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**Unlocking the Potential of Low-Trophic  
Aquaculture in the EU/EEA: Pathways  
to Scale Sustainable Marine Biomass**

**BELLONA REPORT**

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# Table of Contents

<b>Executive summary</b> .....	<b>3</b>
<b>1. Introduction</b> .....	<b>4</b>
<b>2. Defining Low-Trophic Aquaculture (LTA)</b> .....	<b>5</b>
2.1 LTA as a climate and nature-positive solution .....	6
2.2 Carbon sequestration potential .....	6
2.3 Carbon sequestration and ocean acidification .....	7
2.4 Nutrient remediation and eutrophication.....	7
2.5 Ecosystem services and biodiversity enhancement .....	8
2.6 The historical and cultural context in Europe .....	8
<b>3.Overcoming barriers to scaling LTA in the EU/EEA</b> .....	<b>10</b>
3.1 Policy and regulatory fragmentation .....	10
3.1.1 Complex and inconsistent permitting processes .....	10
3.1.2 Lack of a dedicated LTA policy framework .....	11
3.2 Economic and market hurdles.....	11
3.2.1 Investment difficulties. ....	11
3.2.2 Low consumer awareness.....	12
3.2.3 Underdeveloped processing.....	12
3.3 Technological and research gaps .....	13
3.3.1 Limited automation.....	13
3.3.2 Lack of knowledge sharing .....	13
3.3.3 Environmental dependency .....	13
<b>4. Case Studies</b> .....	<b>15</b>
4.1 Case Study #1: Co-location offshore may be part of the solution .....	15
4.2 Case Study #2: IMTA .....	16
4.3 Case Study #3: Look to Europe .....	17
<b>5.Conclusion: LTA looking forward</b> .....	<b>18</b>



## Executive summary

**Low-Trophic Aquaculture (LTA)** focuses on the cultivation of species such as seaweeds and bivalves and **represents a fundamental cornerstone for a future European bioeconomy**. Unlike conventional high-trophic aquaculture systems that rely on external feeds and contribute to resource depletion, **LTA leverages the ocean's natural processes to produce biomass without the need for additional inputs**. By providing critical ecosystem services, **LTA functions as a powerful tool with the potential for contributing to climate mitigation, nature restoration and a base for future biotechnological industries across Europe**, directly aligning with the EU's Green Deal and Bioeconomy Strategy objectives.

Despite these compelling benefits, **the European LTA sector remains a niche industry hampered by regulatory fragmentation, underdeveloped processing infrastructure, and market immaturity**. Current obstacles, such as competition for coastal space and fragmented bureaucracy, prevents the sector from achieving the industrial scale necessary to impact global markets. To unlock its full potential, **Europe must move beyond small-scale pilots toward strategic offshore co-location (e.g., within wind farms) and the development of regional biorefining hubs**. By harmonising policy frameworks and de-risking investments, the EU can transition from a nutrient-input monoculture model to a circular, low-carbon marine-based bioeconomy, **repositioning European aquaculture as a catalyst for further environmental and economic sustainability**.

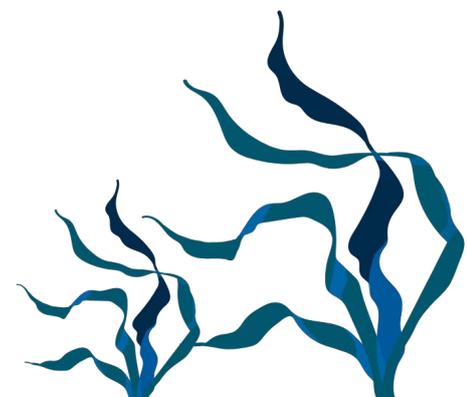
# 1. Introduction

The European Union faces a pressing challenge: transitioning to a sustainable, low-carbon economy while simultaneously restoring the health of its natural ecosystems. Within this context, the oceans offer vast, largely untapped potential for delivering renewable biomass, supporting climate mitigation, and providing critical ecosystem services. Low-Trophic Aquaculture (LTA), the cultivation of seaweeds and bivalves, represents a promising solution at the intersection of these challenges, combining ecological restoration with economic opportunity.

Unlike conventional high-trophic aquaculture systems, which rely on external feed inputs and contribute to resource depletion, LTA leverages the ocean's natural productivity. For instance, seaweeds capture carbon and nutrients directly from the water column, while bivalves filter excess phytoplankton, collectively contributing to carbon sequestration, nutrient remediation, and habitat enhancement. This positions LTA as a climate- and nature-positive sector capable of supplying sustainable biomass for food, feed, and other bio-based industrial applications, directly supporting the EU Green Deal and the EU Bioeconomy Strategy, and aligning with the EU initiatives that promote sustainable aquaculture, valorise underused marine biomass, and strengthen resilient marine value chains, which are key pillars of the blue bioeconomy.

Despite these environmental and economic advantages, the European LTA sector remains a nascent industry. Its growth is constrained by fragmented regulatory frameworks, limited processing infrastructure, and market immaturity. Competition for coastal and offshore space, coupled with inconsistent permitting and high investment risk, has so far prevented the sector from reaching the scale necessary to achieve meaningful impact.

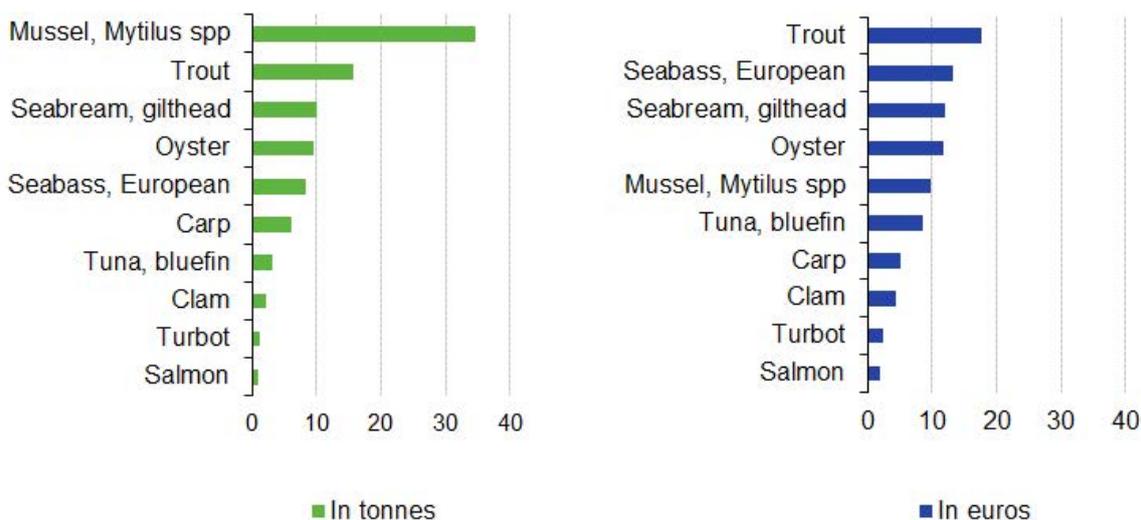
This report explores the pathways for unlocking the potential of LTA across the EU and EEA. By examining the ecological benefits, technological innovations, policy frameworks, and market dynamics shaping the sector, it highlights strategies for scaling LTA through offshore co-location, regional biorefining hubs, and harmonised regulatory support. In doing so, the report positions LTA not only as a sustainable food and biomass source, but as a strategic lever for the EU to transition toward a circular, low-carbon marine bioeconomy.



## 2. Defining Low-Trophic Aquaculture (LTA)

Low-Trophic Aquaculture (LTA) is an ecologically restorative form of food production focused on species at the base of the marine food web. Unlike conventional European aquaculture, which is typically dominated by high-trophic carnivorous finfish like trout, seabass, seabream, carp, tuna and salmon (accounting for over 60% of production value)<sup>1</sup>, LTA cultivates species like seaweeds (macroalgae) and bivalve molluscs (mussels, oysters, and scallops). These species grow by consuming naturally available resources: seaweeds use sunlight and dissolved nutrients through photosynthesis, while bivalves filter phytoplankton and organic particles from the water column.

**Main species in aquaculture production (% EU, 2023)**  
(% EU, 2023)



Source: Eurostat (online data code: fish\_aq2a)



Figure 1: Main species of aquaculture production (% EU, 2023) Source: Eurostat

This biological distinction translates directly into LTA's superior environmental and economic efficiency, as LTA systems operate without external feed. In contrast, high-trophic systems rely on external feed, often derived from wild fish meal and soy, contributing to resource depletion and a higher carbon footprint.<sup>2,3</sup> The inherent efficiency of LTA, coupled with its ability for

1 Eurostat. Aquaculture statistics - Statistics explained. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture\\_statistics](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture_statistics)

2 Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., ... & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, 591(7851), 551-563.

3 Hua, K., Cobcroft, J. M., Cole, A., Condon, K., Jerry, D. R., Mangott, A., ... & Strugnell, J. M. (2019). The future of aquatic protein: implications for protein sources in aquaculture diets. *One Earth*, 1(3), 316-329.

bioremediation and a sustainable source for food production, positions it as a net-positive activity for ecosystems. This makes LTA a key pillar of a blue bioeconomy, where biomass is not only food but a raw material for diverse industries, including hydrocolloids, bioplastics, pharmaceuticals, and low-carbon biofuel feedstocks.<sup>4</sup> This multi-faceted value transforms LTA into a cornerstone of a sustainable, low-carbon industrial model aligned with the EU's Bioeconomy Strategy.<sup>5</sup>

## 2.1 LTA as a climate and nature-positive solution

**Society is currently facing a dual crisis of climate change and biodiversity loss, demanding an immediate, systemic transition away from fossil fuels and unsustainable land use.** The escalating global average temperature and increased frequency of extreme weather events underscore the urgent need to decarbonise all major economic sectors. Simultaneously, the collapse of natural ecosystems, driven largely by terrestrial agriculture and resource extraction, necessitates new, restorative models for economic growth and energy production. Ocean resources, particularly the vast and underutilised potential of marine primary producers, offer a compelling alternative to dependence on petrochemicals for energy and industrial materials. LTA emerges as an essential component in this necessary industrial shift, leveraging the ocean's regenerative capacity to deliver biomass that is both carbon negative and nature positive, offering measurable ecosystem services that contribute to climate mitigation, biodiversity restoration, and the sustainable blue bioeconomy. These benefits align closely with key EU priorities, such as the European Ocean Pact's goals to protect and restore ocean health and strengthen the competitiveness of sustainable marine sectors.

## 2.2 Carbon sequestration potential

Seaweeds are one of the most significant and productive primary producers in the ocean, making them a cornerstone of the global "blue carbon" agenda. Their climate change mitigation potential stems from a dual function:

- 1. Standing stock: Seaweeds act as a vast, temporary carbon reservoir by fixing atmospheric CO<sub>2</sub> through photosynthesis and storing it in their biomass, contributing an estimated 1.5 billion metric tons of net primary productivity globally each year.<sup>6</sup>**
2. Long-term sequestration: Through the natural biological carbon pump, a portion of macroalgal detritus (particulate and dissolved organic carbon) is exported to the deep sea, sinking below the 1000 m sequestration flux depth to be assimilated into stable marine sediments. Current estimates suggest that this process can contribute 153

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4 Sadhukhan, J., Gadkari, S., Martinez-Hernandez, E., Ng, K. S., Shemfe, M., Torres-Garcia, E., & Lynch, J. (2019). Novel macroalgae (seaweed) biorefinery systems for integrated chemical, protein, salt, nutrient and mineral extractions and environmental protection by green synthesis and life cycle sustainability assessments. *Green Chemistry*, 21(10), 2635–2655.

5 European Commission: Directorate-General for Research and Innovation. (2022). The EU's bioeconomy strategy – A policy framework for sustainability. Publications Office of the European Union. <https://data.europa.eu/doi/10.2777/787912>

6 Krause-Jensen, D., Lavery, P., Serrano, O., Marbà, N., Masque, P., & Duarte, C. M. (2018). Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology letters*, 14(6).

million metric tons of macroalgae carbon to long-term storage per year, exceeding the combined burial rates of seagrasses, mangroves, and salt marshes.<sup>7</sup>

For aquaculture, the pragmatic and scalable approach to carbon removal is not based on unfeasible mass sinking, but on the principles of Carbon Capture and Utilisation (CCU) and Biomass with Carbon Capture and Storage (BECCS).<sup>8</sup> The LTA biorefinery model offers a market-driven strategy: harvested biomass can first be processed for high-value products (e.g., food, pharmaceuticals), and the remaining low-value residue can then be converted into stable, carbon-storing materials like biochar via hydrothermal carbonisation, or used as low-carbon bioenergy via anaerobic digestion.<sup>9 10</sup>

## 2.3 Carbon sequestration and ocean acidification

The cultivation of seaweeds offers a nature-based mechanism for combating climate change. As highly efficient primary producers, common macroalgae like *Saccharina latissima* (sugar kelp), *Laminaria hyperborea* (cuvie kelp), and *Ascophyllum nodosum* (knotted wrack) remove dissolved inorganic carbon ( $\text{HCO}_3^-$  and  $\text{CO}_2$ ) from the water column through photosynthesis.<sup>11</sup> This process not only sequesters atmospheric carbon but also locally raises the pH of the surrounding water, a critical service in regions impacted by ocean acidification. **Research has shown that dense seaweed farms can create localised "pH refugia," buffering acidic conditions and protecting vulnerable calcifying organisms such as bivalves, corals, and crustaceans.**<sup>12</sup>

## 2.4 Nutrient remediation and eutrophication

Eutrophication, defined by the excessive enrichment of water with nutrients such as nitrogen and phosphorus, is a chronic issue in many European coastal waters, particularly the Baltic Sea<sup>13</sup> and parts of the North Sea<sup>14</sup>. Eutrophication can lead to harmful algal blooms and widespread hypoxia<sup>15</sup> and LTA can provide a direct, biological solution. Bivalves, as filter-feeders, actively consume excess phytoplankton and suspended particles, as well as trap nutrients.<sup>16</sup> **For example, many bivalves can filter up to 50 litres of water per day,**

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7 Krause-Jensen, D., & Duarte, C. M. (2016). Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience*, 9(10), 737-742.

8 Kemper, Jasmin. "Biomass and carbon dioxide capture and storage: A review." *International Journal of Greenhouse Gas Control* 40 (2015): 401-430.

9 Hinks, J., Edwards, S., Sallis, P. J., & Caldwell, G. S. (2013). The steady state anaerobic digestion of *Laminaria hyperborea*—Effect of hydraulic residence on biogas production and bacterial community composition. *Bioresource technology*, 143, 221-230.

10 Shrestha, A., Acharya, B., & Farooque, A. A. (2021). Study of hydrochar and process water from hydrothermal carbonization of sea lettuce. *Renewable Energy*, 163, 589-598.

11 Beer, S., & Beardall, J. (2025). Inorganic carbon acquisition and photosynthetic metabolism in marine photoautotrophs: A summary. *Plants*, 14(6), 904.

12 Xiao, X., Agustí, S., Yu, Y., Huang, Y., Chen, W., Hu, J., ... & Duarte, C. M. (2021). Seaweed farms provide refugia from ocean acidification. *Science of the Total Environment*, 776, 145192.

13 Andersen, J. H., Carstensen, J., Conley, D. J., Dromph, K., Fleming-Lehtinen, V., Gustafsson, B. G., ... & Murray, C. (2017). Long-term temporal and spatial trends in eutrophication status of the Baltic Sea. *Biological Reviews*, 92(1), 135-149.

14 Lenhart, H. J., Mills, D. K., Baretta-Bekker, H., Van Leeuwen, S. M., Van Der Molen, J., Baretta, J. W., ... & Wakelin, S. L. (2010). Predicting the consequences of nutrient reduction on the eutrophication status of the North Sea. *Journal of Marine Systems*, 81(1-2), 148-170.

15 Dorgham, Mohamed M. "Effects of eutrophication." *Eutrophication: Causes, Consequences and Control: Volume 2*. Dordrecht: Springer Netherlands, 2013. 29-44.

16 Kotta, J., Futter, M., Kaasik, A., Liversage, K., Rätsep, M., Barboza, F. R., ... & Virtanen, E. (2020). Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. *Science of the Total Environment*, 709, 136144.

**removing large volumes of suspended solids and improving water clarity.** This natural filtering capacity can be leveraged in future restoration projects across European coastal areas where mussel and oyster farms can be deployed specifically to improve water quality<sup>17</sup> and help meet ecological objectives of the Marine Strategy Framework Directive (MSFD).

Similarly, seaweeds are highly effective biofilters that have been shown to absorb dissolved inorganic nutrients.<sup>18</sup> A study in Denmark for instance found that sugar kelp cultivation has the capability of annually removing 23 kg of nitrogen, 0.8 kg of phosphorous and 145 kg of carbon per hectare.<sup>19</sup> The resulting nutrient-rich biomass, once harvested, is not just waste, but valuable input for a circular economy. It can be transformed into high-quality organic biofertilisers, replacing synthetic agricultural inputs and closing the nutrient loop between land and sea.

## 2.5 Ecosystem services and biodiversity enhancement

LTA farms offer ecological benefits that can extend beyond nutrient and carbon cycling, serving as habitats for marine life and boosting local biodiversity. The structures used in LTA, such as the ropes, buoys, and rafts for seaweed and mussel cultivation, create complex three-dimensional habitats in the water column. This increases the available surface area and can provide substrate for epifauna (e.g., barnacles, sponges, and small invertebrates) and attracting wild fish and other motile species. There are indications that kelp farms may in fact create new habitat types, supporting marine communities not necessarily associated with traditional kelp forests.<sup>20</sup>

Although they are no replacement for kelp forests as natural habitats and nursing grounds, these complex LTA structures can function as a type of nursery for juvenile fish<sup>21</sup>, including commercially important species like cod and herring. **This can lead to a positive spillover effect, where the presence of LTA farms contributes to the replenishment of local wild fish stocks, benefiting both commercial fisheries and marine conservation efforts.**

## 2.6 The historical and cultural context in Europe

The cultivation of low-trophic species is deeply rooted in Europe's coastal heritage, providing a strong cultural foundation for future growth. **For centuries, communities across the European continent have relied on bivalve and seaweed harvesting and farming as a vital source of food and economic livelihood.** Although low-trophic organisms such as mussels and kelp have been a staple of the European diet for thousands of years, with evidence

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17 Lindahl, O., Hart, R., Hernroth, B., Kollberg, S., Loo, L. O., Olrog, L., ... & Syversen, U. (2005). Improving marine water quality by mussel farming: a profitable solution for Swedish society. *AMBIO: A Journal of the Human Environment*, 34(2), 131-138.

18 Xu, S., Yu, Z., Zhou, Y., Yue, S., Liang, J., & Zhang, X. (2023). The potential for large-scale kelp aquaculture to counteract marine eutrophication by nutrient removal. *Marine Pollution Bulletin*, 187, 114513.

19 Bruhn, A., Boderskov, T., Nielsen, M. M., Schmedes, P. S., Taylor, D., Høgslund, S., ... & Ehrenreich, J. L. (2025). Cultivation of sugar kelp as a marine measure for mitigating eutrophication: Production in large-scale, nutrient removal efficiency, environmental impacts, and economy.

20 Forbes, H., Shelamoff, V., Visch, W., & Layton, C. (2022). Farms and forests: evaluating the biodiversity benefits of kelp aquaculture. *Journal of Applied Phycology*, 34(6), 3059-3067.

21 Underwood, L. H., & Jeffs, A. G. (2023). Settlement and recruitment of fish in mussel farms. *Aquaculture Environment Interactions*, 15, 85-100.

going back as far as 6000 B.C., one of the first recorded examples of LTA in Europe involves the French bouchot system.<sup>22</sup> This system, which dates back to the 1300s, uses wooden poles for vertical cultivation of blue mussels.

The use of seaweed also has a long history in a European context. In Ireland and Scotland, species like *Palmaria palmata* (dulse) and *Alaria esculenta* (badderlocks) were traditionally consumed for nutritional and medicinal purposes and used as a bio-fertiliser on coastal farms. The same goes for the Nordic region, where seaweed has been used for food and medicine, with a variety of preservation methods historically used.

This cultural context provides an advantage for the future growth of the LTA sector in Europe. By modernising established practices, the EU can build on existing expertise, maintain cultural ties to coastal traditions, and support local economies that have been sustained by the sea for generations, making its scaling a matter of strategic policy alignment rather than a fundamental cultural change.



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<sup>22</sup> Prou, J., & Gouletquer, P. (2002). The French mussel industry: present status and perspectives. Bulletin of the Aquaculture Association of Canada, 102(3), 17-23.

## 3. Overcoming barriers to scaling LTA in the EU/EEA

Despite the compelling environmental arguments for expanding Low-Trophic Aquaculture, the sector currently faces significant friction points across policy, market, and technological domains within the European Union, with much of LTA in the EU having decreased since 1990<sup>23</sup> and higher trophic level aquaculture increasing.<sup>24</sup> These systemic obstacles prevent LTA from moving beyond niche production into a large-scale, industrial solution capable of contributing significantly to the EU Bioeconomy Strategy objectives. Addressing these challenges requires coordinated action from Member States and the European Commission to de-risk investment and standardise operations.

### 3.1 Policy and regulatory fragmentation

**The most immediate challenge to LTA growth is the dense and often contradictory regulatory landscape governing marine activities, which can create uncertainty and high compliance costs.** This regulatory maze can deter both new startups and existing producers from expanding operations into LTA.

#### 3.1.1 Complex and inconsistent permitting processes

Permitting for new LTA sites is currently characterised by a confusing patchwork of national, regional, and local regulations that lack a unified, streamlined approach across the EU. Developers frequently encounter extremely long and unpredictable approval timelines, spanning many years, due to the need for sign-off from multiple overlapping authorities and management bodies. This can often create inter-agency conflict and a lack of a cohesive marine planning portal for project developers, which creates substantial regulatory risk, raising costs disproportionately for small and medium-sized companies and start-ups. Additionally, identical LTA projects might face different approval timelines across the different EU Member States, making investment and planning difficult.

The deployment of LTA is heavily constrained by the intense competition for coastal and offshore space, a challenge exacerbated by certain aspects of the implemented Maritime Spatial Planning (MSP) Directive.<sup>25</sup> Marine areas are largely being allocated to established, higher-value sectors like commercial shipping, offshore wind energy, and traditional fisheries. LTA, as a nascent sector, frequently lacks prioritised status, effectively relegating it to marginal areas where environmental conditions or logistical access may be poor. This is a critical failure, as co-location, particularly with offshore wind farms, offers immense potential for LTA

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<sup>23</sup> Avdelas, L., Avdic-Mravljic, E., Borges Marques, A. C., Cano, S., Capelle, J. J., Carvalho, N., ... & Asche, F. (2021). The decline of mussel aquaculture in the European Union: causes, economic impacts and opportunities. *Reviews in Aquaculture*, 13(1), 91-118.

<sup>24</sup> Guillen, J., Asche, F., Borriello, A., Carvalho, N., Druon, J. N., Garlock, T., ... & Macias, D. (2025). What is happening to the European Union aquaculture production? Investigating its stagnation and sustainability. *Aquaculture*, 596, 741793.

<sup>25</sup> Zauha, J., Gee, K., Ramieri, E., Neimane, L., Alloncle, N., Blažauskas, N., ... & Ehler, C. N. (2025). Implementing the EU MSP Directive: Current status and lessons learned in 22 EU Member States. *Marine Policy*, 171, 106425.

expansion by utilising available space and providing operational synergies. However, regulatory frameworks often erect complex barriers to co-location due to concerns over navigation, gear conflict, and liability, preventing the integration of biomass production and clean energy.<sup>26</sup>

Moving forwards, LTA's restorative nature within MSP will need to be incorporated to a larger degree, avoiding any spatial exclusion that will severely limit its growth potential in coastal waters.

### 3.1.2 Lack of a dedicated LTA policy framework

While LTA is conceptually supported in overarching EU documents like the Strategic Guidelines for EU Aquaculture<sup>27</sup>, it critically lacks a dedicated, targeted regulatory framework, particularly for emerging sectors like seaweed farming. The regulatory frameworks governing algae production are often less developed or explicitly defined than those for traditional finfish, creating substantial uncertainty for investors and operators. For complex, integrated systems like Integrated Multi-Trophic Aquaculture (IMTA)<sup>28</sup>, the multi-species nature of the farm complicates existing single-species regulations, often forcing these ecologically complex systems into a bureaucratic grey area. Resolving this ambiguity is critical to meet the goals of initiatives like the EU Algae Initiative. **Crucially, the EU has been slow to integrate LTA's climate benefits, specifically its carbon and nutrient removal capability, into overarching EU frameworks.**

## 3.2 Economic and market hurdles

Economic viability remains challenging for LTA producers, particularly in the difficult task of establishing robust, high-volume supply chains that can efficiently link biomass production to diverse, high-value markets internationally.

### 3.2.1 Investment difficulties

Establishing new, resilient offshore LTA infrastructure is capital-intensive, often requiring specialised vessels capable of handling extreme weather, durable and expensive deep-water mooring systems, and significant investment in hatchery and seeding technology. Coupled with a complex regulatory context, this can create a steep barrier to entry, limiting participation mostly to larger integrated companies or small, government-subsidised pilots. Traditional commercial financial institutions are often reluctant to invest in LTA due to the perceived novelty of the sector, the unproven economies of scale for offshore systems, and the inherent biological risks (e.g., disease, extreme weather damage, mortality).<sup>29</sup>

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<sup>26</sup> Van Hoey, G., Bastardie, F., Birchenough, S., De Backer, A., Gill, A., De Koning, S., ... & Hintzen, N. (2021). *Overview of the effects of offshore wind farms on fisheries and aquaculture*. Publications Office of the European Union.

<sup>27</sup> European Commission. (2021). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030*. COM(2021) 236 final.

<sup>28</sup> Barrington, K., Chopin, T., & Robinson, S. (2009). Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. *Integrated mariculture: a global review*. *FAO Fisheries and Aquaculture Technical Paper*, 529, 7-46.

<sup>29</sup> Aguilar-Manjarrez, J., Soto, D., & Brummett, R. (2017). *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. A handbook*. Food and Agriculture Organization of the United Nations/The World Bank.

Furthermore, the typical return on investment timeline for LTA is longer than conventional aquaculture, therefore likely requiring an initial public investment to de-risk the investment stage, perhaps through dedicated EU guarantee schemes or public-private partnerships focused on building foundational shared infrastructure, such as processing hubs and dedicated LTA ports.

### 3.2.2 Low consumer awareness

**Despite the long historical context of bivalve and seaweed consumption in European coastal regions, market penetration for many modern LTA products remains low across much of the EU.** In many central and northern European regions, consumer demand and acceptance for products like cultivated seaweed are substantially lower than for traditional animal proteins, creating an immediate hurdle for scaling production. The perception of seaweed often defaults to it being a niche health food rather than a sustainable, everyday staple. Low consumer awareness regarding the significant health benefits (e.g., iodine, fibre, protein) and climate advantages of LTA products hinders consistent, high-volume demand growth.<sup>30</sup>

Compounding this, the sector lacks continent-wide standardised quality metrics, certification schemes, and clear labelling that communicate LTA's sustainability credentials effectively to consumers. To combat this, efforts are ongoing, such as the EU Aquaculture campaign and the EU Algae Initiative, which are specifically designed to increase public understanding and acceptance of these products. However, these programs require substantial, sustained support over long periods of time to truly shift consumption patterns. This market immaturity leads to fragmented demand, price volatility, and makes it challenging for producers to secure stable contracts necessary for scaling up large production facilities. **It is therefore unlikely that LTA's primary focus in a European context should be based on consumption, but rather on the role of LTA and biomass production in other processes as outlined later in this report.**

### 3.2.3 Underdeveloped processing

The EU LTA sector suffers from a critical lack of large-scale, centralised processing infrastructure, which is the key bottleneck preventing the industry from moving into industrial production. **Macroalgae is high-volume and low-density, often consisting of 80–90% water upon harvest.**<sup>31</sup> This necessitates immediate and energy-intensive steps like drying or freezing before any value-added processing can occur. The absence of regional biorefining hubs means producers must currently transport massive volumes of biomass long distances, incurring high logistic and energy costs.

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<sup>30</sup> Tett, P., Charalambides, G., Franco, S. C., Hughes, A. D., Mikkelsen, E., Nielsen, K. N., ... & James, P. (2025). Leaving the niche: Recommendations for mainstreaming Low Trophic Aquaculture in countries around the Atlantic basin. *Marine Policy*, 171, 106475.

<sup>31</sup> Hemavathy, R. V., Ragini, Y. P., Shruthi, S., Ranjani, S., Subhashini, S., & Thamarai, P. (2025). Biofuel production from marine macroalgae: Pathways, technologies, and sustainable energy solutions. *Industrial Crops and Products*, 224, 120282.

This processing gap limits producers' ability to reliably supply high-volume industrial markets (e.g., bio-fertiliser, bioplastic feedstocks, or bulk animal feed ingredients), forcing most current production to remain restricted to small, high-cost ventures focused mainly on niche markets.

### 3.3 Technological and research gaps

**To achieve global competitiveness and long-term climate resilience, targeted technological advances and better knowledge exchange are necessary across the entire LTA value chain, from seed to sale.**

#### 3.3.1 Limited automation

Much of European LTA production, especially for new seaweed farms, relies heavily on manual or semi-manual labour for critical steps like seeding, long-term maintenance, and, most importantly, harvesting.<sup>32</sup> The lack of robust automated technology for high-volume LTA is a contributing obstacle, and technological advancement and modifications will need to be implemented in a European market to keep labour costs down.<sup>33</sup>

#### 3.3.2 Lack of knowledge sharing

Research efforts across EU Member States and industry regarding LTA species domestication, optimised cultivation techniques, and processing methods are often highly fragmented and siloed. This lack of coordination prevents the rapid and efficient translation of promising pilot findings into best practice and commercially viable, standardised technologies. Furthermore, a pervasive lack of standardised data collection protocols across companies, EU Member States and industry partners impedes efforts to accurately quantify and reliably monetise the full spectrum of ecosystem services provided by different LTA species in specific EU marine environments. **For example, without a unified methodology, it is impossible to accurately compare the nutrient removal capacity of a mussel farm in the Baltic Sea versus a kelp farm in the Mediterranean, making it difficult for policymakers to allocate funds or integrate these services into a future European LTA market.**

#### 3.3.3 Environmental dependency

The sector's dependency on environmental conditions introduces significant biological and operational risks to LTA farms.<sup>34</sup> While LTA is a net-positive activity, its success is intrinsically tied to stable marine conditions, making it vulnerable to external stressors. LTA, especially in open-water environments, is highly susceptible to subtle changes in temperature and salinity gradients, which can affect reproductive cycles and growth rates. Furthermore, while LTA is a

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<sup>32</sup> Khan, N., Sudhakar, K., & Mamat, R. (2024). Macroalgae farming for sustainable future: Navigating opportunities and driving innovation. *Heliyon*, 10(7).

<sup>33</sup> Edwards, M., & Watson, L. (2011). Aquaculture explained. *Aquaculture*, 26, 1–71.

<sup>34</sup> Wong, A., Frommel, A. Y., Sumaila, U. R., & Cheung, W. W. (2024). A traits-based approach to assess aquaculture's contributions to food, climate change, and biodiversity goals. *Npj Ocean Sustainability*, 3(1), 30.

remediation tool, it can also bioaccumulate contaminants in polluted areas, making water quality and coastal pollution a key risk factor for both food safety compliance and market acceptance.

Extreme weather events, such as increased storm frequency, also pose a direct physical risk to infrastructure, leading to gear damage and stock mortality, which undermines investor confidence. Key commercial species, such as the sugar kelp (*Saccharina latissima*), are highly susceptible to thermal stress, which can lead to crop failure as ocean temperatures rise. There is a possibility of targeted selective breeding to identify, develop, and deploy locally adapted, climate-resilient strains of key LTA species (e.g., heat-tolerant kelp or disease-resistant mussels). **Without dedicated European seed banks and implementing controlled breeding and genetics programs, the long-term stability and security of LTA production in a warming ocean environment may be jeopardised, undermining its role as a reliable, future-proof biomass source.**



## 4. Case studies

### 4.1 Case Study #1: Co-location offshore may be part of the solution

To scale up and meet the EU's necessary production needs for LTA, the sector must overcome the acute competition for marine space in coastal zones. Coastal areas are already saturated with shipping routes, traditional fishing grounds, and conservation zones, often relegating LTA to suboptimal locations. This spatial constraint necessitates an integrated approach, for example through the move to offshore, multi-use sites. Co-locating LTA operations within existing or planned offshore wind farms is the most effective spatial strategy available, turning a limiting factor of scarce space into an opportunity for massive, industrial-scale growth. The co-location of LTA, specifically kelp farming, with offshore wind energy represents a crucial, scalable strategy for the EU to address its dual targets for rapid renewable energy deployment and sustainable marine biomass production.

In Germany for instance, the cultivation of macroalgae such as sugar kelp (*Laminaria saccharina*) and dulse (*Palmaria palmata*) integrated with offshore wind showed that these species experienced very favourable growth conditions in the nutrient-rich environments of the North Sea.<sup>35</sup> However, challenges related to the establishment of juvenile plants (sporophytes) in offshore environments can sometimes be a biological bottleneck. Health benefits, including low occurrences of parasites and toxins, make offshore areas particularly attractive for aquaculture. The combination of different species, such as mussels, oysters, and kelp, can reduce economic risks.<sup>36</sup> To support sustainable development of offshore aquaculture, the study recommended political measures and improved cooperation among stakeholders.

The compelling case for prioritising offshore co-location is fundamentally driven by the sheer scale of production potential. Research from the Norwegian Institute for Water Research (NIVA) and SINTEF<sup>37</sup> indicates that kelp cultivation on the continental shelf can yield approximately 150 tons per hectare, which is twice the biomass achievable in coastal areas. This exceptional efficiency underscores why multi-use sites are strategically critical to achieving the EU's Green Deal goals for sustainable feed ingredients and rapid clean energy deployment. Success depends on five key enablers: the creation of integrated regulatory frameworks, public-private collaboration to share investment risks, targeted R&D for offshore technologies, the launch of large-scale industrial pilot projects across the EU, and accelerated market development for kelp-based final products. Addressing these structural barriers through cohesive EU policy are essential for positioning Europe as a global leader in sustainable marine resource co-management.

<sup>35</sup> Buck, B. H., Krause, G., Pogoda, B., Grote, B., Wever, L., Goseberg, N., ... & Czybulka, D. (2017). The German case study: pioneer projects of aquaculture-wind farm multi-uses. In *Aquaculture perspective of multi-use sites in the open ocean: The untapped potential for marine resources in the Anthropocene* (pp. 253-354). Cham: Springer International Publishing.

<sup>36</sup> Buchholz, C. M., Krause, G., & Buck, B. H. (2012). Seaweed and man. In *Seaweed biology: Novel insights into ecophysiology, ecology and utilization* (pp. 471-493). Berlin, Heidelberg: Springer Berlin Heidelberg.

<sup>37</sup> Broch, O. J., Alver, M. O., Bekkby, T., Gundersen, H., Forbord, S., Handå, A., ... & Hancke, K. (2019). The kelp cultivation potential in coastal and offshore regions of Norway. *Frontiers in Marine Science*, 5, 529.

## 4.2 Case Study #2: Integrated Multi-Trophic Aquaculture

Integrated Multi-Trophic Aquaculture (IMTA) represents an attempt at creating a more ecologically restorative aquaculture production model, fundamentally distinct from monoculture by intentionally mimicking natural marine food webs. This system involves the co-cultivation of multiple species from different trophic levels—specifically fed species (like finfish or shrimp) with extractive species (LTA species like bivalves and seaweeds). IMTA systems are balanced through the inclusion of species from different marine niches: seaweeds absorb dissolved inorganic matter (like nitrates and phosphates), bivalves filter particulate organic matter (uneaten feed and feces), and often, detritivores clean up residual organic waste from the sediment.<sup>38</sup> In this system, the waste from fed species is captured and recycled by the extractive species, converting potential pollutants into valuable nutrients further down the food web. This holistic process can deliver bioremediation, reducing the environmental footprint of the entire farm by closing portions of the nutrient loop and improving the final product quality.<sup>39</sup>

The global success of LTA and IMTA is most powerfully demonstrated in China, which serves as a benchmark for industrial-scale potential globally. China's national aquaculture strategy has successfully integrated LTA species, particularly seaweeds and bivalves, as its dominant production base. **This has resulted in China consistently producing over 60% of the world's total farmed aquaculture.**<sup>40</sup> Since the early 2000s China has incorporated IMTA into their production systems, which today accounts for more than 40% of the country's marine aquaculture production. There are many drivers behind China's shift towards IMTA, including coastal pollution and eutrophication typically associated with fed aquaculture systems.<sup>41</sup> In coastal regions, IMTA in China has been deployed over massive scales, such as the multi-species systems combining sea cucumber, scallop, and kelp, covering thousands of hectares.<sup>42</sup> The sheer volume and efficiency of these large-scale Chinese facilities illustrate that IMTA and LTA are a central pillar of national food security and coastal management. China's centralised planning and sustained investment in research and infrastructure provide a transferable lesson for the EU: policy support and scale are essential to unlock the full economic and ecological benefits of marine circularity in aquaculture systems.

<sup>38</sup> Ridler, N., Wowchuk, M., Robinson, B., Barrington, K., Chopin, T., Robinson, S., ... & Boyne-Travis, S. (2007). Integrated multi-trophic aquaculture (IMTA): a potential strategic choice for farmers. *Aquaculture Economics & Management*, 11(1), 99-110.

<sup>39</sup> Neori, A., Chopin, T., Troell, M., Buschmann, A. H., Kraemer, G. P., Halling, C., ... & Yarish, C. (2004). Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. *Aquaculture*, 231(1-4), 361-391.

<sup>40</sup> Food and Agriculture Organization of the United Nations. (2018). *The state of world fisheries and aquaculture*. FAO.

<sup>41</sup> FAO. (2022). *Integrated multitrophic aquaculture: Lessons from China*. Food and Agriculture Organization of the United Nations.

<sup>42</sup> Hossain, A., Senff, P., & Glaser, M. (2022). Lessons for coastal applications of IMTA as a way towards sustainable development: A review. *Applied Sciences*, 12(23), 11920.

### 4.3 Case Study #3: Look to Europe

Despite the multiple challenges facing LTA in Europe, there are many initiatives and companies attempting to lay the groundwork for LTA as a cornerstone of a future European circular bioeconomy. Kelp farming, a cornerstone of LTA, is likely the foundation for LTA in a broader European context.

#### 1. Ocean Rainforest (Faroe Islands)

One pioneering example is Ocean Rainforest in the Faroe Islands, which provides a blueprint for making kelp farming viable in rough marine coastal areas. Their work directly addresses the critical LTA challenge of offshore resilience. The company specialises in large-scale cultivation of native kelp species, such as *Saccharina latissima* (sugar kelp).<sup>43</sup> The majority of their cultivated seaweed is used for animal feed, with 80% of their product in 2021 being sold for further processing into pig feed.<sup>44</sup> Seaweed contains important nutrients, proteins, lipids and fibres shown to benefit the immunity and health of livestock<sup>45</sup>, and feed with added seaweed has additionally been shown to reduce greenhouse gas emissions from livestock.<sup>46</sup>

#### 2. Nordic SeaFarm (Sweden)

In contrast, Nordic SeaFarm, based on the West Coast of Sweden, demonstrates a pathway focused on culinary integration and market acceptance within the Nordic region and has primarily had focus on this up until now.<sup>47</sup> They mainly produce *Saccharina latissima* (sugar kelp), but were the first in Europe to also try to expand and cultivate *Ulva* species on a large-scale in the ocean.<sup>48</sup>

Nordic SeaFarm's market focus is distinctly culinary, highlighting kelp's role as a sustainable culinary ingredient for direct consumer markets. They supply fresh and dried kelp products directly to fine dining restaurants, placing kelp as a premium, locally sourced alternative to traditional ingredients.

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43 Ocean Rainforest. (n.d.). Official website. <https://www.oceanrainforest.com>

44 The Fish Site. (n.d.). Restorative aquaculture: Ocean rainforest. <https://thefishsite.com/articles/restorative-aquaculture-ocean-rainforest>

45 Rajauria, G. (2015). Seaweeds: a sustainable feed source for livestock and aquaculture. In *Seaweed sustainability* (pp. 389-420). Academic press.

46 De Bhowmick, G., & Hayes, M. (2023). Potential of seaweeds to mitigate production of greenhouse gases during production of ruminant proteins. *Global Challenges*, 7(5), 2200145.

47 Nordic SeaFarm. (n.d.). Official website. <https://www.nordicseafarm.com>

48 Aquaculture Magazine. The Swedish company Nordic Seafarm brings its sustainably farmed seaweed to Nobel Prize dinner. <https://aquaculturemag.com/2024/01/05/the-swedish-company-nordic-seafarm-brings-its-sustainably-farmed-seaweed-to-nobel-prize-dinner/>

## 7. Conclusion: LTA looking forward

The future of European aquaculture must be defined by a rapid and decisive shift toward LTA and IMTA based systems. This transition is not merely about species diversification, it represents the necessary evolution from a nutrient-input, monoculture systems, long dominated by resource intensive carnivorous finfish production, to a nutrient-extractive, circular marine bioeconomy. **By embracing LTA, Europe can fundamentally reposition its seafood production as an environmental solution, using organisms like kelp and mussels as valuable ecosystem service providers that actively remove excess nutrients and provide biomass as a basis for future bio-economies.**

To successfully incorporate these systems at the necessary scale, Europe must prioritise three key areas for action. First, regulatory frameworks need streamlining and harmonisation across member states, specifically creating dedicated licensing pathways for multi-trophic and offshore farms to reduce investor uncertainty and overcome reluctance. Second, significant public and private investment is required to bridge the crucial processing gap, fostering regional biorefining hubs that can efficiently process raw LTA biomass into high-value products like specialised feeds, bio-fertilisers, and sustainable ingredients. Finally, consumer and legislator awareness initiatives must be scaled up to generate stable demand for these novel products, not just as food, but as a basis for future biomass needs.

The immediate next steps must be viewed through the lens of the climate and nature crises. LTA and IMTA deployment are an important tool for meeting the objectives of the European Green Deal, particularly the Farm to Fork Strategy and the Marine Strategy Framework Directive (MSFD). The time for small pilot projects is passing. The next decade demands the European Union provide financial backing and political will to move LTA from the periphery to the core of Europe's blue economy strategy.

# References

- Aguilar-Manjarrez, J., Soto, D., & Brummett, R. (2017). *Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. A handbook*. Food and Agriculture Organization of the United Nations/The World Bank.
- Andersen, J. H., Carstensen, J., Conley, D. J., Dromph, K., Fleming-Lehtinen, V., Gustafsson, B. G., ... & Murray, C. (2017). Long-term temporal and spatial trends in eutrophication status of the Baltic Sea. *Biological Reviews*, 92(1), 135-149.
- Aquaculture Magazine. *The Swedish company Nordic Seafarm brings its sustainably farmed seaweed to Nobel Prize dinner*. <https://aquaculturemag.com/2024/01/05/the-swedish-company-nordic-seafarm-brings-its-sustainably-farmed-seaweed-to-nobel-prize-dinner/>
- Avdelas, L., Avdic-Mravljje, E., Borges Marques, A. C., Cano, S., Capelle, J. J., Carvalho, N., ... & Asche, F. (2021). The decline of mussel aquaculture in the European Union: causes, economic impacts and opportunities. *Reviews in Aquaculture*, 13(1), 91-118.
- Barrington, K., Chopin, T., & Robinson, S. (2009). Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. *Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper*, 529, 7-46.
- Beer, S., & Beardall, J. (2025). Inorganic carbon acquisition and photosynthetic metabolism in marine photoautotrophs: A summary. *Plants*, 14(6), 904.
- Broch, O. J., Alver, M. O., Bekkby, T., Gundersen, H., Forbord, S., Handå, A., ... & Hancke, K. (2019). The kelp cultivation potential in coastal and offshore regions of Norway. *Frontiers in Marine Science*, 5, 529.
- Bruhn, A., Boderskov, T., Nielsen, M. M., Schmedes, P. S., Taylor, D., Høgslund, S., ... & Ehrenreich, J. L. (2025). Cultivation of sugar kelp as a marine measure for mitigating eutrophication: Production in large-scale, nutrient removal efficiency, environmental impacts, and economy.
- Buchholz, C. M., Krause, G., & Buck, B. H. (2012). Seaweed and man. In *Seaweed biology: Novel insights into ecophysiology, ecology and utilization* (pp. 471-493). Berlin, Heidelberg: Springer BerlinHeidelberg.
- Buck, B. H., Krause, G., Pogoda, B., Grote, B., Wever, L., Goseberg, N., ... & Czybulka, D. (2017). The German case study: pioneer projects of aquaculture-wind farm multi-uses. In *Aquaculture perspective of multi-use sites in the open ocean: The untapped potential for marine resources in the Anthropocene* (pp. 253-354). Cham: Springer International Publishing.
- De Bhowmick, G., & Hayes, M. (2023). Potential of seaweeds to mitigate production of greenhouse gases during production of ruminant proteins. *Global Challenges*, 7(5), 2200145.
- Dorgham, M. M. (2013). Effects of eutrophication. In *Eutrophication: Causes, consequences and control* (Vol. 2, pp. 29-44). Springer Netherlands.
- Edwards, M., & Watson, L. (2011). Aquaculture explained. *Aquaculture*, 26, 1-71.

European Commission. (2021). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030*. COM(2021) 236 final.

European Commission: Directorate-General for Research and Innovation. (2021). *European Green Deal – Research & innovation call*. Publications Office of the European Union. <https://data.europa.eu/doi/10.2777/33415>

European Commission: Directorate-General for Research and Innovation. (2022). *The EU's bioeconomy strategy – A policy framework for sustainability*. Publications Office of the European Union. <https://data.europa.eu/doi/10.2777/787912>

Eurostat. (n.d.). *Aquaculture statistics – Statistics explained*. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture\\_statistics](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture_statistics)

FAO. (2022). *Integrated multitrophic aquaculture: Lessons from China*. Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization of the United Nations. (2018). *The state of world fisheries and aquaculture*. FAO.

Forbes, H., Shelamoff, V., Visch, W., & Layton, C. (2022). Farms and forests: evaluating the biodiversity benefits of kelp aquaculture. *Journal of Applied Phycology*, 34(6), 3059-3067.

Guillen, J., Asche, F., Borriello, A., Carvalho, N., Druon, J. N., Garlock, T., ... & Macias, D. (2025). What is happening to the European Union aquaculture production? Investigating its stagnation and sustainability. *Aquaculture*, 596, 741793.

Hemavathy, R. V., Ragini, Y. P., Shruthi, S., Ranjani, S., Subhashini, S., & Thamarai, P. (2025). Biofuel production from marine macroalgae: Pathways, technologies, and sustainable energy solutions. *Industrial Crops and Products*, 224, 120282.

Hinks, J., Edwards, S., Sallis, P. J., & Caldwell, G. S. (2013). The steady state anaerobic digestion of *Laminaria hyperborea*—Effect of hydraulic residence on biogas production and bacterial community composition. *Bioresource technology*, 143, 221-230.

Hossain, A., Senff, P., & Glaser, M. (2022). Lessons for coastal applications of IMTA as a way towards sustainable development: A review. *Applied Sciences*, 12(23), 11920.

Hua, K., Cobcroft, J. M., Cole, A., Condon, K., Jerry, D. R., Mangott, A., ... & Strugnell, J. M. (2019). The future of aquatic protein: implications for protein sources in aquaculture diets. *One Earth*, 1(3), 316-329.

Kemper, J. (2015). Biomass and carbon dioxide capture and storage: A review. *International Journal of Greenhouse Gas Control*, 40, 401-430.

Khan, N., Sudhakar, K., & Mamat, R. (2024). Macroalgae farming for sustainable future: Navigating opportunities and driving innovation. *Heliyon*, 10(7).

Kotta, J., Futter, M., Kaasik, A., Liversage, K., Rätsep, M., Barboza, F. R., ... & Virtanen, E. (2020). Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. *Science of the Total Environment*, 709, 136144.

- Krause-Jensen, D., Lavery, P., Serrano, O., Marbà, N., Masque, P., & Duarte, C. M. (2018). Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology letters*, *14*(6).
- Krause-Jensen, D., & Duarte, C. M. (2016). Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience*, *9*(10), 737-742.
- Lenhart, H. J., Mills, D. K., Baretta-Bekker, H., Van Leeuwen, S. M., Van Der Molen, J., Baretta, J. W., ... & Wakelin, S. L. (2010). Predicting the consequences of nutrient reduction on the eutrophication status of the North Sea. *Journal of Marine Systems*, *81*(1-2), 148-170.
- Lindahl, O., Hart, R., Hernroth, B., Kollberg, S., Loo, L. O., Olrog, L., ... & Syversen, U. (2005). Improving marine water quality by mussel farming: a profitable solution for Swedish society. *AMBIO: A Journal of the Human Environment*, *34*(2), 131-138.
- Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., ... & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, *591*(7851), 551-563.
- Neori, A., Chopin, T., Troell, M., Buschmann, A. H., Kraemer, G. P., Halling, C., ... & Yarish, C. (2004). Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. *Aquaculture*, *231*(1-4), 361-391.
- Nordic SeaFarm. (n.d.). *Official website*. <https://www.nordicseafarm.com>
- Ocean Rainforest. (n.d.). *Official website*. <https://www.oceanrainforest.com>
- Prou, J., & Gouletquer, P. (2002). The French mussel industry: present status and perspectives. *Bulletin of the Aquaculture Association of Canada*, *102*(3), 17-23.
- Rajauria, G. (2015). Seaweeds: a sustainable feed source for livestock and aquaculture. In *Seaweed sustainability* (pp. 389-420). Academic press.
- Ridler, N., Wowchuk, M., Robinson, B., Barrington, K., Chopin, T., Robinson, S., ... & Boyne-Travis, S. (2007). Integrated multi-trophic aquaculture (IMTA): a potential strategic choice for farmers. *Aquaculture Economics & Management*, *11*(1), 99-110.
- Sadhukhan, J., Gadkari, S., Martinez-Hernandez, E., Ng, K. S., Shemfe, M., Torres-Garcia, E., & Lynch, J. (2019). Novel macroalgae (seaweed) biorefinery systems for integrated chemical, protein, salt, nutrient and mineral extractions and environmental protection by green synthesis and life cycle sustainability assessments. *Green Chemistry*, *21*(10), 2635-2655.
- Shrestha, A., Acharya, B., & Farooque, A. A. (2021). Study of hydrochar and process water from hydrothermal carbonization of sea lettuce. *Renewable Energy*, *163*, 589-598.
- Tett, P., Charalambides, G., Franco, S. C., Hughes, A. D., Mikkelsen, E., Nielsen, K. N., ... & James, P. (2025). Leaving the niche: Recommendations for mainstreaming Low Trophic Aquaculture in countries around the Atlantic basin. *Marine Policy*, *171*, 106475.
- The Fish Site. (n.d.). *Restorative aquaculture: Ocean rainforest*. <https://thefishsite.com/articles/restorative-aquaculture-ocean-rainforest>
- Underwood, L. H., & Jeffs, A. G. (2023). Settlement and recruitment of fish in mussel farms. *Aquaculture Environment Interactions*, *15*, 85-100.

Van Hoey, G., Bastardie, F., Birchenough, S., De Backer, A., Gill, A., De Koning, S., ... & Hintzen, N. (2021). *Overview of the effects of offshore wind farms on fisheries and aquaculture*. Publications Office of the European Union.

Wong, A., Frommel, A. Y., Sumaila, U. R., & Cheung, W. W. (2024). A traits-based approach to assess aquaculture's contributions to food, climate change, and biodiversity goals. *Npj Ocean Sustainability*, 3(1), 30.

Xiao, X., Agustí, S., Yu, Y., Huang, Y., Chen, W., Hu, J., ... & Duarte, C. M. (2021). Seaweed farms provide refugia from ocean acidification. *Science of the Total Environment*, 776, 145192.

Xu, S., Yu, Z., Zhou, Y., Yue, S., Liang, J., & Zhang, X. (2023). The potential for large-scale kelp aquaculture to counteract marine eutrophication by nutrient removal. *Marine Pollution Bulletin*, 187, 114513.

Zaucha, J., Gee, K., Ramieri, E., Neimane, L., Alloncle, N., Blažauskas, N., ... & Ehler, C. N. (2025). Implementing the EU MSP Directive: Current status and lessons learned in 22 EU Member States. *Marine Policy*, 171, 106425.



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