An overview on seaweed uses in the UK: past, present and future

J.M.M.Adams IBERS, Aberystwyth University, Gogerddan, Aberystwyth. SY23 3EE jaa@aber.ac.uk

Introduction

The UK has a coastline in excess of 31,400 km and has macroalgae growing off-shore for the majority of its length (Fig 1). An estimated 10 million tonnes of seaweed surrounds the Scottish shores alone. Seaweed grows rapidly and is capable of yielding more kg of dry biomass m^{-2} $year^{-1}$ than fast growing terrestrial crops such as sugarcane, due to its ability to take up nutrients over its entire surface and a lack of lignin-like energy-intensive supporting tissue which is necessary for land plants. Seaweed also has a number of significant benefits over terrestrial crops including not being a food, not requiring land or fresh water and having rapid growth. Despite this, seaweed is not currently used to its full potential in the UK with factors for this including the availability of cheap imports and a lack of mechanical harvesting processes. Historically, though, seaweed has been used much more extensively for a number of purposes.

Fig. 1 Map of the British Isles showing national divisions. © Enclyclopaedia Britannica Inc.

Historical uses of seaweed in the UK

There is evidence that the consumption of seaweed in Japan has occurred for 6,000 years and in Europe the consumption of seaweed is now associated with Japan and other Eastern countries. However, seaweed has been part of the UK and Irish diets for at least 4,000 years and was a common food addition in coastal regions until 50-100 years ago.

Soda production

Seaweeds, and in particular kelps (Laminariaceae), were historically used in Scotland for the production of soda. Soda, or sodium carbonate, is required for the glass and soap industries and following the identification of kelp as a source of soda in the late 17th century it became in time one of the earliest chemical industries in the UK. *Laminaria, Saccharina* and *Ascophyllum* species were cut, collected and dried against 'tangle dykes' or low walls made specifically for drying the kelp on. Once the moisture content was low enough, the kelp was burnt in shore kilns, stone lined pits sited nearby with the ash subsequently collected, bagged and sold (Fig. 2).

Fig. 2 Burning kelp on Holm, Orkney Islands. Courtesy of the North Ronaldsay heritage archive

In 1720 the price of soda ash was £2 t^{-1} (approximately £270 or ¥42K in today's money). As the century progressed, this industry became more established and prices were raised as demand increased. Towards the end of the century the French revolutionary and Napoleonic wars in mainland Europe affected trade with other countries, preventing the other main soda source, Spanish Barilla soda, from being imported. This soda was extracted from a range of saltwort plants, including *Salsola soda*, and could have a purity of up to 30% soda. This buoyed the British soda industry, which in 1800 produced 20,000 t ash which retailed at up to £22 t^{-1} (£1600 or ¥250K t^{-1} in today's prices). As the wars began to cease, Barilla soda was again available, and at £10 t^{-1} and a greater purity than kelp soda, led to a demand slump and related price crash. In 1820, the price per tonne of soda was £2, as it was in 1720, but with a current value of approximately £140 or ¥22K. This rapid loss of relative prosperity to the landowners and crofters in Scotland contributed to the Highland clearances, a mass migration process which occurred between 1750 and 1880. This was instigated by the landowners, who collectively drove more than half of the Scottish people from their homes within this period to allow the land to be used for more profitable livestock grazing instead.

Iodine production

Following the decline of the soda industry, the production of iodine from kelps began. This was also produced from kelp ash but fresh kelp was required for this product which had not been rained on or been contaminated by sand. The burning process was also more controlled, requiring set burning times and temperatures. This was also lucrative initially but as cheaper mineral deposits from Chile became available this also declined and was effectively over by 1900.

Alginate production

In the 1880s E. Stanford discovered alginates in British kelp and between 1940 and 1975 harvesting kelp was again important in Scotland. Following storms, wave-cast kelps were collected and fronds removed before the stipes were dried, tied in bundles and shipped to alginate extraction factories. In later decades the increasing logistical costs combined with cheaper imports meant a declining industry with large-scale alginate production finishing in the UK in 2008. In recent years, a few small companies have been established extracting high quality alginate from kelps in the UK, leading to a possible future resurgence of British alginate production.

Fertiliser

Seaweed can be placed in layers with sand on protected areas of poor land or even bare rock to grow crops such as potatoes. This technique allows crops to be grown in coastal areas where none would otherwise grow, providing nutrients, organic carbon and alginic acids to retain moisture and hold the 'soil' particles together. This occurred on many islands historically, with the Aran Islands on west coast Ireland the most well-known. Further inland, or with better soil, seaweed can be used as a fertiliser to enhance the growth of crops, through the supply of micronutrients or elements in deficient soil.

A more transportable form of seaweed is that of liquid seaweed fertilisers, extracts of seaweeds often produced using water alone, then reduced to form a concentrate. The addition of re-diluted preparations of the liquid seaweed is reputed to improve crop and fruit yield; and to provide resistance to stresses such as frost. This market is expanding as people move towards both more renewable and organic fertilisers.

Animal feed

A range of seaweeds have been used historically and are still used in animal feed. This can be through allowing grazing animals to have access to a beach with fresh or cast seaweeds (Fig. 3); or through provision in their feed. Supplying elements, vitamins and nutrients including protein, the seaweeds used include *Laminaria, Macrocystis* and *Ascophyllum* species. The seaweeds are typically dried and milled before mixing or adding as a supplement of ≤10%. Seaweed supplements have been shown to benefit a wide range of animals including pigs, cattle, horses, sheep, fish and domestic pets.

Fig. 3 Sheep feeding on seaweed on North Ronaldsay. Image by Jessica Adams

Food and food additives

Seaweeds can be eaten either as extracts or whole. Extracts of seaweed include the hydrocolloids, predominantly alginate (from brown seaweeds), agar and carrageen (both from red) which are used as stabilisers and thickeners in a wide range of food and non-food products. Different chemical structures constituting each hydrocolloid type make them suitable for different roles, with chemical properties such as the insolubility of calcium-poly-guluronic alginate from stipes of *Laminaria hyperborea* providing particularly high quality alginate opportunities. These can vary from medical and tissue culture advances to flavoured beads on food dishes.

Seaweeds can and are also eaten whole or milled, with the most popular species in the UK being

laver or nori (*Porphyra umbilicalis*), dulse (*Palmaria palmata*), carrageen or Irish moss (*Chondrus crispus*), sea lettuce (*Ulva lactuca*), sea spaghetti (*Himanthalia elongata*), Alaria esculenta and kombu (a range including *Saccharina latissima* and *Laminaria digitata*). Imports, especially dried *Porphyra* and nori sheets for sushi, are also major contributors to seaweed consumption.
Seaweeds can be used as wraps on sushi but are also added to foods. These include soups, breads, salads and as a low-sodium salt replacement. Consumption is much lower than in Japan but in the UK there are increasing numbers of small companies which are harvesting and selling seaweed; more chefs on television shows cooking with seaweeds and a growing interest in more 'healthy' products such as low-sodium salt additives. Together this is causing a gradual move towards a greater consumption of seaweeds for people with middle and higher incomes. However, as the cost of harvested seaweed is still relatively high, people of lower incomes are unlikely to include seaweeds in their diets in the near future unless they have harvested it themselves.

Welsh laver bread

One region of the UK where seaweed is eaten regularly is south Wales. In addition to a number of cottage industries, where *Porphyra umbilicalis* is wild-harvested and prepared for the household or a local farmer's market, there are two main companies which sustainably harvest from the west coast of the UK under licence. In both cottage industry and industrial processes, the *Porphyra* is washed and cooked for several hours to become a dense, spinach-like product called laver. Traditionally this is mixed with milled oats and made into round discs (Fig. 4). These are then fried and eaten with pickled cockles (small bivalves preserved in vinegar) and bacon for breakfast. It has been suggested that this diet was encouraged during the industrial revolution to address nutritional deficiencies in the diets of local coal miners and their families.

Fig. 4 Left: cooked laver, Right laver bread. ©Getty images

Seaweed extracts

The main extracts currently produced from seaweeds are the hydrocolloids as discussed above. In addition, a small but growing area is that of further extracts from seaweed for markets including the pharmaceutical, healthcare, cosmetic, hair and skincare product ranges. Many of the elements, vitamins and iodine in the seaweeds can be removed in extracts and taken up through surfaces such as the skin and hair, meaning that the majority of products available in shops are shampoos, shower gels, moisturisers, face masks and bath additives. There is also a market for whole seaweed in this area, especially in Ireland where dried whole *Fucus vesiculosis* and other wracks can be added to your bath tub for an 'Irish bath' experience. Bathing with seaweed is reputed to aid rheumatism and arthritis, it may also reduce cellulite and has been used to treat liver complaints and relieve depression. It is also supposed to soften the skin, improve circulation and drain the lymphatic system.

Seaweed as biofuels

Seaweeds were not exempt from the focus in the 2000s to explore sources of biomass for conversion to biofuels, primarily ethanol, with the aim to partially replace petrol in vehicles and thus reduce the quantity of carbon dioxide released from fossil fuel sources. To date, the majority of UK-based research into biofuels from macroalgae has been conducted on kelps due to their prevalence, high yields, ease of culture and minimal current use for other products or processes. In other regions of the world, research into biofuels have considered red or green seaweeds too where they can be cultured to produce high yields or are otherwise available, for example as large quantities of cast algae. Research into biofuels from seaweeds has led to a renewed interest in this material and more information regarding its composition and variety have been discovered through this research. However, though there are many advantages in using seaweeds over terrestrial biomass as detailed above, biofuels from seaweeds are yet to be commercially produced. There are a number of reasons for this including that of high water and elemental contents; and issues surrounding harvesting and cultivation costs. Ethanol yields greater than the 4 - 5% economically viable concentration for distillation have been achieved but only after producing extracts or using *E. coli* as a host expressing genes capable of synthesising ethanol, hydrolysing alginic acid and laminarin and utilising mannitol.

Seaweed biorefineries

Seaweed biofuels do have a place in seaweed processing, but will only work in a biorefinery scenario (Fig. 5). If high value extracts may be taken from different seaweed species leaving a non-toxic residue, this could be used to produce a range of lower value products in subsequent processes as the bulk of the costs such as harvesting and cultivation will fall to the initial high value extract. Subsequent extractions of medium-value products include elemental extractions or conversion to fertiliser or animal feed. Residues from this could be fermented to generate ethanol, but they could also be used to produce a range of other platform chemicals and biofuels such as butanol; lactic or succinic acids; or undergo anaerobic digestion to produce methane and hydrogen.

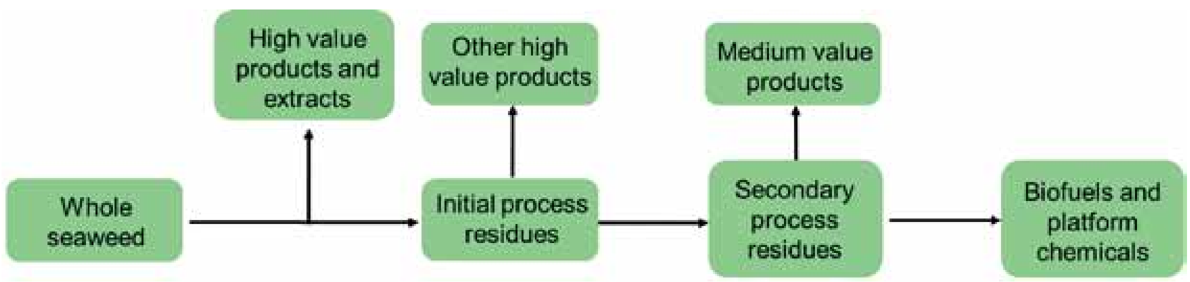

Fig 5 Diagram showing seaweed biorefinery system

Systems such as this could seem overly complicated but it is becoming increasingly important that as our reliance on oil decreases in future we have processes in place which can replace not just our transport requirements but also the whole of the petrochemical industry and a range of feedstocks are needed to fill this gap. Seaweed has great potential and could play an increasingly large role in the lives of UK people, through diet, supplements, improved crops, healthcare products and energy. The resurgence of interest in seaweeds in all these areas in recent years suggests that this may be fulfilled to a greater degree in the next few decades, benefitting the British public through improved diet, health and greater chemical and energy sufficiency.

Key references

Adams, J.M., J.A. Gallagher, and I.S. Donnison, Fermentation study on Saccharina latissima for bioethanol production considering variable pre-treatments. Journal of Applied Phycology, 2009. 21(5): p. 569-574.

Cannell, R., Algal Biotechnology. Applied Biochemistry and Biotechnology, 1990. 26(1): p. 85-105.

Carlsson, A., et al., Micro- and macro-algae: utility for industrial applications. Outputs from the EPOBIO project, D. Bowles, Editor. 2007, CNAP, University of York: York, UK. p. 82.

Gao, K. and K. McKinley, Use of macroalgae for marine biomass production and CO_2 remediation: a review. Journal of Applied Phycology, 1993. 6: p. 45-60.

Horn, S.J., Bioenergy from brown seaweeds, in Department of Biotechnology. 2000, Norweigian University of Science and Technology: Trondheim, Norway. p. 148.

Kelly, M. and S. Dworjanyn, The potential of marine biomass for biofuel: a feasibility study with recommendation for further research, C.b.T.C. Estate, Editor. 2007, Scottish Association for Marine Science (SAMS). p. 95.

MacArtain, P., et al., Nutritional value of edible seaweeds. Nutrition Reviews, 2007. 65(12): p. 535-543.

McHugh, D., A guide to the seaweed industry. Fisheries technical paper 441. 2003, Food and Agriculture Organisation of the United Nations (FAO) Rome. p. 105.

Wargacki, A.J., et al., An Engineered Microbial Platform for Direct Biofuel Production from Brown Macroalgae. Science, 2012. 335(6066): p. 308-313.

Websites such as www.seaweed.ie ©M.D. Guiry 2000-2016 are also good sources of general information

Acknowledgements

This report is based on the seminar "A European and personal perspective on seaweed uses: historical, present and future" given by Dr Jessica Adams at the Tokyo University of Marine Sciences and Technology on the 17th March 2016 and hosted by Prof. Daisuke Fujita. Travel to Tokyo was funded by the Welsh Government and HEFCW through a Returning Fellowship from the Sêr Cymru National Research Network for Low Carbon, Energy and Environment (R39GO1/CC8004/RFS001).

Dr. Jessica Adams making a speech in joint-seminar (left) and joining a seaweed party in Laboratory of Applied Phycology (right) in TUMSAT. (Photo, D. Fujita)