

Seaweeds and their Farming Methods

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As the global demand for food, bio-based products, and sustainable livelihoods continues to increase, there is a growing need to utilize natural resources in ways that balance economic development with environmental sustainability. In response to this challenge, attention is increasingly shifting towards renewable marine resources that can support future food systems, coastal economies, and ecosystem resilience. Among these resources, seaweeds have emerged as one of the most promising biological assets, offering opportunities that extend far beyond their traditional use (Khan, Sudhakar and Mamat, 2024). In recent years, seaweeds have attracted considerable scientific, industrial, and policy attention owing to their versatility and their potential to contribute to multiple sectors simultaneously (Buschmann *et al.*, 2017). Their expanding applications, increasing global demand, and compatibility with sustainable production systems have positioned seaweed farming as an emerging marine enterprise with significant economic and environmental relevance. For coastal nations such as India, endowed with an extensive coastline and favourable environmental conditions, seaweed cultivation offers an opportunity to diversify marine-based livelihoods while promoting the sustainable utilization of coastal resources. The development of a successful seaweed sector, however, depends on more than cultivation alone. A comprehensive understanding of the resource, appropriate farming practices, post-harvest management, product diversification, and the broader socio-economic and environmental significance of seaweed farming is essential for realizing its full potential. Bridging scientific knowledge with practical applications is therefore crucial for promoting the sustainable growth of the sector and ensuring its long-term benefits for coastal communities.

Keeping these aspects in view, this chapter presents a comprehensive overview of seaweeds and their importance, followed by an account of their global market potential, cultivation practices, post-harvest handling, value addition, livelihood relevance, women's empowerment, and their role in addressing climate change and advancing the Blue Economy. The chapter is intended to provide scientifically sound and practically relevant information for researchers, extension professionals, students, entrepreneurs, and coastal farming communities involved in the development of the seaweed sector.

What are seaweeds?

Seaweeds are large, photosynthetic marine algae, commonly referred to as marine macroalgae, that grow naturally in coastal and marine environments across the world (Adarshan *et al.*, 2023). Unlike microscopic algae (phytoplankton), which are too small to be seen with the naked eye, seaweeds are multicellular organisms that vary greatly in

size, shape, colour, and habitat. They range from a few centimetres to several metres in length and form an important component of marine ecosystems. Found attached to rocks, coral reefs, shells, or other firm substrates in shallow coastal waters, seaweeds flourish in regions where sunlight penetrates the water column, enabling them to perform photosynthesis efficiently (Pereira, 2021). Like terrestrial plants, seaweeds contain chlorophyll and other photosynthetic pigments that enable them to convert sunlight, carbon dioxide, and dissolved nutrients into organic matter while releasing oxygen into the surrounding water. However, despite their plant-like appearance and ecological role, seaweeds are not true plants. They lack specialized tissues such as true roots, stems, leaves, flowers, seeds, and vascular systems that transport water and nutrients in land plants. Instead, the entire body of a seaweed is known as a thallus, which is structurally simple yet highly adapted to survive in dynamic marine environments. The thallus generally consists of three main parts. The holdfast anchors the seaweed firmly to hard surfaces such as rocks or artificial farming structures but does not absorb nutrients like the roots of terrestrial plants. The stipe is a stem-like structure that provides support and flexibility, allowing the seaweed to bend with waves and currents without breaking. The broad, leaf-like blade serves as the primary photosynthetic surface where sunlight is captured for food production. In some species, small gas-filled structures known as air bladders or pneumatocysts are present, which help keep the blades buoyant and closer to the water surface where light availability is greater (Khan, Sudhakar and Mamat, 2024). Seaweeds absorb water, dissolved minerals, and nutrients directly across the entire surface of their thallus rather than through a root system. This unique adaptation enables them to efficiently utilize nutrients available in seawater, making them highly productive even without soil, freshwater irrigation, or chemical fertilizers (Roleda and Hurd, 2019). Their growth is influenced by several environmental factors, including light intensity, water temperature, salinity, nutrient availability, water movement, and tidal fluctuations. Consequently, healthy seaweed beds are commonly found in clear, nutrient-rich coastal waters where these conditions are favourable.

Based on the dominant photosynthetic pigments they contain, seaweeds are broadly classified into three major groups: Green Seaweeds (Chlorophyceae), brown seaweeds (Phaeophyceae), and red seaweeds (Rhodophyceae). The colour of each group is determined by the pigments that mask or complement chlorophyll, enabling different species to absorb light efficiently at varying water depths. Green seaweeds (Chlorophyta) are characterized by their bright green colour due to the dominance of chlorophyll *a* and *b*. They are commonly found in shallow coastal waters where sunlight is abundant. Fast-growing genera such as *Ulva* are increasingly studied as sources of food, animal feed, and bio stimulant or biofertilizer products because of their high growth rates and favourable nutrient profile (Hofmann *et al.*, 2025), while *Caulerpa* species are likewise valued as edible seaweeds and sources of bioactive compounds for food and nutraceutical applications (Pangestuti *et al.*, 2021). Brown Seaweeds (Phaeophyceae) possess the pigment fucoxanthin, which gives them their characteristic brown or olive-

green colour. They generally occur in temperate and colder marine waters, although several tropical species are also distributed along the Indian coastline. Brown seaweeds, including *Sargassum*, *Turbinaria*, and *Padina*, are economically important because they are rich sources of alginate, a valuable hydrocolloid extensively used in the food, pharmaceutical, textile, and cosmetic industries (Anjana and Arunkumar, 2024). Red Seaweeds (Rhodophyta) contain pigments such as phycoerythrin and phycocyanin, which allow them to absorb blue-green wavelengths of light and grow at greater depths than many other seaweeds (Mendes et al., 2024). This group includes commercially significant genera such as *Kappaphycus*, *Gracilaria*, *Gelidiella*, and *Hypnea*. Red seaweeds are the principal source of agar and carrageenan, two commercially important hydrocolloids that have widespread applications in food processing, microbiological media, pharmaceuticals, cosmetics, and biotechnology.

India possesses a rich diversity of marine macroalgae distributed along its extensive coastline, particularly along the shores of Gujarat, Tamil Nadu, Andhra Pradesh, Lakshadweep, and the Andaman and Nicobar Islands. Species such as *Kappaphycus alvarezii*, *Gracilaria* spp., *Ulva*, *Sargassum*, *Turbinaria*, and *Hypnea* are of particular scientific and commercial interest owing to their abundance, biochemical composition, and cultivation potential (Rao and Mantri, 2006). The diversity observed among seaweed species is reflected not only in their colour and morphology but also in their growth characteristics, habitat preferences, and biochemical constituents. These differences determine their suitability for specific purposes, ranging from food and hydrocolloid production to agricultural and industrial applications. As scientific research and commercial cultivation continue to expand worldwide, seaweeds are increasingly being recognized as one of the most valuable renewable resources of the marine environment (Buschmann et al., 2017). Understanding their diverse functions and applications is therefore essential to appreciating their growing importance in sustainable coastal development.

Importance and uses of seaweeds

Seaweeds are among the most valuable biological resources of the marine environment because of their remarkable diversity in chemical composition and functional properties. Rich in carbohydrates, proteins, vitamins, minerals, dietary fibre, essential amino acids, polyunsaturated fatty acids, and a wide range of bioactive compounds, seaweeds have become indispensable in several sectors, including food, agriculture, pharmaceuticals, cosmetics, biotechnology, environmental management, and renewable energy. Their ability to grow rapidly without the need for freshwater, fertile land, or chemical fertilizers further enhances their significance as a sustainable marine resource.

Food and Nutritional Importance

Seaweeds have been consumed as food for centuries, particularly in countries such as Japan, China, Korea, and Indonesia, where they form an integral part of the daily diet. In

recent years, their popularity has expanded globally owing to increasing awareness of healthy and functional foods. Nutritionally, seaweeds are an excellent source of dietary fibre, essential minerals such as iodine, calcium, iron, magnesium, and potassium, vitamins including A, C, E, and several B-complex vitamins, as well as proteins and bioactive compounds with antioxidant properties. Many species are naturally low in fat while containing valuable polyunsaturated fatty acids, making them suitable for balanced diets. Regular consumption of edible seaweeds has been associated with improved digestive health, better mineral intake, enhanced immune function, and a reduced risk of certain lifestyle-related disorders, although these benefits depend on the species consumed and the quantity included in the diet (Kumar, Tarafdar and Badgujar, 2021). Beyond direct human consumption, seaweeds are increasingly incorporated into processed foods such as soups, salads, noodles, snacks, bakery products, beverages, and health supplements. Their unique gelling, thickening, and stabilizing properties also improve the texture and shelf life of many food products.

Applications in Agriculture

Seaweeds have gained considerable importance in sustainable agriculture because they serve as natural biofertilizers and plant bio stimulants. Seaweed extracts contain naturally occurring plant growth regulators such as auxins, cytokinins, gibberellins, and betaines, along with essential micronutrients, amino acids, and polysaccharides that stimulate plant growth and improve overall crop performance. Application of liquid seaweed extracts or seaweed-based formulations has been shown to enhance seed germination, root development, nutrient uptake, chlorophyll synthesis, flowering, fruit set, and crop yield. In addition, these products improve plants tolerance to drought, salinity, and other environmental stresses while supporting beneficial soil microorganisms (Khan *et al.*, 2009). As agriculture increasingly shifts towards environmentally friendly production systems, seaweed-based bio stimulants are becoming an important component of integrated nutrient management and organic farming. Seaweeds are also used as feed supplements for livestock, poultry, and aquaculture species. Their nutritional composition and bioactive compounds can improve feed quality, animal health, growth performance, and disease resistance when included in balanced diets.

Industrial Applications and Hydrocolloids

One of the most economically important uses of seaweeds is the extraction of hydrocolloids-natural polysaccharides with excellent thickening, gelling, stabilizing, and emulsifying properties. These compounds have become indispensable raw materials for numerous industries. Agar, primarily obtained from red seaweeds such as *Gracilaria* and *Gelidium*, is widely used in the food industry as a gelling agent and in microbiology laboratories as a culture medium for growing microorganisms. It also finds applications in pharmaceuticals, confectionery, and biotechnology (Lee, Lim and Ho, 2022).

Carrageenan, extracted mainly from red seaweeds such as *Kappaphycus* and *Eucheuma*, is extensively used to improve the texture, stability, and viscosity of dairy products, processed foods, meat products, toothpaste, cosmetics, and pharmaceutical formulations (Campbell and Hotchkiss, 2017). Alginate, obtained from brown seaweeds such as *Sargassum*, *Turbinaria*, and *Laminaria*, is valued for its water-binding and film-forming properties. It is widely utilized in the textile industry, paper manufacturing, wound dressings, pharmaceuticals, food processing, dental impression materials, and several other industrial products. The global demand for these hydrocolloids continues to increase, making commercially important seaweeds valuable industrial raw materials.

Pharmaceutical and Biomedical Applications

Seaweeds are the rich sources of biologically active compounds, including polyphenols, flavonoids, sulphated polysaccharides, pigments, sterols, peptides, and antioxidants. These compounds have attracted considerable scientific interest because of their diverse biological activities. Numerous laboratory and clinical studies have demonstrated that seaweed-derived compounds possess antioxidant, antimicrobial, antiviral, anti-inflammatory, anticoagulant, immunomodulatory, antidiabetic, and anticancer potential. Consequently, seaweeds are increasingly being explored for the development of pharmaceuticals, nutraceuticals, functional foods, wound-healing materials, and biomedical products (Lomartire and Gonçalves, 2022). Although many applications are still under active research, seaweeds represent a promising source of novel bioactive molecules for future drug discovery and healthcare innovations.

Cosmetics and Personal Care Products

The cosmetic industry extensively utilizes seaweed extracts because of their moisturizing, antioxidant, anti-ageing, and skin-conditioning properties. Seaweed-derived compounds are incorporated into facial creams, lotions, shampoos, soaps, sunscreens, face masks, body scrubs, and spa products (Pereira, 2018). Polysaccharides and antioxidants present in seaweeds help retain skin moisture, improve elasticity, protect against oxidative stress, and promote healthier skin and hair. Growing consumer preference for natural and sustainable cosmetic ingredients has further increased the demand for seaweed-based formulations.

Environmental Importance

Apart from their commercial value, seaweeds perform several vital ecological functions that support the health of marine ecosystems. Through photosynthesis, they absorb carbon dioxide and release oxygen, thereby contributing to primary productivity and maintaining ecological balance in coastal waters. Seaweeds efficiently absorb dissolved nutrients such as nitrogen and phosphorus from seawater, helping reduce nutrient pollution and mitigate eutrophication (Cotas et al., 2023). Their ability to remove excess nutrients has led to their use in wastewater treatment systems and integrated multi-

trophic aquaculture (IMTA), where they improve water quality while producing valuable biomass. Seaweed beds also provide food, shelter, nursery grounds, and breeding habitats for numerous fish, crustaceans, molluscs, and other marine organisms, thereby enhancing marine biodiversity and supporting coastal fisheries. Furthermore, because of their capacity to absorb atmospheric carbon dioxide during growth, seaweeds are increasingly recognized for their potential role in climate change mitigation through carbon sequestration and blue carbon initiatives.

Bioenergy and Emerging Biotechnological Applications

Growing concerns regarding fossil fuel depletion and climate change have stimulated research into renewable sources of energy. Owing to their rapid growth rate, high biomass productivity, and absence of competition with agricultural land and freshwater resources, seaweeds have emerged as a promising feedstock for the production of bioethanol, biogas, biohydrogen, and other renewable biofuels ([Samal and Sukla, 2025](#)). In addition, advances in marine biotechnology have opened new opportunities for utilizing seaweeds in the production of biodegradable packaging materials, bioplastics, pharmaceuticals, nanomaterials, enzymes, pigments, and high-value specialty chemicals. These emerging applications are expected to further expand the commercial importance of seaweeds in the coming decades. The extraordinary versatility of seaweeds, combined with their environmental sustainability and wide-ranging industrial applications, has transformed them from a traditionally harvested marine resource into a globally important bioresource. Their increasing demand across diverse sectors not only highlights their economic value but also underscores their potential to support sustainable agriculture, food security, environmental conservation, and coastal livelihood development. This growing global demand has, in turn, accelerated interest in commercial seaweed cultivation, making seaweed farming an increasingly attractive and economically viable enterprise.

Global market and emerging opportunities

The expanding range of applications of seaweeds has led to a rapid increase in their global demand over the past few decades. Asian countries, particularly China, Indonesia, the Republic of Korea, and the Philippines, account for the largest share of global seaweed production and supply much of the raw material required by the food, hydrocolloid, pharmaceutical, cosmetic, and agricultural industries ([Belattmania, Reani and Sabour, 2022](#)). The global seaweed industry has evolved from a traditional coastal activity into a multi-billion-dollar bioeconomy, driven by the increasing demand for healthy foods, natural bio stimulants, hydrocolloids, sustainable packaging materials, pharmaceuticals, cosmetics, and renewable bio-based products. Continuous research and technological advancements are further expanding the commercial applications of seaweeds, creating new opportunities for farmers, entrepreneurs, and coastal industries.

Although India possesses a long coastline and rich seaweed biodiversity, commercial cultivation is still at a developing stage compared to several leading seaweed-producing nations. However, favourable coastal conditions, growing domestic demand, supportive government initiatives, and increasing private-sector participation provide significant opportunities for expanding seaweed farming in the country. With appropriate scientific cultivation practices, value addition, and market linkages, India has considerable potential to emerge as an important contributor to the global seaweed industry. The growing domestic and international demand for seaweed products has made seaweed farming an increasingly attractive livelihood option ([Krishnan and Kumar, 2010](#)). Understanding the factors that make seaweed cultivation economically, socially, and environmentally beneficial is therefore essential for promoting its wider adoption among coastal communities.

Why should we promote seaweed farming?

The increasing global demand for seaweed products, coupled with the abundance of suitable coastal resources, has made seaweed farming an attractive opportunity for sustainable coastal development. Compared to many conventional farming activities, seaweed cultivation requires relatively low investment, simple infrastructure, and minimal external inputs. Since it is carried out in the sea, it does not compete for agricultural land or freshwater resources, making it particularly suitable for countries with extensive coastlines such as India. Another major advantage of seaweed farming is its short cultivation cycle. Most commercially cultivated species can be harvested within 30-45 days, allowing farmers to obtain multiple harvests in a year and generate regular income ([Seth and Shanmugam, 2016](#)). The activity can also be integrated with existing fishing and aquaculture practices, providing an additional source of livelihood during periods of low fishing activity or seasonal fishing restrictions. Seaweed farming is well suited to small-scale coastal communities because it is relatively easy to learn and can be adopted using locally available materials and appropriate technical guidance. It provides opportunities for individual farmers, fisher groups, self-help groups, and community-based organizations to participate in income-generating activities. Moreover, the increasing emphasis on sustainable marine resource utilization and government support for seaweed cultivation further strengthens its potential as a future-oriented coastal enterprise ([Rebours *et al.*, 2014](#)). With its low resource requirement, quick returns, and expanding market opportunities, seaweed farming represents a practical and sustainable option for improving coastal livelihoods while supporting the long-term development of the marine sector.

Seaweed farming practices

The successful adoption of seaweed farming depends not only on the growing market demand but also on the application of appropriate cultivation practices. Although seaweed farming is relatively simple compared with many other aquaculture activities,

its productivity and profitability are strongly influenced by the selection of suitable species, appropriate farming sites, and the cultivation method employed. Careful planning at each stage helps ensure healthy crop growth, higher biomass yield, and improved product quality.

Selection of Species

The first step in successful seaweed farming is the selection of a suitable species. This decision should be based on local environmental conditions, market demand, availability of healthy planting material, and the intended end use of the harvested biomass. A species that performs well in one coastal region may not necessarily thrive in another due to differences in temperature, salinity, water movement, and seasonal variations ([Radulovich et al., 2015](#)). In India, commercially cultivated species include *Kappaphycus alvarezii*, *Gracilaria* spp., and *Ulva* spp., owing to their rapid growth, good adaptability, and industrial importance. Selecting healthy, disease-free planting material from reliable sources is equally important, as it directly influences crop establishment and overall productivity.

Site Selection

Selection of a suitable farming site is one of the most critical factors determining the success of seaweed cultivation. An ideal site should provide environmental conditions that support healthy growth while minimizing physical damage to the crop. The farming area should have clean, unpolluted seawater with good water exchange to ensure a continuous supply of dissolved nutrients and oxygen. Salinity and temperature should remain within the tolerance range of the cultivated species, while sufficient sunlight is essential for efficient photosynthesis. Moderate water currents are desirable because they facilitate nutrient transport and prevent the accumulation of sediments on the seaweed surface. However, sites exposed to strong waves, cyclones, or excessive turbulence should be avoided, as they may damage farming structures and dislodge the crop. Water depth should allow the seaweed to remain submerged during low tide while still receiving adequate sunlight. The site should also be free from industrial discharge, sewage outfalls, excessive siltation, and heavy grazing by herbivorous fishes or sea urchins. In addition to environmental suitability, practical considerations such as ease of access, availability of labour, transportation facilities, and proximity to landing centres are important for efficient farm management and harvesting operations ([Kim et al., 2017](#)).

Seaweed Farming Methods

Seaweed cultivation can be carried out using different farming methods depending on the cultivated species, water depth, tidal range, wave action, current velocity, and available farming infrastructure ([García-Poza et al., 2020](#)). Although the design of each farming system varies, the basic principle remains the same: healthy seaweed propagules are attached to a suitable support, such as ropes or nets, and allowed to grow

under favourable environmental conditions until they attain harvestable size. Selecting an appropriate farming method is therefore essential for ensuring healthy crop growth, minimizing production losses, and improving overall farm productivity.

1. Floating Raft Method

The floating raft method is one of the most widely adopted techniques for commercial seaweed farming, especially in sheltered coastal waters such as bays, lagoons, and estuaries. It is particularly suitable for species such as *Kappaphycus alvarezii* and *Gracilaria* spp. In this method, a square or rectangular raft is constructed using bamboo, PVC, or HDPE pipes and kept afloat with buoyant materials. The raft is anchored securely to the seabed to prevent drifting. Culture ropes are stretched across the frame, and seaweed fragments are tied at regular intervals. As the raft floats with the natural movement of the sea, the crop remains suspended in the upper water column, where favourable light and water conditions support rapid growth. The floating raft method facilitates easy monitoring, cleaning, and harvesting of the crop. It is highly productive but requires sturdy anchoring and periodic inspection, particularly during rough weather.

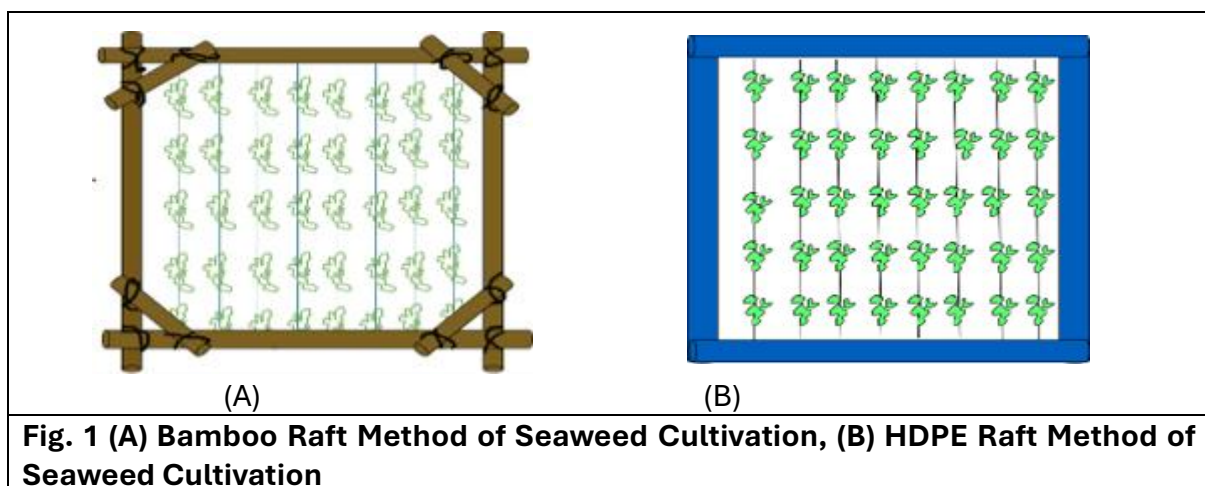


Fig. 1 (A) Bamboo Raft Method of Seaweed Cultivation, (B) HDPE Raft Method of Seaweed Cultivation

2. Long-line Method

The long-line method is widely used for commercial farming in relatively deeper coastal waters. It is especially suitable for large-scale cultivation because it allows efficient utilization of available farming space with comparatively less structural material. A strong horizontal rope, known as the main line, is anchored at both ends and supported by floating buoys. Seaweed seedlings are attached either directly to the main rope or to shorter culture lines suspended from it. This arrangement provides ample space for growth while allowing the farm to cover a much larger area than a raft system. The long-line method is relatively easy to expand, making it suitable for commercial enterprises. However, the stability of the system depends on proper anchoring, particularly in areas with strong currents or seasonal storms (Ganesan *et al.*, 2019; Mantri, 2025).

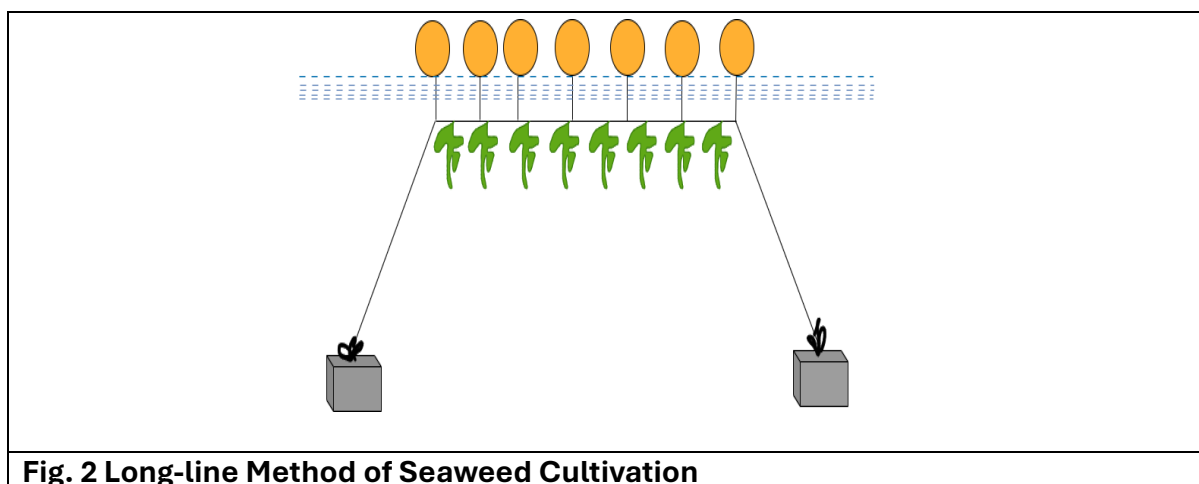


Fig. 2 Long-line Method of Seaweed Cultivation

3. Off-bottom Method

The off-bottom method is commonly practiced in shallow coastal areas where the seabed is sandy, muddy, or covered with seagrass. It is one of the most economical farming techniques and is widely adopted by small-scale coastal farmers. The method involves fixing wooden, bamboo, or PVC stakes into the seabed and stretching culture ropes between them approximately 20–50 cm above the bottom. Seaweed propagules are tied to these ropes at predetermined intervals. Raising the culture ropes above the seabed reduces sediment deposition on the crop while allowing adequate water movement around the growing seaweed. Because of its simple construction and low investment requirement, the off-bottom method is particularly suitable for community-based farming programmes ([Hurtado-Ponce, Agbayani and Chavoso, 1996](#)). However, it performs best in protected coastal areas where wave action is minimal.

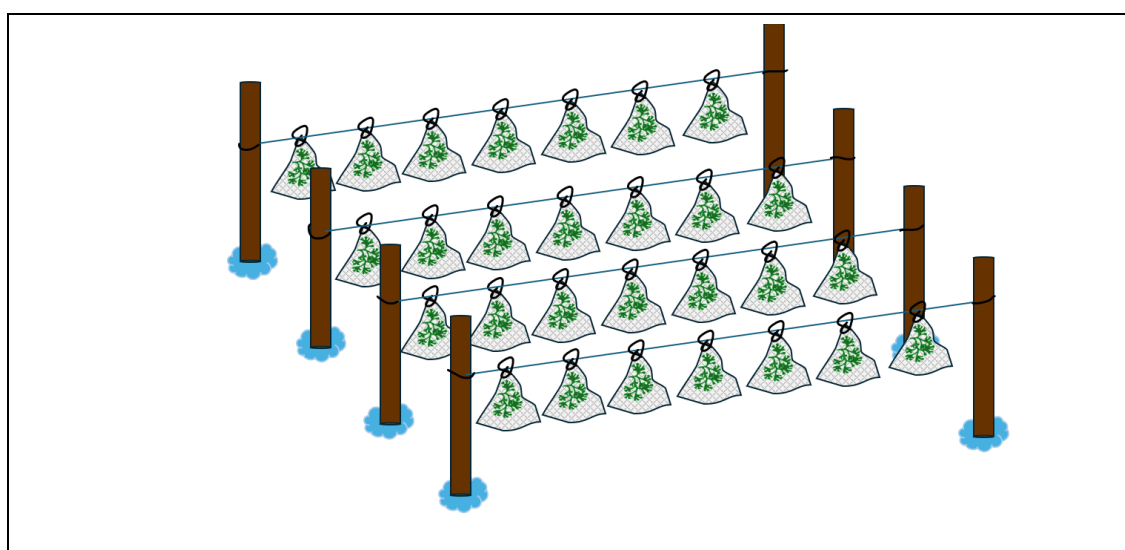


Fig. 3 Off bottom net bag method of Seaweed Cultivation using Bamboo Poles

4. Monoline Method

The monoline method is a simplified version of rope-based cultivation and is generally

adopted for small-scale farming, pilot demonstrations, and experimental cultivation. In this method, a single culture rope is stretched horizontally between two fixed supports or anchored floats. Seaweed fragments are tied directly onto the rope at regular intervals and left to grow until harvest. The system is inexpensive, easy to install, and requires minimal construction materials, making it suitable for beginners and resource-limited farmers. However, because only one culture line is used, the production capacity is lower than that of raft or long-line systems (Kavale, Yadav and Mantri, 2021).



Fig. 4 Monoline Method of Seaweed Cultivation

5. Tube-net Method

The tube-net method is particularly useful for fragile or loosely attached seaweed species that may not remain securely tied to ropes

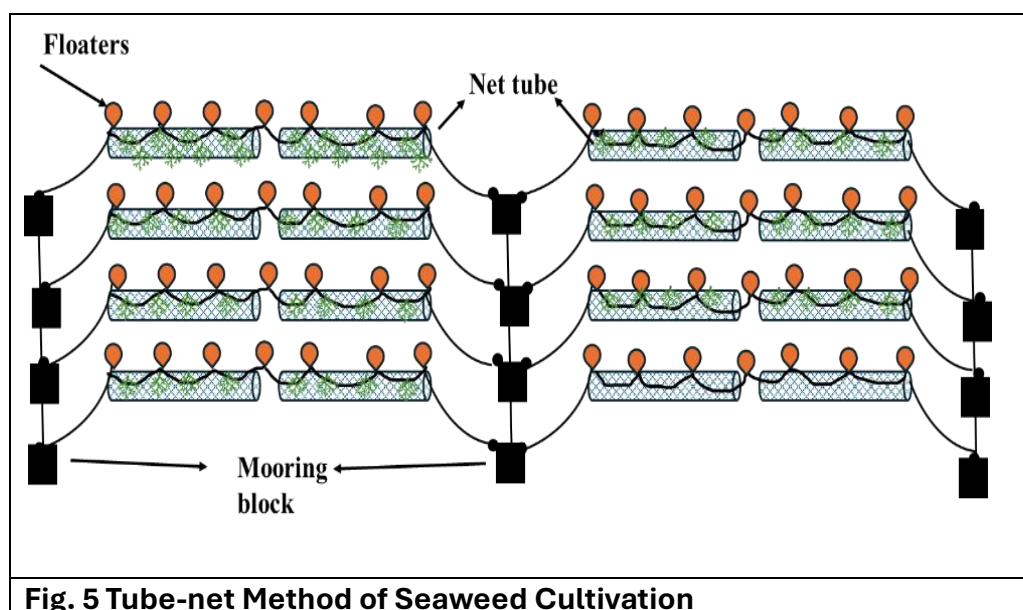


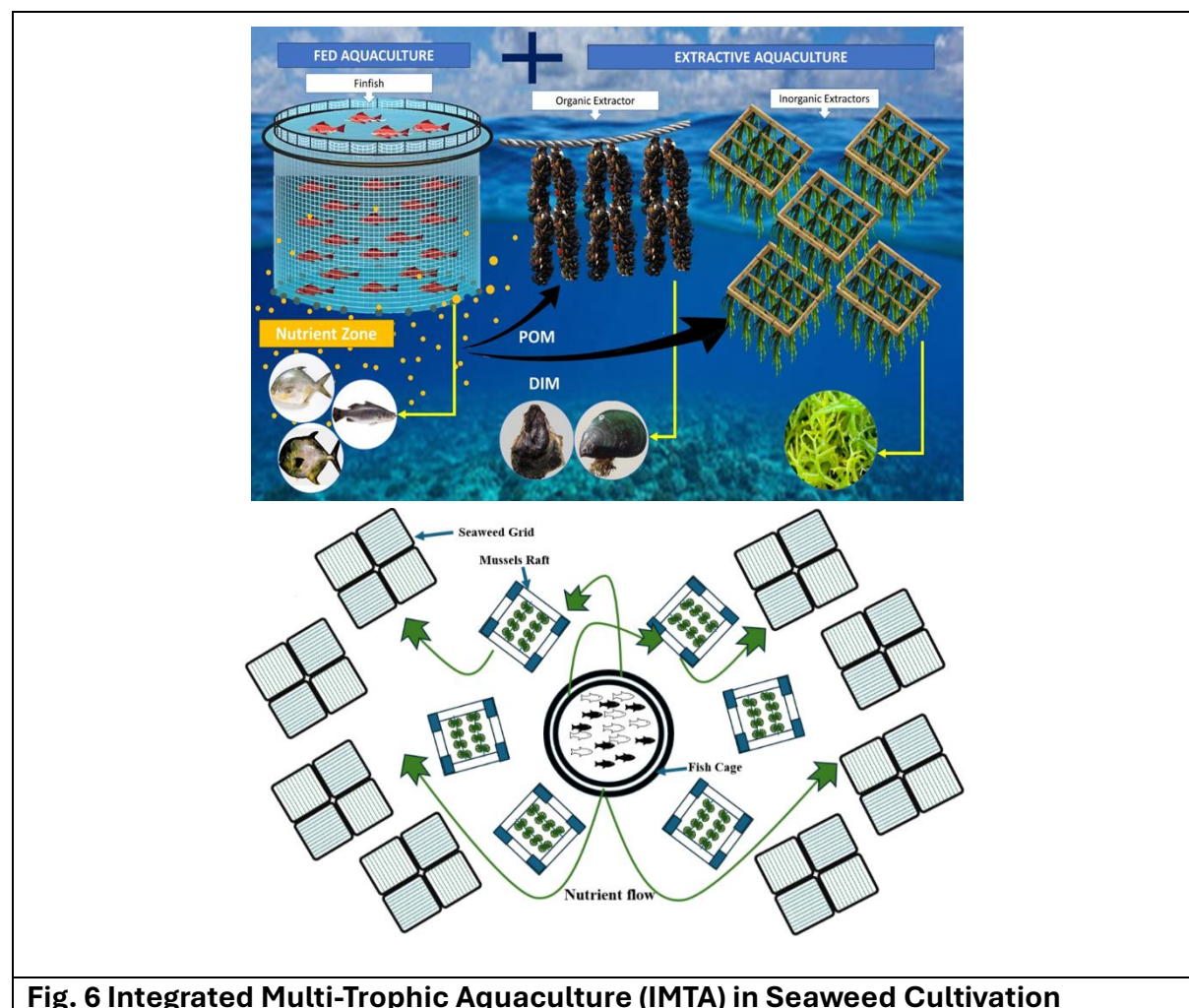
Fig. 5 Tube-net Method of Seaweed Cultivation

during cultivation. Instead of fastening individual propagules onto ropes, the planting material is placed inside long cylindrical mesh tubes. These nets are suspended from floating rafts or long-line systems, allowing seawater to flow freely through the mesh

while preventing the propagules from being dislodged by waves or currents (Megarajan *et al.*, 2024). The mesh also provides partial protection against grazing by herbivorous organisms. To maintain healthy growth, the nets should be inspected and cleaned periodically to remove fouling organisms that may reduce water exchange and light penetration.

6 Integrated Multi-Trophic Aquaculture (IMTA)

Integrated Multi-Trophic Aquaculture (IMTA) is an advanced and sustainable aquaculture approach in which seaweeds are cultivated together with other aquatic organisms occupying different trophic levels, such as finfish, shrimp, mussels, or oysters. In this system, dissolved nutrients released from the cultured fish or shrimp, particularly nitrogen and phosphorus, are utilized by seaweeds for growth, while filter-feeding organisms remove suspended organic matter from the water (Neori *et al.*, 2004). This natural recycling of nutrients improves resource-use efficiency, enhances water quality, and reduces the environmental impacts associated with aquaculture (Nederlof *et al.*, 2022). By integrating seaweed cultivation with other aquaculture practices, IMTA not only promotes environmentally sustainable production but also provides farmers with an additional source of income through diversified farming.



Post-harvest handling and value addition

The success of seaweed farming does not end with harvesting. Proper post-harvest handling is equally important to preserve product quality and maximize its market value. Poor handling practices can lead to contamination, quality deterioration, and reduced returns, making careful processing an essential part of the seaweed value chain. Seaweeds should be harvested at the appropriate stage of maturity and handled carefully to minimize damage. Immediately after harvesting, the biomass is washed with clean seawater to remove sand, shells, epiphytes, and other adhering impurities. It is then sorted to separate healthy material from damaged or discoloured portions, ensuring a clean and uniform product for further processing. Drying is the most critical post-harvest operation, as freshly harvested seaweed contains high moisture content and is highly susceptible to spoilage. Sun drying on clean nets, bamboo mats, or raised platforms is the most commonly adopted method because it is simple, economical, and suitable for coastal communities. Proper drying reduces the moisture content to a safe level, thereby improving shelf life and facilitating storage and transportation. Once dried, the seaweed should be packed in clean, moisture-resistant bags and stored in a cool, dry, and well-ventilated place to maintain its quality until marketing or processing ([Sánchez-García et al., 2021](#)). While dried seaweed itself is a valuable commercial product, value addition can substantially enhance farmers income and create new market opportunities. Depending on the species and intended use, seaweed can be processed into products such as seaweed powder, flakes, liquid seaweed extracts, biofertilizers, plant bio stimulants, animal feed supplements, and food ingredients. At the industrial level, commercially important hydrocolloids such as agar, alginate, and carrageenan are extracted from selected seaweed species and are widely used in the food, pharmaceutical, cosmetic, and biotechnology industries ([Anjana and Arunkumar, 2024](#); [Rupert et al., 2022](#)). Thus, efficient post-harvest handling combined with value addition not only improves product quality and shelf life but also increases profitability, reduces post-harvest losses, and strengthens the overall sustainability of the seaweed farming enterprise.

Livelihood relevance and women's empowerment

Seaweed farming has emerged as a promising livelihood option that supports the economic development of coastal communities while promoting the sustainable use of marine resources. In many coastal regions, fishing remains the primary source of income, however, seasonal fishing bans, declining fish catches, and climate-related uncertainties often affect household earnings. Seaweed cultivation offers an alternative and supplementary livelihood that can be integrated with existing fishing and aquaculture activities, thereby improving income stability and enhancing the resilience of coastal communities. Beyond cultivation, seaweed farming generates employment across the entire value chain, including nursery development, preparation of planting material, farm installation, crop maintenance, harvesting, drying, processing, value

addition, packaging, and marketing (Duarte, Bruhn and Krause-Jensen, 2022). These diverse activities create opportunities for entrepreneurship, support the development of small-scale enterprises, and strengthen local economies. The formation of self-help groups (SHGs), cooperatives, and farmer producer organizations (FPOs) further facilitates collective production, improves access to markets, and enhances the adoption of improved farming technologies. A notable feature of the seaweed sector is its potential to empower women through meaningful participation in both production and post-harvest operations (Msuya and Hurtado, 2017). Activities such as seedling preparation, tying of propagules, sorting, drying, grading, processing, packaging, and value addition require skill, precision, and careful handling, enabling women to play a central role in the seaweed value chain. Participation in these activities provides opportunities for income generation, entrepreneurship, capacity building, and financial independence while strengthening their role in household decision-making and community development. Across several coastal regions, women-led self-help groups have successfully demonstrated that seaweed farming can serve as an effective tool for socio-economic empowerment and inclusive rural development. By creating sustainable livelihood opportunities, generating employment, and promoting women's economic participation, seaweed farming contributes significantly to the overall development of coastal communities. Its ability to combine livelihood enhancement with social inclusion makes it an important component of sustainable coastal development.

Seaweed farming, climate change and the blue economy

Climate change has emerged as one of the greatest challenges affecting marine ecosystems and coastal livelihoods. Rising sea surface temperatures, ocean acidification, changing rainfall patterns, and the increasing frequency of extreme weather events have significantly influenced marine biodiversity and fisheries production. In this context, seaweed farming is increasingly recognized as a nature-based solution that can contribute to climate resilience while supporting sustainable coastal development. As seaweeds grow, they absorb carbon dioxide through photosynthesis and convert it into biomass, thereby contributing to the marine carbon cycle (Bhuyan *et al.*, 2021). They also take up dissolved nutrients, such as nitrogen and phosphorus, from seawater, helping to improve water quality and reduce nutrient enrichment in coastal ecosystems. Although seaweed farming alone cannot mitigate climate change, it can complement broader climate adaptation and mitigation strategies by promoting healthier and more productive coastal environments. Seaweed farming is also closely aligned with the principles of the Blue Economy, which emphasizes the sustainable use of ocean resources for economic growth, improved livelihoods, and environmental conservation. Unlike many land-based production systems, seaweed cultivation does not require fertile land, freshwater, or chemical fertilizers, making it a resource-efficient and environmentally sustainable marine enterprise. In addition to supporting food, agriculture, pharmaceuticals, and other industries, seaweed farming creates employment opportunities, encourages entrepreneurship, and strengthens the resilience of coastal communities. With increasing scientific research, technological advancements, and supportive government initiatives, seaweed farming is gaining recognition as an important component of

sustainable coastal resource management. By integrating environmental stewardship with livelihood generation and economic development, seaweed farming has the potential to play a significant role in building climate-resilient coastal communities and advancing a sustainable Blue Economy (Saravanan, Chatterjee and Bhowmick, 2023).

Government schemes and initiatives for promoting seaweed farming in India

Recognizing the immense potential of seaweed farming for livelihood generation, sustainable aquaculture, and the Blue Economy, the Government of India has introduced several policy initiatives and financial support programmes to promote the development of the seaweed sector. These initiatives focus on expanding commercial cultivation, strengthening infrastructure, improving access to quality planting material, enhancing post-harvest management, and creating market opportunities for seaweed farmers.

1 Pradhan Mantri Matsya Sampada Yojana (PMMSY)

In June 2020, the Government of India introduced the Pradhan Mantri Matsya Sampada Yojana (PMMSY) with a total budget of ₹20,050 crore to accelerate the expansion of the fisheries sector, with seaweed cultivation as a key area (Krishna, 2021). Between 2020 and 2025, ₹640 crore has been earmarked specifically for promoting seaweed cultivation, reflecting the government's commitment to developing this sustainable sub-sector. Of this allocation, ₹194.09 crore is dedicated to flagship initiatives such as the establishment of a Multipurpose Seaweed Park in Tamil Nadu and a Seaweed Brood Bank in Daman and Diu. To scale production, approvals have been granted for 46,095 rafts and 65,330 monoclone tube nets for seaweed farming. Under PMMSY, India targets an increase in seaweed production to 1.12 million tonnes over the next five years (Dineshkumar, Bhagiya and Mantri, 2025). Indian seaweed cultivation currently depends on *Kappaphycus alvarezii* along with a narrow set of native species, and this narrow genetic base is contributing to weaker growth rates and greater vulnerability to disease outbreaks. To address this challenge, the Department of Fisheries notified guidelines on 31 October 2024 for the import of live seaweeds, enabling access to improved strains and supporting productivity, biosecurity, and trade expansion. The Union Budget 2026–27 provides a record ₹2,761.80 crore for the fisheries sector, with ₹2,530 crore for scheme-based support. PMMSY remains the core programme, receiving ₹2,500 crore to strengthen fisheries and aquaculture development.

2 Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PMMKSSY)

The Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PMMKSSY) complements PMMSY by promoting modernization and formalization of the fisheries sector. Although it is not exclusively designed for seaweed farming, the scheme supports activities related to quality assurance, traceability, market access, digitalization, infrastructure development, and value chain strengthening. These interventions benefit seaweed farmers by improving market connectivity, encouraging value-added processing, and enhancing the competitiveness of seaweed-based products in domestic and international markets.

3 Seaweed Mission

Due to seaweed's potential for industrial uses, climate resilience, livelihood generation, and nutritional security, the Indian government has designated seaweed production and value addition as a priority area under the blue economy. Under the PMMSY (Pradhan Mantri Matsya Sampada Yojana), the government has set aside a total budget of Rs. 640 crores for seaweed cultivation in India between 2020 and 2025. In order to expand and strengthen the seaweed production ecosystem and value chain, the Indian government has identified and prioritized seaweed resources as essential to the growth of the blue economy and has launched a number of initiatives, including seed banks, seaweed parks, clusters, and CoE, improved seaweed germplasm, climate resilient villages, and farming models. The mission aims to transform seaweed farming into a sustainable livelihood option while enhancing India's contribution to the growing global seaweed industry (Singh *et al.*, 2026).

These initiatives collectively are creating an enabling ecosystem for the sustainable growth of seaweed farming in India by integrating scientific research, infrastructure development, capacity building, entrepreneurship, and market support. Such coordinated efforts are expected to enhance farmers' incomes, strengthen coastal livelihoods, and promote the sustainable development of the country's marine bioeconomy.

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