SEAGROWN

SeaGrown: Transforming UK offshore marine algae biomass production

NZIP Biomass Feedstocks Innovation Programme: SEA – 133 BFI

Redacted Project Final Report

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1. Executive Summary

Seaweed grows naturally and abundantly around much of the UK's coastline. Seaweed relies only on the energy and nutrients of the sun and the sea to grow, without the addition of any chemicals or fresh water or the use of valuable land resources, which are perhaps better used to produce food crops. It is a versatile source of biomass which can deliver a huge number of valuable outputs for a wide range of industrial sectors. Seaweed grows fast, making it a truly renewable resource, taking up excess nutrients and carbon from the sea as it grows and providing biodiversity uplift.

Within the project 'Transforming UK offshore marine algae biomass production' SeaGrown has developed an innovative new system for seaweed cultivation which delivers efficiencies across all stages of the process, from seed production to grow-out to harvesting. The system is fully automated and can work in offshore environmental conditions. Importantly, this new system is also capable of working in harmony with other major marine industries such as offshore renewables, fishing and commercial shipping, or in ecologically sensitive areas, a key consideration for regulators when issuing marine licenses to operate. As such, SeaGrown's new system is poised to be the leading technology used by the burgeoning seaweed industry in the UK and worldwide.

2. Graphical Abstract

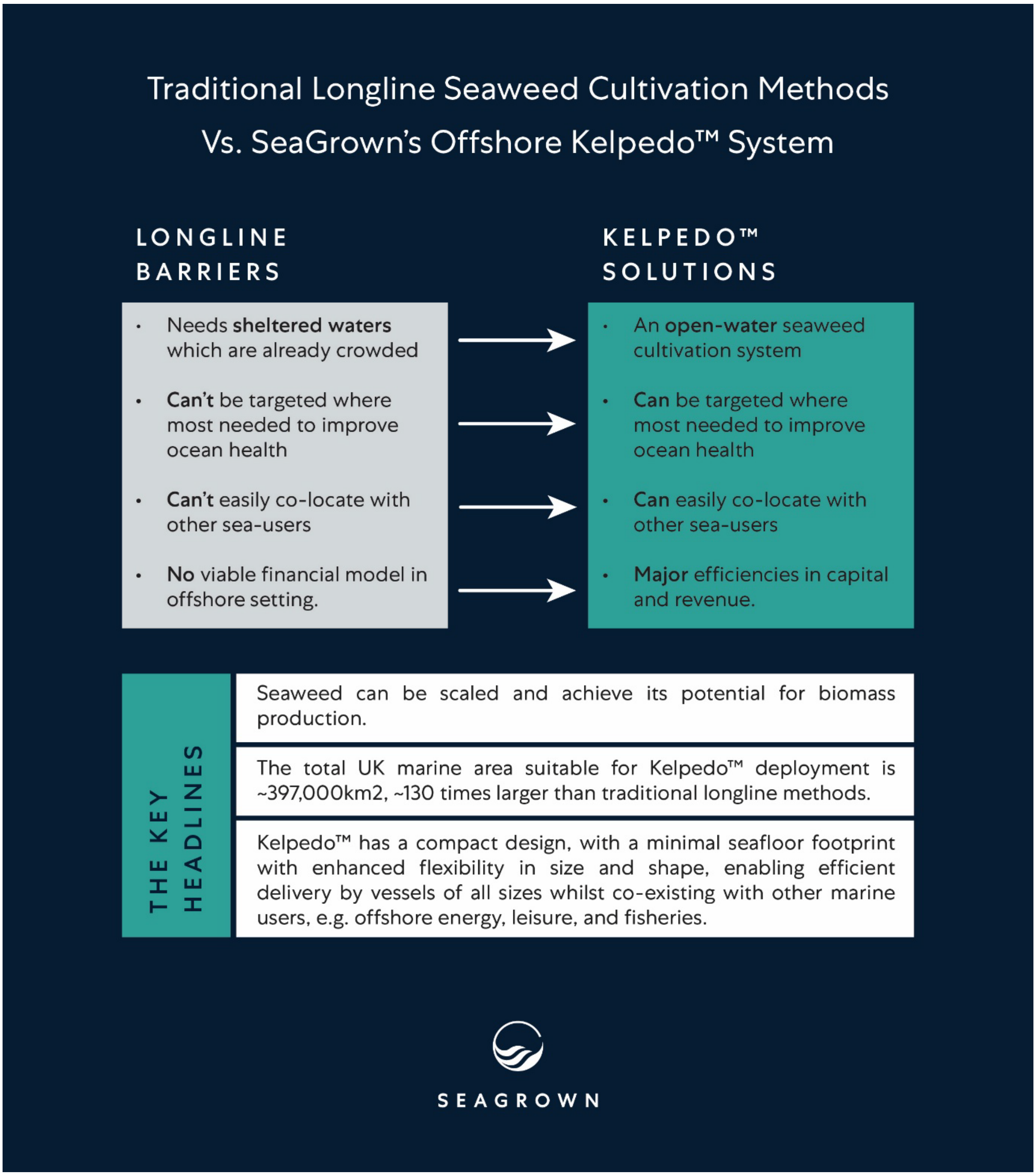

Figure 1. Graphical abstract: traditional longline seaweed cultivation methods vs. SeaGrown's offshore Kelpedo system.

3. Background

SeaGrown is the UK's only offshore seaweed cultivation company, founded in 2018 by Captain Wave Crookes and Professor Laura Robinson combining their expertise in marine operations and science.

After a year of research and licensing applications, SeaGrown launched its first range of products from wild harvested intertidal seaweed in 2019. Over the next three years SeaGrown secured the UK's first offshore seaweed farming licence, a 25-hectare aquaculture site 4 miles out from Scarborough on the North Yorkshire Coast and initiated operations. This period required intensive research and development, purchase and deployment of substantial capital assets, hiring of key personnel and business development. Despite a backdrop of two years of COVID-19 the business was successful in developing a nationwide retail market and seeding and harvesting farmed seaweed in open waters. In addition, the company ship 'Southern Star' houses the company headquarters, acts as the marine and science hub, as well as accommodating a visitor outreach centre and café. All this came with increasing media interest, a strong social licence and support from the local community including regular sellout of some retail lines.

SeaGrown has 15 permanent members of staff, rising to a complement of ~25 over the busy summer months. SeaGrown has a strong leadership team with a Board of four comprising two Executive and two Non-Executive Directors. SeaGrown's Senior Management team includes a General Manager who works closely with the Executive Directors.

This ambitious project, funded by DESNZ, applied SeaGrown's hard-won experience to develop a method to automate seaweed cultivation and make expansion into offshore areas a realistic possibility. Seaweed cultivation is currently limited by a time consuming, labour-intensive and failure-prone process which must be carried out in sheltered, inshore waters and requires streamlining and automation. By increasing the efficiency of deployment and harvesting using a modular, mechanised approach SeaGrown has challenged previous assumptions and opened the seaweed industry to open water areas where cultivation was not previously possible and, in doing so, leveraged overall UK production capability.

The project aim was to identify the operation and refinement of the Fully Automated Transportable Holistic Offshore Macroalgae System (FATHOMS) quantifying and verifying capital savings, running costs efficiencies and seaweed biomass yield. The in-water part of this system, known as 'Kelpedo', provides further efficiencies, and has opened up areas of the marine realm that would previously not have been available for seaweed aquaculture. Overall, the system has achieved significant savings in time, capital and running costs for an offshore seaweed site as compared to the traditional inshore longline systems which are currently being almost exclusively used worldwide.

4. Technical Elements

Aquaculture is identified as a strategic sector and priority industry requiring rapid innovation and disruptive advancement (Huntington and Cappell, 2020). Through this project SeaGrown has disruptively innovated seaweed aquaculture, leading to the opportunity for a step change in UK output once SeaGrown’s system is made commercially available.

In the UK, scientific and small-scale seaweed farming has been trialled in calm sheltered waters such as sea lochs. This inshore cultivation draws on the approach used in mussel farming infrastructure – growing seaweed on parallel longlines (Figure 2). In this method, a strong backline rope is suspended horizontally at the required depth using a series of surface buoys with counterbalance weights and anchors at each end to hold the line in position. During deployment a thin, pre-seeded string is wound around the backline at slow speed, the string carries the seed and the backline takes the tensile environmental load as the seaweed grows. This process is labour-intensive, from seeded string production in a hatchery (~8 weeks) through to deployment at sea (>3 hours for 100m line length). Capital costs are also high, requiring at least 2 anchors, backline, multiple buoys and weights for only ~100-150m of growing line. Additionally, since seeding in this manner requires extensive manual handling under load, it can only be carried out in calm seas, restricting available sea-days and driving up costs and labour requirements.

There are two main barriers to scaling up the biomass that can be grown on longlines in inshore areas: a) nutrient limitation and thermal stress limits the seaweed growing season, and b) spatial competition for aquaculture developments in sheltered bays, lochs and estuaries. These restrictions drive the need for rapid offshore expansion, however longline aquaculture is not viable at offshore sites for several reasons.

First, longline infrastructure does not cope well with strong current and wave conditions in offshore settings, with rapid failure of longlines in offshore settings (Figure 2), and requiring significantly increased spacing between longlines (we have modelled this at 100m for our spatial analysis). Second, the current longline cultivation approach is not deemed financially viable at scale – it is capital intensive, requires extended hatchery incubation times, and is inefficient to deploy and recover. Furthermore, the footprint required for seaweed longlines and their immobile nature makes them difficult to co-locate with other marine activity.

Phase 1: Offshore Longline Trial and New Developments

During Phase 1 SeaGrown conducted extensive at-sea trialling of longline deployment and recovery, assessing the closest line spacing and examining efficiencies throughout the process. SeaGrown established that it was not possible to work multiple closely spaced longlines in an offshore setting without adjacent lines interfering with their neighbours or with the safe operation of the workboat.

The main physical influences on the longlines are current and wave action, so they must be oriented with the prevailing current. This avoids the current causing adjacent lines to overlap, shifting the anchors and damaging the gear.

However, even if longlines are oriented with the current, the strongest influence on the workboat is often the wind and waves, especially at low speeds. This means that the workboat is prone to being blown across adjacent seaweed lines, with evidenced risk of damage to the vessel and the lines. This situation is especially acute once the workboat has lifted the first anchor during recovery, causing the fixed anchor at the other end to act as the fulcrum for a huge pendulum with the workboat at the end of it. The farm is unworkable under these conditions unless the growing lines are spaced at minimum 100m intervals. With such spacing offshore seaweed farming cannot be economically viable.

Whilst spacing of 100m allows for working of the longlines, a second barrier prevents their use in exposed settings. We found that longlines catastrophically failed within a month at exposed sites such as those at the SeaGrown location in the North Sea where wave heights can exceed 10m. This failure was manifest by breakage in the backline and subsequent tangling of the gear. Evidence of this breakage is shown in Figure 2.

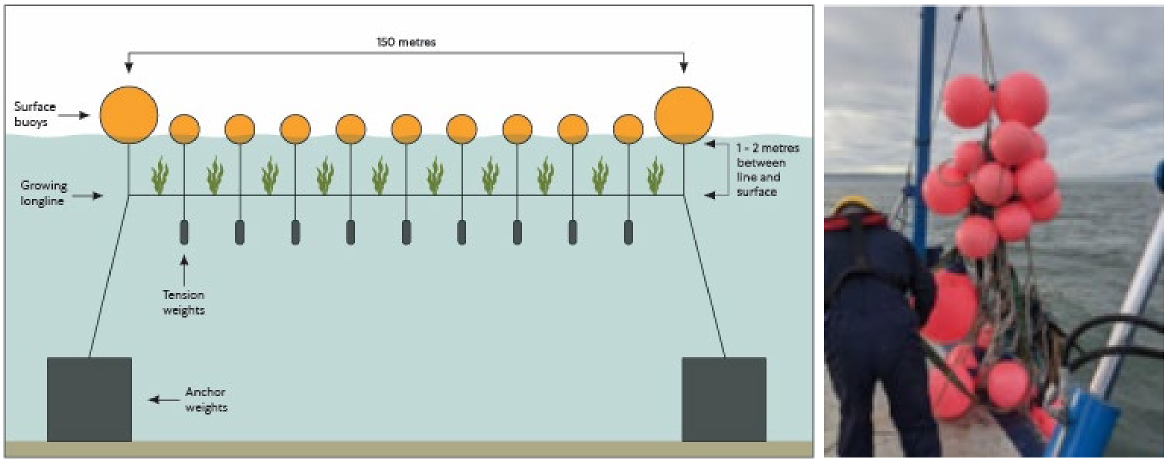

Figure 2. Left: Representation of a simple longline seaweed aquaculture set-up. **Right:** SeaGrown trialled longlines of ~200m length (150m growing length) tethered by two anchors. An initial spacing between lines of 50m was used but this spacing was deemed too close due to adjacent lines interfering with each other or with the safe operation of the workboat. A spacing of 100m was then implemented. Whilst 100m proved to be a more workable spacing, the equipment was found not fit for offshore conditions: strong wave and current action at the open-water site caused breakage of the longlines, rendering them unworkable in open water – as shown in the photograph.

With innovation, offshore cultivation has the potential to circumvent many of these problems and dramatically upscale biomass production because seaweed (kelp) thrives in high-energy open water environments, where strong currents and mixing replenish nutrients, maintaining cooler temperatures and huge areas are available for cultivation. With this clear justification for moving towards offshore sites, the challenge is creating infrastructure that can withstand the harsh environmental conditions at an economic level. Overcoming these barriers could unlock huge swathes of the UK EEZ, potentially also previously inaccessible areas such as offshore windfarms. This step change has the potential to transform the UK's capability to produce marine biomass at volume to support industrial challenges including sustainable food and decarbonisation without the need to use any land.

During Phase 1 SeaGrown designed an innovative new operating method which avoided the problems encountered with the highly restrictive longline method, allowing large amounts of seaweed line to be deployed quickly and safely in modular, rigid frames at close spacing. Phase 1 findings signposted a bold, disruptive departure from the traditional longline method in favour of a modular approach which concentrates up to 180m of growing line into a single mooring.

These modules were successfully validated offshore in Phase 1. They proved their durability by surviving, undamaged, extreme conditions during Storm Arwen in November 2021. Arwen caused waves as high as 13-14m and was one of the most extreme events in the last decade. Challenges with the technology were identified and addressed during Phase 2 (see below).

Phase 2: Developments and Efficiencies

SeaGrown identified four fundamental bottlenecks to increasing biomass production to commercial scale: a) streamlined and consistent production of seaweed seeds, b) capital costs for in-water rigging, c) efficient seeding and deployment of growing lines, and d) efficient harvesting of cultivated seaweed. During the 3-year project, all of these bottlenecks were addressed and significantly reduced, creating an integrated, mechanised system for rapid, consistent cultivation of marine biomass. Phase 2 addressed these bottlenecks.

a) Streamlined and consistent production of seaweed seeds

Seeded string is a recognised bottleneck, requiring extensive hatchery incubation and labour intensive at-sea deployment. Further, longlines carrying seeded string can only be deployed in sheltered waters and benign conditions.

In order to avoid the use of seeded string completely, SeaGrown has adopted a 'Direct Seeding' methodology, whereby seed solution is directly introduced to the growing line avoiding the requirement for the string.

As the evolution of the in-water seaweed gear and handling equipment progressed throughout the project, it became apparent that hatchery output had to be increased to keep pace with the efficiencies being generated in all other stages of the process. SeaGrown had previously used a system of seawater tanks containing seeded spools of growing line, but this was a slow process which took up a large amount of space and required extensive associated infrastructure, so it had to change.

During the project, we have developed an innovative hatchery system for maintaining and bulking seaweed seeds.

b) Capital costs for in-water rigging

As described above, having ruled out the longline system for offshore, open-water operations, during Phase 1 SeaGrown made a complete departure from traditional cultivation protocols and developed an alternative, completely different approach.

Utilising in-house prior experience as a foundation, the SeaGrown team were able to redesign not only the in-water equipment but also the handling system on the deck of the workboat to accommodate the new design.

The new design and handling significantly reduces capital and running costs.

c) Efficient seeding and deployment of growing lines

During the project, SeaGrown introduced automation to the seeding process for the growing lines.

d) Efficient harvesting of cultivated seaweed

Manual harvesting is the current default in the UK seaweed industry but is unsuitable for commercialisation. The SeaGas project trialled a prototype harvester, but it was not sufficiently robust. In fact, the simplest ‘stripper’, a hole cut in steel sheet, was the most effective method but with obvious rope handling and snarling issues. During the project we incorporated a newly designed powered stripper unit for harvesting.

Demonstration and Results

Objectives

1. Assessed and confirmed overall capital savings of >46% and running cost efficiencies of >62% from the FATHOMS system when operated at a 40,000m scale.
2. Refined overall manufacturing cost efficiencies to >46% in comparison to longline systems.

3. Rigging Labour Costs – confirmed >32% efficiency savings in comparison to longline systems.
4. Hatchery – confirmed viability and uptake success of hatchery-produced seaweed seed after implementation of streamlined hatchery procedures.
5. Offshore Deployment – confirmed staffing reduction onboard for deployment and recovery.
6. Harvesting – confirmed staffing reduction onboard for deployment and recovery.
7. Confirmed density of units which can be operated efficiently within one hectare (see Section 5).
8. Quantified the biomass yield and modelled the economic viability of a 40,000m seaweed farm system (see Section 5).

5. Key Successes

Via this project, SeaGrown has developed a new integrated and automated system based around Kelpedo (Figure 3).

Figure 3. Left: SeaGrown vessel Bright Blue deploys Kelpedo at sea, with cutaway image showing anchor, riser line, Kelpedo and surface buoy. **Right:** Examples of use cases of Kelpedo including ports, estuaries, co-existence with fishing and leisure, and co-location with the offshore wind industry.

The Kelpedo system is set to revolutionise seaweed farming by delivering the following critical benefits over the traditional longline method:

1. It is modular, with each Kelpedo deployed separately using only one anchor, riser and buoy per unit allowing scaling and low navigational risk.
2. Each Kelpedo can deploy the equivalent amount of seaweed growing line as a full longline system, using only one anchor and one buoy.
3. The modular nature of the system allows it to be deployed in any pattern, in any shape or size of area. This makes it possible to co-locate Kelpedo with other activities such as offshore wind power generation, where the equipment will need to be accurately deployed close to high value subsea assets. Longline ‘boxes’ cannot be accommodated in these areas.
4. Kelpedo does not deny access to other water users, each unit is marked by a single, low-profile surface buoy which can be safely passed in any direction by other vessels.
5. SeaGrown has developed a hydraulic handling system for Kelpedo, this sits on the deck of a workboat and automates the process of deployment and recovery, seaweed seeding and harvesting.
6. Kelpedo will make the marine licensing process easier owing to its ability to co-locate with other activities and the increased levels of navigational safety.
7. Kelpedo is easy to inspect during the growth cycle to monitor growth rates and component wear.
8. Each Kelpedo unit is individually trackable, allowing rapid location and recovery in the unlikely event of it coming adrift. This is highly desirable by licensing authorities, offshore operators and marine regulatory agencies.
9. Kelpedo is scalable, downwards for use by small fishing vessels or upwards for industrial users with larger, more powerful vessels.
10. Kelpedo works in the offshore environment, as demonstrated by SeaGrown in the offshore North Sea across the last three winter seasons. It is therefore able to open up previously inaccessible offshore areas for seaweed farming – essential for getting the industry to scale.
11. There is no need for extended hatchery incubation times or for seeded string – the Kelpedo system applies seaweed seed directly onto the growing ropes as each Kelpedo is being prepared for deployment into the water.

6. Potential Impact of Innovation on Greenhouse Gas Emissions

At the SeaGrown site (30m water depth) we have established an optimal spacing of 50m, giving four Kelpedo units per hectare. For 40,000m equivalent line length (or approximately 400T), this would require 100 hectares for Kelpedo, or 467 hectares for longlines in an offshore setting for comparison. The table below summarises the metrics for a 400T biomass site using Kelpedo.

Spacing (m)	50
Yield (T/unit)	1
Wet biomass (T/hectare/year)	4
Dry biomass (T/hectare/year)	0.8
Area required for 400T (hectares)	100

Table 1. Potential yield and metrics for Kelpedo in an exposed offshore setting.

We have carried out a GIS mapping project to examine and quantify the UK Economic Exclusive Zone (EEZ) area which could be used by longline and Kelpedo and used this to extrapolate the potential biomass supply, and potential carbon leveraging. For Kelpedo a depth range of 5-120m was used, and a setting of either exposed (offshore) or sheltered conditions, based on field trials and physical modelling. This analysis shows that ~397,000km^2, equivalent to >50% of the UK EEZ, is available for operation of Kelpedo. This is more than 130 times the area available for longlines (see Figure 4).

With this scaling capability, the Kelpedo system has the potential to enable substantial expansion of the UK's seaweed standing stock, absorbing up to ~0.3 million tonnes of CO_2 (~0.1% of UK emissions) with Kelpedo deployment across 1% of the available UK EEZ.

Biochar is identified as the most advanced route for carbon sequestration. The net CO_2 sequestration by seaweed biochar is estimated to be 0.6T CO_2 per tonne of seaweed dry weight, but the economics are not likely to be viable as a stand-alone revenue stream for aquaculture.

The most promising carbon reduction routes for UK seaweed are decrease in agricultural inorganic fertiliser use with seaweed-based biostimulant (4-40T CO_2 equivalent per tonne of seaweed dry weight) and reduction of high carbon intensity foods such as beef by supplementing meat content in products such as burgers and sausages (up to 20T CO_2 equivalent per tonne of seaweed dry weight). This could increase the Greenhouse Gas Impact by up to a factor of 20-40 – i.e. 2-4% of UK CO_2 emissions.

In terms of policy barriers, there has been no formal recognition of seaweed carbon in the UK carbon market. In addition, there are no net zero incentives and subsidies for seaweed biomass growth in line with international examples.

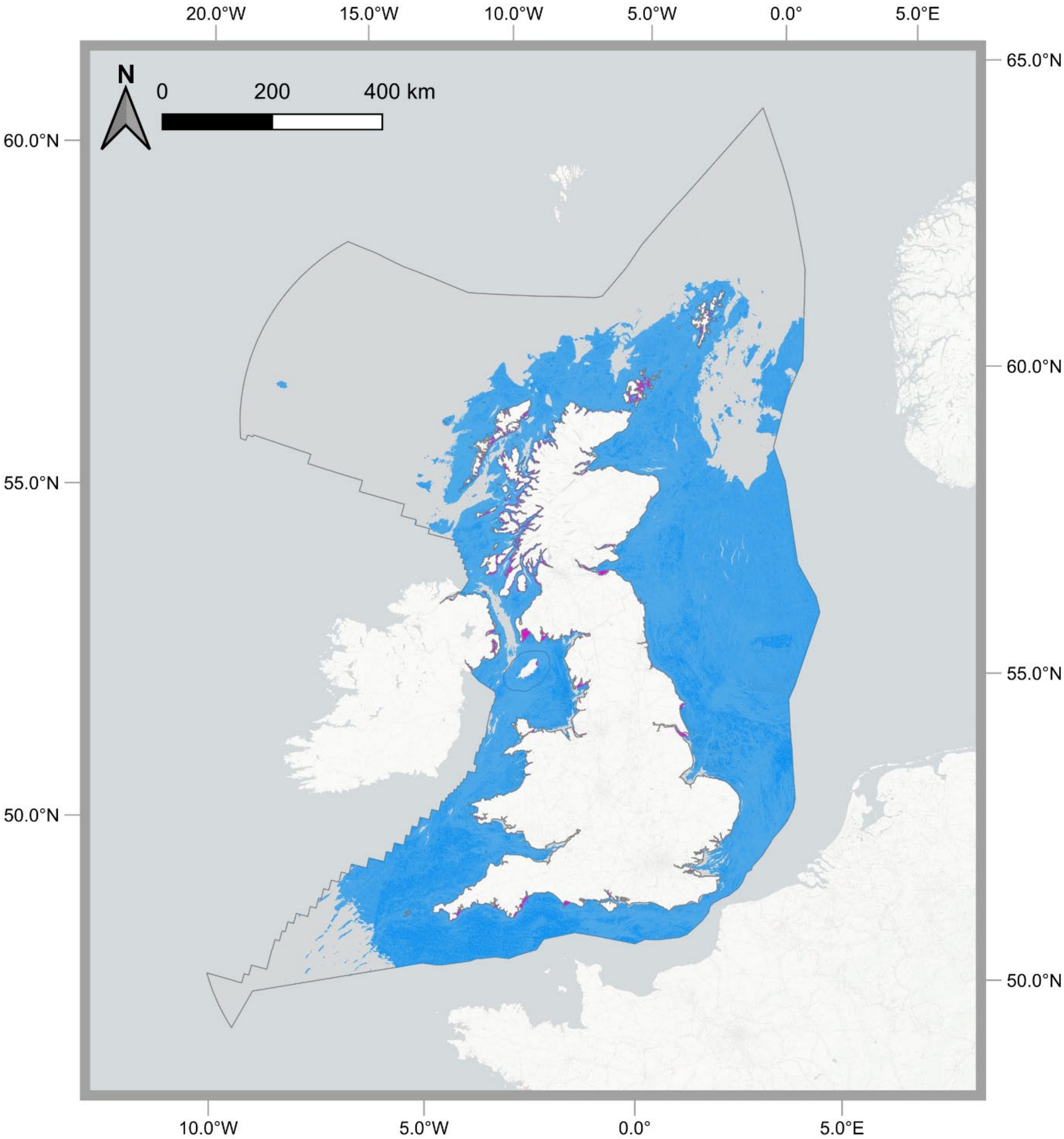

Figure 4. Blue shading shows area of the UK EEZ which is suitable for Kelpedo in terms of depth (5-120m) and environment (sheltered or exposed). Pink shading shows area of the UK EEZ assessed to be suitable for traditional longlines in terms of depth (5-25m) and environment (sheltered). Note this analysis does not include consideration of other marine usage. Coordinate reference system is ETRS89-extended/LAEA Europe (EPSG: 3035). Bathymetry from EMODnet Bathymetry Consortium (2022). UK EEZ boundary from Flanders Marine Institute (2023).

7. Commercialisation Opportunities

The global seaweed market is estimated at over £12.3 billion, based on growth projections since 2012, with 95% of production attributed to the Chinese and Asian markets (Capuzzo and McKie, 2016). Europe currently accounts for only 1% of production (Capuzzo and McKie, 2016). However, a recent report commissioned by Seaweed for Europe highlighted the huge growth potential of seaweed aquaculture in Europe (De Chaisemartin et al., 2021). Specifically, they estimated that by 2030 the European seaweed market would reach £7.9 billion, cover 27,000 hectares and employ up to 85,000 people (38,000 directly). At the same time, they estimated that this growth could take up 5.4 million tonnes of carbon dioxide equivalent (CO_2e) and remove 20,000 tonnes and 2,000 tonnes per year of nitrogen and phosphorous respectively (De Chaisemartin et al., 2021). The global seaweed market is estimated at over US$15 billion, based on growth projections since 2012, with 95% of production attributed to Asian markets. Europe currently accounts for only 1% of production, dominated by small estuarine and intertidal farm operators. The development of the UK's contemporary seaweed industry is in its infancy, with SeaGrown operating the first licensed offshore seaweed farm in the UK.

With competition and spatial conflict in UK waters increasing significantly due to the expansion of Oil and Gas, Windfarm and Marine Protected Areas, regulators are now acknowledging that licensing sites for single use will no longer be possible, and they are seeking opportunities to develop co-location mechanisms. DEFRA, Natural England, the Marine Management Organisation, IFCA, CEFAS and the Environmental Agency have all pro-actively engaged via the marine Natural Capital Ecosystem Assessment programme with SeaGrown to discuss seaweed aquaculture including opportunities for co-location, improving water quality and decarbonisation.

SeaGrown has experienced high demand for consultancy services from prospective seaweed farmers across the world following exposure in high profile print, TV and online media. Requests for support have been received from across the UK as well as internationally. As such, market demand is buoyant with increasing enquiries from a wide range of potential customers.

Project SEA SWELL

Arguably the most important development of this project is that the system can be deployed anywhere, and at any scale (see Figure 2). As documented elsewhere the system provides cost savings over longline – but this cost saving is less important than the scaling potential. Kelpedo has now been demonstrated to be viable in offshore waters through extreme storms, generating the potential for massive scaleup around the UK. This scaleup could include offshore (e.g. through collaboration with fixed or floating offshore wind) or within high traffic density estuaries with specific water quality issues or in unusual deployment areas such as along outfall pipelines or renewable energy cable routes. The potential for Kelpedo co-location (e.g. with offshore wind, or fishing/leisure) is looking likely to be a key enabler for seaweed aquaculture in the busy UK marine setting.

Recognising this potential, the Crown Estate (and other stakeholders) are interested in SeaGrown leading a regional demonstration of the scale-up potential of seaweed farming. We are working towards this goal by engaging with a wide range of stakeholders to develop a project – currently known as ‘SEA SWELL’.

8. Lessons Learned

The environmental conditions in the North Sea created an excellent proving ground for this technology. Strong winds, tidal streams and large wave heights, particularly during storm conditions, were factors which had to be overcome. Any equipment deployed needs to be able to live with these environmental factors comfortably, this requirement possibly outranks all others for offshore aquaculture equipment.

The biodiversity uplift potential of the system is high, with encouraging results from initial observation periods, in particular for birds.

A key strength of the Kelpedo system is the ability to co-locate. This needs further demonstration in the field, and at scale, and communication of this capability will be crucial for commercial success.

9. Secondary Project Benefits

Traditional Media

- Yorkshire By the Sea documentary (TV)
- Saturday Morning Kitchen with James Martin and Tom Kerridge (TV)
- The One Show (TV)
- Country Living – 8-page spread
- The Guardian

Conferences/Talks

- Coastal Futures – London 2025
- Blue Earth Summit – London 2024
- Floating Offshore Wind – Aberdeen 2024
- World Ocean Summit – Lisbon 2024
- Restoring Meadow, Marsh and Reef Conference – Scarborough 2023, 2024
- York and North Yorkshire Business Summit – York 2023
- Conference on Wind Energy and Wildlife Impacts – Croatia 2023

Local Direct Engagement

- Local schools – including school visits on board, SG staff visiting schools and an annual work experience week.
- Regional universities – hosting field trips, talks and engaged in research co-operations.
- Local community – hosted and given a wide range of local and regional talks.

Published Papers

- Cunningham, E.M., Wright, L.S., Crowe, M., Healey, E., Robinson, L.F., Ng, H.C. and Kregting, L. (2024). Under pressure: inhibited sporophyte growth of the sugar kelp *Saccharina latissima* (Phaeophyceae). *Journal of Applied Phycology, 36,* 3605-3610.
- Bennett, J.P., Robinson, L.F. and Gomez, L.D. (2023). Valorisation strategies for brown seaweed biomass production in a European context. *Algal Research, 75,* 103248.

10. Conclusions and Next Steps

The project was able to deliver on its overall objectives, in many cases exceeding original predicted efficiencies.

As discussed with MOs and DESNZ during the project, cost rises and supply chain issues post COVID led to some challenges and delays during the project.

Challenges remain for SeaGrown to communicate this new capability both to clients and regulators/policy makers, however good connections have been made and SeaGrown's internal knowledge of governmental process and target sectors for commercialisation has increased throughout the project.

In conclusion, we feel that the project has been an overall success. It has delivered compelling results on all objectives, and most importantly has transformed the UK's ability to deploy seaweed in high impact use-cases to positively benefit our environment whilst creating and safeguarding jobs. This success reflects directly on the enlightened view of the DESNZ team to adopt SeaGrown onto the Biomass Feedstocks Innovation programme as an outlier to the more common land-based applications.

11. References

Capuzzo, E. and McKie, T. (2016). Seaweed in the UK and abroad – status, products, limitations, gaps and Cefas role. Available at: https://www.gov.uk/government/publications/the-seaweed-industry-in-the-uk-and-abroad

De Chaisemartin, M., Furlan, T. and Vincent, A. (2021). The case for seaweed investment in Europe. Available at: https://www.seaweedeurope.com/resources

EMODnet Bathymetry Consortium (2022). EMODnet Digital Bathymetry (DTM 2022). Available at: https://doi.org/10.12770/ff3aff8a-cff1-44a3-a2c8-1910bf109f85

Flanders Marine Institute (2023). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 12. Available at: https://doi.org/10.14284/632, http://www.marineregions.org

Huntington, T. and Cappell, R. (2020). English aquaculture strategy. Available at: https://www.seafish.org/document/?id=9efe670c-847b-4a4f-b8ec-72f2e5396df6