COMPLETED PROJECT CASE STUDY

IMPROVING HARVESTS, PRESERVATION, AND PRODUCT DIVERSIFICATION FOR SCOTTISH KELP

PARTNERS

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BACKGROUND

Kelp farming is an emerging industry in Scotland, offering sustainable solutions for food production and carbon capture. However, it faces major operational and economic barriers. Among the most pressing challenges are a short harvest window, rapid onset of biofouling, and limited post-harvest infrastructure.

The sector's most valuable product, food-grade kelp, requires early-season harvests when yield is at its lowest and the risk of biofouling is highest. Biofouling, particularly from bryozoans, hydroids, and molluscs, reduces market value and forces producers to discard large portions of their crops. To meet strict food-market standards, including allergen-free certification, farmers often rush to harvest clean fronds, shortening the season and further reducing yields. Delays caused by poor weather or processing backlogs increase the risk of crop loss.

Drying remains the dominant preservation method but is limited by insufficient infrastructure and high energy demands. Alternatives like freezing are similarly costly. These constraints drive waste and limit the sector's ability to scale. New preservation and processing techniques are critical to improving economic viability and environmental sustainability.

To address these barriers, this project brought together several collaborators. KelpCrofters was the project lead, which provided seaweed for study, developed a novel harvesting pontoon, participated in method development, and coordinated the project from start to finish. EcoCascade and Seaweed Enterprises provided processing support; Scottish Agronomy led barley field trials; the Danish Technological Institute contributed to fermentation development; and PRM Waste and Efficiency Technologies advised on engineering and scale-up.

Together, the team built expertise across harvesting, fermentation, dewatering, and extract development.

AIMS

This project set out to address the above challenges by developing more efficient harvest, storage, and processing strategies for farmed kelp, while also exploring new product development opportunities.

The key objectives were to:

1. Increase harvest efficiency and extend the productive season;
2. Manage biofouling and identify value-added uses for lower-grade kelp;
3. Reduce the environmental and financial costs of drying through dewatering;
4. Develop ensiling and fermentation techniques to stabilise kelp post-harvest;
5. Investigate commercial opportunities for kelp-derived liquid by-products.

The project was structured into five work packages (WPs) spanning the kelp value chain: project coordination, harvesting improvements, post-harvest preservation, dewatering, and market development.

To enhance harvesting (WP2), a novel pontoon system was developed and tested at KelpCrofters seaweed farm on the Isle of Skye. Paired with a semi-submerged barge, the system allowed fresh kelp to be stored and transported at sea, preserving quality between harvest and landing (Figure 1). This innovation increased harvest capacity and allowed operations to continue during a broader range of weather conditions. Efforts were also made to extend the harvest season by exploring ways to reduce biofouling, particularly from problematic organisms like bryozoans, hydroids, and allergenic molluscs, which reduce kelp quality and narrow the harvest window.

Figure 1: Seaweed harvesting pontoon 'Harvie' consists of two harvesting 'gantries' with haulers to allow two lines of kelp to be harvested simultaneously. NOTE: One kelp line is being harvested in these images. The black semi-submerged transport barge is positioned next to 'Harvie' and is used for storing and transporting bags of harvested kelp in seawater, thereby maintaining its freshness.

Post-harvest storage and preservation (WP3) focused on developing cost-effective, low-impact alternatives to drying. Current drying methods are expensive, time-consuming, energy-intensive and under-capacity, presenting major sustainability and processing challenges. Ensiling and fermentation are potentially faster and more environmentally friendly ways to preserve kelp after harvest. The latter methods lower pH to inhibit microbial growth by drying kelp, thereby preserving kelp for months at ambient or refrigerated temperatures (with a pH below 3.7 or 4.3 respectively).

Laboratory trials tested the effect of various acid and microbial inoculants, including lactic acid, formic acid, and lactic acid bacteria (LAB), with and without added sugar. pH stability, odour, and microbial activity were monitored across 12 months.

The preserved biomass and resulting liquid extracts were then analysed for heavy metal content, iodine levels, and digestibility to assess suitability for feed, food, and high-value ingredient markets. Heavy metals and iodine in kelp are a major barrier to accessing food and feed markets, with concentrations often above permitted EU limits.

To address kelp's high water content and bulk, mechanical dewatering (WP4) was tested using a screw press. Fresh kelp, containing up to 90% water, is difficult to store and transport. High in natural sugars, it decomposes quickly if not preserved. The dewatering process reduced water content before drying and enabled recovery of liquid extracts, which were further analysed for nutritional and chemical properties. Chopping methods were also evaluated to reduce kelp volume for transport and storage, as well as to support ensiling.

Finally, liquid by-products were assessed for use in biostimulants and cosmetics (WP5). Samples were analysed for minerals, bioactive compounds and antioxidant properties, and field trials evaluated their potential as ingredients in the cosmetic and biostimulant sectors. These are two fast-growing markets increasingly seeking sustainable, natural alternatives.

RESULTS

The harvesting pontoon significantly improved daily capacity and operational flexibility. This helped alleviate seasonal bottlenecks and reduced crop losses from weather delays. While freshwater washing removed some biofouling such as snails and crustaceans, it had a limited effect on more persistent organisms like hydroids and bryozoans, which can cause lasting damage to seaweed quality. As such, monitoring biofouling onset remains essential, and markets for lower-grade kelp should be further explored.

Ensiling and fermentation proved successful at stabilising kelp for long-term storage. The most effective approach involved adding lactic or formic acid to rapidly drop the pH, maintaining levels below 3.7 for up to a year. Adding sugar accelerates fermentation by feeding LAB. A three-strain LAB inoculum was particularly effective at lowering pH and avoiding spoilage indicators like gas or odour.

Fouling organisms significantly affected fermentation, with biofouled kelp harvested later in the season requiring up to four times more acid due to buffering from calcium carbonate in encrusting organisms. Despite this, roughly 60% of barrels yielded well-preserved silage. Failures were linked to poor mixing and air leaks, highlighting the need for airtight, mechanically mixed storage systems. Trials in intermediate bulk containers (IBCs) produced similar results, underscoring the importance of homogenising the kelp mixture and oxygen displacement using CO_2.

Ensiling also reduced heavy metals, such as cadmium, arsenic, mercury, and iodine levels, often below EU thresholds for animal feed, likely due to the transfer of soluble compounds into the liquid fraction. However, this 'silage shrinkage' led to significant biomass loss: only 3–6% of the original wet kelp biomass remained when the kelp was dried after ensiling and fermentation. Despite the volume reduction, the in-vitro digestibility assays for monogastric animals showed that the digestibility of kelp improved markedly after fermentation: *Alaria esculenta* by 12.5%, and *Saccharina latissima* by 37%. These findings suggest fermented kelp could serve as a superior feed supplement compared to traditional species like *Ascophyllum*, however the low price point and high volume requirements for the feed industry remain major barriers to entering this market.

Chopping trials showed that reducing kelp size improved packing density and pumpability. Coarsely chopped kelp (10–20cm) fit 1.8 times more mass per volume, while finely minced kelp (4–6mm) tripled storage capacity and eased handling during processing. Fine particle size also enabled better mixing with liquids and reduced blockages between tanks, making it more suitable for automation at scale.

Dewatering with a screw press reduced water content by 35–43% for *Alaria* and up to 73% for *Saccharina*. This cut drying time by approximately six hours per tonne, resulting in estimated CO_2 savings of 130kg based on reduced diesel use. Dewatering also reduced iodine and heavy metal content, though it altered the flavour, making the kelp blander, which could limit its appeal in food applications.

The liquid extracts recovered through pressing and fermentation were rich in nutrients and bioactive compounds, including macro and micro-nutrients, seaweed sugars, phenolics, and amino acids. The process of ensiling and fermentation enhanced these compounds in the liquid (compared to pressing fresh kelp), and therefore offered greater complexity and bioactivity, suggesting potential in plant and skin care applications.

Field trials on spring barley confirmed the biostimulant potential of kelp extracts. All treatments improved yields, with ensiled *Saccharina* at 10 L/ha achieving up to 19% increases and an average 8% improvement across test plots, and with ensiled Alaria also delivering significant increases in yield. Fermented Alaria showed diminished returns at higher doses, indicating that formulation and dosage need refining, and that fermented products illicit a different response in plants when compared to ensiled kelp extracts.

In cosmetics, fermented extracts consistently outperformed cold-pressed counterparts, with fermented *Saccharina* showing the highest antioxidant activity. This suggests microbial fermentation may unlock phenolic compounds, positioning fermented seaweed extracts as promising ingredients for skincare, however, its sensory attributes remain challenging. This is pending further work on formulation compatibility and safety.

IMPACT

This project represents a step-change for the Scottish kelp industry, tackling critical bottlenecks and unlocking new commercial pathways. The custom-built harvesting pontoon significantly improved capacity and reduced weather-related downtime, offering a scalable solution for producers. Rinsing protocols and monitoring also helped extend the food-grade harvest season, though persistent biofouling remains a barrier, emphasising the need for alternative markets for lower-quality kelp.

The development of ensiling and fermentation protocols is particularly significant. These methods enable long-term, low-energy storage of wet kelp, reducing waste and seasonal pressures while enhancing market flexibility. In parallel, fermentation improved product digestibility and reduced heavy metal content, opening the door to feed applications currently restricted by regulatory limits.

Dewatering technologies, especially the screw press, delivered practical wins in reducing energy use, transport costs, and emissions. By simplifying logistics and decreasing processing time, these techniques improve both economic and environmental sustainability.

Perhaps most importantly, the project demonstrated viable routes to higher-value products. Liquid extracts from fermented and ensiled kelp show promise as plant biostimulants and cosmetic ingredients. Early field trials and lab tests indicate strong potential, setting the stage for future product development and commercialisation.

Collaborations with processing and technical partners were vital to success, laying the groundwork for continued innovation. The knowledge generated here supports industry growth by addressing real-world constraints, reducing waste, and increasing profitability across the seaweed value chain. With further R&D and scale-up, these innovations could transform Scotland's kelp sector, delivering environmental and economic benefits.