SEAWEED BIOSTIMULANTS:
A guide for seaweed farmers entering the biostimulants market

July 2026

The Nature Conservancy

HATCH BLUE

WORLD BANK GROUP

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Authors

Lead author		
Catriona Macleod, Adjunct Professor, University of Tasmania		
Co-authors		
The Nature Conservancy	**The World Bank**	**Hatch Blue**
Tiffany Waters, Global Aquaculture Associate Director	Harrison Charo Karisa, Senior Fisheries (Aquaculture) Specialist	Peter Green, Project Manager
Heidi Alleway, Senior Aquaculture Scientist	Vivek Prasad, Knowledge and Innovation Specialist	Tanja Hoel, Managing Director
Kayleigh Hamernick, Mariculture Policy Project Lead	Jeehye Kim, Senior Agriculture Economist	
Taylor Voorhees, Global Aquaculture Director		

Attribution

The Nature Conservancy, The World Bank, and Hatch Blue. (2026). *Seaweed biostimulants: A guide for seaweed farmers entering the biostimulants market*. https://www.aquaculturescience.org/seaweed-biostimulants-farmer-brief

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Back cover photo: Seaweed harvest on Pemba Island, Tanzania. Photo by Roshni Lodhia, © TNC.

Copy editing and design: Tracey Westfield, Horizon26.

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Acknowledgments

This guide is the second of two reports prepared in response to the requirements and aspirations voiced at an October 2025 convening of industry, research, and government professionals in Washington, DC, U.S., organized by The Nature Conservancy, The World Bank, and Hatch Blue. See the appendix for a full list of participants. One objective of this roundtable was to enhance understanding and facilitate knowledge exchange regarding the opportunities and challenges inherent in establishing a robust global seaweed biostimulant market and industry. Another was to begin identifying priority interventions. The first report is a white paper, separate from this guide, that provides an overview of the advantages of seaweed biostimulants, outlines the benefits they offer to agriculture and regional economies, and provides a structured roadmap for integrating seaweed biostimulants into sustainable agricultural practices. This guide is the second report and serves as a resource for seaweed farmers, aiming to equip them with market and regulatory knowledge of the global seaweed biostimulants industry.

We express our sincere gratitude to each of the roundtable participants and to the many individuals and companies whose generous contributions of time and resources enabled these discussions to take place.

The team would like to acknowledge the Global Directors of Farming and Agribusiness (FAB) and Environment (ENV) departments, Anup Jagwani (FAB), and Valerie Hickey (ENV), Shobha Shetty (Snr Adviser Agriculture and Head GAFSP), and Managers Marianne Grosclaude (FAB), and Jiang Ru (ENV) for encouraging publishing this work.

We would like to express our many thanks to the International Finance Corporation's headquarters staff for providing the convening space for the roundtable, in particular Ramon Yndriago and colleagues for their wonderful support. We would also like to express our gratitude to Toby Berkman, Sofia Soto Reyes, and Charlotte Goodman at Consensus Building Institute for their expert roundtable facilitation. Last, but not least, we would like to thank the Korea World Bank Partnership Facility and the Builders Vision for their generous financial support of the roundtable and this white paper, as well as Norad, the Norwegian Agency for Development Cooperation, for their support.

Supported by

Acronyms

BAFS	Philippines Bureau of Agriculture and Fisheries Standards
CAGR	compound annual growth rate
CE	Conformité Européenne
EAE	enzyme-assisted extraction
EBIC	European Biostimulants Industry Council
EU	European Union
EUR	euro
FCO	Fertilizer Control Order (India)
FPA	Philippines Fertilizer and Pesticide Authority
FPR	Fertilizing Products Regulation (EU)
MAE	microwave-assisted extraction
PLE	pressurized liquid extraction
R&D	research and development
SFE	supercritical fluid extraction
TNC	The Nature Conservancy
UAE	ultrasound-assisted extraction
U.S.	United States
USD	U.S. dollar

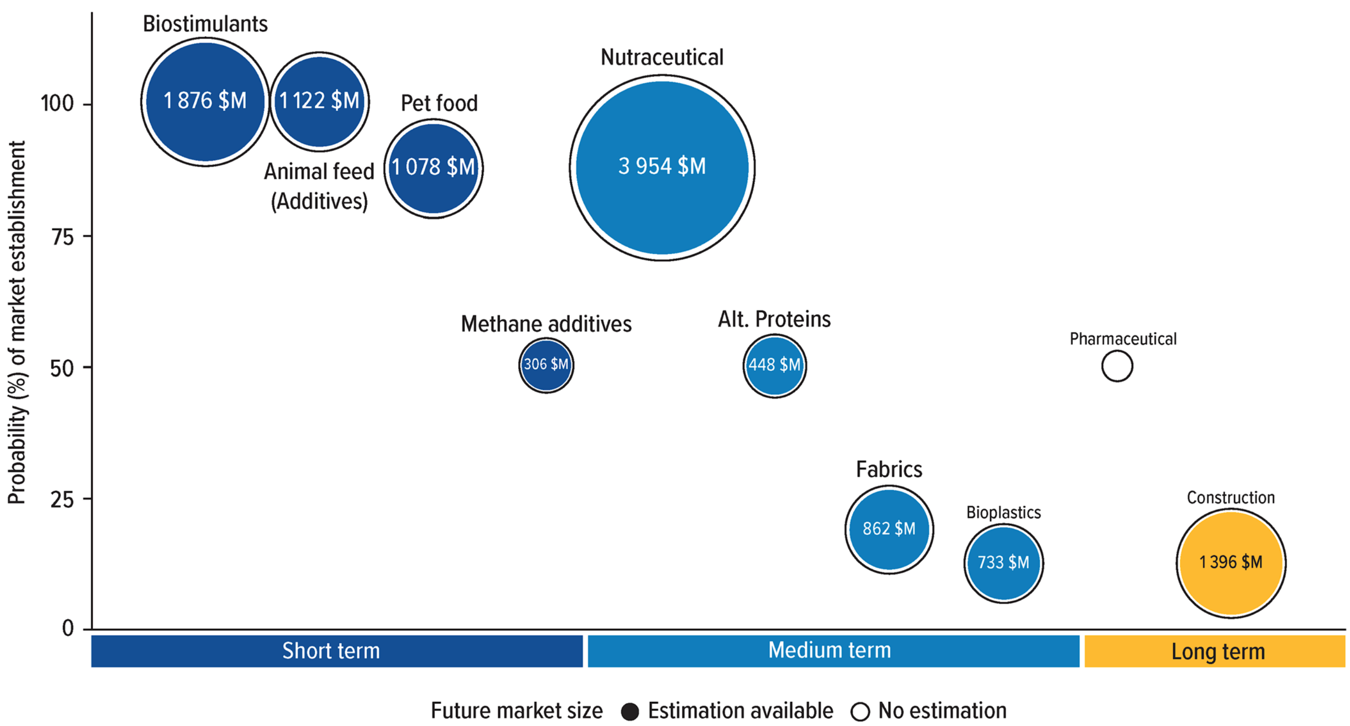
1. Introduction

Seaweed aquaculture presents substantial possibilities. Not only does seaweed provide a sustainable way to produce food, but it also creates economic prospects in both new and traditional bioproduct sectors and offers opportunities for environmental restoration. Meeting the projected demands of a growing global population will require a significant increase in food production by 2050 (Daszkiewicz, 2022). While cultivated seaweed has gained significant attention as a promising alternative food source to address this need (Figure 1; World Bank, 2023), it also offers potential benefits as a biostimulant, which can support conventional food production systems by increasing crop resilience and performance and reducing environmental pressures on terrestrial agriculture.

The substantial challenges confronting our food production systems—including those arising from climate change, food insecurity, limited freshwater resources, and soil degradation—may be mitigated, in part, by incorporating seaweed-derived biostimulants. These biostimulants have demonstrated positive effects, such as enhanced plant growth, improved stress resilience, and increased soil health (Ali et al., 2021). As such, seaweed farming could play an important role in advancing sustainable livelihoods, mitigating climate change, and bolstering food security (World Bank, 2023), with these advantages potentially exceeding those associated with simply using seaweed as an alternative food source.

Seaweed farming is gaining attention as a potential solution for climate change mitigation, showing promise as a low-carbon product alternative and offering diverse potential environmental co-benefits. Yet, outside of Asia and other key geographic areas, the sector remains limited in extent, and efforts to establish new enterprises over the last several decades, particularly in temperate regions, have had low success rates. Without secure, robust markets, it is likely that the current seaweed momentum will be fleeting and will collapse, and with it, the key climate and biodiversity benefits a scaled industry would bring. The sector should promote its benefits and learn from others to avoid becoming isolated.

Figure 1. World Bank report estimate of future market size (World Bank, 2023).



Research from The Nature Conservancy & Bain (2023), the World Bank (2023), and the International Finance Corporation (2025) analyzed the top markets to support the growth of the seaweed industry. All reports identified biostimulants as the most or one of the most viable and promising near-term markets. While seaweed farming is a common global industry, large-scale biostimulant production via aquaculture is a relatively recent development with the potential to deliver notable economic and environmental benefits. DunhamTrimmer has estimated the 2024 global seaweed biostimulant market to be over USD 1.4 billion, with projections suggesting it could reach USD 2.4 billion by 2030 (DunhamTrimmer, 2025). In 2024, seaweed-based plant biostimulants accounted for 31.6% of the global biostimulant market, with projections indicating that this share would roughly hold at 30.9% by 2030. As such, seaweed farming could play an important role in advancing sustainable livelihoods, mitigating climate change, and bolstering food security (World Bank, 2023).

While biostimulants are promising, challenges remain. Seaweed farmers and biostimulants manufacturers must understand the market and value chain to align their business models effectively. Small-scale seaweed farmers that are primarily focused on production and are not virtually integrated should understand the basic needs of the market that they are selling into, including processing requirements. Virtually integrated seaweed farmers and biostimulant manufacturers should have clarity on processing, identifying low-cost extraction methods, defining a minimum viable product, and understanding biostimulant benefits and product refinement. Aligning suppliers with buyers requires investments and partnerships with downstream market players. Seaweed farmers and biostimulants manufacturers cannot build the biostimulants market alone—they must collaborate with land-based farmers to develop these markets together.


Seaweed farm in Placencia, Belize. Photo by Randy Olson, © TNC.

2. Seaweed biostimulants market

2.1. Global market status

A recent economic study valued the seaweed biostimulants market at roughly USD 1.4 billion globally, with USD 391.2 billion for Latin America, USD 355.8 million for the Asia-Pacific region, USD 313.6 million for the United States and Canada, USD 225.2 million for Europe, and USD 125.9 million for Africa (DunhamTrimmer, 2025). Latin America's seaweed biostimulant sector has expanded to nearly 27%, while the Asia-Pacific region's market has grown to 25% (Figure 2). Although growth in the United States and Canada is slowing due to the regional market's maturity, this region continues to have a large overall market value, and Canada has among the highest projected growth rates (10.7% compound annual growth rate [CAGR]; DunhamTrimmer, 2025). Forecasts show both Latin America and the Asia-Pacific region will sustain robust expansion (12% CAGR) through 2030 and beyond, especially as demand rises in China and India. Brazil and China have surpassed previous predictions, with Brazil experiencing strong compound growth and China likely still undervalued (DunhamTrimmer, 2025).

Beyond its economic value, the seaweed biostimulants market offers benefits for agricultural production and sustainability. Despite some signs of slowing economic growth in China and other Asian countries, projections indicate substantial population increases in Africa and highlight the urgent need to boost agricultural and aquaculture production to meet rising demand (World Bank, 2023).

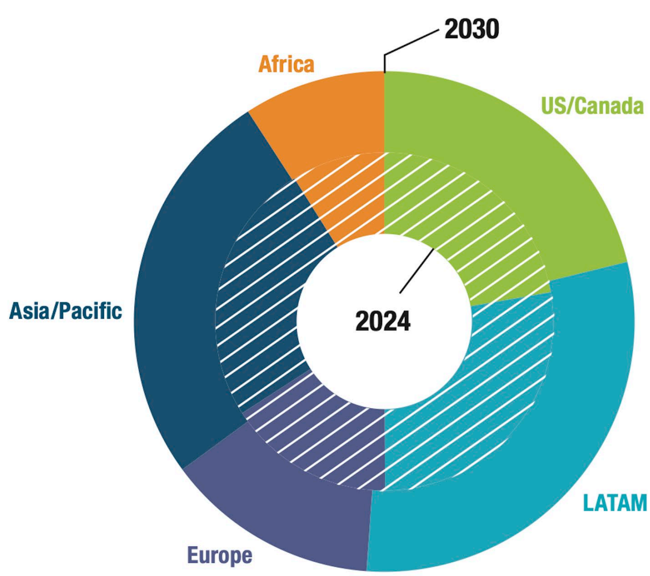
The Middle East and Asia, particularly India, are expected to see even faster growth. Although there are risks of the seaweed biostimulants market becoming commoditized, profit margins remain appealing due to relatively low production costs and strong commercial strategies (DunhamTrimmer, 2025).

The global agricultural sector, including intensive farming, subsistence agriculture, forestry, and horticulture, is increasingly susceptible to the impacts of climate change. Consequently, there is a growing

Figure 2. Seaweed biostimulants: Regional market size (DunhamTrimmer, 2025).

GLOBAL SEAWEED EXTRACTS: REGIONAL SHARES 2024, 2030

REGION	2024	2030
US/Canada	22.2%	21.2%
LATAM	27.7%	30.0%
Europe	16.0%	13.8%
Asia/Pacific	25.2%	25.9%
Africa	8.9%	9.2%



demand for solutions that effectively improve current farm management practices, optimize fertilizer application, enhance soil quality, and maximize water-use efficiency. Seaweed-based biostimulants can serve an important function in sustainably increasing productivity and supporting the achievement of these objectives.

2.2. Products, components, and functions

Seaweed biostimulants are most commonly available as liquid extracts but can also be accessed as dried and granular products. They are designed to enhance plant growth, improve stress tolerance, optimize nutrient uptake, and increase crop quality. These benefits could potentially reduce dependence on other fertility and nutrition inputs by improving their effectiveness (European Biostimulants Industry Council [EBIC], 2023; Goñi et al., 2021; Nanda et al., 2022; Panday et al., 2024).

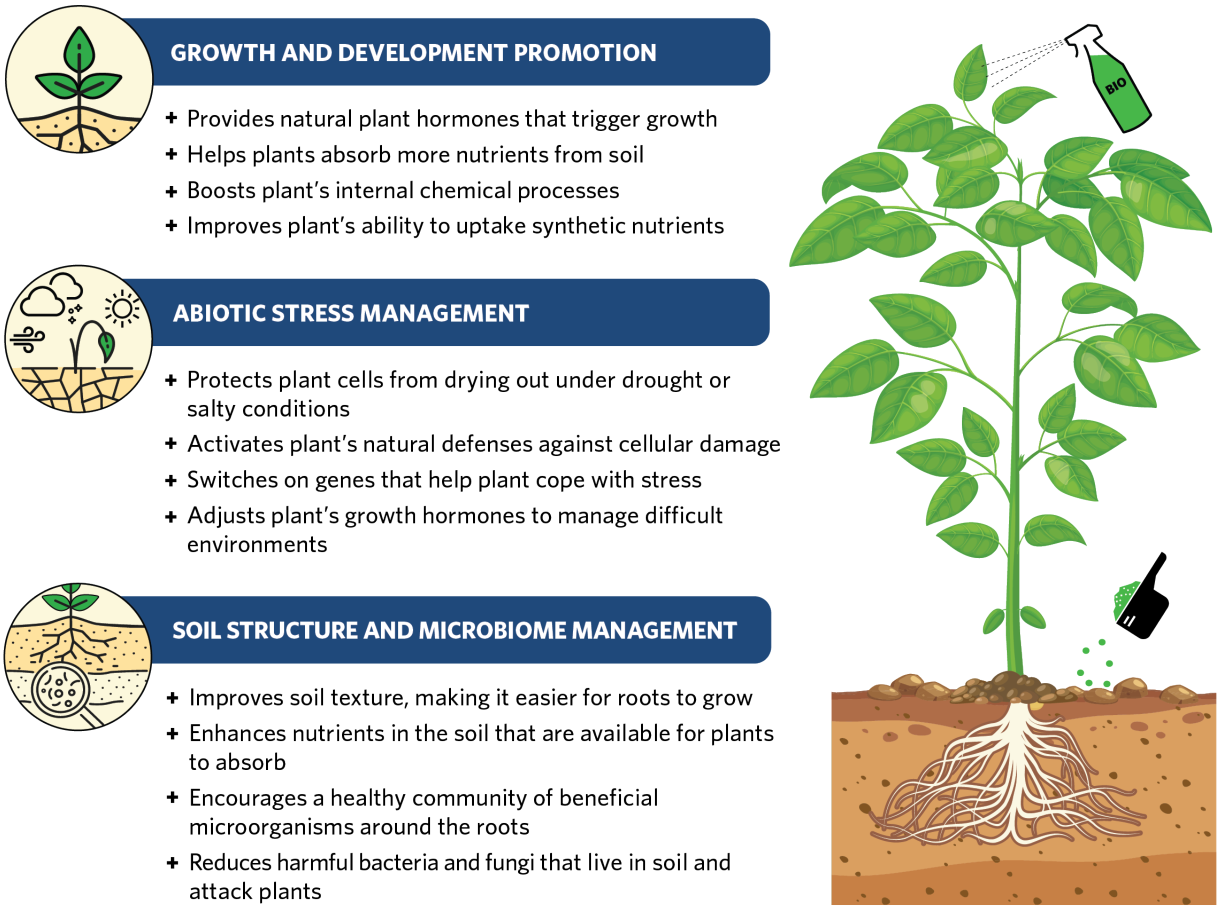
Additionally, biostimulants may help plants better endure environmental stresses, including drought (Goñi et al., 2018; Martynenko et al., 2016; Rasul et al., 2021), and support increased microbial activity (Khan et al., 2009; Renaut et al., 2019), making them especially advantageous in systems that are not irrigated and of particular interest to organic and regenerative agricultural systems. Although the precise modes of action are not always fully understood, the cumulative benefits are well documented. Figure 3 shows some of the key mechanisms, or modes of action, by which seaweed biostimulants can improve plant performance.

A substantial proportion of seaweed biostimulant products currently available are derived from brown seaweed species. The most frequently utilized is *Ascophyllum nodosum*. The following species are also among the most frequently used: *Ecklonia maxima*, *E. cava*, and species in the genera *Sargassum*, *Fucus*, and *Laminaria*; however, numerous other seaweeds cultivated for other applications have been shown to possess biostimulatory properties, as discussed in Section 5.1, titled "What species?"

While the specific ways that individual biostimulant products work are not always fully understood, it is known that certain core biostimulatory ingredients

Sweet potato farm, Mechanicsville, VA, U.S. Photo by Lance Cheung, U.S. Department of Agriculture, public domain.

Figure 3. Overview of the known mechanisms, or modes of action, by which seaweed extracts benefit plant and soil systems, adapted from Rabhi et al. (2025).



have well-established effects. Many seaweed species include several of these effective components (Stirk et al., 2020):

- **Plant hormones** (e.g., auxins and cytokinins): natural regulators of plant growth that help boost root formation and overall vitality.
- **Polysaccharides**: complex carbohydrates, such as alginates and fucoidan, that enhance plant resilience and improve nutrient uptake efficiency.
- **Amino acids**: essential for healthy plant development and managing stress responses.
- **Vitamins, minerals, and micronutrients**: contributors to plant metabolism and overall health.

While it is possible to pinpoint the exact active compounds in each seaweed species and product, such analyses are expensive. Understanding how seaweed biostimulants influence crop responses may be more important than focusing solely on their active ingredients. To do so effectively, biostimulant producers need to clearly understand the benefits their customers hope to achieve. Additionally, it is crucial to recognize how the biostimulatory components in these products can change over time due to factors like location and harvest timing, as environmental conditions play a significant role.

There are three ways to differentiate and build a market for a product: reinforce the proposition for an existing market or application, develop a new market or application for the existing product benefits, and/or identify a novel aspect or need for the product (DunhamTrimmer, 2025; Figure 4). Companies need to consider their options in each category.

2.3. Are the economics viable?

The seaweed biostimulants sector is highly competitive at present. While there are some well-established players in the market, many current manufacturers are small businesses with limited distribution networks, competing against each other as much as the established suppliers of synthetic products. However, ongoing investment in research and development (R&D), paired with scientifically backed product claims, continues to set seaweed biostimulant companies apart as a competitive prospect within the broader biostimulants industry (DunhamTrimmer, 2025).

In North America, seaweed for biostimulants is generally traded as a liquid extract priced at USD 8 to USD 20 per liter. However, there is considerable variation based on species and quality. In Europe, wild-harvested *Ascophyllum nodosum* extracts are priced between EUR 5 and EUR 16 per liter (approximately USD 5.30–USD 16.96), while *Ecklonia*-based products retail at a higher price point, around EUR 20 per liter (about USD 21.20; World Bank, 2023). These examples indicate that products that effectively address market needs and demonstrate reliable performance and quality can secure higher pricing.

The production of farmed seaweed typically incurs higher costs compared to wild-harvested seaweed, primarily due to infrastructure requirements and governance standards. Furthermore, both production and processing methods influence the product's cost structure and final composition, thereby affecting market demand and pricing. Extraction processes play a critical role in determining yield and product quality; advanced or proprietary extraction techniques, while potentially improving results, generally involve greater expense. Efficient production and processing can lower costs.

Additional factors impacting price and profitability:

Geographic origin: Some buyers prefer locally sourced products for quality assurance and biosecurity reasons, which may lead to premium pricing for such items. Globally, regions with lower production costs, such as China, exert downward pressure on prices due to heightened competition.

Market demand and supply: Increasing interest in seaweed-derived biostimulants, coupled with limited availability of high-quality products, can contribute to upward pricing trends. However, the limited margin in most terrestrial farming situations can make any price increase challenging.

2.4. Continuity and consistency of supply

If not carefully managed, wild harvesting can deplete stocks and disrupt habitats, and also lead to inconsistencies in biomass and quality (Kraan, 2020; Lauzon-Guay et al., 2021). In certain geographies, sustainable harvesting from wild populations has proven effective, thanks to healthy stocks and protective regulatory systems. However, overall, global declines in wild seaweed populations due to environmental change and broader anthropogenic impacts may necessitate capping harvests to ensure their continued viability and the health of wild stocks.

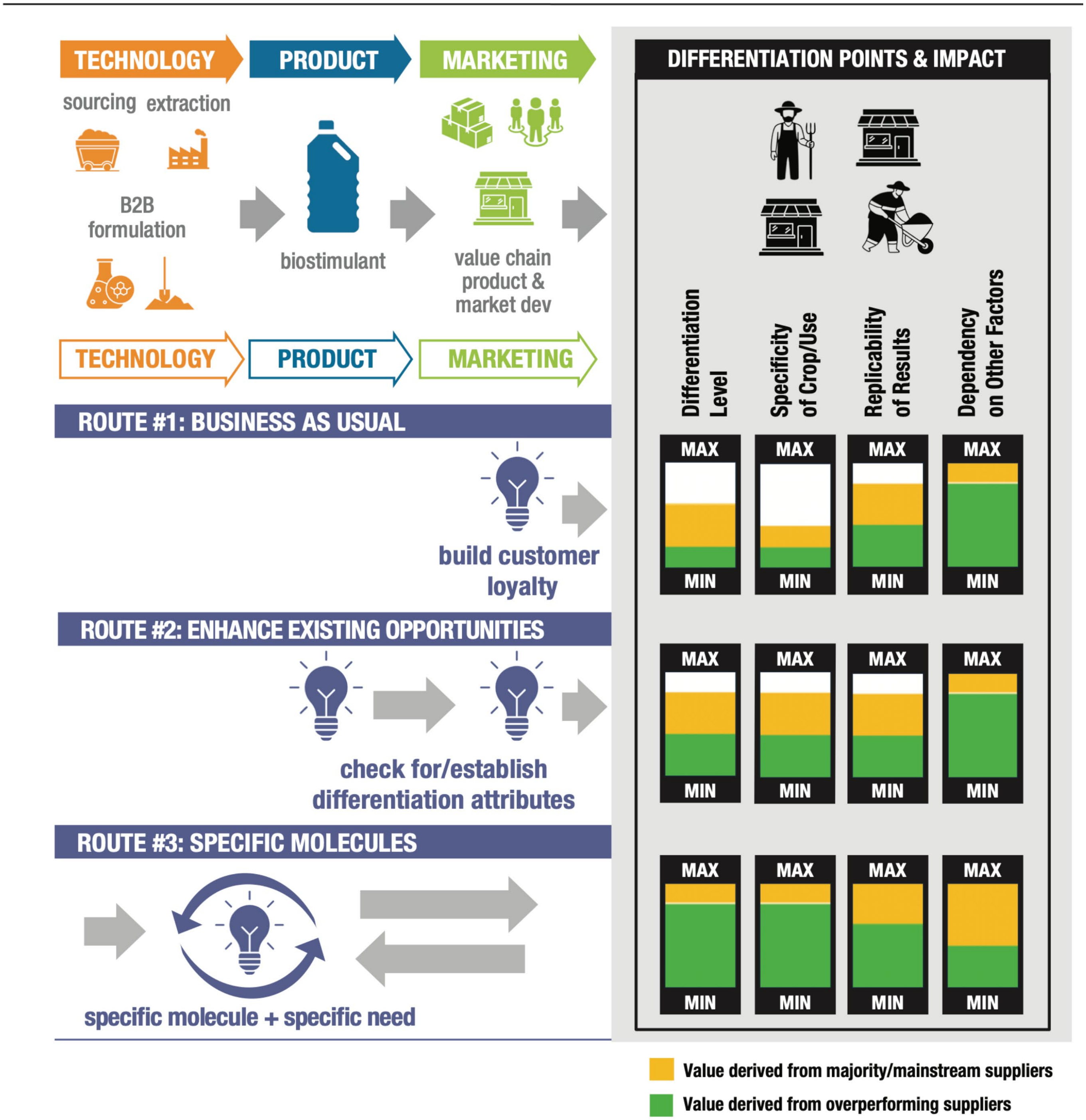
The transition to aquaculture and application of advanced farming techniques presents a significant opportunity to enhance both the availability and quality of species and products.

Seaweed aquaculture can be conducted either in water or on land, each method presenting specific challenges and advantages. In-water approaches utilize longlines, nets, or rafts, selected according to species requirements, environmental conditions, and regulatory frameworks. Land-based systems encompass tanks, raceways, and outdoor ponds. While ponds are generally more cost-effective and straightforward, they offer limited control over environmental factors and, similar to in-water methods, may entail higher biosecurity risks and product variability. Tanks and raceways improve the management

Figure 4. Routes to innovation (DunhamTrimmer, 2025).

Three Routes of Innovation

There are three different paths of innovation that biostimulant companies can pursue in order to differentiate their product(s) or brand, with activities that take place at the Technology, Product, or Marketing level. The more these activities are focused on specific elements of the Technology and Product, the more exclusive the list of companies that are realizing value.



of production conditions in large-scale operations but require greater initial capital, which impacts overall costs. At present, large-scale production of seaweed for biostimulant applications primarily concentrates on kelp species, which are predominantly cultivated in open-water marine environments. It is essential to clearly understand expectations and trade-offs when formulating a business plan.

Key challenges in growing the seaweed biostimulant sector, such as hiring skilled staff, controlling costs, and ensuring seedstock supplies, mirror those faced by the wider seaweed aquaculture industry. Seedstock propagation and strain development require specialized facilities and expertise, often necessitating collaboration among industry players, research organizations, governments, and investors. Although established companies may be further along with these technologies, newcomers might need additional assistance.

Similarly, efforts to optimize biostimulant production are likely to rely on technological advancements across the sector, which can improve operational efficiency and lower the costs associated with farming, harvesting, product extraction, and refinement. As demand for these products grows, economies of scale combined with ongoing innovations should facilitate further cost reductions. However, realizing these benefits will necessitate collaboration among sector participants, government entities, and industry stakeholders to promote the research and innovation required to implement effective cost-reduction measures.

It is essential to recognize that biostimulants are not one-for-one substitutes for fertilizers or other conventional agricultural inputs. Instead, they help increase nutrient uptake efficiency, improve crop quality and performance, and potentially lessen dependence on fertilizers and agricultural inputs. Therefore, their cost should be evaluated alongside these advantages.

2.5. Competitive landscape

Seaweed biostimulants face competition from more affordable, established synthetic fertilizers and conventional agricultural inputs. As previously mentioned, biostimulants are not intended as direct substitutes for fertilizers. Instead, they are generally applied as supplements to improve fertilizer uptake, enhance soil conditions, and improve vegetable or fruit quality (e.g., color, flavor). As many consumers in export supply chains will pay more for higher-quality products, biostimulants typically command premium pricing. This premium is especially true for products derived from seaweed, which are positioned in the higher-end market segment, where their elevated prices are supported by a strong reputation and perceived agronomic benefits, fostering greater acceptance among consumers compared to other biostimulant categories (DunhamTrimmer, 2025).

While market interest is increasing, farmer confidence remains a significant barrier to widespread adoption. Farmers remain skeptical that seaweed biostimulant products deliver enough value to justify the price. Although the organic and sustainable agriculture industries are increasingly recognizing the value of seaweed biostimulants, awareness among farmers more broadly is still limited, and there is an ongoing demand for clear, evidence-based results, the lack of which can slow adoption. Inconsistent field performance and the necessity for comprehensive, multilocation trials continue to present barriers in the efforts to convince farmers to reduce or support synthetic products with seaweed-based solutions (DunhamTrimmer, 2025).

To justify both the benefits and the potential higher costs to producers, manufacturers of seaweed biostimulants must demonstrate clear efficacy and a return on investment for farmers. Scientific validation of product effectiveness and claims across diverse crops, soils, and climates is critical for successful market promotion, substantiation of commercial statements, and demonstration of farmers' return on investment. However, achieving this validation can require extensive and costly field trials

spanning multiple seasons, and farmers may be reluctant to expose their crops and resources to such risk. Increased government support for research and financial safeguards—such as insurance programs to cover potential losses—would significantly facilitate adoption and promote greater data sharing within the sector.

3. Entering the industry: The business model

When considering the biostimulant business model, seaweed farmers must decide whether they are going to also be seaweed or biostimulant producers. While seaweed biostimulants offer significant market potential, many seaweed farmers have viewed them as a low-return option, often using them to support other products or to offload lower-quality harvests. Many seaweed biostimulant manufacturers still operate multiple product lines to take advantage of market opportunities, with biostimulants as just one segment.

The final product determines costs and return on investment for biostimulant producers. Consequently, understanding market demand and product needs is essential for engaging customers and setting achievable price points. Processing methods influence the type and effectiveness of bioactives in seaweed extracts, and as such, seaweed farmers need to be quite clear whether they are providing a raw material or developing a product, not least because the end product will influence both species selection and processing techniques.

Seaweed producers have participated in the seaweed biostimulants sector through various business models. The best model depends on each company's individual goals:

Production focus: Most biostimulants are still currently sourced from wild-harvested seaweed, but rising demand and supply limitations are encouraging companies to engage in aquaculture for biostimulants. Consequently, many companies like Kelpinor (Norway), Cascadia (Pacific Northwest), and Kelp Blue (global) are increasingly focusing their seaweed farming on this market.

Processing focus: Some companies focus solely on biostimulant production by sourcing raw seaweed externally and developing specialized formulations. Examples include Brandt, Inc. (U.S.), FMC Corporation (U.S.), Haifa Negev Technologies (Israel), and AgriSea (New Zealand).

Partnerships: Increasing partnerships reflect the sector's growth, with producers teaming up with agricultural companies (e.g., BASF and Acadian) for better farmer access or merging to form targeted "biologicals" businesses (e.g., Syngenta and Valagro). In other partnerships, individual companies have retained their own identity but have chosen to collaborate to offer greater mutual benefits (e.g., AgriSea working with GreenWave to source kelp from a wider network of regenerative ocean farmers).

As the industry matures and differentiates, more producers may specialize or increase processing capacity, with growing demand driving product innovation.

4. Regulatory barriers to entry

Seaweed products face several key hurdles in accessing the biostimulant market. Key among these are the complexity of regulations and lack of product standardization (Deepika et al., 2022; Du Jardin, 2015; World Bank, 2023). It is important to understand the complex and varying regulatory landscapes for each country in which a business needs to operate and, in particular, the data required for product registration, product approval, and the development of underlying product claims and descriptions that could affect approval.

A primary challenge globally has been the lack of a consistent, internationally agreed-upon definition of biostimulants and a unified understanding of their mode of action. The trend would seem to be moving toward integrating biostimulants into fertilizer or specific bioagricultural frameworks, driven by increasing demand for sustainable agricultural practices. The need to define the *mode of action*—how a product influences the target of its intended application—for classification can be challenging for seaweed biostimulants, as it is often unclear how the effect occurs, even when the actual benefits are well described. Seaweed biostimulants often have a complex and highly variable chemical composition, which makes it difficult to standardize products, understand their precise modes of action, and fit them into existing, often rigid, criteria for agricultural inputs. Often, how a product is classified closely matches the claims made about it, and these claims can either facilitate or restrict access to the market.

Regulatory clarity and consistency are essential. Harmonized product standards for seaweed biostimulants will facilitate global market access, supported by clearer product classification criteria and comprehensive technical guidelines. These measures will help streamline market entry, bolster farmer confidence, and safeguard product efficacy and safety. Achieving these objectives requires a cooperative strategy involving land-based farmers (as customers), seaweed farmers and processors (as producers), and robust regional governmental backing to promote quality assurance, consistency, and expanded international market opportunities.

4.1. Current regulatory and standardization barriers

Different standards and regulations exist worldwide across different levels of governance (Table 1). Many lack clear definitions, standards, or guidelines, resulting in regulatory complexity and confusion, and potentially leading to products being inappropriately classified, restricted, or denied market access.

The United States and China are leaders in the biostimulants market, but neither has a clear national framework or a central registration system. India has made good regulatory progress, establishing its Fertilizer Control Order (FCO) in 2021, which provides clear product categories and mandatory registration, alongside standards for licensing, safety testing, and efficacy validation.

The European Union (EU) stands out as the global leader for harmonized biostimulant regulations and clear testing standards. The EU Fertilizing Products Regulation (FPR), adopted in July 2022, established a unified CE-marking system for biostimulants, including those derived from seaweed, across all 27 member states (EU, 2019). This regulatory framework streamlines product approvals, ensures consistent standards, and reduces barriers to market entry, fostering innovation and growth in the sector. (CE stands for Conformité Européenne, and the CE mark on product packaging indicates that a fertilizing product has been assessed and meets all harmonized EU requirements.)

Beyond the variability among regulatory frameworks, the effectiveness of seaweed biostimulants can also vary greatly based on species, origin, and processing methods. This variability makes it difficult to guarantee product consistency and hence maintain farmer confidence. Complicating matters further, as previously discussed, the exact mode of action for many biostimulants is often unclear. However, improving governance and standardization is crucial for establishing quality and building confidence in seaweed biostimulants. Consequently, instead of focusing solely on molecular mechanisms, attention needs to shift to the actual benefits of biostimulants for crops and soil. Since biostimulants function through complex, multicomponent actions, rather than a single pathway, evaluating efficacy can require robust field data from multiple locations, focusing on tangible results such as improved stress resilience and resource efficiency.

The EU FPR has introduced a CE-marking system for biostimulants to overcome these quality and efficacy concerns. It ensures products comply with rigorous safety, health, and environmental standards (EU, 2019). Obtaining this certification streamlines the approval process, reduces market barriers, and has the potential to advance sector growth. The EU CE certification provides a model for potential adoption in other regions. However, obtaining the CE mark is a complex process: products must undergo thorough third-party evaluation to confirm adherence to EU requirements for health, safety, and environmental protection, as well as validation of agronomic claims according to relevant standards. For biostimulants, manufacturers are required to submit a declaration and provide a comprehensive technical dossier supporting their claims, frequently supplemented by field trial data. Acadian Plant Health has successfully attained certification for its *A. nodosum* products.

A comprehensive review of biostimulant regulations on a global scale is essential to support the development of seaweed production. By examining regulatory frameworks in key regions, such as the EU, the United States, and China, stakeholders can identify optimal strategies for market entry and ensure compliance with regional requirements.

4.2. Aquaculture permitting

Obtaining leases and licenses for seaweed farming is often similarly complicated by inconsistent regulations, which rarely address seaweed directly and can be overly restrictive. Streamlining these laws could enable wider cultivation, promote co-location with renewable energy or other forms of aquaculture, and facilitate international trade.

Table 1. Overview of current regulatory tools and standards for biostimulants in key markets worldwide.

Region	Regulatory framework	Details and standards
European Union	Fertilising Products Regulation (FPR) 2019/1009.	Biostimulants are recognized as a distinct category of "fertilizing products." Products must meet specific safety and efficacy requirements to receive the CE mark, allowing free movement within the EU market. The regulation specifically identifies seaweed extracts.
Africa	Regulation managed at national level, often under existing laws for fertilizers or agricultural remedies. An increasing trend toward specific guidelines and harmonization.	**South Africa – *Fertilizers, Farm Feeds, Seeds, and Remedies Act 36 of 1947*.** South Africa's Department of Agriculture, Land Reform and Rural Development provides detailed guidelines. Biostimulants are typically classified as "agricultural remedies" or "fertilizers." **Kenya – *Fertilizers and Animal Foodstuffs Act (Cap 345)*.** The regulatory program is managed by the Ministry of Agriculture. The Kenya Bureau of Standards sets and enforces product quality standards. **Nigeria – *National Agency for Food and Drug Administration and Control*.** The agency oversees customized regulations for biopesticides with specific requirements, including efficacy and safety data. **Tanzania, Uganda, and Ghana –** The countries are developing new fertilizer laws and standards to include novel inputs like biostimulants. Many rely on basic data requirements and general regulatory processes similar to those for biopesticides.
Australia	No formal framework. Fragmented at regional level.	Regulation is generally quite loose, with the government promoting sustainable agriculture and organic farming practices. Specific regulations vary by state and product type. Fertilisers Australia is currently framing a code of practice for plant biostimulants.
Brazil	Integrated into existing agricultural laws.	Biostimulants fall under existing legislation for agricultural inputs, which emphasizes agronomic efficiency, human health, and environmental safety. Brazil's Ministry of Agriculture focuses on efficacy, while other agencies manage health and environmental impact.
Canada	No formal framework.	Canada generally treats biostimulants as low-risk products and regulates them as fertilizer supplements, simplifying the market entry process compared to more rigid systems.
China	No formal framework.	China has a low-risk classification for biostimulants and strong government initiatives promoting organic agriculture, leading to a large and growing market.
India	Regulated under the Fertilizer Control Order (FCO).	India established a clear regulatory identity for biostimulants in 2021, bringing them under the FCO. Products must meet prescribed quality and safety specifications, undergo efficacy trials, and adhere to specific labeling rules.

Region	Regulatory framework	Details and standards
Indonesia	No formal framework.	Indonesia's Ministry of Agriculture is the main authority. Biostimulants are often treated as fertilizers or, depending on product specifications, as pesticides or plant-growth regulators. The focus is on testing for safety and efficacy to protect public health and the environment.
Korea	No formal framework.	Korea requires a careful assessment of a product's function to determine the applicable regulatory path. Oversight comes under Korea's Ministry of Agriculture, Food, and Rural Affairs for fertilizers and general agricultural inputs. Korea's National Agency for Food and Drug Administration and Control (or an equivalent agency) oversees food safety, and the Plant Quarantine Authority oversees imported products.
Japan	No single, specific regulatory framework for biostimulants.	Japan's Ministry of Agriculture, Forestry, and Fisheries is the main authority for agricultural inputs. The Food and Agricultural Materials Inspection Center handles product registration and inspection. Products that provide nutrients or improve soil conditions fall under the Fertilizer Control Act. Products that claim plant protection or pest/disease control are subject to the Agricultural Chemicals Regulation Act. All others are managed through plant-quarantine regulations.
Philippines	No single, specific regulatory framework.	Regulation is managed by the Department of Agriculture—either in the Bureau of Agriculture and Fisheries Standards (BAFS) or the Fertilizer and Pesticide Authority (FPA). Products classified as organic inputs or soil conditioners are regulated through BAFS under the Revised Rules and Regulations on the Registration of Organic Fertilizer Producers. Products classified as plant-growth promoters/regulators may be classified as pesticides/plant-growth regulators and are subject to stricter controls through FPA.
United Kingdom	No formal framework.	The key determinant for regulation is the product's claim. If it claims to stimulate plant nutrition, it is classed as a biostimulant and takes a simple path to market. If the product claims to have an influence on pest/disease control, it is classed as a pesticide and experiences a more rigorous approval process.
United States	Fragmented, pending ratification of federal Plant Biostimulants Act 2025.	Regulation is handled at the state level under a range of feed and fertilizer laws, with inconsistent requirements across states. The 2018 Farm Bill mandated that the U.S. Department of Agriculture shall identify regulatory issues related to biostimulants, and there is a clear path to market under the "Beneficial Substances" category in state legislation. The proposed Plant Biostimulant Act of 2025 aims to create a unified framework, likely recognizing biostimulants as a type of fertilizing material to align with global standards.

5. Seaweed farming: Species, locations, and methods

5.1. What species?

Choosing which species to farm is a major decision. As shown in Table 2, numerous species are known for their biostimulant properties, but only a select few are currently cultivated on a large scale. Table 2 outlines the principal species farmed worldwide and indicates whether they are or could be utilized for biostimulant production. Most of these species were originally gathered from the wild based on documented evidence of a particular product value. While brown seaweeds and kelps have generally been the most extensively researched in relation to biostimulants, other species have also demonstrated biostimulant properties and are often incorporated into existing products. The shift to aquaculture now offers an exceptional opportunity: focus can be placed on enhancing both the supply and quality of established biostimulant species through farming techniques. There is also an opportunity to adopt other species that, currently, are predominantly cultured for other uses. Focusing on species that are already locally cultivated for food or other uses can offer significant advantages over introducing entirely new species, notably because fundamental husbandry practices are already established, and not all species can be farmed everywhere.

Having said all this, the selection of species for cultivation should be guided by market demands and expectations, which will vary by region.

Seaweed aquaculture in Kenya. Photo by Hannah Packman, © TNC.

Table 2. Common seaweed species with the potential for biostimulant-focused aquaculture.

Species	Product use and relevance to biostimulant market	Aquaculture status
BROWN SEAWEEDS – Traditionally used most in agriculture.		
***Alaria* spp.** Common names: winged kelp, badderlocks, dabberlocks, and Atlantic wakame.	*Alaria* spp. (primarily *A. esculenta*) are recognized as traditional foods in various regions and have demonstrated notable biostimulant properties.	*Alaria* spp. are found in cold temperate waters in the North Atlantic and North Pacific Oceans. Several countries, including China, Indonesia, and the Philippines, cultivate *Alaria* spp. Within Europe, Ireland and Norway are the leading producers of *A. esculenta*. Additionally, the United States, Chile, and Sweden are actively developing cultivation capabilities.
***Ascophyllum* spp.** Common names: rockweed, knotted wrack, egg wrack, Norwegian kelp, sea whistle, and knobbed wrack, among others.	The wild-harvested product (primarily *A. nodosum*) has an established market, supported by substantial evidence of its efficacy as a biostimulant (Shukla et al., 2019). This species is among the most frequently utilized in biostimulant products.	*Ascophyllum* spp. seaweeds, primarily *A. nodosum*, are found in the North Atlantic Ocean along the coasts of Europe and North America. While wild harvesting remains significant, aquaculture production is on the rise, with several prominent companies cultivating *Ascophyllum* spp. commercially in northern temperate regions such as Norway, Canada, and the United Kingdom.
***Durvillaea* spp.** Common names: bull kelp, southern bull kelp, and cochayuyo.	*Durvillaea* spp. are among the most extensively utilized for biostimulants. *D. potatorum*, in particular, is widely adopted due to its high concentration of alginates and compounds that promote plant growth.	*Durvillaea* spp. are found exclusively in the Southern Hemisphere (Australia, New Zealand, and South America) and subantarctic islands on rocky, wave-exposed shorelines. Aquaculture for this large kelp species remains in the developmental stage, with notable technical challenges associated with at-sea cultivation.
***Ecklonia* spp.** Common names: golden kelp, common kelp, spiny kelp, and leather kelp.	Primary product development has centered on alginate, fucoidan, and animal feed additives, with additional interest in phlorotannins.	*Ecklonia* spp. are primarily found in temperate coastal waters of the Southern Hemisphere and parts of East Asia. However, there is an emerging aquaculture industry for *E. maxima* in the Northern Hemisphere, as well as some focus on *E. radiata* in Australia and New Zealand
***Fucus* spp.** Common names: rockweed, bladderwrack, and kelp	*Fucus* spp., particularly *F. vesiculosus*, are frequently incorporated into commercial biostimulant products, as well as functional food and nutraceutical formulations.	*Fucus* spp. are found primarily in the intertidal zone on temperate rocky shores in the Northern Hemisphere. Key species of interest are *F. vesiculosus* and *F. spiralis*. The aquaculture of *Fucus* spp. is highly developed, with established aquaculture companies operating in most key production regions.

Species	Product use and relevance to biostimulant market	Aquaculture status
***Laminaria* spp.** Common names: These are probably the seaweeds most often referred to as "kelp," but they are also known as oarweed, sea tangle, sea girdle, devil's apron, tangle, and cuvie. Numerous regional names exist for specific species; for example, in Japan, *Laminaria* sp. is called kombu.	*Laminaria* spp. are widely used in food products and serves as a source of industrial extracts, such as alginates, mannitol, and iodine. Additionally, it is employed in pharmaceutical and nutraceutical formulations, as well as in livestock feed and biostimulants.	*Laminaria* spp. are cold-water seaweeds distributed throughout the Atlantic and Pacific Oceans. While wild harvesting remains predominant, several species are now commonly cultivated in East Asia—including China, Japan, and South Korea—with expanding cultivation efforts in other cold-water regions, notably Scotland and Ireland.
***Macrocystis* spp.** Common names: giant kelp, giant bladder kelp, string kelp, and iodine kelp.	The use of *Macrocystis* spp. in biostimulant production is increasing, attributed to its rapid growth rate and its popularity in aquaculture, particularly in response to restoration initiatives in regions where natural populations have declined due to climate change.	This genus thrives in cool, temperate waters and is distributed globally along coastal regions of the Eastern Pacific, Southwestern Pacific, Southern Atlantic, and Southern Indian Oceans. As *Macrocystis* spp. are sensitive to water temperature, aquaculture efforts have been supported by rehabilitation programs aimed at restoring natural populations.
***Nereocystis* spp.** Common names: bull kelp, bullwhip kelp, ribbon kelp, and sea otter's cabbage.	Some initial studies (Verschuren Centre, 2025) have identified biostimulatory properties and outlined specific benefits associated with extracts from *Nereocystis* spp.	While commercial harvesting primarily targets its use as a food source, it is also utilized in biostimulant production. Aquaculture efforts are progressing alongside *Saccharina* spp.; however, the cultivation of *Nereocystis* spp. presents additional challenges.
***Saccharina* spp.** Common names: *S. latissimi* is commonly called sugar kelp or winged kelp. *S. japonica* is called Japanese kelp.	*Saccharina* spp. are among the most widely used species in biostimulant production. Both *S. japonica* and *S. latissimi* are popular due to their rich mineral and vitamin content, and they are well known as effective biostimulants.	While *Saccharina* spp. were originally harvested from the wild, they are now cultivated extensively along the coasts of Asia (especially China, Japan, and Korea), North America, and Europe, providing a sustainable and reliable source for biostimulant manufacturing.

Species	Product use and relevance to biostimulant market	Aquaculture status
***Sargassum* spp.** Common names: gulfweed and sargasso weed, among others. Specifically, *S. fusiforme* is called hijiki, and the invasives *S. muticum* and *S. horneri* are known as wireweed and devil weed, respectively.	*Sargassum* spp. are among the most commonly used for biostimulants. This seaweed offers a variety of uses—from extracts in cosmetics and livestock feed to biofuel production and materials for fabric or construction. Rich in growth hormones, nutrients, and beneficial bioactive compounds, *Sargassum* spp. are particularly valuable as biostimulants.	The market for wild-harvested *Sargassum* spp. as biostimulants is expanding, driven by both increased nutrient enrichment and problems caused by mass strandings. *S. fusiforme* (hijiki) has a long history of cultivation for food in Japan, Korea, and China. While aquaculture for other species is still in its early stages, there is growing interest throughout Pacific countries.
RED SEAWEEDS – Limited use in biostimulants so far, but interest is growing. Aquaculture practices are well developed due to long-term farming in Southeast Asia.		
***Acanthophora* spp.** Common names: erect sea moss, spiny red seaweed, and spiny algae, as well as regional names such as *bulung tombong bideng* and *kulot*.	*Acanthophora* spp. have demonstrated significant potential for application in biostimulants.	Found both intertidally and as free-floating mats in tropical and subtropical regions globally, *Acanthophora* spp. are native to the Caribbean and Southern Atlantic, yet they have a broad distribution. These species also exhibit epiphytic growth on other algae. Traditionally utilized in food and medicine, as well as a source of carrageenan, current aquaculture research (Guillén et al., 2022) is increasingly focused on their use as a feed additives.
***Asparagopsis* spp.** Common names: harpoon weed and red sea plume.	There is significant potential for utilizing *Asparagopsis* spp. as secondary material in biostimulants. The bioactive compounds present in *Asparagopsis* spp. are well-characterized due to their application as an animal feed additive, where these compounds have demonstrated efficacy in promoting plant growth.	Currently, the primary focus of *Asparagopsis* spp. cultivation lies in their role as a livestock feed supplement to reduce methane emissions. Nonetheless, the resulting waste from this process offers valuable opportunities for development and application in the biostimulant sector.
***Eucheuma* spp.** Common names: sea moss and agar-agar, but there are also many regionally used names—e.g., gusô, ruprupuuk, canot-canot, chilints'ai, or qilin cai.	Recent studies have highlighted the potential of *Eucheuma* spp. for use as biostimulants, with documented bioactive compounds demonstrating benefits in crops, such as sweet peppers (Sari et al., 2022).	These species are extensively cultivated throughout Asia, primarily for hydrocolloid extraction, particularly carrageenan. Additionally, *Eucheuma* spp. are applied in the food industry, pharmaceuticals, and cosmetics.

Species	Product use and relevance to biostimulant market	Aquaculture status
***Gelidium* spp.** Common names: agarweed, kanten, hai-ten-gusa, makusa, isinglass, as well as regionally specific names such as chasca, tengusa, and umutgasari.	Studies have documented biostimulatory properties. However, due to high market demand for superior-quality agar and the challenges inherent in cultivation, *Gelidium* spp. are unlikely to become a major source for biostimulants.	*Gelidium* spp. are distributed globally along intertidal to subtidal rocky shores, spanning cold-temperate to tropical climates. They are primarily harvested from the wild for production of high-grade medical agar, with significant contributions from France, Indonesia, South Korea, Mexico, Morocco, and Spain. While aquaculture efforts are ongoing, the development of *Gelidium* spp. cultivation lags behind that of *Gracilaria* spp., largely due to its slow growth rate.
***Gracilaria* spp.** Common names: Irish moss, ogonori, Ceylon moss, and gulaman.	Recent research (Alam et al., 2024; Mannan et al., 2023) has demonstrated the biostimulant properties of *Gracilaria* spp. extracts, with studies indicating improvements in crop yield, drought tolerance, chlorophyll content, plant growth, and resilience to abiotic stressors such as drought and salinity.	*Gracilaria* spp. are found globally from the intertidal zone to subtidal areas within tropical to temperate coastal waters, particularly across Asia, as well as the coasts of India, Australia, and parts of South America. *Gracilaria* spp. are widely cultivated for agar production and, to a lesser extent, for use in biostimulants.
***Kappaphycus* spp.** Common names: sea moss, elkhorn sea moss, guso, tambalang, agar-agar, agar-agar besar, and cottonii.	Recent studies (Shukla et al., 2024; Trivedi et al., 2023) have documented biostimulatory activities.	Widely cultivated in Southeast Asia for food, pharmaceuticals, and cosmetics but mostly for carrageenan. However, these species are increasingly being researched for their biostimulatory properties.
***Pyropia* spp.** Common name: nori, laver, gim, zicai, and sloke. (Previously classified as *Porphyra.*)	*Pyropia* spp. have documented biostimulatory effects and are occasionally incorporated into biostimulant formulations, though they are not a primary focus of commercial production.	*Pyropia* spp. are distributed intertidally in cold-temperate coastal regions worldwide. Commercial cultivation is prevalent in East Asia, especially in China, Japan, and Korea, where *Pyropia* spp. are widely processed for culinary uses.
GREEN SEAWEEDS – Green seaweeds are both fast-growing and nutrient-absorbing, making them a good candidate for biostimulants.		
***Ulva (Enteromorpha)* spp.** Common names: sea lettuce, limu, green nori, green string lettuce, and aonori, with certain species distinguished by	Studies have identified significant biostimulatory properties in *Ulva* spp. extracts, demonstrating their potential to enhance seed germination and support plant resilience under stress conditions.	*Ulva* is a widespread and frequently opportunistic genus, with species distributed globally in intertidal and subtidal zones across temperate and tropical regions, inhabiting both marine and brackish environments. Several species are capable of tolerating freshwater conditions. Typically, *Ulva* spp. attach themselves to rocks, other algae, or various structures.

Species	Product use and relevance to biostimulant market	Aquaculture status
specific names, such as branched string lettuce for *U. prolifera* and gutweed or grass kelp for *U. intestinalis*.		The genus has diverse applications, including human consumption, animal feed, pharmaceuticals, biomaterials, and biofuels. There is growing utilization of *Ulva* spp. in biofiltration and biostimulant production. Commercial farming of *Ulva* spp. is expanding internationally, predominantly within land-based systems and increasingly in integrated multi-trophic aquaculture as well as polyculture operations.
***Caulerpa* spp.** Common names: sea grapes and green caviar for edible species (e.g., *C. lentillifera* and *C. racemosa*) and feather algae and fern algae for *C. mexicana*.	*Caulerpa* spp. are an emerging source of biostimulants; research (Ali et al., 2025; Lalruatfeli et al., 2024) indicates that extracts from this genus can enhance plant growth, yield, and resilience to environmental stressors.	This broad group of seaweeds is predominantly distributed in tropical regions worldwide, though invasive populations have also been identified in temperate waters. *Caulerpa* spp. are utilized as food products, as aquarium plants, and in pharmaceutical applications, with demonstrated antioxidant and anti-inflammatory properties. In Southeast Asia and the Pacific, commercial cultivation of edible *Caulerpa* spp. (sea grapes) has been practiced since the 1950s, using traditional seabed planting approaches to enhance natural populations. More recently, cage and tray farming have helped enhance natural populations, and longline systems, tanks, and raceways have been used to support aquaculture production.
***Codium* spp.** Common names: dead man's fingers, sponge weed, velvet horn, green sea fingers, oyster thief, green sponge, and forked felt alga.	*Codium* spp. not only are utilized as a food source and in medicinal preparations but also are valued for their biostimulant properties. Research (El Bzar et al., 2026; Rossini et al., 2024) indicates that extracts from *Codium* spp. can improve seedling vigor, promote root development, and elevate grain protein content, enabling plants to better withstand environmental stressors such as drought and salinity.	*Codium* spp. are distributed globally on hard substrates in both intertidal and subtidal zones, with the greatest diversity observed in temperate and subtropical regions. While commercial cultivation originated in Asia, production has since expanded worldwide, utilizing both land-based tank systems and open-sea farming. Techniques have been developed for both vegetative and sexual propagation to optimize yield and sustainability.

5.2. Regional variations

Table 2 demonstrates that seaweed production is truly a worldwide industry. While China, Indonesia, and the Philippines are the leaders in production volume, seaweed farming takes place across the globe—from Tanzania to Tasmania, and from Chile to Canada (see Figure 5). In nearly every area, different species are grown that have potential for biostimulant use, whether as whole products or by-products.

Some buyers may prefer local sourcing for quality and biosecurity reasons, potentially increasing prices for local products. The ability to sell products locally offers several advantages, including reduced requirements for product stabilization and processing, as well as lower transportation costs. Furthermore, regulatory controls governing product usage and importation may differ across regions, making local markets more attractive.

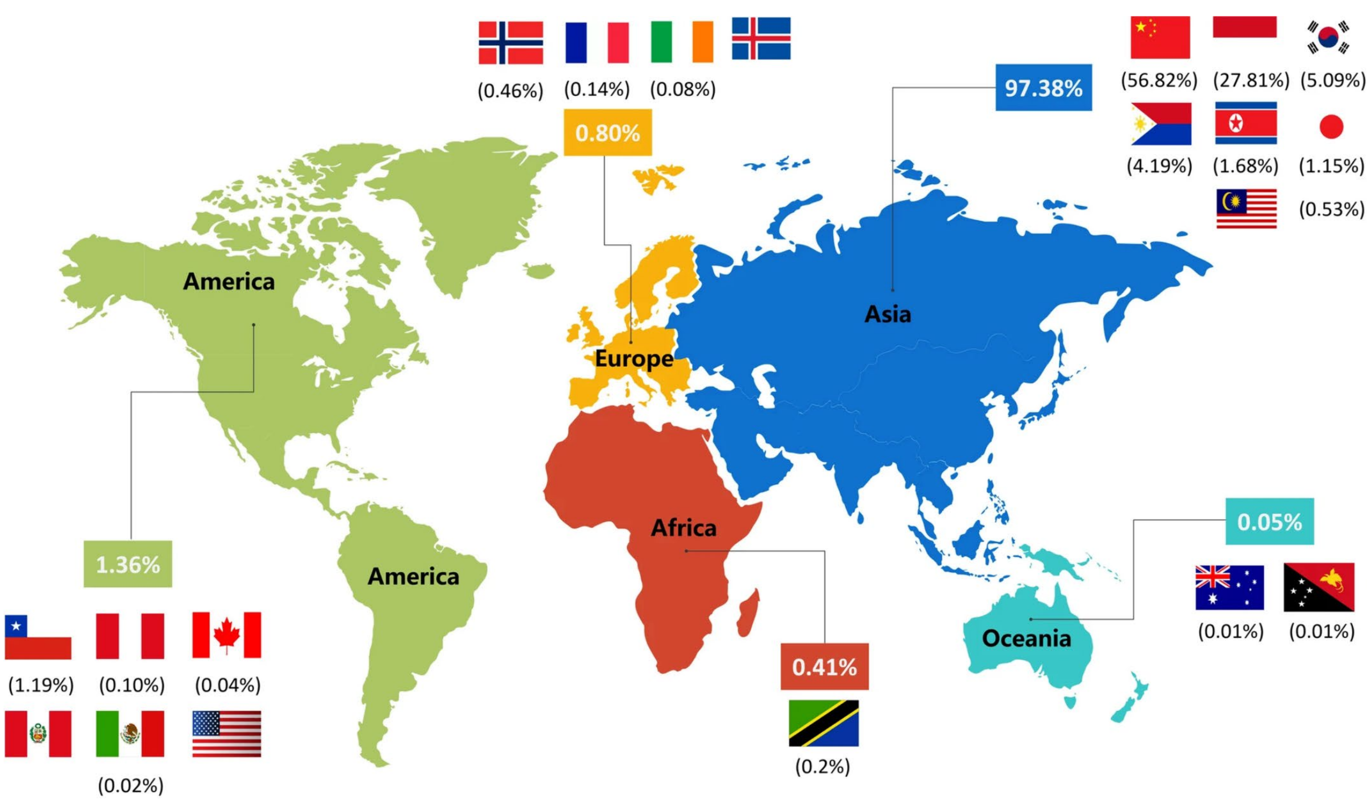
Cultivating local species may present fewer technical challenges and offer greater adaptability compared to introducing non-native species. If locally produced species can meet the needs of regional farmers, it may provide a compelling reason to prioritize their cultivation, irrespective of potential differences in final price. Considerations such as market demand and operational efficiencies can significantly contribute to overall business viability.

Agricultural requirements vary substantially between countries, influencing reliance on fertilizers and other biostimulant and soil improvement products. Globally, competition from regions with lower production costs will influence prices. These factors may draw increased government support, particularly where there is a broader agricultural development agenda or sustainability imperatives.

5.3. Farming basics

The practicalities of farming are very important in deciding which species to farm. It is essential to have both the necessary skills and established cultivation techniques. Some species can be grown from cuttings, while others require sexual reproduction, making their propagation more complex. This complexity might require specialist hatcheries and technically skilled staff.

Figure 5. Seaweed production in 2019, from Zhang et al. (2022).



The choices of equipment and of whether to use land-based or in-water culture systems are also crucial and complex. Land-based systems often involve higher start-up costs but allow tighter control over growing conditions. Often, land-based systems are used for seedstock production where greater control of environmental conditions and contamination is necessary, while growing commercial stock at scale is often undertaken in open water. In-water systems can have greater biosecurity challenges and the potential for adverse environmental interactions, but these concerns can generally be more readily managed during adult production stages. Not all species thrive in tank environments. Some, like the large kelps, rely on the natural fluctuations found only in open water. To date, many commercial biostimulant products are derived from these larger kelp species, and as such, most production is from open-water cultivation.

Many species are seasonal with specific harvest seasons that must be carefully timed for optimal product quality. This seasonality affects facility operations and staffing needs and can influence market supply. Maintaining a skilled workforce year-round is challenging when production is seasonal. Harvesting throughout the year or running multiple crop cycles offers a continuous supply but introduces other logistical challenges. Some crops are best harvested all at once, while others benefit from regular partial harvesting, known as top cropping.

Fully understanding each species' life cycle needs is vital for optimizing production and directly impacts costs and overall success.

6. Product development and processing

6.1. Product definition

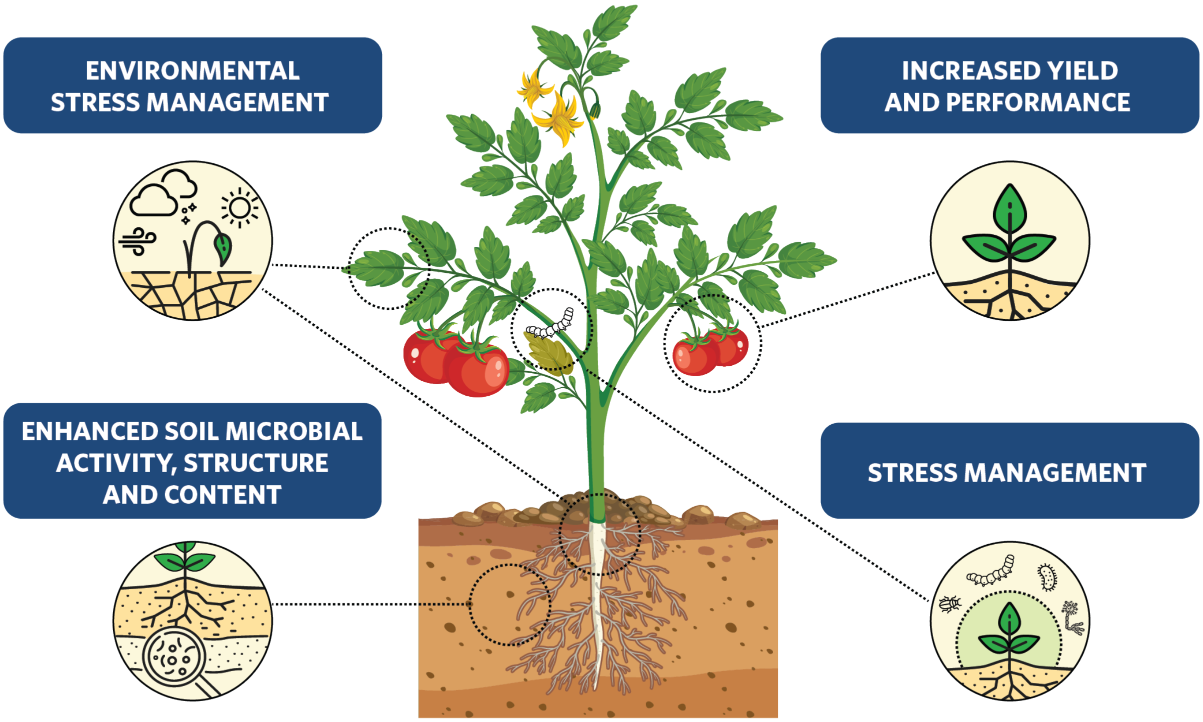
As discussed in previous sections, the manner in which a product is characterized carries significant implications for market access, affecting both regulatory approval and consumer perceptions. The EU FPR defines *biostimulants* as "a product stimulating plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: nutrient use efficiency; tolerance to abiotic stress; quality traits; availability of confined nutrients in soil or rhizosphere" (EU, 2019), distinguishing them from fertilizers and plant protection products. A simpler definition from a product marketing perspective might be "biologically derived products that enhance productivity due to their unique mix of constituents, not just known nutrients or protective agents" (Yakhin et al., 2017).

For a product to be classified as a biostimulant, it must facilitate increased efficiency in the utilization of nitrogen, phosphorus, and potassium; enhance micronutrient absorption; and/or mitigate abiotic stress. Unlike fertilizers, which supply nutrients directly to plants, biostimulants activate the plant's inherent capacities for nutrient uptake and its management of environmental stress without direct nutrient supplementation. While fertilizers and biostimulants both contribute to improved growth and yield, they often function synergistically, with fertilizers providing essential nutrients and biostimulants optimizing their use. Figure 6 summarizes the key benefits of seaweed-based biostimulants.

When developing a new biostimulant, identifying and understanding its specific advantages is key. Validating specific product claims for biostimulants is essential. Land farmers invest in these products with certain expectations, so field trials and scientific evidence provide assurance that a biostimulant will deliver as promised and will offer a dependable return on investment. In many regions, regulatory approval also mandates that manufacturers prove their product performs according to its label claims.

The biostimulant industry, including the seaweed sector, faces ongoing challenges due to inconsistent results and insufficient scientific validation for some offerings. Sound, science-based testing helps differentiate reliable, high-quality biostimulants from less effective ones, building trust in the

Figure 6. Overview of the positive effects of seaweed extracts on plant and soil systems. © TNC.



market and encouraging wider adoption of seaweed-based solutions. However, many seaweed biostimulants have complex modes of action, and while gaining a better understanding of the specific bioactives may lead to more advanced and targeted products in the future, this knowledge is not farmers' primary interest at this stage. Verifying the benefits of seaweed biostimulants remains the most critical factor, as this is what matters most to land farmers.

7. Factors affecting biostimulant quality

The effectiveness of seaweed-based biostimulants is influenced by factors like seaweed type, environmental conditions, processing methods, application timing and method, and crop or soil characteristics. These variables together determine the product's overall impact. As a result, it is important to understand the effectiveness of different biostimulant products and application methods for a range of crops and scenarios, so improvements can be made. Although seaweed farmers could individually verify their own products, this effort would require more time and resources than most currently have. Given the significant potential benefits, it would be far more effective to approach verification as a sector or global collaboration, bringing together seaweed and land-based farmers, governments, and investors to share performance information and confirm the advantages of using seaweed additives for better crop quality, healthier soils, and greater environmental resilience.

7.1. Biostimulant extraction and processing

The way products are processed affects their quality, specifications, suitability, and price. Different extraction methods are used across the industry: some companies prefer basic techniques for general-purpose products, whereas others focus on processes tailored to specific physiological effects or particular crops. For example, the simplest form of liquid fertilizer can be produced by fermenting seaweed in water. Table 3 outlines key extraction methods, potential cost structures, and possible partnership models. Although all methods aim to release bioactive ingredients, their efficiency and costs vary widely. Understanding what is expected from a product helps select targeted extraction strategies that boost effectiveness.

One major challenge for scaling up production, especially in new cultivation regions, is the lack of facilities for large-scale product stabilization and processing. Adopting a biorefinery approach, which utilizes the entire seaweed biomass to create several high-value products, can enhance both economic viability and sustainability. Consistent extraction practices are essential for dependable results and efficient retention of bioactive compounds. However, advanced techniques call for specialized expertise, associated skills, and greater financial investments. As a result, businesses must decide whether to process in-house or outsource to dedicated biorefineries, which increasingly provide options for developing specific seaweed-based products. This choice involves distinct investment strategies and can affect market value in different ways. Careful business planning should weigh these factors. Consistently achieving optimal extraction remains an ongoing challenge throughout the industry (Baghel, 2023).

Developing integrated biorefinery models for sustainable and scalable production, along with life cycle assessments and environmental impact studies for different processing methods, is important and may be an area where investors and governments can play significant roles.

Harvested seaweed in Indonesia. Photo by Tomi Prasetyo Wibowo, © TNC.

Table 3. Summary of key extraction methods, investment risks, and potential product partnership models.

Extraction process	Description	Capital expenditure	Operational cost	Product specifications	Potential production relationships
Water-based extraction	Dried seaweed is soaked and blended in water; undissolved solids are filtered out. Efficient for maintaining phytohormone-like activity.	LOW	LOW	Basic product production/ product stabilization – raw materials only.	Raw material production only. Needs further processing to develop higher-value products.
Acid hydrolysis	Fresh seaweed chopped and incubated in strong acid at 40–50 °C for ~30 min. Removes complex phenolics. Reduces polysaccharide complexity. Yields fucoidans and commercial products.	LOW Requires some specialist equipment and potentially a specialist facility. Health and safety compliance required.	LOW- MODERATE Needs trained staff.	Still only basic product extraction but with greater potential for the differentiation of active ingredients.	Raw material production only. Needs further processing to develop differentiated products.
Alkaline hydrolysis	Uses bases (NaOH, KOH) at 70–100 °C to extract biostimulants. Depolymerizes polysaccharides to oligosaccharides; produces by-products from polyphenols; and may lose some bioactive compounds. Widely used industrially.	HIGH Requires specialized equipment. Will require compliance with a range of health and safety standards and facility standards.	MODERATE Needs trained/ specialist staff.	Still only basic product extraction but with greater potential for differentiation of active ingredients.	Raw material production only. Needs further processing to develop differentiated products. Strategic partnerships or integration with specialized processors (biorefineries) needed to achieve differentiated products.
Microwave-assisted extraction (MAE)	Dried seaweed is made into a slurry and heated by microwaves in water or other solvents. Efficient. Preserves the integrity of bioactives. Preferred for carbohydrates, proteins, or phenolics.	HIGH Specialist equipment required.	MODERATE - HIGH Needs trained/ specialist staff.	Can obtain a range of differentiated products with various market applications.	This would be a fully integrated production/ processing business ***OR*** a partnership with specialized processors (biorefineries).

Extraction process	Description	Capital expenditure	Operational cost	Product specifications	Potential production relationships
Ultrasound-assisted extraction (UAE)	Uses ultrasound waves to trigger cavitation in a solvent, facilitating the transfer of bioactives. Widely used for isolating laminarin and other compounds. Reduces extraction time and preserves chemical structure.	HIGH Specialized equipment required.	HIGH Needs specialist staff to operate equipment and will require a high level of compliance requirements.	Can obtain a range of differentiated products with various market applications.	This would be a fully integrated production/ processing business ***OR*** a partnership between producers and processors.
Pressurized liquid extraction (PLE)	Uses high pressure (3.5–20 MPa) and temperature (50–200 °C) to extract biochemicals. Faster extraction and higher mass transfer rates. May affect antioxidant properties at high temp/pressure.	HIGH Very specialized equipment required.	HIGH Needs highly specialist staff to operate the equipment and will require a high level of compliance requirements.	Can obtain a range of differentiated products with various market applications. Can tailor the process for targeted product extractions.	Most likely undertaken by a dedicated bioprocessing facility using stabilized raw materials.
Enzyme-assisted extraction (EAE)	Uses specific enzymes to degrade complex compounds, releasing bioactives. Hydrolytic enzymes convert insoluble to soluble; no solvents needed. Green technology, tailored to target specific compounds, but can be time-consuming and may yield less than chemical methods. Enhances antioxidant properties.	HIGH Very specialized equipment required.	HIGH Needs highly specialist staff to operate the equipment and will require a high level of compliance requirements.	Can obtain a range of differentiated products with various market applications.	Most likely undertaken by a dedicated bioprocessing facility using stabilized raw materials.
Supercritical fluid extraction (SFE)	Uses supercritical fluids (e.g., carbon dioxide) to extract compounds, avoiding chemical solvents.	HIGH Very specialized equipment required.	HIGH Needs highly specialist staff to operate the equipment and will require a high level of compliance requirements.	Can obtain a range of differentiated products with various market applications. Can tailor the process for targeted product extractions.	Most likely undertaken by a dedicated bioprocessing facility using stabilized raw materials.

8. Business planning: Product and market development

Most seaweed biostimulants are available commercially as liquids, which are usually applied through foliar spraying or irrigation and may include other active ingredients. Dried versions are also available. The choice between liquid and dried products depends on several factors: the type of seaweed being cultivated, its known biochemical makeup, market demands and downstream value chain expectations, specific benefits the farmer or producer aims to deliver, access to extraction and processing resources, and distribution availability and costs.

If the goal is simply to offer raw material, the process is straightforward. However, if the aim is to create a tailored product, then the farmer or producer must consider which crops they intend to support and their particular requirements. This decision should be guided by the seaweed species' specific compositions and benefits. This can then inform the optimal extraction method to maximize these advantages, maintain quality and consistency throughout production, and develop a precise application plan to ensure the product's effectiveness.

Key determinants for the successful development and consolidation of the seaweed biostimulants sector include establishing a dependable supply chain for raw materials, developing purpose-fit processing capabilities that yield high-quality products, implementing clear and consistent regulatory frameworks, and ensuring rigorous scientific validation of product claims. Many of these aspects have been addressed in previous sections.

It is also essential to consider competitive dynamics. This guide has primarily focused on internal issues within the seaweed biostimulants production sector. However, biostimulants are derived from numerous sources, including microorganisms (such as bacteria and fungi), humic and fulvic acids, amino acids, and protein hydrolysates (EBIC, 2023). This diversity introduces significant competition. Seaweed enterprises can address this challenge by collectively differentiating their products with unique value propositions and consistently superior quality. This approach must be substantiated by reliable and transparent data to build and sustain market trust in seaweed-based products.

Consequently, sustained investment in R&D remains vital. The agricultural sector is increasingly driven by research and innovation, employing advanced technologies to meet growing global food demands and evolving sustainability requirements. Active collaboration within the industry and strategic partnerships are imperative to align with these progressive trends.

Presently, interest in seaweed-derived biostimulants is substantial, which should be leveraged by clearly demonstrating return on investment. Limited availability of high-quality products is contributing to upward pricing pressures; however, sustaining current interest requires a comprehensive understanding of customer needs and articulating the role of seaweed biostimulants in advancing sustainable agriculture. These products offer the potential to increase crop yields, reduce dependence on chemical fertilizers and pesticides, and improve soil health, making them particularly attractive to informed users. Nonetheless, government support will be instrumental in fostering effective collaboration and propelling technological progress.

9. Summary and recommendations

Seaweed biostimulants promote plant growth, improve crop yield and quality, augment nutrient uptake, boost stress tolerance, and enhance soil health (Ali et al., 2021; Craigie, 2011; El Boukhari et al., 2020; Illera-Vives et al., 2020)—unlike conventional fertilizers that mainly provide nutrients. Traditionally, brown seaweeds, especially kelps, have been the primary source for these biostimulants. At present, most products come from wild harvesting, which limits supply and can put pressure on wild populations; as a result, farming is viewed as a scalable and sustainable alternative; however, further research is necessary to advance aquacultured species and expand technical capacity.


Seaweed in Belize, © TNC.

When combined with standard fertilizers, seaweed biostimulants often exhibit synergistic effects, decreasing reliance on synthetic fertilizers and pesticides and benefiting both agricultural productivity and the environment. Seaweed extracts are particularly valued for their environmentally friendly properties, offering alternatives to chemical products and helping mitigate ecological damage while improving soil and water conditions. The effectiveness of these products depends on several variables, such as the species used, cultivation and processing techniques, and application strategies. Targeted research is required to verify benefits, identify bioactive components, and optimize production and processing outcomes.

There are also important challenges related to expanding the market, including addressing regulatory issues and discrepancies in standards and product classifications, which restrict market access. Unified standards and transparent product specifications are pressing needs. In turn, they need collaborative efforts between the aquaculture and agricultural industries. Perhaps most essential will be lowering the cost of production via increased efficiencies and economies of scale, given that aquaculture requires a higher price than wild-harvest alternatives. Specific R&D recommendations are below.

9.1. R&D recommendations – Production development

Optimize cultivation techniques: Advocate for R&D into cost-effective, high-efficiency cultivation methods, strain selection that enhances desirable biostimulant properties, and robust public or private hatchery networks to guarantee a reliable supply of high-quality, disease-free seedstock—an essential factor for industry expansion. Several companies in the sector, such as GreenWave in the United States and Pure Ocean Algae in Ireland, have already implemented these measures to guarantee supply security.

Advance postharvest processing technologies: Provide funding for R&D on advanced, economically viable postharvest processing facilities, aimed at producing superior, quality extracts while reducing waste.

9.2. R&D recommendations – Product development

Clarify agricultural expectations (field trials and data collection): Collaborate on comprehensive research to identify agricultural requirements and evaluate the efficacy of seaweed biostimulants. Organize extended field trials across diverse crops and environments to generate robust data regarding yield enhancement, nutrient uptake, and stress tolerance. Sponsor studies investigating the effects of seaweed extracts on plant physiology and stress resilience. Promote research focused on selecting strains with optimal biostimulant characteristics. Advancing related expertise will facilitate improved application strategies and enhance product quality. These outcomes are essential for increasing farmer adoption and satisfying regulatory standards.

Clarify the bioactivity mechanism: Beyond studying the effects of seaweed extracts, as mentioned in the previous paragraph, fund research aimed at understanding the precise modes by which seaweed extracts support plant physiological functions and improve stress resistance. This insight will allow for the optimization of application protocols and improve product development.

Screen novel bioactive compounds: Investigate indigenous and underutilized seaweed species to discover new compounds with biostimulant or other beneficial properties, promoting market diversification and creating opportunities for additional revenue generation.

9.3. R&D recommendations – Knowledge sharing and capacity development

Encourage industry collaboration: Develop online platforms and strengthen industry associations to facilitate cooperation between researchers, industry professionals, producers, and government bodies, ensuring R&D efforts reflect market needs.

Enhance workforce skills: Support education and training programs focused on seaweed aquaculture, biotechnology, and processing.

9.4. Advocacy and government engagement recommendations

Streamline regulation: Advocate for a simplified permitting system to lower expenses, reduce administrative burden, and minimize unnecessary delays across relevant government entities.

Support product standards and traceability: Support the development of standardized testing protocols and certification schemes for seaweed biostimulants, thereby strengthening product credibility and facilitating access to premium markets.

Advance financial incentives: Propose the inclusion of seaweed aquaculture and biostimulant products within national environmental credit frameworks (e.g., carbon or biodiversity credits) to generate additional revenue streams for producers and promote sustainable practices.

In conclusion, challenges exist for the farmed seaweed biostimulant market, but with continued R&D in seaweed production, product development, knowledge sharing, and capacity, as well as strong government engagement and support, the farmed seaweed biostimulant value proposition can and will continue to strengthen. Joint investment from both the aquaculture and agriculture industries and governments will be critical to achieving the cost efficiencies, scale of production, and validated product quality needed for widespread sector success. And the success of this sector is increasingly vital in the light of mounting pressures on the global food production systems and the potential of farmed seaweed biostimulants to reduce reliance on synthetic fertilizers, improve soil health, and deliver co-benefits for coastal livelihoods, marine water quality, and biodiversity.

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Appendix:
Participants at the Seaweed Biostimulants Roundtable, October 2025

Name	Organization
Heidi Alleway	The Nature Conservancy
Luke Ansell	Algapelago Marine
Humphrey Atkinson	Algapelago
Azzedine Badis	Global Seaweed Coalition
Drusila Esther Bayate	Fisheries, Department of Agriculture, the Philippines
David G. Beaudreau, Jr.	DC Legislative and Regulatory Services, Inc.
Toby Berkman	Consensus Building Institute
Toby Sheppard Bloch	GreenWave
Anouk Bosman	Kelp Blue
Clare Bradley	AgriSea New Zealand & AgriSea Seaweed, Corp.
Tane Bradley	AgriSea New Zealand Seaweed
Nigel Bradly	EnviroStrat, Ltd.
Erin Bremner-Mitchell	Cascadia Seaweed
Carolina Camus	Universidad de Los Lagos
Geoffrey Chapin	Carbonwave
Tessa Charupatanapongse	Potato Impact Partners
Jingjie Chu	The World Bank
John D. Coates	University of California Berkeley, International Bioeconomy & Macroalgae Center
Jason Cole	MacroCarbon
Anoushka Concepcion	Global Seaweed Coalition
Megan Considine	The Nature Conservancy
Michael Coogan	University of New Hampshire
Thiago Correa	University of California Berkeley, International Bioeconomy & Macroalgae Center
Elizabeth Cottier-Cook	Scottish Association for Marine Science
Alan T. Critchley	Verschuren Centre
Melanie Cueff	Global Seaweed Coalition
Cristhian Danko	The Nature Conservancy
Paul Dobbins	World Wildlife Fund
Johanan Dujon	Algas Organics
Juan Gonzalo Flores	International Finance Corporation

Rod Fujita	Ocean Innovations
Adrian Gagu	International Finance Corporation
Robert Galbraith	Builders Vision
Dale Galvin	Global Fund for Coral Reefs / Pegasus Capital
Arash Ghale	Rodale Institute
Natalio Godoy	The Nature Conservancy
Stephane Granato	Southeast Conference Alaska
Peter Green	Hatch Blue
Ólavur Gregersen	Ocean Rainforest
Donna Hazard	Vital Ocean Ventures
Sophia Herrou	International Finance Corporation
Nick Hill	Coast 4C
David Hiltz	Hiltz BioAg Consulting
Shannon Hood	Conservation International
Aaron Huang	OoNee
Patrik Huber	Mawimbi Ocean Innovations, Ltd.
Alaine Janosy	Nestle Purina PetCare
Keith Jones	Biological Products Industry Alliance
Harrison Charo Karisa	The World Bank
Jeehye Kim	The World Bank
Adrianna Kochanska	Ocean Rainforest
Conner Lachenbruch	Conservation International
Colin Lanzl	MarinElixirs
Guillaume Lefranc	Acadian Seaplants
Annie Li	World Wildlife Fund
Fernanda Lopez	International Finance Corporation
Catriona Macleod	University of Tasmania
Susan McCarthy	World Wildlife Fund
Doug Middleton	Ocean Organics
Nikhil Neelakantan	Ocean Visions
Sergey Nuzhdin	University of Southern California / Kelp Ark
Susan Otieno	Aquaculture and Fisheries, Kenya
Utsav Oza	Sea2Carbon
Hannah Packman	The Nature Conservancy
Todd Paige	World Wildlife Fund

Virginia Pan	SWEN Blue Ocean
Valentin Pitiot	Kelp Blue
Payam Pourtaheri	AgroSpheres
Vivek Prasad	The World Bank
Nichole Price	Bigelow Center for Seafood Solutions
Maria Gabriela Reyes Calderin	TIDE, C.A
Jennifer Rix	Fertum USA (U.S. Subsidiary of Patagonia Biotecnología)
Michael Y. Roleda	University of the Philippines, Marine Science Institute
Aly Rose	Millbor Foundation
Andrew Rose	Chesapeake Sun
Whitney Rottman	Wildflower Ventures
George Seaver	George Seaver
Mirko Serkovic	The World Bank
Alex Shapiro	World Wildlife Fund
Pushp Sheel Shukla	Sea6 Energy Private Limited
William Soid	TIDE, C.A.
Sofia Soto Reyes	Consensus Building Institute
Thew Suskiewicz	Atlantic Sea Farms
Bernice Tang	Potato Impact Partners
Miguel Torres	International Finance Corporation
Elymi Ar-J S. Tunacao	Bureau of Fisheries and Aquatic Resources, the Philippines
Taylor Voorhees	The Nature Conservancy
Sarah Wan-Yau	Potato Impact Partners
Tiffany Waters	The Nature Conservancy
Gracie White	Conservation International Ventures
Michael Williamson	Cascadia Seaweed
Michael Wironen	The Nature Conservancy
Charles Yarish	University of Connecticut / Woods Hole Oceanographic Institution / The GreenWave Organization

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