species

S. No	Reference	Organization	Species	Phyco-colloid derived
1	Ganesan, M., Trivedi, N., Gupta, V., Madhav, S. V., Reddy, C. R., & Levine, I. A. (2019a). Seaweed resources in India–current status of diversity and cultivation: prospects and challenges. Botanica Marina, 62(5), 463-482.	CSMCRI	*Gracilariasalicornia*	Agar
2	Ganesan, M., Trivedi, N., Gupta, V., Madhav, S. V., Reddy, C. R., & Levine, I. A. (2019a). Seaweed resources in India–current status of diversity and cultivation: prospects and challenges. Botanica Marina, 62(5), 463-482.	CSMCRI	*Gracilariacrassa*	Agar
3	Veeragurunathan, V., Prasad, K., Vizhi, J. M., Singh, N., Meena, R., &Mantri, V. A. (2019). *Gracilariadebilis* cultivation, agar characterization and economics: bringing new species in the ambit of commercial farming in India. Journal of Applied Phycology, 31(4), 2609-2621.	CSMCRI	*Gracilariadebilis*	Agar
4	Mantri, V. A., Shah, Y., &Thiruppathi, S. (2020b). Feasibility of farming the agarose-yielding red alga *Gracilaria dura* using tube-net cultivation in the open sea along the Gujarat coast of NW India. Applied Phycology, 1(1), 12-19.	CSMCRI	*Gracilaria dura*	Agar
5	Mantri, V. A., Ashok, K. S., Musamil, T. M., Gobalakrishnan, M., Saminathan, K. R., Behera, D. P., Veeragurunathan, V., Eswaran, K., Thiruppathi, S., Pothal, J.K. & Ghosh, P. K. (2017). Tube-net farming and device for efficient tissue segregation for industrially important agarophyte*Gracilariaedulis* (Rhodophyta). Aquacultural Engineering, 77, 132-135.	CSMCRI	*Gracilariaedulis*	Agar

6	Ganesan, M., Thiruppathi, S., Eswaran, K., Reddy, C. R. K., &Jha, B. (2009). Cultivation of *Gelidiellaacerosa* in the open sea on the southeastern coast of India. Marine ecology progress series, 382, 49-57.	CSMCRI	*Gelidiellaacerosa*	Agar
7	Ganesan, M., Thiruppathi, S. &Jha, B. (2006). Mariculture of Hypneamusciformis (Wulfen) Lamourex in the south east coast of India. Aquaculture 256: 201–211.	CSMCRI	*Hypneamusciformis*	Carrageenan
8	Ganesan, M., Meena, R., Siddhanta, A.K., Selvaraj, K. &Chithra, K. (2015). Culture of red alga *Sarconemafiliforme* in offshore waters and hybrid carrageenan from cultivated seaweed. J. Appl. Phycol. 27: 1549–1559.	CSMCRI	*Sarconemafiliforme*	Carrageenan

3.3. Seed banks

Since there is no cultivation of multiple seaweed species, seed banks have not been developed for native seaweed species, even the predominantly cultivated exotic *K. alvarezii* has also been said to have lost its virulence. Hence, the continuous supply of seaweed seeds to seaweed farmers is a huge problem faced by the seaweed industry in Tamil Nadu. Many of the established rafts and monoline setups are left empty due to the unavailability of seed banks. Without continuous supply of seeds from seed banks, the seaweed industry in Tamil Nadu will not be sustainable.

3.4. Efficiency in field collection of seeds

Seaweed resources are plenty along the Tamil Nadu coast, but the collection of seeds from the seaweed beds has been a problem due to the lack of adequate knowledge and skills. Seaweed farmers and practitioners are not scuba divers and hence do not know the location of commercially important seaweeds and they do not dive to collect seeds. Moreover, the lack of commercially viable technologies for native seaweed collection restricts them from going for field collection of effective seeds.

3.5. Wild collection techniques

The traditional seaweed collectors along the Tamil Nadu coast, especially in the Gulf of Mannar and Palk Bay coasts use very old techniques of reef walking or skin diving (Fig. 20). Wild collection of seaweeds needs to be executed with advanced techniques for better collection quantity and to reduce the impact on other benthic resources like coral reefs, seagrass beds and associated biodiversity.

Fig. 20: Wild collection technique in the Gulf of Mannar

3.6. Infrastructure facilities for seaweed farmers

Infrastructure facilities for seaweed cultivation are severely lacking and are affecting the cultivation potential significantly. Cultivation sites are along the coast where sanitation and the availability of basic amenities are not available. Drinking water, shade for the seaweed farmers, roads for transportation, etc. are lacking at the cultivation sites. More importantly, the drying of seaweeds happens on beach soil which is not hygienic and thus reduces the quality of seaweeds (Fig. 21). The lack of storage options for cultivated seaweeds on the shore is another important issue.

Fig. 21: Unhygienic drying of collected seaweeds

3.7. Financial constraints of seaweed farmers

Seaweed cultivation is carried out predominantly by poor coastal people who cannot spend much on raw materials. To set up rafts or monolines or tube nets, they need to spend a significant amount of money amid their financial constraints. Further, the materials used in seaweed cultivation are not durable and need to be replaced every now and then.

3.8. Climatic conditions

During monsoon seasons, rainy seasons and storms, it is difficult for seaweed farmers to protect their cultivation infrastructures. Loss of raw materials and cultivated materials are common and cause significant financial loss to seaweed farmers. Sea level rise and coastal erosion have reduced the shore available for seaweed cultivation and initial processing. Hot weather during summer months is also an important problem as there are no shelters along the shore for the fishermen to take refuge.

3.9. Marketing

Marketing is another important issue for seaweed farmers in Tamil Nadu as there is no proper link between demand and supply. It is a well-known fact that seaweed products such as agar, alginate and carrageenan are in heavy demand globally. However, the demand has not reached the cultivation sites and seaweed farmers. Only the cultivation of exotic*K. alvarezii* is promoted among the fishermen because the expenses of cultivating native species are high even though they are ecologically not harmful.

3.10. Nodal agency

There is no nodal agency so far to manage seaweed cultivation in Tamil Nadu. Due to this, focused policy, action plan and guidelines have not been developed so far for the seaweed industry. A fully operational nodal agency that promotes, monitors, and manages seaweed cultivation in the state should be established first, before going for wide-scale initiatives for promotion of seaweed industry including cultivation.

3.11. Research and Development

Research and development of the seaweed industry are still in the primitive stage as viable commercial technologies for multiple seaweed species have not been developed, and commercialization of value-added seaweed products has not taken off, land-based cultivation technologies similar to shrimp farms have not been developed, and long-term seed storage capacity has not been developed.

3.12. Policy and action plan

There is no policy, action plan and guidelines for the seaweed industry. Without these, lacunae in the industry are not properly identified and the execution of seaweed cultivation initiatives is not properly managed. Sporadic studies by the research institutions, short-term project-based initiatives, lack of responsibility to environmental concerns, lack of market regularization and cost fixing, compensation to the farmers during loss, etc. cannot be regularized without policy and action plan.

4. Ecological Impact

Though the cultivation of seaweeds offers innumerable benefits, there are some serious ecological issues associated with this activity. The coast of Tamil Nadu is blessed with important marine natural treasures such as coral reefs and seagrass beds. The Gulf of Mannar and Palk Bay are provided with a great extent of coral reefs and seagrass beds which are the best in the Indian mainland in terms of diversity, abundance and health. Climate change and other factors are already causing significant disturbances to these marine habitats. Thousands of people along the coast of the Gulf of Mannar and Palk Bay depend directly on fishery resources associated with coral reefs and seagrass beds for their livelihood. Promotion of seaweed farming should not in any way affect these fragile ecosystems and their sustainable long term benefit. Hence, it is imperative that utmost care must be given before selecting sites or species for seaweed cultivation. It should be ensured that coral reefs and seagrass beds are not affected by the seaweed industry. Several ecological impacts caused by seaweed farming are given in the figure 22.

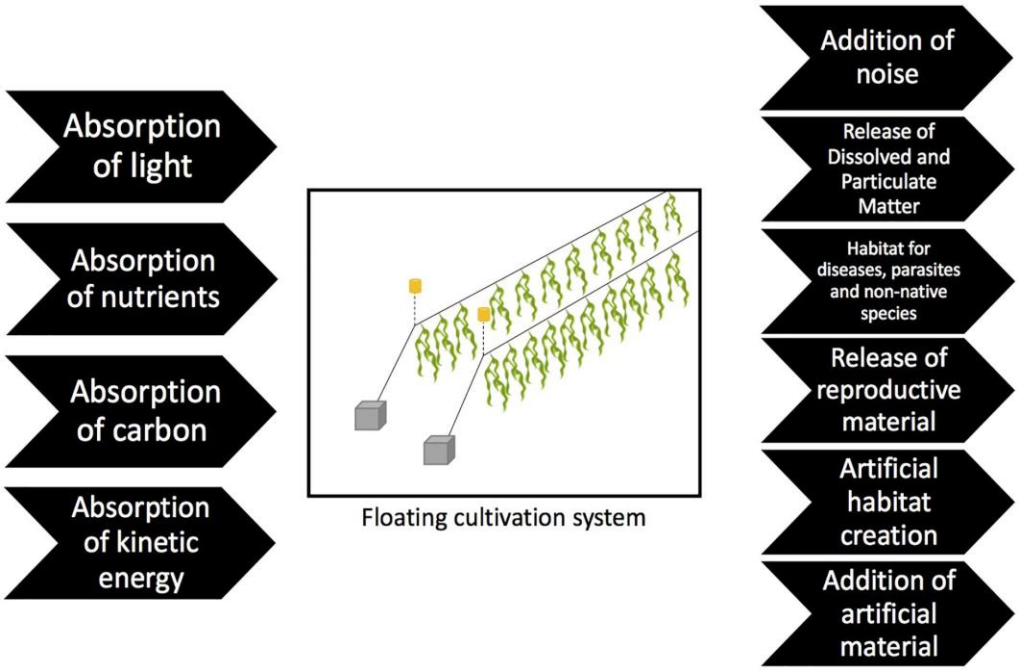


Fig. 22: Ecological issues associated with seaweed farming (Source: Campbell et al. 2019)

4.1. Light absorption

Seaweed cultivation sites differ from natural seaweed beds as seaweeds are cultivated in surface waters at depths that optimize levels of Photosynthetically Active Radiation. Thus, cultivation of seaweeds on surface waters shades the underlying habitats such as seagrasses and coral reefs that require sunlight. It is certain that shading caused by

seaweed cultivation kills the benthic macrophytes by blocking the light. Further, shading also affects pelagic communities such as phytoplankton (Campbell *et al.* 2019). Shading has also been reported to affect the carbon sequestration capacity of seagrasses (Dahl *et al.* 2016).

4.2. Absorption of Nutrients and carbon

Seaweeds use the nutrients available in the cultivation sites while growing (Marinho et al., 2015). When this nutrient intake by seaweeds causes the nutrient levels to go below the optimum levels, it will affect primary productivity (Campbell *et al.* 2019). Further, seaweed cultivation can also remove large amounts of carbon from the marine environment (Tang et al., 2011).

4.3. Habitat destruction by farming activities

As most of the seaweed cultivation activities happen on the Tamil Nadu coast along the Gulf of Mannar and Palk Bay, they may overlap and affect, directly or indirectly, important marine ecosystems such as coral reefs and seagrass beds. As seaweeds are farmed in open culture systems, the risk of fragmentation and spread of farmed seaweed fragments into surrounding habitats is always there (Eggertsen and Halling 2021). Dugongs generally inhabit shallow waters, remaining at depths of around 10 m, although they occasionally dive to depths of 39 m to feed. These shallow areas are typically located in protected bays, wide mangrove channels and in sheltered areas of inshore islands. Seagrass beds consisting of phanerogamous seagrasses, their primary source of nourishment, coincide with these optimal habitats.

4.3.1. Impact on seagrass beds

Only 3.6% of surface light reaches underneath the algal canopy while seagrass growth rates, shoot density and biomass are negatively affected by shading (Eklöf*et al.* 2006; Moreno *et al.* 2021; Moreira-Saporiti*et al.* 2021) (Fig.23). Impact on the structural complexity of seagrass habitat affects the structure of associated organisms also (Eklöf*et al.* 2006). Trampling associated with seaweed farming also affects seagrass beds and the associated biodiversity (Moreira-Saporiti*et al.* 2021). About 30% decline in primary production has been reported due to algae farming (Eklöf*et al.* 2006). Carbon and nitrogen sequestration capacity of seagrass habitats has been reported to be reduced under seaweed farming (Moreno *et al.* 2021). Mechanical abrasion by the algae also affects seagrass and associated organisms (Eklöf*et al.* 2006). The farmed seaweeds produce potentially toxic hydrogen peroxide when stressed by the presence of seagrasses (Eklöf*et al.* 2006) that will eventually affect the marine organisms.

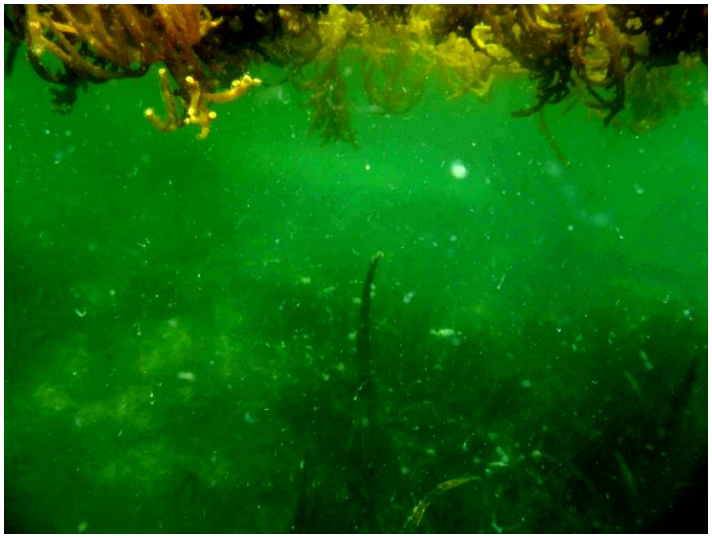


Fig. 23: Shading by seaweed farming on seagrass bed in Palk Bay

4.3.2. Impact on coral reefs

Seaweed farms occurring near coral regions affect both the biological and physical structure of coral reefs, leading to loss of diversity and decrease in abundance and biomass (HehreandMeeuwig 2015). If seaweed farms are set up above coral reef areas, the light penetration will be reduced/blocked and so the benthic corals dwelling on the sea bottom will receive poor light or no light at all. Corals are animals that depend on photosynthetic zooxanthellae for nutrition and hence shading caused by seaweed farming would affect the photosynthetic effort of zooxanthellae and would kill the corals eventually. One of the important impacts of seaweed farms on coral reefs has been reported to be the overgrowth of reef benthos by seaweed fragments that escape cultivation sites and reach the reefs through transport via currents. This overgrowth can smother corals and cause a decline in coral cover over time (Kelly *et al.* 2020). In case seaweed farms are above the reefs, in addition to blockage of light there is also the danger of fragments falling directly on the corals and smother them. The abandoned seaweed farming gear has been reported to entangle and damage coral reefs in areas where farming had ceased for long (Pollnac*et al.* 1997). Corals in the vicinity of seaweed farming are affected by trampling, shading, siltation, impairment of recruitment ability and mechanical damage (Sievanen*et al.* 2005). The abundance, diversity and biomass of the reef fishes have also been reported to be affected (HehreandMeeuwig 2015).

4.3.3. Non-native (exotic) species

Introducing non-native species for seaweed farming may contaminate the genetic integrity of local species and pose risks to biodiversity and biosecurity (Cai*et al.* 2021). Invasive seaweeds affect the equilibrium of the local marine ecosystems, their structure and function

by modifying, creating, maintaining or destroying habitats (Thomsen *et al.* 2016; Pinteus*et al.* 2018). The seaweed industry in Tamil Nadu depends on the invasive *K. alvarezii*. This exotic red alga has been termed "a destructive invasive species" and "a serious danger to coral reefs" by the Global Invasive Species Database (GISD) of the International Union for Conservation Network (IUCN) (http://www.iucngisd.org/gisd/species.php?sc=738). Cultivation of invasive seaweed has caused significant damage to critical ecosystems such as coral reefs and seagrass beds in many areas around the world including the Tamil Nadu coast.

4.3.4 Impact on coral reefs of the Gulf of Mannar

- Without a proper scientific understanding of its invasiveness and without assessing its environmental impact, the exotic red alga *K. alvarezii* was introduced in the Gulf of Mannar in the 1990s as an alternate livelihood option for fishermen by the CSMCRI, who entered into agreement with Pepsico India Holding Pvt Ltd. Being of invasive nature and capable of growing fast (doubling the biomass in 15 days), *K. alvarezii* can grow over live corals and destroy them.
- Invasion of *K. alvarezii* into the coral reef areas of the Gulf of Mannar was initially reported in 2005 (Pereira and Verlecar, 2005), and the Government of Tamil Nadu, with the objective to conserve the ecologically sensitive habitats like coral reefs and seagrass beds, issued an order to disallow the cul*tivation of K. alvarezii* near the Marine National Park and eco-sensitive zones of the Gulf of Mannar and Palk Bay [Copy of G.O. Ms. No.229, E & F (EC.3) Department dated 20.12.2005]. This order allows the cultivation of *K. alvarezii* only in the seawaters north of Palk Bay and south of the Tuticorin coast in the Gulf of Mannar, and thereby the order seeks to protect the rich coral reefs and seagrass beds of Gulf of Mannar and Palk Bay from the exotic invasive *K. alvarezii*.
- The issue of bioinvasion came to the limelight when a group of scientists from Thiagarajar College, Madurai found a severe invasion of *K. alvarezii* in Krusadai Island (Figs. 24 and 25) off the Gulf of Mannar during their study visit (Chandrasekaran et al., 2008).
- Since then significant coral mortalities due to the bioinvasion of *K. alvarezii* have been reported in the Gulf of Mannar by several studies till date (Kamalakannan et al., 2010, 2014; Edward and Bhatt 2012a,b; Edward *et al.* 2015; Joshi and Marimuthu, 2015; NCSCM Interim Report 2014; MoEF&CC Project Report, 2018; GOMBRT Project Report, 2021; Arasamuthu et al., 2023)

- In spite of the Government Order, cultivation is still happening illegally in south Palk Bay, which is closer to the coral reef areas in Gulf of Mannar Marine National Park in the Mandapam coast, and so fragments of *K. alvarezii* are continuously transported to the coral reefs areas.
- Though attempts have been made to nullify the impact of the invasion, there has only been increasing severity of the invasion as a handful of research and field visits by several administrators and experts have confirmed. A joint inspection (06.08.2021 & 07.08.2021)encompassing experts and officials from the GOMBRT, GOMMNP, FCRI, CSMCRI, SDMRI and MK University also confirmed the intensity of the invasion of *K. alvarezii* in the Gulf of Mannar (GOMBRT Joint Field Visit Report, 2021).
- Among the 21 islands, six islands namely Shingle, Krusadai, Poomarichan, Mulli, Valai and Thalaiyari have their coral reefs already invaded by *K. alvarezii* in a total reef area of over 2,341 sq m (Arasamuthu*et al.* 2023).
- The continuous effort to manually remove the alga by Tamil Nadu Forest Department from 2010 till date has kept the invasion somewhat under control.
- Continuous stretches of interlocking branching acroporan corals have been found to be the preferred substrates for *K. alvarezii*in the Gulf of Mannar (Arasamuthu*et al.* 2023) (Fig. 26). The south of the Gulf of Mannar Marine National Park has a better coral cover (Raj *et al.* 2021) with continuous stretches of branching acroporans. Hence, it is highly likely that fragments of *K. alvarezii*can establish in islands further south where continuous stretches of branching acroporans are available.
- The introduction and continuation of *K. alvarezii* cultivation in the Indian waters near eco-sensitive areas of coral reefs and seagrass beds in the name of providing alternate livelihood to fishermen would significantly affect the sustainable socio-economic benefits offered by coral reefs and seagrass beds through fishery resources and coastal protection of the Gulf of Mannar and Palk Bay to thousands of fishermen and coastal areas.
- There are 4,223 reported species of flora and fauna in the Gulf of Mannar due to the availability of coral reefs and this rich biodiversity will vanish or be disturbed if corals are affected by bioinvasion.
- There are more than 100,000 low-income fishermen solely depending on the associated fishery resources of the coral reef ecosystem for their daily livelihood and the loss of coral reefs would affect their economic status directly.

Fig. 24: Invasion of K. alvarezii in the reef areas of Krusadai Island

Fig. 25: Live coral colony covered by K. alvarezii (mat formation) in Krusadai Island

Fig. 26: Invasion of K. alvarezii in the reef areas of Valai Island

4.3.4.1 Impact on environment

Corals are considered as the ultimate keystone and foundation species because they provide the underlying structure for reef communities, supplying with nutrients, shelter and the right habitat for many species. They also provide nursery habitat for many commercially and ecologically important species of fishes and invertebrates. Therefore,

- The impact on corals leads to loss of habitat and associated biodiversity, which in turn alters the ecological balance.
- Loss of habitat leads to migration and depletion of native fish populations and results in decreased fish production.
- Loss of corals means loss of genetic diversity. So far 4,223 faunal and floral species have been reported from Gulf of Mannar including 117 coral species, 1,041 mollusc species and 1,147 fish species.

4.3.4.2 Impact on Society

- The loss of corals leads to depletion of fish production, on which more than 100,000 low-income fishermen depend for their daily livelihood. Coral habitat loss develops a long-term irrevocable livelihood crisis for the fisher folk, who fully depend on the reef associated fisheries.
- Corals act as natural barriers in coastal protection. Loss of corals will lead to coastal erosion, which will affect the fishing activity and fisher folk habitation. In the absence of natural barriers like coral reefs, the coastal villages will face the brunt of cyclones, tsunamis etc.
- Gulf of Mannar has twenty-one reef islands. The major coral reefs and coral-associated ecosystems with rich biodiversity have developed around these islands. The loss of corals due to coral mining in the 1960s caused the submergence of two islands through heavy erosion. Therefore, corals are the natural barriers for these islands and any loss of these barriers would lead to the submergence of these islands due to heavy erosion, which would affect the coast and the society.

4.3.4.3 Impacts on economy

- Though seaweed cultivation is a good income-generative option, the advantages are short term benefiting not even 5% of the low-income fishing community living along the coastline.
- Furthermore, the cultivation of invasive *K. alvarezii* in the vicinity of coral reefs would directly affect the ecological balance and impact the livelihood of thousands of dependent low-income fisher-folks.

Loss of fishery:

The low-income fisher folk who depend for livelihood on coral-associated fishery resources will be affected. This will have an impact on their social status due to loss of income.

Loss of Island ecosystem:

The loss of island ecosystem and associated biodiversity will alter the islands' environmental conditions, which would entail heavy cost for restoration in the long run.

Coastal erosion:

There will be huge cost involved in the mitigation and management of eroded coasts.

Loss of genetic diversity:

The coral reef ecosystem is complex and the flora and fauna are part and parcel of the ecosystem. The loss of corals (keystone / foundation species) causes loss of genetic diversity, which will have greater impact on the economy.

5. Existing Legal Provision

In India, seaweed cultivation is managed by the Department of Fisheries under the Ministry of Fisheries, Animal Husbandry & Dairying. In Tamil Nadu state, the Department of Fisheries and Fishermen Welfare is managing seaweed cultivation. There is no separate body to manage seaweed industry including cultivation as it is seen as a marine resource similar to fishes.

The Coastal Aquaculture Authority Act, 2005 (24 of 2005) enacted by the Parliament of India on 23 June 2005 provides for the establishment of the Coastal Aquaculture Authority for regulating the activities connected with coastal aquaculture in coastal areas and matters connected therewith or incidental thereto. The Act mandates the Central Government to take all such measures as it deems necessary or expedient for regulation of coastal aquaculture by prescribing guidelines, to ensure that coastal aquaculture does not cause any detriment to the coastal environment and the concept of responsible coastal aquaculture contained in the guidelines shall be followed in regulating coastal aquaculture activities to protect the livelihood of various sections of people living in the coastal areas.

5.1. The Coastal Aquaculture Authority (Amendment) Bill, 2023

The Coastal Aquaculture Authority (Amendment) Bill, 2023 was introduced in Lok Sabha on April 5, 2023. It amends the Coastal Aquaculture Authority Act, 2005. According to this 2023 Bill, seaweed culture, pen culture, raft culture and cage culture activities will be allowed in Coastal Regulation Zones.

The 2023 Bill widens the definition of "coastal aquaculture" or "coastal aquaculture activity" to mean "rearing and cultivation of any life stages of fish, including crustacean, mollusc, finfish, seaweed or any other aquatic life under controlled conditions, either indoor or outdoor, in cement cisterns, ponds, pens, cages, rafts, enclosures or otherwise in saline or brackish water in coastal areas, including activities such as production of brood stock, seed, grow out, but does not include freshwater aquaculture."

Moreover, the Bill aims to promote environment-friendly coastal aquaculture such as "cage culture, seaweed culture, bi-valve culture, marine ornamental fish culture, and pearl oyster culture" that has the potential for creating employment opportunities on a large scale for coastal fisher communities and especially fisherwomen.

5.2. The Gulf of Mannar Marine National Park

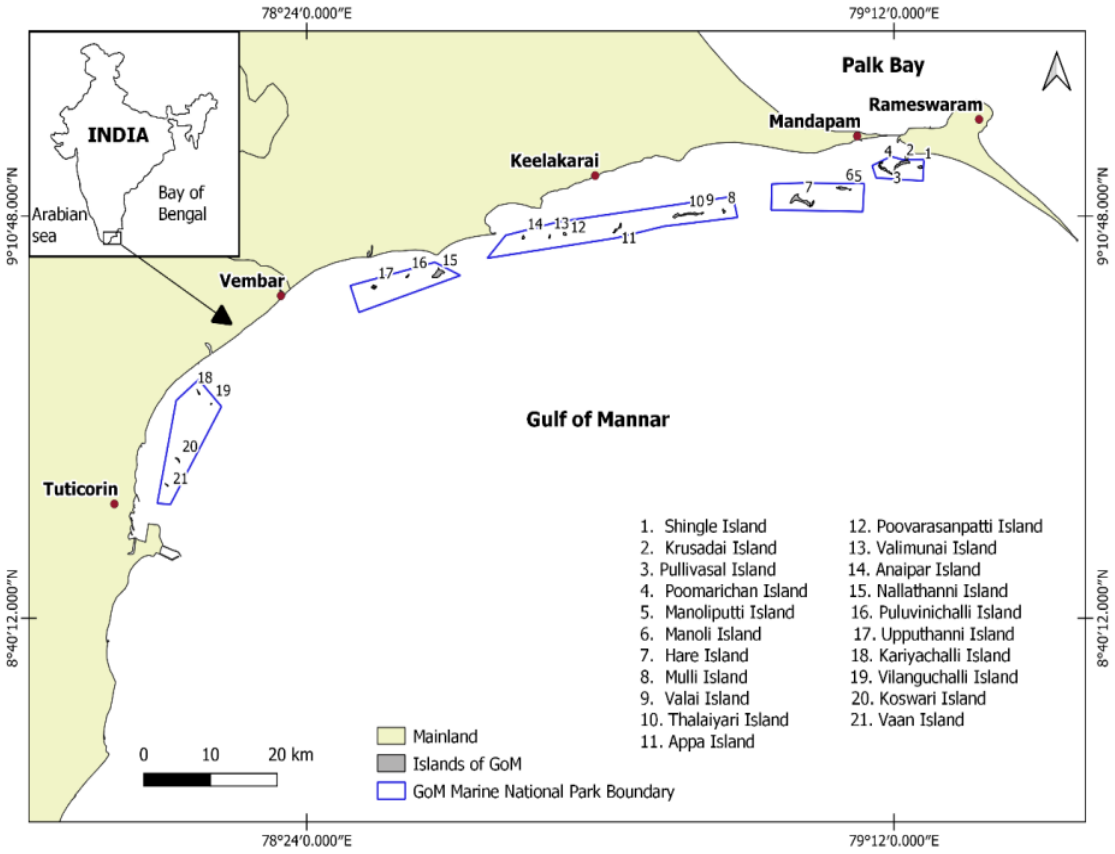


Fig. 27: Map showing the islands of the Gulf of Mannar

The 21 islands of the Gulf of Mannar between Rameswaram and Tuticorin covering 160 km coastline have been put into three groups namely the Mandapam group, the Keelakarai group and the Thoothukudi group. Each group comprises seven islands and these islands lie parallel to the mainland. In order to protect marine wildlife and their environment, the Government of Tamil Nadu in 1986 declared the 21 islands and the surrounding shallow coastal waters as the Gulf of Mannar Marine National Park (GOMMNP) (Fig. 27). The Gulf of Mannar Biosphere Reserve between Rameswaram and Kanyakumari covering 365 km coastal line has anarea of10,600 sq.km. The Marine National Park is located within the Marine Biosphere and is the Core Zone of the Biosphere reserve with about 560 sq. km area and the remaining 9,960 sq. km area is the Buffer Zone of the Biosphere Reserve. The GOMMNP is a 'no go' and 'no take zone' where seaweed cultivation, collection of seeds and any other related human activity is not allowed.

There is also a 720.89 sq. km area of eco-sensitive zone around the GOMMNP that varies from 0.73to 5.57 km around the Park (Fig. 28) (MoEF&CC Notification dated 01.01.2020). .

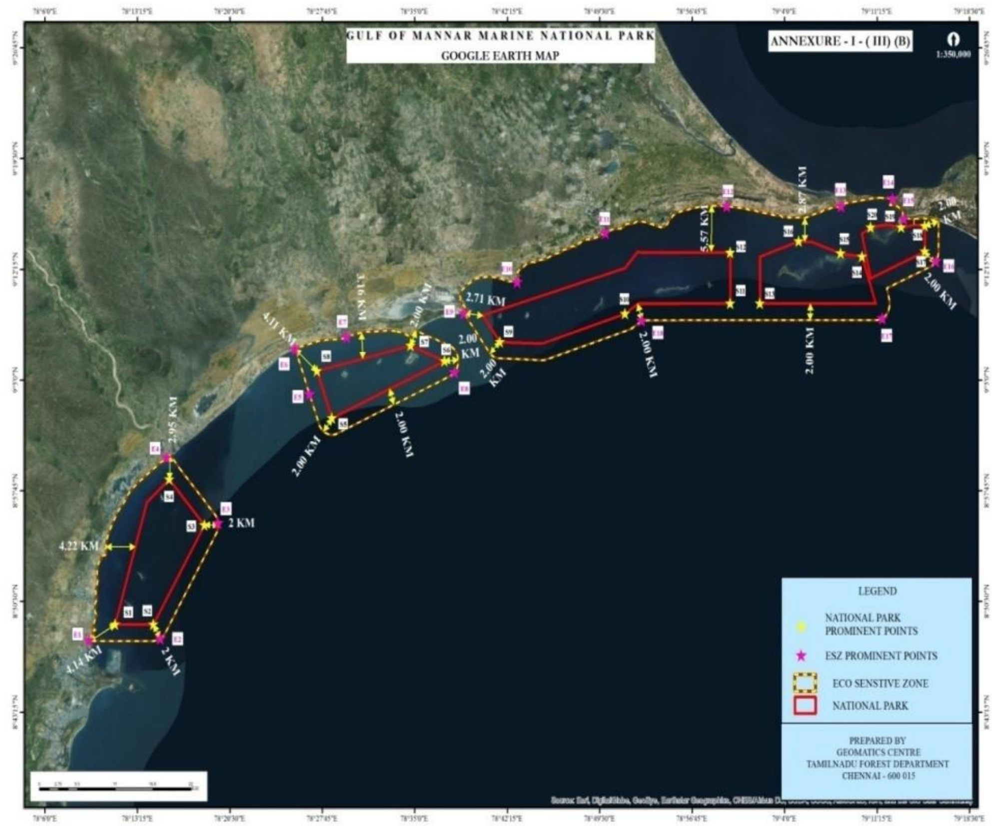


Fig. 28: Map showing the eco-sensitive zone of the Gulf of Mannar Marine National Park (Source: MoEF&CC Notification dated 01.01.2020)

The coral reef areas in the Gulf of Mannar come under Gulf of Mannar Marine National Park, which is a protected area under Wildlife Protection Act, 1972. The Marine National Park also has Eco Sensitive Zones. *Wildlife* (Protection) *Act* 1972 provides legal protection to the prescribed areas and certain species including marine species. All coral species are protected under this act. India's *Coastal Regulation Zone Notification* 1991 regulates onshore development activities which affect coastal environments. Coral reef conservation is also included in the *Environmental Protection Act* (1986), *the National Conservation Strategy and Policy Statement on Environmental Development* (1992) and the Action Plan of the Ministry of Environment and Forests. Corals and coral reefs and associated biodiversity categorized as CRZ-I A (Ecologically Sensitive Areas) receive the highest degree of protection under the CRZ notification of 2011.

The Government of India has laws to protect coral reefs and other coastal environments and prohibits the collection of corals. All the scleractinian corals and gorgonids have been included in Schedule I of *Wildlife (Protection) Act* 1972 from July 2001. Collection of several species associated with coral reefs such as sponges, molluscs, sharks and skates is banned and such collection is punishable offence under the Wildlife Act 1972.

5.3. Tamil Nadu Government Order on the cultivation of exotic species *Kappaphycusalvarezii*

In order to protect the ecologically sensitive and productive habitats like coral reefs and seagrass beds of the Gulf of Mannar and Palk Bay, the Tamil Nadu Government passed an Order in 2005 to restrict the cultivation of exotic *K. alvarezii* near eco-sensitive zones. The Government of Tamil Nadu Order issued in December 2005 [G.O. Ms. No.229, E & F (EC.3) Department dated 20.12.2005] clearly states that *K. alvarezii* can be cultivated only in the seawaters North of Palk Bay and South of Tuticorin Coast by members of Self Help Groups, i.e. in regions beyond Nagapattinam in Palk Bay in the north (Ramanathapuram district) and beyond Periyathazhai in the south (Tuticorin district).

In spite of this order, cultivation of exotic *K. alvarezii* is happening in the south Palk Bay causing stress to the seagrass beds and becoming a source for the invasion in the coral reef areas in Gulf of Mannar. However, this order does not restrict the cultivation of native seaweed species.

5.4. Dugong Conservation Reserve

On 21.09.2021, Government of Tamil Nadu announced the creation of "Dugong Conservation Reserve" (G.O. Ms. No.165, Environment, Climate Change and Forests (FR.5), 21st September 2022)covering a total coastal area of 448.34 sq km slong Palk Bay from Adirampattinam to Ammapattinam in the Coastal waters of Thanjavur and Pudukkottai Districts to protect and conserve dugongs and their habitats (seagrasses). As mentioned above, unprecedented, unscientific and unsustainable seaweed farming would affect the seagrass beds of this conservation reserve.

6. Livelihood opportunities in Seaweed (Role of Eco development and GOMBRT)

6.1. Alternate livelihood option

Alternative livelihood option is considered as a very good solution to the issues of overfishing and destructive fishing. Mariculture is probably the best alternative livelihood option for the small-scale fishermen communities along the Tamil Nadu coast. Mariculture boosts the standard of living of coastal communities and more importantly it reduces the fishing pressure. Seaweed farming has been widely suggested and used around the world as both a means to improve economic conditions and a system to reduce fishing pressure. Due to the technology, low capital investment and relatively high return, seaweed offers a good alternative livelihood option (Crawford 2002). Thousands of fishermen along the coast of Tamil Nadu will get benefited if seaweed industry is rationalized and modernized to ensure economic and ecological sustainability.

6.2. Seaweed farming and women empowerment

More than 50% of the people are women among the seaweed farming coastal communities in Tamil Nadu (Krishnan and Kumar 2010). The income from seaweed cultivation has been reported to help women's economic empowerment and improved family food security (Sultana *et al.* 2022). The income generated by women's participation and entrepreneurship in seaweed cultivation helps them to upgrade their standards of living by providing funds for their children's education, medical care, public housing and clothing improvements (Msuya and Hurtado 2017).

6.3. The role of Eco development and GOMBRT

For the effective conservation and management of resources in Gulf of Mannar, community participation has been encouraged since the establishment of Marine National Park in 1986. All stakeholders including research institutions and Non-Governmental organizations have participated in the implementation of various projects funded by Union and State Governments and International agencies. The launching in 2002 of the collaborative initiative of the Government of India, the Government of Tamil Nadu and the Global Environment Facility (GEF)-United Nations Development Programme (UNDP) on *"Conservation and Sustainable Utilization of Gulf of Mannar Biosphere Reserve's Coastal Biodiversity"* brought the community together to take part in the conservation and management along with the authorities of Marine National Park (Melkani 2012). A special agency, the Gulf of Mannar Biosphere Reserve Trust (GoMBRT),

a registered Trust of the Government of Tamil Nadu under the Chairmanship of Chief Secretary to Government of Tamil Nadu was formed to ensure effective inter-sectoral coordination and main-streaming of biodiversity conservation issues into the productive sector and policy development. Grass-root level community organizations like Village Marine Conservation and Eco-Development Committees (VMC and EDCs) with a mandate for linking conservation with livelihood improvements have been established in 252 villages/hamlets along the coastal stretch from Rameswaram (Ramanathapuram District) to Periathalai (Tuticorin District). About 2,400 Self Help Groups (SHGs), mainly with women members, are functioning in the area in association with VMC & EDCs. The SHG's have been trained and supported with funds of varying amounts to start various alternate and income generating livelihood activities and the repayment of credits has been prompt. As many as 52 types of activities are being pursued by various groups (Melkani, 2012). The VMCs and EDCs continue to actively take part in the conservation and management activities with the support from Government of Tamil Nadu till date.

One of the main components of the Gulf of Mannar Biosphere Reserve Trust (GOMBRT) is to involve communities as active partners in conservation in the region through sustainable resource management and alternative livelihood initiatives. Mechanisms to do this include the development and strengthening of local institutions, capacity building of local communities in integrated marine resources management and provision of alternative livelihoods, the institution of co-management regimes for marine resources and improved access to credit and markets through micro-credit arrangements and local infrastructure (Bhalla*et al.* 2011).

GOMBRT has made significant achievements in its effort to involve primary stakeholders, the fisher folk. Two approaches have been used for this.Micro-credit groups were established to facilitate investments into alternative livelihoods through access to credit and capacity building and placement of trained youth in alternative livelihoods were provided. The micro-credit interventions have resulted in a high overall rate of loan recovery leading to a large capital being revolved among the EDCs. The loans have been largely used for productive purposes, and this indicates that the strategy has worked. On the other hand, the financial and jurisdictional limitations of the Trust have created an artificial cap on the quantum of loans available and limited the range of marketing linkages that can be explored (Bhalla*et al.* 2011).

Thus, the already established system to work with the coastal communities, GOMBRT will be key player in promoting and managing seaweed cultivation initiatives along the coast of the Gulf of Mannar. The beneficiaries of GOMBRT will be much interested in engaging in seaweed cultivation activities through GOMBRT.

7. Seaweed Promotion in TN

The habitat loss, decline in fishery resources, climate change implications, increased coastal population, and unemployment predominantly felt among the coastal communities offers an opportunity to the seaweed industry in Tamil Nadu for promoting seaweed cultivation. The coastal people of Tamil Nadu have a good knowledge of seaweed cultivation because they have received training and participated in several awareness camps on seaweed cultivation during the past several years. Industries need support for the promotion of seaweed cultivation in Tamil Nadu. The following suggestions would help for seaweed promotion.

7.1. Promotion of technology

There is lack of field-tested and commercially viable technology for cultivation of multiple native seaweed species. It is the responsibility of research institutions to develop commercially viable cultivation technologies and transfer to fisher folk in order to make the wide-scale promotion of the seaweed industry in Tamil Nadu. For reasons unknown, all attention and efforts are only towards the exotic red algae*K.alvarezii*. The focus has to be shifted to multiple native species, and the fishermen are to choose which is best for them in terms of labour and return.

7.2. Promotion through funding support and subsidies

Investment is needed to initiate any business. The coastal people do not have adequate resources. To promote the seaweed industry and to show it a lucrative one, the industries and the Government should provide the seaweed farmers with initial funding and subsidies for infrastructure development and subsidies to continue the business.

7.3. Promotion through awareness creation

Awareness creation among the fishermen about the global and local demand for seaweed products and the potential of seaweed farming to provide them with surplus returns should be carried out in all the coastal villages of Tamil Nadu. It will make the fishermen think about this sustainable income-generating industry.

7.4. Promotion through value-added seaweed products

Value-added fish products such as fish pickles and prawn pickles are familiar among the common public. Such initiatives should be made in the seaweed industry to make it more lucrative. Cultivating, harvesting, and processing of seaweeds and selling them as value-added products itself will act as an advertisement and encourage the fisher folk to take up seaweed cultivation resulting in significant advancement of the seaweed industry.

8. Recommendations

Tamil Nadu has a long coastline of 1,076 km (which is 15% of the country's seacoast) along the Bay of Bengal, Indian Ocean, and Arabian Sea. It encompasses 14 coastal districts with a fishermen population of about 1.05 million. The availability of plenty of seaweed resources, the long coast, dense coastal communities, and the increasing demand for seaweed products give an opportunity to promote wide-scale seaweed cultivation along the coast of Tamil Nadu. The coastal people in particular the fisher folk of Tamil Nadu are well aware about seaweed cultivation. It is known that that fishery resources have declined over the years along the Tamil Nadu coast and people are actually looking for alternative livelihood options. Global demand for seaweed products is heavy and the economic need of the coastal people is also great making the scenario apt for seaweed promotion. The recent announcement for the establishment of a seaweed park by the Tamil Nadu Government will enable the modernization of the seaweed industry. However, there must be a holistic approach to promote seaweed industry considering the economic benefit to coastal community & industry, sustainability, environment, and the protection of indigenous biodiversity for the long-term food security and livelihood.

The following recommendations will help the industry to take off to meet the local and global demands judiciously in a sustainable manner:

8.1. Survey and assessment

Tamil Nadu and Gujarat are the seaweed hotspots of the country. Tamil Nadu coast is endowed with significant seaweed resources due to the availability of various marine habitats such as coral reefs, seagrass beds, rocky areas, sandy areas, etc. Most of the research works on seaweeds are on diversity and the secondary metabolites that seaweeds produce. The lack of proper underwater studies on the abundance, biomass, deep-water seaweed beds, etc needs to be addressed. Research on seaweeds during the past several decades has not involved scuba diving and there has been no exploration in deep waters. Research on intertidal seaweeds and shore-stranded samples alone will not provide critical details on the state's seaweed resources and standing stock. Hence, the following measures have to be taken:

- Survey & assessment: A detailed underwater survey and assessment should be carried out to assess the diversity, abundance, biomass, and seasonal changes of seaweed resources on the Tamil Nadu coast. The study should be done by researchers having professional dive capacity and following standard underwater protocols along the entire Tamil Nadu coast covering the 14 coastal districts including deep waters to map the critical seaweed beds of the state.

- Demarcation, zonation and mapping of seaweed areas for wild and seed collection: Based on the underwater study and assessment, the demarcation of seaweed areas should be made to help the fishermen who do wild seaweed collection. So far, the seaweed collectors often use the areas within the boundary of the Gulf of Mannar Marine National Park (GOMMNP), which is not permissible as per the existing rules.
- Based on the study that is proposed to be undertaken, zonation should be made preferably using the geospatial technologies and mapped with GPS coordinates according to the availability of seaweed resources along the Tamil Nadu coast. The areas with commercially important seaweed species should be marked to aid in seed collection.

8.2. Development of technologies

Even after several decades of research, the absence of commercially viable technologies to cultivate native seaweed species is one of the most important and pressing issues along the Tamil Nadu coast. It is the responsibility of research institutions that work on seaweeds to develop experimentally successful techniques into commercially viable methods. The establishment of the seaweed park in Tamil Nadu requires research institutions to commercialize techniques of native species for seaweed culture. Tamil Nadu coast has a total of 181 reported seaweed species. Noteworthy among them in commercial terms are like *Gracilaria, Gelidiella, Hypnea, Sarconema, Sargassum*, and *Turbinaria*. Due to wild collection and overexploitation in the intertidal areas, many of the above resources are getting depleted. In order to overcome the issues of overexploitation the following steps can be carried out.

- Identification of all commercially important seaweed species available on the Tamil Nadu coast is the first step. It can be made possible by knowing this from the existing literature and by assessing the chemical composition of commonly available seaweed species of the state.
- The global and local demand for agar, align and carrageenan is heavy, but the importance has so far been given only to the exotic carrageenophyte *K. alvarezii*. Commercially viable technologies to cultivate native agarophytes and alginophytes should be developed.
- Many research papers have been published on the experimental success of many native species apart from the exotic *K. alvarezii* (Ganesan *et al.* 2019a). However, there has been very less effort in converting these technologies into commercially viable ones. In light of many experimentally successful technologies, immediate steps must be taken to transfer these technologies to seaweed farmers with adequate training, demonstrations, technical support and follow ups.

- Shallow-water cultivation methods which are currently in practice has to be supplemented with offshore cultivation technologies to avoid conflict between fishermen who depend solely on fishing and to avoid environmental concerns pertaining to ecologically sensitive near-shore habitats like coral reefs and seagrass beds.
- Surface cultivation techniques such as rafts, monolines, and tube nets often affect the movement of fishing boats. The development of bottom culture would be highly beneficial to the fishermen as evident in many other countries.
- Seaweed cultivation in Tamil Nadu has been happening only in the sea but the development of land-based cultivation methods will be suitable for cultivating a wide range of seaweed genera. Land-based cultivation allows the farmers to better monitor and regulate cultivation proceedings. Land-based cultivation methods can become very successful as land-based shrimp farms are highly successful and income-generating along the Tamil Nadu coast. According to MPEDA, the area under culture for shrimp farms (including tiger shrimp, Pacific white shrimp and scampi) in India has increased from 116784 ha during 2009-10 to 166722.5 ha during 2020-21. In Tamil Nadu including Pondicherry, it has increased from 2265 ha during 2009-10 to 8630 during 2020-21.

8.3. Infrastructure for seaweed farming

Majority of the coastal people along the coast of Tamil Nadu are low-income fisher folk who cannot afford much on infrastructure and other facilities. This will keep them away from seaweed cultivation as they are comfortable doing their fishing activities. Hence, seaweed farming should be promoted as a lucrative business that will earn them sufficiently and sustainably to provide them with job satisfaction. The following infrastructure facilities to the seaweed farmers would help them initiate and sustain this as their primary or secondary occupation.

- Schemes should be developed to provide raw materials such as bamboo, ropes, tube nets, anchors, etc. for the cultivation setup for the fishermen to initiate the activity. Contract farming initiatives can be implemented by the industries wherein the industries should provide the fisher folk with raw materials and assist them when replacing worn-out materials and technology, and in marketing the products. It will attract the fisher folk to seaweed farming as they will do it without investing much.
- Schemes to provide financial subsidies to the fisher folk for establishing and maintaining the cultivation setup will aid the fisher folk to take up and sustain the seaweed cultivation. It will also encourage the non-cultivators to opt for seaweed cultivation.

- Self Help Groups, which have proved successful in various fields, need to be connected with the seaweed industry. Similarly, Eco Development Committee (EDC) members of the Gulf of Mannar Biosphere Reserve Trust (GOMBRT) should also be linked with the seaweed industry for better effectiveness as Ramanathapuram is one of the major areas for seaweeds.
- Seed banks have not been developed for commercially important native seaweed species in Tamil Nadu. Hence, seedling facilities/nurseries/brood banks have to be established. The continuous supply of seaweed seeds to seaweed farmers is very important to keep the seaweed farmers in the business. Preference should be given to the native seaweed species that has commercial value.

8.4. Facilities and subsidies for seaweed farmers

The lack of facilities at the cultivation sites is a major obstacle faced the fisher folk in pursuing seaweed cultivation activities on the Tamil Nadu coast. Coastal areas in Tamil Nadu have extreme weather conditions such as hot weather and humidity. Seaweed farming should be treated as an agricultural activity and should be provided with facilities similar to agriculture.

- As the seaweed cultivation sites are along the coast, basic infrastructure facilities such as drinking water, shade for the seaweed farmers, roads for transportation, sanitary facilities, etc. should be developed.
- Facilities to dry the harvested seaweeds should be provided to avoid unhygienic drying on the sand.
- Storage facilities should be developed for the harvested seaweeds that would help them to store for longer before selling. The seaweed farmers can use schemes like Agro Processing Cluster where groups of producers/ farmers are linked to the processors and markets through well-equipped supply chain with modern infrastructure.
- Cultivation sites are on the shore where there are no road connections for transport and it should be addressed for better transportation of harvested seaweeds.
- The loss of raw materials during extreme weather conditions costs the fishermen much and an insurance system similar to agriculture activities should be established to make the fishermen feel secure about their business.

8.5. Capacity building and awareness creation

Coastal communities along the Tamil Nadu coast have been traditionally fishers and they have little knowledge of advanced cultivation technologies. Capacity building of coastal people on cultivation technologies, harvesting methods, processing techniques, and marketing practices is very important for efficient execution. Moreover, most of the fishermen are not scuba divers and do not have much knowledge of underwater seaweed resources, which needs to be addressed.

- Instead of providing training on the old methods involving raft, monoline, and tube net, the fishermen should be educated on innovative methods to cultivate multiple seaweed species. Hands-on training should be given to them both in the classroom and in the field on land-based techniques, offshore cultivation methods, and bottom culture.
- Based on the baseline studies on seaweed resources of Tamil Nadu, the fishermen should be provided with information on seaweed beds such as GPS locations of seaweed areas, zonation of seaweed resources, and boundaries where they can/cannot collect seaweeds.
- As traditional seaweed collectors are skin divers, they predominantly target the shallow reef areas of the Gulf of Mannar. These seaweed collectors should be trained in scuba diving to allow them to collect seaweeds in deeper waters outside the boundary of the GOMMNP.
- Seaweed collectors should also be trained in eco-friendly collection methods and should also be made aware of the importance of conserving critical marine habitats such as coral reefs and seagrasses.
- The fishermen should be made aware of the global and local demand for seaweed products and the possibility of making good money out of it.
- Value-added marine products such as fish and prawn pickles have become familiar among the general public. Similarly, seaweed farmers should be trained in producing value-added seaweed products with edible seaweed species.

8.6. Marketing

One of the important issues in the seaweed industry of Tamil Nadu is the poor marketing facilities available for the fisher folk. The seaweed farmers depend on very few buyers and in most cases there is monopoly and the traders fix prices for the harvested seaweeds. The market monopoly forces the fisher folk to exit seaweed cultivation. In spite of the high

demand for seaweeds, fisher folk do not earn much from seaweed cultivation due to monopoly which needs to be addressed to expand the industry like the shrimp industry.

- The marketing system for harvested seaweeds should be regulated. Monopoly and middlemen in marketing should be removed. The Government should fix the prices to help the fisher folk to earn more out of their labor. The global demand for agar, alginate, and carrageenan should be considered when the seaweed farmers sell the harvested seaweeds.
- Apart from the existing seaweed processing industries, more industries should be developed close to the cultivation sites to reduce transportation costs and to give fishermen the confidence to continue their business. Government should help those industries with subsidies and facilities.

8.7. Nodal agency

In Tamil Nadu state, the Department of Fisheries and Fishermen Welfare is managing the subject of seaweed cultivation and there is no single Nodal Agency exclusively to manage seaweed cultivation, as it is seen as a marine natural product similar to fishing and shrimp industry.

- Hence, Tamil Nadu Government may consider the establishment of an exclusive Nodal Agency for seaweed industry under the Department of Fisheries and Fishermen Welfare with administrators and researchers to monitorand regulate seaweed farming in the state. This would boost and sustain the industry significantly.
- Tamil Nadu Forest Department is the department in charge of the conservation and management of protected areas in the coastal region of Tamil Nadu. It is therefore recommended that the Tamil Nadu Forest Department be made to be part of the Nodal Agency so that sustainable seaweed farming activities along the coasts of Tamil Nadu can be implemented. The role of the Forest Department shall be crucial in the selection of sites and for effective monitoring and enforcement in order to protect the ecosystems and associated marine life for the benefit of environment and sustainable livelihood to the thousands of coastal people.
- The nodal agency including the Department of Fisheries and Fishermen Welfare and Tamil Nadu Forest Department may be given the task of developing necessary action plan and guidelines for the promotion and sustainability of seaweed industry.
- Research institutions such as Central Salt and Marine Chemical Research Institute (CSMCRI), Central Marine Fisheries Research Institute (CMFRI), Tamil Nadu JJ Fisheries University, SuganthiDevadason Marine Research Institute (SDMRI), National

Centre for Sustainable Coastal Management (NCSCM), Central Institute of Brackish Water Aquaculture and other relevant universities / Institutions shall be involved in research, survey and monitoring along with Department of Fisheries and Fishermen Welfare and Tamil Nadu Forest Department

8.8. Seaweed cultivation in the eco-sensitive areas

Coral reefs and seagrass beds are fragile marine habitats that support rich biodiversity and provide sustainable livelihood to the coastal communities. The Gulf of Mannar and Palk Bay are provided with such important habitats offering sustainable livelihood to thousands of coastal people. Hence, seaweed farming activities in these ecologically sensitive areas should be carefully carried out not to affect coral reefs and seagrasses. It is therefore recommended that

- No activity should be permitted including native seaweed collection within the Gulf of Mannar Marine National Park. The eco-sensitive zones of Marine National Park can be allowed for small-scale native seaweed cultivation by the eco-development committee members of GOMBRT comprising of Self-Help Group members with prior permission from Wildlife Warden, GOMMNP, Ramanathapuram.
- The Wildlife Warden, Ramanathapuram should grant permission for native seaweed cultivation for the above-said stakeholders only in the selected locations in eco-sensitive zones of the Gulf of Mannar Marine National Park. At present seaweeds are cultivated mostly using rafts, which shade the healthy coral patches and seagrass beds and affect the photosynthesis capacity of corals and seagrasses causing degradation. Hence, the selection of locations in eco-sensitive zones is important and should be done with the help of relevant experts in order to avoid areas with coral patch and dense seagrass bed.
- In Palk Bay, native seaweed cultivation should not be permitted in the "Dugong Conservation Reserve". In other areas, respective District Forest Officers shall grant permission for native seaweed cultivation to individuals, groups, or industries. Here too, seaweeds are cultivated at present mostly using rafts, which shade the healthy coral patches and seagrass beds and affect the photosynthesis capacity of corals and seagrasses causing degradation. Hence, the selection of locations in Palk Bay is to be done with help of relevant experts in order to avoid any coral patch and dense seagrass bed areas.
- A standard protocol for giving permission should be developed and followed. Also the permission granting authority can be arbitrary.

- Environment Impact Assessment should be done for the polluting industries. The Coastal Zone Regulation notified by Ministry of Environment, Forest and Climate Change prohibits setting up and expansion of units or mechanism for disposal of waste in high tideline to 500 metres on the landward side along the seafront.

8.9. Restriction and management of the cultivation of exotic *K. alvarezii*

It was reported that fragments of cultivated seaweeds sometimes successfully colonized seagrass beds adjacent to seaweed farms in Venezuela (Barrios et al. 2007) and Panama (Sellers et al. 2015). In Venezuela, *K. alvarezii* thalli grew in arborescent forms in seagrass beds dominated by the seagrass *Thalassia testudinum* (Barrios et al. 2007). In Panama, *K. alvarezii* was observed growing in mats up to 72 m^2 , which covered shallow seagrass beds and Porites spp. reef patches (Sellers et al. 2015). Seaweed farming has reduced the abundance of macroalgae within seagrass beds (Ekl¨of et al. 2005) and epiphyte cover on seagrass leaves (Ekl¨of et al. 2006), which may increase seagrass production but may also alter other ecosystem dynamics.

The most documented impact of seaweed farms on coral reefs was overgrowth of reef benthos by seaweed fragments that either escaped cultivation via neglect or physical damage during storms or were transported via currents. This overgrowth can smother corals and cause a decline in coral cover over time. An early and well-documented example of this phenomenon occurred in Kaneohe Bay, Oahu, Hawaii, where carrageenophytes were grown experimentally in the 1970s. Following experiments, seaweeds were left in situ, and by the 1990s vegetative fragments had spread up to 6 km from experimental site (spread rate of 250 m/year) (Rodgers & Cox 1999). Algae cover exceeded 50% on some reefs, and biomass on invaded reefs was esti-mated at 10 kg/m^2 ; seaweeds overgrew and smother reef-building corals (Conklin & Smith 2005).

It has been proved by several studies and reported in many research publications and further field-witnessed by many researchers, organizations, and administrators that *K. alvarezii* has caused a significant impact on the coral reef ecosystems of the Gulf of Mannar. The exotic red algae, *K. alvarezii* is a "destructive invasive species" and "a serious danger to coral reefs" termed by the Global Invasive Species Database (GISD) of the International Union for Conservation Network (IUCN) (http://www.iucngisd.org/gisd/species.php?sc=738). The introduction of this exotic species by CSMCRI in 1990s as an alternate livelihood option caused significant coral mortalities due to bio-invasion. The coral reefs around six of the 21 islands in the Gulf of Mannar, namely Shingle, Krusadai, Poomarichan, Mulli, Valai, and Thalaiyari have been invaded by *K.*

alvarezii in a total reef area of over 2,341 sq m and it is posing a persistent threat. When expanding the seaweed industry in Tamil Nadu, the invasive capacity of the alga should be taken into serious consideration. Jeopardizing the livelihood of the people by promoting *K. alvarezii* near the reef areas can be avoided. Hence, the following recommendations are made to address the issue,

- It is recommended that under any of the seaweed industry promotion programmes including the seaweed park project on seaweed farming in Tamil Nadu, the following TN GO should be strictly enforced: Government of Tamil Nadu Order issued in December 2005 [G.O. Ms. No.229, E & F (EC.3) Department dated 20.12.2005] that *K. alvarezii* can be cultivated only in the seawaters North of Palk Bay and South of Tuticorin Coast by members of Self Help Groups. Fisheries department, forest department and local district administration should be strengthened to monitor, regulate and to enforce this.
- The cultivation (onshore and offshore) of exotic seaweed, *K. alvarezii* in other coastal areas of Tamil Nadu (areas not specified in TN GO Ms. No.229, E & F (EC.3) Department dated 20.12.2005) shall be strictly monitored and regulated to restrict transportation of fragments into eco sensitive areas.
- It is also recommended that continuous monitoring of the already affected coral reef sites in the six islands (namely Shingle, Krusadai, Poomarichan, Mulli, Valai, and Thalaiyari) and other reef areas in the Gulf of Mannar should be made mandatory to identify fresh invasions early to take steps immediately. A rapid response team with trained staff and experts should be constituted to monitor and manage the invasion regularly.
- The impact of *K. alvarezii* on the reefs of the Gulf of Mannar and the tireless effort put in for more than a decade to reduce the stress through regular monitoring and removal will be a lesson to reef managers when considering any species without proper studies near the sensitive coral reef areas in the future. Therefore, Tamil Nadu Forest Department should continue to monitor the status of bio invasion and management of invaded reefs areas.

8.10. Seaweed Farming Policy for Tamil Nadu

As of now, there is no policy on seaweed farming in the state and it is practiced without any regulation. Seaweed industry would provide additional/alternative livelihood options to the thousands of fisher folk and help to enhance their socio-economic status, to reduce fishing pressure, to mitigate climate change impacts, and to protect the environment from degradation. To promote and sustain the industry, more priority and importance has to be given by the Government of Tamil Nadu. Therefore,

- Tamil Nadu Government may consider developing an exclusive "Seaweed Farming Policy for Tamil Nadu" to promote and sustain seaweed industry including development of action plan, guidelines, eco-friendly multispecies seaweed farming in the state by utilizing the native seaweed resources, creating sufficient infrastructure, allocating sufficient funds, developing expertise and technology for field-tested, commercially viable native seaweed cultivation, establishing marketing links and providing special government schemes and subsidies to fisher folk and industries who wish to engage in seaweed farming in particular native seaweed and other allied activities.

The policy must be developed in very clear terms to exclude the introduction of exotic seaweed species like the invasive *K. alvarezii* particularly in areas such as the Gulf of Mannar and Palk Bay where eco-sensitive habitats like coral reefs and seagrass beds with rich associated biodiversity are present, and on which thousands of low-income fisher folk depend for their sustained livelihood. The policy should also aim at forming and promoting Fish Farmer Producer Organization (FFPO) to support the small-scale aquaculture farmers in cultivating the indigenous seaweed species and they can be encouraged to take up Integrated Multitrophic Aquaculture (IMTA) system by providing financial incentives to tap the real potential of seaweed aquaculture.

ANNEXURE

Workshop Discussions

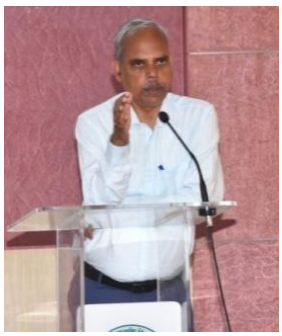
Following the sectoral discussion with the Department of Fisheries and fishermen welfare, State Planning Commission decided to have a detailed discussion with the experts related to seaweed and its cultivation. Accordingly, a discussion was convened at SPC in the month of November 2022 with experts from Department of Fisheries, Department of Environment, Forest and Climate Change, CMFRI, NCSCM, SDMRI, Bay of Bengal Programme and other related institutions. During the discussion, it was decided that one day workshop would be organised by SPC through Tamil Nadu State Land Use Research Board in coordination with Dr. J. Jayalalithaa Fisheries University.

The workshop was conducted in the month of January 2023. It had seven presentations by selected experts representing research institutes, private industry and government departments. The topics covered are - species diversification of seaweed, impact of seaweeds on biodiversity, impact of seaweed culture in the ecosystem, particularly in Gulf of Mannar and Palk Bay, potential industrial opportunities, infrastructure required and the livelihood opportunities. A total of 70 participants including the host institute and State Planning Commission, State Fisheries Department, farmers and seaweed cultivators, fisherwomen, industry, forestry department and the scientific community attended the Technical Sessions.

The inaugural session was chaired by Dr.J.Jeyaranjan, Vice Chairman, State Planning Commission and the special guest was Thiru. Subrat Mohapatra IFS, Principal Chief Conservator of Forests (Head of Forest Force). Followed by the inauguration, technical sessions were conducted. Seven speakers offered insightful talks on various topics related to seaweeds.

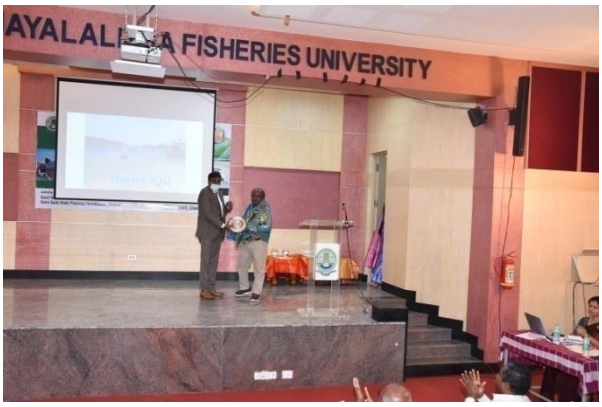
The technical presentations were followed by discussions and interactions. A panel discussion chaired by Professor. M. Vijayabaskar, Additional Full time Member, State Planning Commission and Dr.G.Sugumar, Vice Chancellor, Dr. J. Jayalalithaa Fisheries University was also conducted where the experts/representatives from various institutions, organisations and government departments offered their opinion after listening to all the technical sessions. Representatives from the fisherwomen communities who are involved in the seaweed collection also offered their opinion.

The following section of this document summarises the highlights of the technical sessions of this workshop and the panel discussion.



Presentation 1 –Dr.M.Ganesan, Senior Principal Scientist (Rtd.,) on "Seaweed cultivation in Tamil Nadu- Prospects and Challenges"

- National and international scenario of seaweed culture production and species diversity were explained with illustrations and figures.
- Species like *Gracilaria dura, G. edulis, G. Salicornia, G. debilis, Gelidiellaacerosa and Sarconemafiliforme* are being cultured at field and lab level for agar, fertilizer, biostimulant and carageenan production
- Factors affecting culture of seaweeds were given as,
- Grazing by parrot fish, surgeon fish and rabbit fish
- Epiphytes which compete for sunlight and nutrient
- Ice-ice disease due to stress like increased salinity, temperature and light intensity
- Aging of thallus
- Sedimentation in subtidal cultivation systems
- Seasonality
- Harsh environmental condition like cyclones



Presentation 2 –Dr. C. R. K. Reddy,Former Chief Scientist, CSIR-CSMCRI &Adjunct Professor, ICT, Mumbai on "Repurposing seaweeds for sustainable inclusive economic growth of coastal communities "

- Innovative utilization methods should be deployed for better use of the seaweed. Algal based mitigation of methane (higher global warming potential) – 90% of methane emission is eliminated by adding seaweed to the feed. Seaweed demand would be approx. 3 MMT on dry matter basis if this technology is being adopted.
- Bioplastics from seaweeds – European technology can be taken as a base for developing the same in Indian conditions.
- The technology of microbial oils production from seaweeds like*Rhodosporidium*, *Rhodotorula*,*Yarrowia*, *Cryptococcus* has been developed by the CSIR lab, which can be transferred for adoption. Technology has to be introduced for human-based applications of algal salts owing to its health benefits.
- Plant-based protein with low carbon footprint– Seaweed *Ulva* with a higher growth rate having hydrolysable proteins, can be utilized for producing protein-based products, which would boost these industries and benefit our economy.
- Dedicated R & D and seaweed centers and specialized scientific technology has to be initiated by the university in Tamil Nadu to work exclusively on seaweed.
- Model structure for seaweed farming and concept for seaweed processing should be developed in our state and country to lead globally in seaweed production in the future.
- The crop study on experimental basis like a "test plot" to be made to identify ideal species, location, physico chemical parameters and recommendations to be made before transfer of the technology
- Seaweed has bioremediation and carbon sequestrating potential, hence through

IMTA (Integrated Multitrophic Aquaculture System) the production of seaweed can be increased

- Seaweed can be used as a fodder replacement for mitigation of methane emission

Presentation 3 - Prof. C. Rajasekaran, Professor, School of Bio Sciences and Technology, VIT, Vellore on " Environmental issues related to Seaweed Cultivation in Tamil Nadu"

- Climate change is the most significant environmental issue of our time. Hence technologies to mitigate climate change through seaweed farming is need of the hour.
- *Ketomorpha sp.* at Ennoreregionhas been identified to have Bio-remediation potentialas in the Pamban region
- The increase in coastal aquaculture effluents has affected the naturally occurring seaweed beds. Hence measures to mitigate the issue have to focus on avoiding problems in seaweed farming in the coastal zone
- The availability of seaweed stock material is crucial for propagating seaweed culture among fisher folk dependent on seaweed farming.
- Phycosociology and area of adoption strategies to be focused on efficiently utilizing the seaweed resources.
- Bioactive compounds from seaweeds can be derived for neutraceuticals.
- Seaweed sp. and products should be promoted as food products in our country.
- The importance of algae in agriculture application must be focussed
- Research can be developed to produce more products from seaweeds.

Presentation 4 -Mr.BakanJagdish Sudhakar, IFS, Wildlife Warden & DFO(A/C),Gulf of Mannar Marine National Park, Tamil Nadu Forest Department on" Impact of exotic seaweed, Kappaphycusalvarezii on Coral Reefs of Gulf of Mannar (2005 to 2023)"

- Tamil Nadu Forest Department has been assessing and studying the impact of exotic seaweed *K. alvarezii* in the field for over 15 years. Several high-level officials from Union and State Governments have witnessed the effect on various occasions.
- Detailed an in-depth presentation on the effects of introducing exotic species, *Kappaphycus,* on the Gulf of Mannar biosphere. Hence, before introducing exotic species, a pilot study has to be made to study the effect of invasive species on corals seagrasses, marine mammals and the species biodiversity in the biosphere. The research institute should focus on earmarking specific areas for promoting exotic species. The focus should be made on propagating native species through cost-effective technology for adoption.
- Long Term Impact Assessment Studies to be made on the problem addressed by the Department of Forest. Taking other countries as an example like Brazil, where seaweed is cultivated in locations specifically allocated to avoid the spread of exotic species, can be initiated. Before implementing the farming technology of introducing exotic species, the policies of the state and central has to be taken into consideration

- The Tamil Nadu Government in 1986 declared the Gulf of Mannar Marine National Park to protect these precious coral reefs and other associated marine life. Hence, Government should not permit further cultivation of *K. alvarezii* (including experimental cultivation) in Gulf of Mannar and must ensure complete protection of the already stressed and ecologically sensitive reef habitats and guarantee the long-term livelihood benefits of the dependent low-income fisher-folk, apart from the protection of the coasts and preservation of genetic diversity.
- Considering the deleterious impact of *K. alvarezii*on corals and associated environment, Tamil Nadu Govt. should take a policy decision not to permit the cultivation of invasive exotic seaweed, K.*alvarezii*in and around the coral reef and seagrass ecosystem in line with TN Govt. GO 2005.

Presentation 5 - Johnson.B, ICAR-CMFRI, Mandapam Regional Centeron" Potential areas and candidate species for seaweed cultivation along the coastal line of Tamil Nadu"

- CMFRI has brought out neutraceutical products from seaweeds in the name of "cadalmin"
- For *Gracilariaedulis* species strain improvement study has to be carried out to increase the growth of the species
- A pilot study has to be carried out based on the suitable species, potential site, locality, seasonality and farming methodto avoid sectoral and species conflict with other livelihoods
- Edible seaweed such as *Ulva* and *Caulerpa* can be initiated and promoted to use in daily meals to increase the utilization of seaweeds
- Implementation of leasing policy, organized market (domestic and international), insurance coverage, commercialization of micropropagation technology will fill the gaps in seaweed farming

Presentation 6 -M. Shanmugam, Aqu Agri Processing Private Limited on "Seaweed Products – Trends and Market Prospects"

- Seaweed reduces mortality and enhances immunity in poultry and fish farming
- Various seaweed products such as Sagarika (AgroBiostimulant), food and feed additives are produced by the industries using the seaweed farmed in Ramanathapuram coast
- Requested to allow *Kappaphycus* culture to promote the seaweed industry


Presentation 7 - V.M. Chandirasekaran, Chief Director, NCDC, Regional Office, Chennai on "Financial Support services for seaweed cultivation"

- Schemes and their funding pattern to FFPO, co-operatives, federations and universities were discussed in detail to take up seaweed farming.
- Support under PMMSY for the FPOs and the implementing agencies were deliberated.


III. Panel Discussion

Experts from various institutions, organizations and Government departments participated in the panel discussion.

1.	Chair	:	**Dr.G.Sugumar,** Vice-Chancellor of Tamil Nadu, Dr. J. Jayalalithaa Fisheries University
2.	Co-Chair	:	**Prof. M. Vijayabaskar,** Additional Full Time Member, SPC
3.	Members	:	**Dr.Naganathan,** APCCF, Chennai
			Mrs. Sudha, IFS, HOD (LU), TN-SLURB,SPC, Chennai
			Mr.LamekJeyakumar, Deputy Director of Fisheries, Dept. of Fisheries & Fishermen Welfare, Chennai
			Mr.BakanJagdishSudhakar, IFS, Wildlife Warden & DFO (A/C), Gulf of Mannar Marine National Park
			Dr.P.Krishnan, Director BOBP-IGO, Chennai
			Dr.C.R.K.Reddy, Former Chief Scientist, CSIR-CSMCRI &Adjunct Professor, ICT, Mumbai
			Dr. J. Stephen Sampath Kumar, Director of Research i/C. TNJFU
			Dr.S.A.Shanmugam, Dean i/C, TNJFU-IFPGS, Chennai
			Dr.B.Johnson, ICAR-CMFRI, Mandapam
			Mr.Sethu Madhavan, Representative from M/s Herblis Healthcare, Madurai
			Dr.Cheryl Antony, Professor & Head, Department of Aquaculture, TNJFU
			Dr.Patterson Edward, Researcher, SDMRI, Thoothukudi
			Dr.Selvakumar, Farmer Representative, Mandapam
			Other faculty staff of TNJFU

The Chair welcomed the group and stressed the importance of the panel discussion and the road map to be drawn for the sustainability in seaweed farming. Technologies that suit different areas and offshore cultivation possibilities, seed production and tissue culture

technology for large-scale expansion were identified as key areas of seaweed farming. He insisted that *Kappaphycus* should be cultivated only as per laid down guidelines since it affects corals and seagrass beds

The Co-Chair stated that the farming area should not be close to the coral reef, and the ability of sea weed spores to travel and its harmful effect must be kept in mind during the selection of sites for farming. He also questioned how best the local fishermen can gain from offshore model and the need for protocol. He also said that a viable model must be developed to ensure that the gains are distributed to cultivators.

The panellist, Dr. C.R.K. Reddy, Former Chief Scientist, CSIR-CSMCRI and Adjunct Professor (ICT, Mumbai), Bengaluru suggested open cage farming and integrated aquaculture as alternative livelihood to the farmers since the mooring system for cages can be used for seaweed farming. He also talked about the importance of environmental impact assessment. Key suggestions provided by him are,

- Exploration of any other areas for cultivation of *Kappaphycus*
- Identification and promotion of indigenous seaweed species
- Convening a meeting with Madurai cottage industry and indigenous farmers of *Gracilaria*
- Identification of alternate livelihoods that will provide the same or better returns to the farmers.
- Agar yielding cottage industries are following primitive technologies, those Industries can be revived with improved technology to increase the agar yield. Hence there will be parallel development between the production and user sectors
- Seaweed farming can be shifted to offshore and IMTA model can be practiced for higher production

Dr.Naganathan, APCCF mentioned that the location must be selected based on the current flow, wind and wave action, nutrient content and shelter area. The Gulf of Mannar and Palk Bay regions are the areas to be protected. As the farmers go for wild collection of seaweed, regulations and institutional framework to ensure the regulations are to be established. He said that it was the private companies that engaged farmers for seaweed cultivation trials in the Palk Bay region. Hence, it cannot be considered as their regular livelihood. He said that cage farming suggested as an alternative livelihood, is affected by legality and spacing out areas for fishermen is difficult. Cage culture in offshore is not cost effective farming and again it affects the navigation of boats. Hence lobster fattening can be promoted as an alternative farming. He also insisted that seaweed farming must be done only with native species, especially in protected areas. The state government must discuss the leasing policy

in concurrence with the central government. Identifying fast-growing genotypes in local species is the need of the hour. The farm size must be standardised to meet out the livelihood of fishermen. He pointed out that seaweed farming will only be a cottage industry, not a large-scale industrial activity. The cottage industry will not be able to provide raw material in bulk to the industry. Also, micropropagation methods are not required for the large-scale production of seaweeds. However, it can be used for genetic improvement and increasing vigour. He emphasised the importance of the revival of the cottage industry at Thirupuvanam. He mentioned that *Gelidiella* and *Gracilaria*have coral particles due to improper cleaning, which affects the cost, and proper cleaning will increase the rate by threefold.

When an opinion was asked from a fisherwoman of Ramanathapuram district, who is undertaking seaweed farming, she mentioned that they have been growing *Kappaphycus*for 17 years. Grazing and discharge from shrimp farms are the major problems faced by them. Dr.Selvakumar, Farmer Representative from Mandapam mentioned that almost 5 villages depend on *Kappaphycus* for livelihood. In total, there would be about 500 families in five villages. During April to May, because of summer, it is said that they have low growth rate of seaweeds, and hence they go for the wild harvest of *Gelidiella*. From November to December, they restart seaweed farming, but cyclone affects the culture. Only from January to March the commercial cultivation of seaweed is possible for them as per her statement.

Dr. P. Krishnan, Director, Bay of Bengal program said that like *Kappaphycus,* local species such as *Gracilaria, Gelidiella*, and *Sargassum also* settle above coral and seagrass beds. If the level of deposition increases, algal shift occurs and needs intervention for conservation. In Palk Bay, *Kappaphycus* culture has been going on for 20 years, but no coral damage has been reported. Kappaphycus farming production has reduced due to loss of nutrient not because of vigour. Environmental impact assessment was done and it was found that production is less in *kappaphycus* farming due to loss of nutrient in the particular region as the rafts are not cleared after the farming. Hence it reduces sunlight penetration and production in that area. Water quality and benthic fauna studies has been carried out for a period of 10 years in Gulf of Mannar and Palk Bay region and it was found to be within the optimal range. Available research reports & studies must be used to identify the methods to control the damage. Already the methodologies have been reported by researchers from CMFRI, CSIR-CSMCRI, NCSM. He insisted that the research organisations MUST be allowed to quarantine and produce improved strains. They must be permitted to hold the strains for two years, State Government should fund the process, and the forest department should oversee the activity. Later private organisations must be identified based on specific criteria and given training, allowing them to culture as per established norms.

Ms. Sudha, IFS, HOD(Land use), Tamil Nadu State Land Use Research Board, State Planning

Commission mentioned that species-wise and zone-wise growth documentation is necessary. She emphasised that apart from promoting seaweed for industrial purposes, it must also be promoted as a food source.

Conclusion

Unlike other forms of aquaculture, seaweed farming foregoes the use of feed and fertilizers and has minimum technological and capital requirements. In addition, grow out cycles are short, normally lasting less than two months. Given these unique characteristics, seaweed farming has generated substantial socio-economic benefits to marginalized coastal communities, most of which have reduced access to alternative economic activities. Given the rising global demand for seaweed-derived products, seaweed farming has the potential to generate further socio-economic benefits to coastal communities.

Hence, the promotion of seaweed will boost the aquaculture in Tamil Nadu in general and attract more foreign investment for processing of value-added products. The commercialization of the seaweed-based products is significant to the mariculture industry and coastal fishermen as this will enhance the demand to produce more seaweeds along the coastline of India.

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Sustainable Seaweed Farming in Tamil Nadu

The cultivation of seaweed is a profitable livelihood opportunity for coastal fishing communities in Tamil Nadu. This report is the result of a workshop on Sustainable Seaweed Farming in the region, jointly organized by the Tamil Nadu State Land Use Research Board and the State Planning Commission.

The objective of this report is to highlight the significance of seaweed cultivation, its positive impact on the environment, and to provide a detailed overview of policies and programs. The report serves as an extensive guide for researchers, policymakers, marine conservationists, industry professionals, and stakeholders, offering valuable insights into the realm of sustainable seaweed farming.

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