From coast to pond: Integrating seaweed aquaculture with brackishwater farming systems

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Seaweed farming in India is an emerging, sustainable aquaculture activity. It creates livelihoods, enhances coastal ecosystem health, and supplies raw material for food, pharmaceuticals, nutraceuticals, cosmetics, biofertilisers, animal feed, and biofuel production. India's extensive estuaries, coastal lagoons, and brackishwater areas present immense potential for expanding seaweed cultivation beyond traditional marine zones. Historically, seaweed farming in India has been restricted to open coastal waters.

Recent research and innovations are opening new opportunities for growing commercially important seaweed species in brackishwater systems, particularly when integrated with shrimp and crab. This integration improves the ecological sustainability of aquaculture and diversifies income for coastal farmers - marking the start of a promising "Blue-Green Revolution". Indian waters contain 865 documented seaweed taxa: 212 species of Chlorophyta, 211 of Ochrophyta, and 442 of Rhodophyta[1].

Promising species for brackishwater cultivation

The most promising brackishwater seaweed species are in the genus *Gracilaria*, including *G. salicornia*, *G. tenuistipitata*, *G. edulis*, and *G. corticata*, which are widely cultivated because of their superior gel strength. *Ulva lactuca* (sea lettuce) is another fast-growing macroalga of commercial importance. These species suit brackishwater environments because of their high tolerance to salinity fluctuations and efficient absorption of dissolved nutrients, contributing to nutrient remediation and improved water quality.

Method of cultivation and key environmental factors

Site selection is critical for successful seaweed cultivation, as environmental stability directly influences growth, biomass yield, and crop quality. In open coastal waters with greater depth and stable salinity, farmers commonly use raft, long-line, or tube-line methods supported by floats and sinkers to keep seaweed within the photic zone. These systems ensure adequate sunlight while minimising physical stress from wave action.

In shallow coastal environments, farmers widely use pole- or stake-based methods, where tube-lines or long-lines are anchored to the substrate for structural stability under fluctuating tidal conditions. In confined or semi-controlled environments such as brackishwater ponds, lagoons, and tanks, farmers can efficiently manage culture conditions. In these systems, both tube-line and raft methods work well, allowing control of stocking density, water exchange, and biofouling.

Gracilaria salicornia.

Gracilaria tenuistipitata.

Gracilaria edulis.

Optimal seaweed production requires adequate sunlight, a continuous supply of dissolved inorganic nutrients, and salinity within the species-specific tolerance range. One major advantage of seaweed cultivation is its short culture cycle and minimal inputs. Most commercially important species need no external feed or fertilisers when grown in nutrient-rich waters. This low-input, eco-friendly nature makes seaweed farming an attractive and sustainable livelihood option for coastal and brackishwater farmers.

Rising momentum and innovative farming practices for brackishwater seaweed

Rising industrial demand and a growing need for sustainable, diversified aquaculture are driving the rapid expansion of seaweed farming in brackishwater systems. Although production volume is important, seaweed biomass quality determines market price and industrial applicability, particularly for agar-bearing red seaweeds. In this context, innovative onshore and integrated farming approaches are increasingly recognised as reliable alternatives to conventional offshore cultivation, as they allow better control over environmental conditions and product quality.

Ulva lactuca.

Seaweed quality determines commercial value, especially in agarophytes, where gel strength, purity, colour, and consistency govern suitability for food, pharmaceutical, and biotechnology industries. Open-water cultivation often exposes seaweeds to epiphytic infestation, fouling organisms, sediment deposition, and grazing, which reduce growth and agar quality, ultimately lowering market acceptance and price. In contrast, confined-water systems such as lined ponds, tanks, and brackishwater enclosures offer better control over key environmental parameters, minimise infestation, and enable production of cleaner, more uniform biomass with superior gel characteristics.

Despite these advantages, seaweed monoculture in confined systems often fails to generate sufficient economic returns to cover operational and maintenance costs. To address this, integrating compatible aquaculture species is essential for improving profitability and sustainability. Integrated farming systems enable efficient use of nutrients from fed species, improve water quality through biological nutrient uptake, generate additional income from multiple crops within the same production cycle, and enhance overall resource-use efficiency. Integrating seaweed into brackishwater farming systems also reduces net greenhouse gas emissions, supports climate-resilient and environmentally sustainable aquaculture, and adds value through carbon-efficient biomass production. Integrating seaweed with fish and shellfish farming also improves immunity, disease resistance, and survival because of the diverse bioactive compounds in seaweeds. The success of such integration largely depends on selecting seaweed species that can tolerate the same salinity as the co-cultured animal and reach maximum biomass within the culture duration of the associated species.

1. Integration of seaweed with shrimp culture

Among various integrated approaches, shrimp-seaweed co-culture has emerged as one of the most promising practices for confined brackishwater systems. Penaeid shrimp farmers typically culture shrimp over 90-120 days at an optimal salinity of 20-32 ppt, which suits most *Gracilaria* species. *G. salicornia* is particularly suitable for integration with shrimp because of its short cultivation cycle of 45-55 days, its capacity for a three- to five-fold increase in biomass, and its high tolerance to the salinity fluctuations common in shrimp ponds. These attributes allow two consecutive seaweed harvests within a single shrimp production cycle, generating additional income without extending the culture duration.

In integrated shrimp ponds, farmers grow seaweed using tube net systems installed so they do not interfere with aeration or shrimp movement. Tube nets are tied to ropes and positioned at the right depth to ensure adequate light penetration, optimal water exchange, and uniform seaweed growth both within and outside the net structure. Proper spacing between ropes is critical to avoid self-shading and maximise biomass accumulation. Regular monitoring and cleaning of tube nets prevent fouling and maintain good growth rates.

Commercial shrimp feeds generally contain 30-40% crude protein. Shrimp assimilate only about 20-25% of this, and the remainder accumulates in the pond as organic waste. Seaweeds efficiently absorb dissolved inorganic nutrients released from uneaten feed and shrimp excreta, supporting their growth without additional fertiliser inputs. As a result, ammonia and nitrite concentrations remain low, water quality is stabilised, turbidity stays at levels favourable for light penetration, and dissolved oxygen is sustained through appropriate aeration and water circulation. Tube nets can be reused for multiple production cycles after proper treatment, reducing operational costs.

Field evaluations and experimental studies have consistently shown that shrimp-seaweed co-culture improves feed utilisation efficiency, reduces the feed conversion ratio, and enhances the nutritional and organoleptic qualities of shrimp, including flesh colour and texture, partly because of the natural live feed associated with seaweed biomass. ICAR-CIBA standardised the co-culture technology of *G. salicornia* with *P. vannamei* under different stocking densities, achieving more than a three-fold increase in seaweed biomass, approximately 1.2 t of seaweed from a 0.1 ha lined pond, and shrimp survival exceeding 95% at a harvest size of 45 count. Field demonstrations at Mulapolam, Andhra Pradesh, in collaboration with MoU partner M/s. Uday Aqua Pvt. Ltd., further validated the technology, yielding higher combined

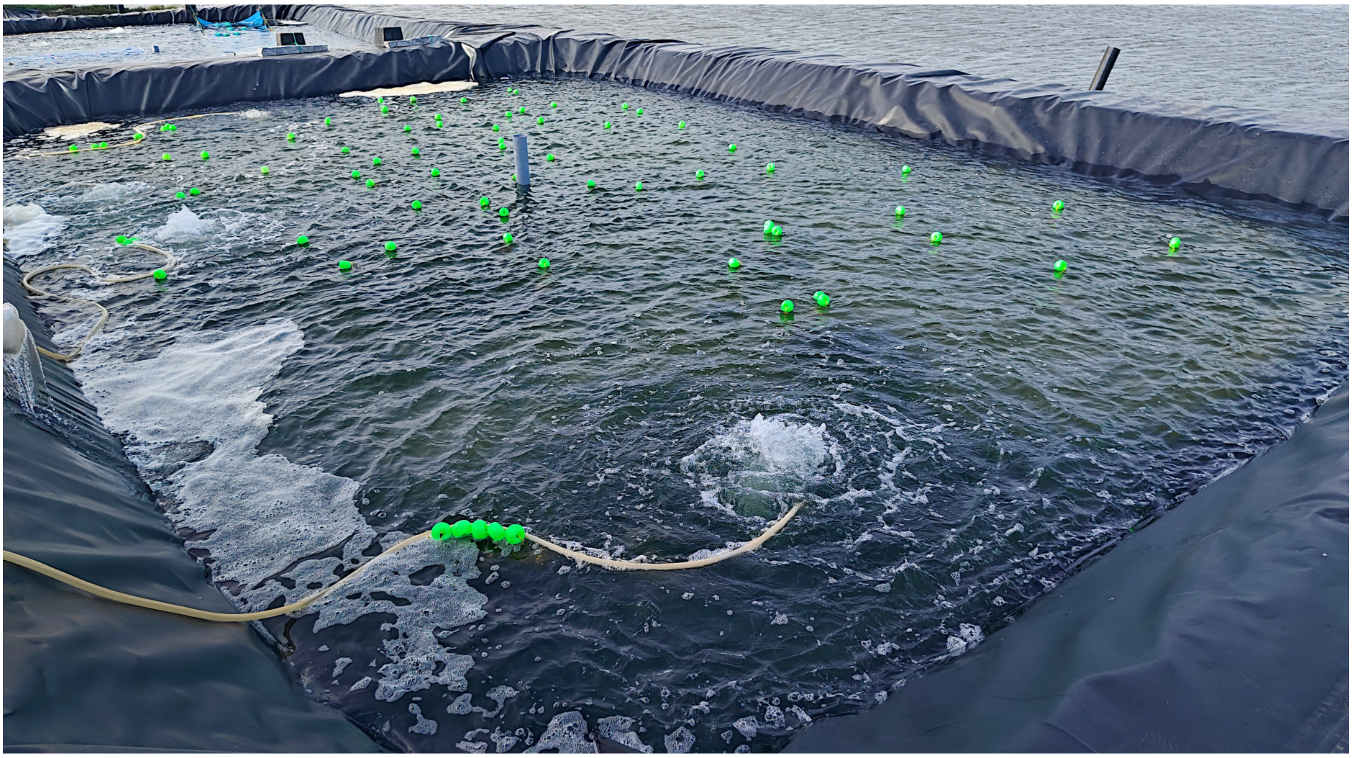
Right, below: Harvested biomass of Gracilaria salicornia from a shrimp pond.

economic returns and a reduced FCR. Retaining a portion of the harvested seaweed as seed material for subsequent crops ensures continuity of production, highlighting the strong potential of this mutually beneficial system for sustainable shrimp farming.

2. Integration of seaweed with mud crab farming

High cannibalism is a major challenge in mud crab farming, from the megalopa stage through grow-out. Adequate shelter is critical for improving survival. Experimental trials at ICAR-CIBA using *G. tenuistipitata* and *G. salicornia* recorded 60-80% survival from megalopa to instar stages, as crab larvae effectively use seaweed thalli as refuge from cannibalism. Before introduction into larval rearing tanks or ponds, seaweeds must be properly treated to remove associated organisms, particularly amphipods and other live feeds. For mid- and grow-out phases, seaweed integration offers both shelter and additional income. Earthen ponds with a water depth of 1.0-1.2 m are ideal for mud crab culture. Farmers can install seaweed tube-nets or place seaweed bunches at strategic locations to act as moulting shelters, reducing predation on soft-shelled crabs. Mud crab grow-out typically lasts 6-8 months at a stocking density of 0.1-0.2 / m², allowing multiple seaweed harvests at 55-day intervals. Harvested seaweed can be marketed fresh or dried. Seaweed also provides shaded microhabitats during periods of high temperature, reducing thermal stress and associated mortality.

Right, harvested biomass of Gracilaria salicornia from a mudcrab pond, below.



3. Integration of seaweed with finfishes

Seaweed can also be integrated with commercially important brackishwater finfishes, where it functions as a nutrient sink and habitat structure. By absorbing excess nutrients, seaweed helps maintain water quality, while fish use the associated natural live feeds, improving the feed conversion ratio (FCR) and growth performance. Suitable species for integrated systems include seabass, mullets, pearlspot, snapper, and milkfish. For herbivorous fish such as milkfish, grazing on seaweed should be prevented by fencing tube nets or culturing seaweed in cages or hapas, depending on fish size and stocking density.

Above, below: Raft cultivation of Gracilaria salicornia in fish pond.

Spatial technologies for managing seaweed resources

Spatial technologies are now available to map, monitor, and manage coastal resources effectively. The rise of temporal and multi-scale satellite data, alongside advances in geographic information systems, has revolutionised how we observe and manage coastal areas, including vital ecosystems such as seaweeds and mangroves. Spectral indices derived from satellite data help identify existing seaweed zones and track their distribution and changes over time. Satellites such as Landsat, Sentinel, MODIS, and WorldView are especially useful for mapping seaweed beds and identifying areas suitable for expanding seaweed and aquaculture. This monitoring is key to promoting the expansion of these vital coastal ecosystems. It supports conservation efforts, informs policy-making, and helps resolve conflicts among multiple users.

Challenges and constraints in brackishwater seaweed farming

Despite its significant potential for sustainable aquaculture diversification, brackishwater seaweed farming in India faces several scientific, technical, and institutional challenges. One primary limitation is the restricted availability of high-quality, disease-free seed stock, largely because of the absence of dedicated large-scale seaweed hatcheries and propagation facilities. As a result, farming operations rely heavily on wild-collected biomass, which requires extensive pre-treatment to eliminate epiphytes, fouling organisms, and potential pathogens, increasing labour inputs and operational costs.

Environmental variability poses another major constraint, particularly in brackishwater systems that are highly susceptible to abrupt salinity fluctuations during monsoon rainfall and freshwater inflow. Such sudden changes affect seaweed physiology, leading to suppressed growth rates and inconsistent biomass yields. Furthermore, more than 95% of seaweed biomass in India is still harvested from wild or open-water sources. This often results in heterogeneous quality, higher contamination levels, and lower market prices compared to biomass produced under controlled farming systems.

In recent years, diseases have become a growing concern in mariculture. Disease outbreaks can significantly reduce the yield and quality of cultivated seaweeds. Major seaweed diseases are caused by pathogenic bacteria, fungi, viruses, and epiphytic algae, as well as environmental stressors such as temperature fluctuations, poor water quality, and nutrient imbalance. Common disease symptoms include bleaching, rotting, tissue softening, and abnormal growth. Effective disease management relies on good farm hygiene, healthy planting material, well-chosen sites with proper water exchange, and regular monitoring to minimise stress and prevent outbreaks.

The absence of standardised price fixation mechanisms for high-quality seaweed produced in confined or integrated systems significantly discourages farmers from adopting improved culture practices. This issue is compounded by the lack of accessible quality assessment and certification facilities. Without these, producers must rely on buyer-driven price determination without objective evaluation of agar yield, gel strength, or purity. Inadequate standardised protocols for harvesting, post-harvest handling, packing, and transportation - particularly regarding optimal moisture content and biomass integrity - result in post-harvest losses and quality deterioration.

Limited awareness and insufficient capacity-building initiatives among coastal and brackishwater farmers also constrain wider adoption of integrated seaweed-based farming models.

Above left, right: Epiphytic growth on seaweed.

Targeted training programmes, extension support, and demonstration of techno-economic viability are essential to overcome these barriers and enable large-scale, sustainable expansion of brackishwater seaweed farming.

Conclusion

Brackishwater seaweed farming, when thoughtfully integrated with shrimp, mud crab, and finfish aquaculture, offers India a sustainable, low-input, high-reward opportunity. By enhancing resource-use efficiency, improving water quality, and generating additional income, integration elevates seaweed farming to the next level. High-quality seaweed biomass commands better market prices and contributes to improved growth, colour, texture, and taste of co-cultured aquatic animals. With growing global demand for seaweed-based products, integrated farming systems can play a crucial role in strengthening the Blue Economy and ensuring the sustainability, resilience, and long-term profitability of brackishwater aquaculture.

References

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