Paludiculture: Opportunities

Savills Rural Research Report for
Vitagrass Farms (Holker) Ltd

Savills Rural Research Report **December 2024_Final**

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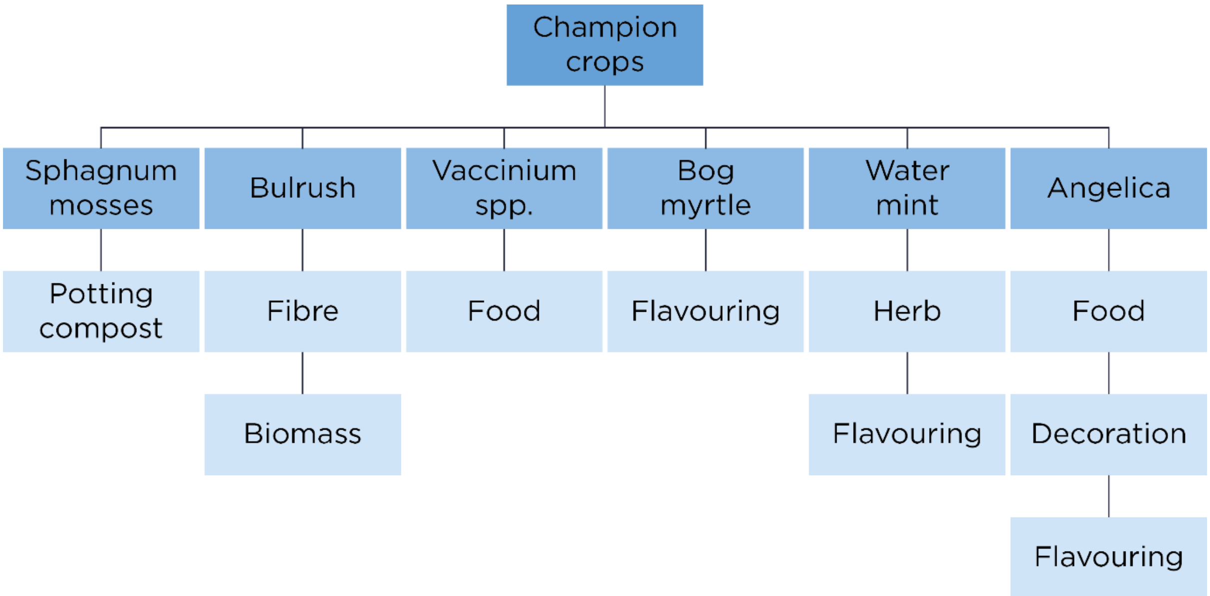
Executive Summary

Vitagrass Farms (Holker) Ltd ceased grass drying operations in 2006 challenged by both operational cost pressures and legislation which ultimately resulted in alternative land uses becoming more profitable. The need to commercially produce crops and minimise negative environmental impact is driving a review of paludiculture opportunities.

Savills research completed a comprehensive literature review comprising 123 plants which could have paludiculture potential. Research then distilled the list to identify six champion crops that could realistically offer opportunities for paludiculture for Vitagrass Farms (Holker) Ltd in a range of different markets from fibres used in clothing to food and energy.



Stakeholder engagement confirmed that much of the trial and investigation work for peatland has focused on restoration rather than growing commercially viable crops. None of the champion crops have a fully developed management system or established market. This means that commercial production is high risk and the estimated return on investment is likely to be under 10%.

It would be appropriate for Vitagrass Farms (Holker) Ltd to defer paludiculture production until:

- Market and technological issues are better understood.
- Legislative issues and barriers have been defined.
- The site can be fully assessed for hydrological and nutrient constraints.

Paludiculture crops have vastly different requirements compared to conventional arable crops, particularly when considering water level, nutrient level and pH. The final selection of potential crops was made using a total of 17 parameters which included:

- Current and potential market competition.
- The suitability of machinery in cultivating, harvesting and processing.
- Price volatility and its sensitivity to supply changes.
- Pre-existing expertise in the cultivation of the crop.
- Their prevalence in the local area.

Each of the 17 parameters was scored, revealing sphagnum moss and the use of bulrush for fibre to be the highest-scoring champion crops. Both scored 72% of the points on offer, with the use of bulrushes for biomass placing third with 61% (bulrushes could conceivably produce both fibre and biomass simultaneously). None of the crops are major food sources, meaning paludiculture will likely contribute to other sectors of the emerging bioeconomy, such as energy and fibre.

Before considering production it is vital to undertake full testing of the soil and water for nutrients and pH. The soil texture also needs to be assessed. Sampling may need to be intensive for those crops requiring a particularly low pH. While the local environment and location are suited to the crops selected, the arable land may have excessive nutrient levels and too high a pH to be capable of a high yield or, initially, satisfactory establishment without remediation. This was highlighted from the site visits undertaken as part of this project, specifically, the Winmarleigh trial site. The top soil needed to be stripped before establishment of sphagnum moss due to excess nutrient levels.
Consistency of water supply needs to be investigated including, any implications for third parties of controlling the water and statutory conditions. If these aspects are satisfactory, the cost of site preparation including, controlling the water table and levelling of the site needs to be costed by water engineers.

It is recommended that the ascetic and environmental implications are discussed with interested parties. The proximity to the SSSI might risk the introduction of alien genetic material even if it is from the same species. While there is unlikely to be a legal barrier to the introduction it might be considered insensitive given the environmental significance. As part of this project, we reviewed the social value of paludiculture and there is a need to baseline land use to take into account social value and understand the impact it could have on other areas of the business. The paludiculture site could provide a visitor point on several nearby trails and improve knowledge and awareness of peatland.

Profitability is likely to be determined by the quality of the marketing and the ability to retain control of production to prevent oversupply. For this reason, we have identified two different routes to market:

1. Where the technical development and expertise of a third party may be used to market the product and provide a barrier to others entering the market (sphagnum and BeadaMoss (brand name used by Micropropagation Services Limited) and Typha latifolia ((T. latifolia) seed down and Ponda/SaltyCo).
2. Initially smaller scale markets capable of direct sale to consumer through the existing Vitagrass Farms (Holker) Ltd infrastructure (this includes flavourings, essential oils, dry herbs for use in a range of products in small quantities and possibly exotic fruit). All the crops selected have the potential to meet more substantial market needs but branding would be necessary to help ensure that sales value was not undermined.

The crops chosen are nearly all found locally and many of them are on the neighbouring SSSI. This is not a guarantee of commercial success but is a good indication that with suitable management they will at least grow.

Our favoured option is the production of sphagnum moss under the umbrella of BeadaMoss. BeadaMoss recognise that the site is unlikely to be a favoured commercial site without irrigation and a history of sophisticated horticultural production. T. latifolia for fibre via Ponda (BioPuff® brand), and ideally sale of biomass for incineration, is easier to grow provided the land can be flooded and remain underwater for most of the year. This crop would be a favoured route to the commercialisation of existing reed beds.

Of the remaining selections, Mentha aquatica looks to be the most interesting. Bog-myrtle and Angelica sit in a similar niche. All have been subject to some agronomic development. Angelica production requires harvest of the root which is likely to be more demanding. Marsh cranberry (Vaccinium oxycoccos) has a distinct and better flavour than its American cousins but would need considerable development if only to obtain sufficient material for planting. This and the other Vaccinium species reviewed (Vaccinium myrtillus (Bilberry/Whortleberry/Blaeberry/European blueberry)) are long-term possibilities. There are likely to be some parallels with the exceptional development and market growth of cranberry and blueberry to build on.

It is likely that an application for the land wetting payments, available under the Countryside Stewardship Higher Tier Scheme (CS), of £1,409/ha/year on cropped or arable peat, and £1,381/ha/year for grassland plus any carbon credits, would provide a higher and more assured return until paludiculture options are proven. This approach was confirmed by the stakeholders we engaged with. These payments are decoupled from production so they do not influence the profitability of the paludiculture crop however, they do incentivise the investment in land change. Care Peat justifies the wetting up of peat solely on a high price for carbon credits and a very long discount period that is unlikely to be satisfactory for an entrepreneurial investor.

Paludiculture poses a threat to existing virgin peat land if it creates value for plants already growing on peat and if a barrier is not imposed to harvesting the surface plant material (e.g. sphagnum). If a barrier were imposed at least some of the area occupied by Vitagrass Farms (Holker) Ltd may become ineligible for commercial production if considered more suited to peat restoration.

Proving that sphagnum moss or T. latifolia can be established is unlikely to help develop paludiculture and will reflect only site preparation and management. The establishment of the other crops selected would prove more demanding and provide a more impressive test.

More work is still needed to identify which crops can support themselves financially and be a sustainable method of peatland preservation. Neither market nor detailed agronomy is established for any crops and achieving this will demand resources. The industry depends on statistically replicated randomised trials to test concepts and these procedures should be adopted.

Contents

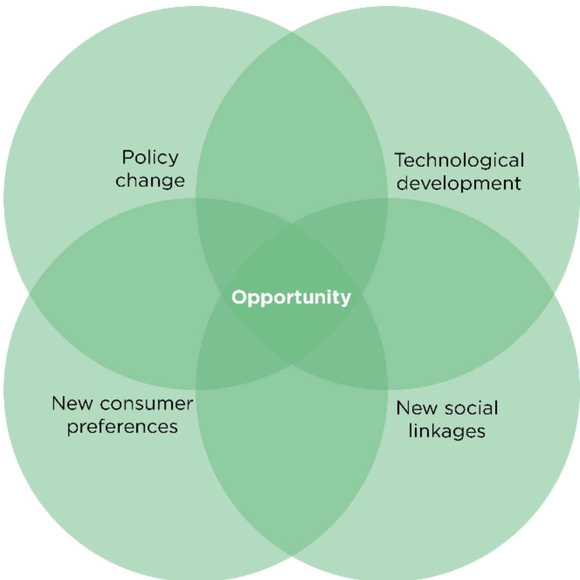
1. Introduction

Vitagrass Farms (Holker) Ltd commissioned Savills to undertake a research project to review the viability of producing a commercial crop from peatland, otherwise known as paludiculture. The aim of this research being two-fold; 1) to maximise profitability from the land and 2) preserve peatland and reduce carbon emissions from the estate.

The increased interest in peatland is driven by the UK target to meet net zero emissions by 2050[1]. Peat soils consist of 30–45% carbon; when the peatland is drained, the peat dries out, vegetation decomposes and carbon is released. In 2020, drained agricultural peatlands in England emitted approximately 8.5 million tonnes of carbon dioxide equivalents per year (UK figure is 16 million[2]). With an estimated 3.2 billion tonnes of carbon stored in UK peatland these soils need to be carefully managed to avoid continued emissions. By maintaining a higher water table and cultivating crops that thrive in those wetland conditions this pauses any kind of decomposition, meaning no carbon is released.

Savills research looked to list potential commercial crop opportunities that existed and against a criteria matrix, identify a number to investigate further from which Vitagrass Farms (Holker) Ltd would make a decision on a candidate to trial to learn how paludiculture can be made commercially viable and rolled out over a wider area of land. Where conventional crops are grown to meet an identified market need, many paludiculture crops are grown in anticipation of finding a market. While the factors are present for the creation of an opportunity (e.g. policy emphasising the need for low carbon materials and consumers preferring the same) paludiculture requires more thorough development to deliver for that opportunity.

Figure 1: Drivers of opportunity



The focus for this research is on commercialisation rather than restoration although co-benefits associated with commercial production may also be realised.

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[1] Net zero emissions target is to reducing emissions by 100% from 1990 levels by 2050

[2] Soil Association: https://www.soilassociation.org/certification/forestry/carbon-schemes/peatland-code/

2. Overview

2.1. Paludiculture crops

Paludiculture is the profitable farming of undrained wetlands making the most of any available competitive advantages. Where land has been previously cropped, drainage is removed preserving peat and reducing greenhouse gas emissions.

Conventional crops tend to have a lower cost of production per unit area than paludiculture crops for the same, or similar outputs and thus achieve higher profitability. To compete, paludiculture crops need to meet unique market requirements or produce a significantly higher yield than conventional crops to lower the cost of production. Conventional crops are more developed agronomically and easier to cultivate on land more suited to mechanisation. Much of the research for peatland has focused on restoration rather that commercial viability of growing crops. Few paludiculture crops have been successfully commercialised. The most significant is rice which is not suited to UK conditions. Rice produces high methane emissions and has a higher greenhouse gas footprint than other grains (estimated in 2021 at 1.0414 kg CO_{2eq}/kg versus 0.1745 kg CO_{2eq}/kg for all other cereal grains[3]). Paludiculture crops can sometimes release methane and do not always reduce carbon emissions.

Other crops considered appropriate paludiculture crops are now often grown in conventional systems with the introduction of management systems that mimic a wetter environment but allow mechanisation (celery) or provide a more consistent and easier-to-manage environment (blueberry). In the UK blueberries are grown in polytunnels often using coir (rather than peat) as the growing medium.

Common reed (phragmites) is a better thatching material than wheat and has little, or no, value at the point of harvest. However, even in coastal areas of the UK, the relative ease of growing and, in particular, harvesting wheat grown specifically for thatching, makes it the more widely used thatching material despite the need for varieties and machinery that differ from conventional wheat grown for grain.

Most potential paludiculture crops provide non-food outputs on land that has previously been the most productive land for vegetable production in the UK.

2.2. Paludiculture versus environmental restoration

To ensure paludiculture crops are commercially viable usually requires a different management regime from that required for restoration.

Table 1: Restoration v's commercial production

Restoration	Commercial production
The objective is environmental protection and increased diversity.	The objective is a saleable good needed by a consumer.
Planting and management to achieve the diversity appropriate to the site.	Planting and management to create a pure stand with minimal loss from weed competition or pest damage.
Plants may be cut to maintain diversity but otherwise, little management is usually necessary.	Plants have to be harvested. Management needed to optimise inputs and protect from threat.

[3] https://www.fao.org/faostat/en/#data/EI

Period until complete cover is achieved is less important than the achievement of quality cover.	A one-year delay in harvest means a potential loss of one year's crop income. This could be in the order of £1,000/ha loss of gross margin and perhaps £700/ha net margin[4]. Alternatively, this might be expressed as a loss of one year's rent. In addition, the future income, relative to the initial cost, is discounted by the rate of interest.
Work can be carried out by hand often using cheap volunteer labour.	Cost of work is crucial and mechanisation is likely to be necessary to compete with other growers.
Hand labour allows the site to be uneven, including trees, rocky areas or wet patches.	Mechanisation requires a level site free from encumbrance.
Water levels need to be managed only as necessary to maintain the site diversity.	Water levels need to be managed to maximise the rate of growth and to allow machinery operation. This may require site levelling and/or irrigation.
Periods of poor growth or poor establishment are tolerated if recovery is likely to occur.	Poor growth or patchy establishment is likely to lead to financial loss.
Contamination with different species or genetic material brought from a distant site is undesirable.	More productive species, or species with better genetic characteristics, are desirable.
The presence of pests and diseases is part of the restoration process.	Pests and diseases reduce the primary output.
Application of manure and fertiliser is usually inappropriate, since it may change the species mix and may lead to pollution of watercourses.	Manure or fertiliser is likely to increase the yield of the target plant. Fertiliser will be needed to replace nutrients lost in harvested matter.
Rotation is to be avoided.	Rotation may be essential to minimise pests and diseases and maintain productive yield.

Greenhouse gas reduction is more complex. The act of wetting up land in both situations is likely to prevent further loss of organic matter (and thus carbon) although there can be an emission of methane, particularly if organic matter decomposes in anaerobic conditions. Some plants appear to reduce methane loss where there is good cover and, control of the water level can also be used to reduce methane emission. Production of biomass to replace the burning of fossil fuels is positive while perennial crops usually reduce carbon loss compared to annual cultivation.

There can occasionally be some environmental gains from paludiculture crops over restoration. For example, pure stands of several of the flowering crops will deliver more pollen and nectar for insects than can be obtained from an otherwise more diverse restoration site.

2.3. Paludiculture compared with conventional cropping

Paludiculture crops can have a more consistent yield than many conventional crops because the managed, permanently waterlogged conditions result in less opportunity for drought stress or flood damage than for a rain-fed crop. Yield consistency may also be enhanced by the high water table maintaining a more consistent temperature (lowering the threat of damaging high temperatures and lowering the risk of frost damage). Conversely, there are several disadvantages, which many may be solved via the development of new technologies or through careful site selection:

- It is more difficult to traverse the land making mechanisation more difficult, particularly for planting and harvesting.

[4] Wheat gross margin with net margin based on the assumption that labour, rent, machinery investment, etc is not reduced with main savings being fuel and repair costs

- Where mechanisation is possible, machinery tends to be specialist. The ability to share operations with other crops is a small raising cost unless it can be operated over a long period within the paludiculture crop. There is also a higher risk that the machinery is worthless if the venture proves unsuccessful resulting in a big loss of capital. This difficulty also applies to some conventional crops, such as potatoes, but even for potato production many of the powered units are likely to be used for other crops and there is an established international market for second-hand potato equipment.
- Suitable sites tend to be small and/or the difficulty of mechanisation often results in small sites and consequently high overheads per unit of production. This might include processing equipment.
- Plant breeding is less advanced and consequently yield potential is likely to be low, at least initially. Even relatively recent crops such as blueberries and cranberries have been domesticated for over 100 years. The introduction of gene editing may erode this difference but the technology might not be acceptable in some of the environmentally focused product marketing.
- There are fewer potential crops making rotation harder and consequently risk of loss from pests and disease is higher. In the short term, there is also an absence of approved pesticides to control threats.
- There is a greater chance of nuisance to other growers where higher water tables may damage drainage infrastructure or lead to disease in crops not able to withstand a higher water table.
- Vast quantities of water may be needed making the crops more vulnerable to water shortage than conventional crops.
- The wide adoption of conventional crops rather than water-based crops suggests that there are few opportunities when a producer can gain a competitive advantage from paludiculture. There are exceptions, most noticeably rice, but the opportunities are relatively few.

2.4. Paludiculture in the agronomic context

Paludiculture crops are more diverse than conventional crops and different crops require particular conditions for profitable growth. The cost of creating appropriate conditions is specific to the site and crop and is likely to be one of the highest costs encountered. Minimisation of the capital cost of customisation, and minimisation of future operating costs, via choice of site is vital to long-term commercial success.

The cost of crop establishment may be the next highest cost element. Several crops are established from expensive nursery stock, are hand-planted and do not produce a harvest until after two or three years have elapsed. Crop failure resulting from a poor choice of site and preparation will mean the cost of replacement plants, the cost of replanting and a further delay in the receipt of income (and consequently loss of a year's income). For some paludiculture crops, there is a complex economic relationship between the cost of planting, plant density and the period until harvest. More work may be needed to derive this optimum.

It is unlikely that infrastructure can be substantially altered post-cropping and it is important to ensure that everything is done to ensure efficiency from the outset. The following specific areas need to be investigated before committing to commercial production.

2.4.1. Water

To optimise yield, most paludiculture crops require a specific water table. Thus the field ideally needs to be flat and level. This may require careful laser levelling, to remove slopes and depressions. The water supply needs to be assured. There may be more flexibility where irrigation is available. Adverse weather conditions are becoming more common due to climate change. The impact of lower production or even plant loss, perhaps resulting in several years' loss of income, may be very high. Where soil water reserves are high, production is likely to be more robust improving supply consistency than possible for conventional crops. Some crops such as T. latifolia can also make use of brackish water further securing production against water shortage to increase resilience.

Drainage systems may need to be blocked to prevent loss of water (raising the water table might lead to drainage silting up).

Those crops where the water table needs to be close to ground level or above ground level are also likely to require the ability to manage the water table and often lower it for planting and harvest.

Where the crop requires flooding it is probably necessary to construct levees to contain the water. Access tracks may need to be isolated from the cropped areas to allow the collection of harvested plant material. The cost tends to be lower per unit area on larger sites.

Land parcels may need surrounding ditches to establish a consistent water table in the field and, if appropriate, assist drainage for harvest and planting.

Adjustment to the water table may have implications for other growers and people in the catchment. Flooding risk may be increased, or the supply of irrigation water jeopardised. Even short-term flooding can result in the loss of crops and the destruction of expensive drainage systems. Statutory bodies such as the Environment Agency and (where they exist) Drainage Boards may need to be consulted.

2.4.2. Nutrients and pH

Nutrient and pH demands vary between paludiculture crops. The fundamental difference is between bog plants and fenland plants. Bog plants tend to prosper in areas with low pH (for some crops down to 4) and low nutrient status whereas fenland plants require a higher pH and higher nutrient status. In the longer term, where cropped, the removal of harvested material is likely to require the replacement of nutrients.

For some crops (usually, those that require a water table below the surface) the standard soil sample down to 15cm is insufficient if the organic soil is sitting on top of mineral soil therefore analysis to twice this depth may be needed. This is most obviously true for Vaccinium crops, where rooting is mainly in the surface layer, and soil texture differs between the layers (both naturally and as a result of management).

Conversion of farmed land (arable or particularly livestock) is likely to leave residual pH and nutrient levels higher than appropriate for the paludiculture crop. Levels need to be tested and if necessary corrected. Correction of pH may be via (for example) the application of sulphur or ammonium sulphate and reduction in nutrient levels by cropping for a few years with a high nutrient-demanding crop such as Typha spp. or miscanthus until nutrient levels fall within the acceptable range.

Nutrient levels and pH in the water are equally as important and may vary over the year. Testing is crucial.

It will be difficult to reduce nutrient levels from upstream Wastewater Treatment Works or activity in another farming business. It would be possible to construct buffer strips where the land is controlled by the same farming business as creating the paludiculture activity or even pay compensation to other farmers to reduce the nutrients in the water (impact tails off with width and 6 m may be sufficient). Where the water is applied via irrigation the pH may be adjusted. Payments for raising water levels in peatland are available through the Countryside Stewardship Higher Tier (CS)[5], a 10 year scheme.

2.4.3. Pesticides

Few of the plants selected are competitive with weeds, particularly in the early years of growth. Use of mulch, plastic covers, stale seedbeds, hand weeding and frequent cutting are used to control weeds but there is a reasonable chance that the application of herbicide may also be required. Some of the plants are vulnerable to pest and disease attacks and both are likely to increase over the lifetime of a perennial crop or under continuous monoculture (as tends to be the case for paludiculture crops).

It is important to ensure that planting material is weed and disease-free. This would be as expected where planted from seed or plugs but several plants are established from broadcasting of harvested material.

While the use of pesticides should be the last resort for the control of pests and diseases, there will be occasions when pesticides are the most effective solution. Data is generally available on what materials are effective but it will be necessary to obtain an extension of authorisation for minor use (EAMU). Where the manufacturer supports the application this should be possible to obtain for under £3,000 where the output is not intended for human consumption. The cost may be considerably higher if residue tests are also needed. It is still a large cost where the site is small and would be better shared with all growers by forming a grower group. Permission is likely to be easier to obtain where the product is not for human consumption.

2.4.4. Soil type

Soil texture may also be important. Most plant roots require a balance between aeration and water availability. Surface layers may need to be a different texture to the subsoil for optimum growth and management. Several crops require the water table to be lowered to allow a competitive rate of harvesting and to be effective the soil needs to release water at least to the extent that low-ground-pressure vehicles can operate.

For most paludiculture crops the organic matter levels need to be high at over 20%. Organic matter such as tree bark or compost, may be added.

2.4.5. Fencing and pest control

Many of the plants are attractive to grazing animals and fencing is likely to be needed where the channels used for flooding do not provide sufficient protection. The fencing cost will usually reduce per unit area cropped since the perimeter length falls with increasing area.

Defra capital grants help to fund fencing with the basic fencing payment of £6.34/m and an additional £5.65/m supplement paid for rabbit proofing. There are specific grants for sheep fencing (£7.47/m) and deer fencing (£10.27/m). The cost of fencing should be relatively trivial although maintenance might be high in the waterlogged conditions proposed for the paludiculture crops.

[5] https://www.gov.uk/government/publications/countryside-stewardship-higher-tier-get-ready-to-apply/countryside-stewardship-higher-tier-preview-guidance

Birds may be a particular problem where fruit is grown. Geese may also graze young plants, particularly at establishment. The acceptability of using bird scarers and/or the practicality of netting needs to be part of the planning process.

2.4.6. Machinery

Unless water tables can be controlled, and soil type is free draining, allowing the use of existing machinery, paludiculture requires specialist machinery adding to the capital and operating costs. To lower the capital cost of machinery per unit area, the operation cost and the investment in the site infrastructure, the area usually has to be large to ensure equipment is fully utilised. Few profitable crops are viable on fewer than 100ha although the area may be divided between several growers sharing machinery costs and marketing infrastructure. Site choice has to be considered carefully to meet these requirements at a minimum cost.

2.4.7. Location

Vitagrass Farms (Holker) Ltd is not in a major area for the distribution of crop outputs, processing of crop outputs (grading, cleaning freezing, packing, juicing) or sharing of arable machinery. Other outputs (such as biomass) are relatively low value and have a high transport cost to the place of consumption.

Products need to be considered in the context of the business location and available facilities.

2.5. Legislation and government intervention

Legislative change (or prospective change) can create new opportunities. The payments for raising water levels to near the land surface in peat soils (£1,409/ha/year cropped or arable peat and £1,381/ha/year for grassland) introduced by Defra under the Countryside Stewardship Higher Tier (CS) scheme are received irrespective of land use and are independent of production although they encourage land use change. Consequently, the payments are largely neutral as far as paludiculture is concerned. According to a Defra spokesman, the detailed guidance determining compatibility with paludiculture is yet to be defined.

Most growers would be better off taking the payment and leaving the land to naturally regenerate. This would allow time for paludiculture crop markets to develop and more investigations and research to be undertaken. Payments for carbon accumulation, brought about by rewetting to protect the peat, are also independent of cropping.

The Peatland Code is the certification standard for peatland restoration in the UK which includes a validation and verification process by an independent body. The output is carbon credits, a tradable commodity which can be sold to secure an income. Carbon credits must be validated and registered in advance of any project taking place and continued monitoring must be undertaken, therefore there is a cost associated with this. There is increasing interest from investors to purchase carbon credits to ‘offset’ emissions. The carbon payments raise the market value for renewable fuel or biochar production supporting biomass at the expense of food crops.

The prospective legislative change to ban peat consumption will change the raw materials used in formulating potting compost and probably raise the price. This has already had an impact on technical development and changed the balance of materials used to manufacture potting compost. This is likely to be positive for the use of sphagnum moss consumption since the characteristics are similar. Sphagnum moss production is one of the more developed paludiculture crops. However, it can be grown in areas that had not previously produced sphagnum moss which would be easier to mechanise. It could also be produced on a very large scale where sphagnum has been established on previously mined areas of peat.

Where materials are new Health and Safety Registration may be required under REACH (UK registration, evaluation, authorisation and restriction of chemicals)[6].

2.6. Other drivers for commercialisation and market protection

Consumer preference towards more environmentally friendly production provides a driver for the development of new sources of materials. This has been positive for all of the proposed products but it needs to be captured.

Both Ponda (producing Typha with their BioPuff® brand) and BeadaMoss[7] (for sphagnum) are in the process of achieving a positive association with an output.

While the branding may protect the supply to the buyer, increase the price paid and raise the quantity required at any given price, the benefit to the grower is only as high as needed to secure supply by the brand holder. It would be a brave grower that was prepared to invest in a multi-year crop without a firm contract and payment during the establishment period to cover investment in converting the land, cost of establishing the crop and loss of crop income in the period until harvest. But these producer-developers do help protect against oversupply, if the venture proves to be worthwhile.

2.7. Competition

If the paludiculture crop is shown to be profitable, other producers will enter production and reduce the market price. New producers may use either semi-natural areas already with an established crop or create conditions for production on arable land where conventional machinery may be used. In these areas, the impact of adverse weather conditions is also likely to be reduced. The barrier to entry is often market establishment and agronomic expertise. Expenditure by pioneering producers without the benefit of patents is likely to make pioneering growers less profitable than newcomers benefitting from the developed technology and establishment of the new market. Branding as Ponda and BeadaMoss are creating may help to manage the supply.

2.8. Crop advocate and collaboration

If paludiculture is to become economically competitive against other crops, development needs to be radical. Most importantly, profitable paludiculture needs individuals with determination to establish the market and production. Technical development alone is very unlikely to be enough to create a new product. While subsidy and research are desirable, the role of the product advocate is more important.

Ponda and BeadaMoss are extremely important to the development of their particular crops and provide a vital service in market and production focus by acting as a central coordination hub. Production focus includes:

1. Management of supply to prevent market collapse.
2. Development of agronomic inputs.
3. Plant selection and distribution.
4. Machinery development.
5. Machinery sharing arrangements.
6. Provision of risk management options.

[6] https://www.hse.gov.uk/reach/index.htm

[7] BeadaMoss is a brand and is used in this report as shorthand to include BeadaMoss Limited (currently dormant), Micropropagation (EM) Services Limited and the dissolved Micropropagation (EA) Services Limited.

The consolidator businesses are, in many cases, more exposed than the growers to financial risk because growers can change crops more easily than the dedicated product developer if profitability falls. Growers will often have a shorter right-down period for investment as farm machinery tends to have a second-hand value if it can be repurposed while processing machinery is often designed to perform a specialist single-purpose specific function. This may be less true for paludiculture where cropping versatility is reduced and crops tend to be perennial.

Collaboration will almost certainly be beneficial for sharing the cost of improving plant genetics, agronomic development and the cost of obtaining off-label use of pesticides (assuming that producers are not in direct competition for a finite market). Marketing will also in many situations be most efficiently carried out on behalf of the growers.

Where products are intended for a niche market over-supply is a threat. Ponda and BeadaMoss are developing branded products that are intended to achieve this end. Both organisations have a vested interest in developing their target crops to lower the cost for their growers. They also act as product advocates promoting production to the government, developing buyers and playing a role in coordinating research. Both Ponda and BeadaMoss are seeking growers with the appropriate expertise and land although this is for testing of systems and commercial arrangements rather than purely commercial production areas. Despite this risk, both Ponda and BeadaMoss have confidence that they can sell large volumes of their respective product at present. Ponda is actively seeking “hundreds or even thousands of hectares”.

2.9. Financial return

None of the crops are established on any scale in the UK and development elsewhere is still being undertaken by researchers rather than commercial bodies. Neither the markets nor the production systems are sufficiently developed to provide commercial confidence to justify investment.

None of the options are likely to produce an Internal Rate of Return (IRR) over 10%. IRR is the most effective means of assessing whether an investment is worthwhile allowing comparison of any investment, not just agricultural investment. IRR also takes into account delayed return and estimated capital appreciation/depreciation (if appropriate). The rate of return needed is dependent on the risk, or put another way, the confidence in achieving the objectives. None of the paludiculture options considered are fully developed agronomically and none have been tested to any extent in the market. The risk is high. For a risk such as this, most entrepreneurs would require at least a 15% IRR.

A further concern is that flooding of the land for paludiculture may be irreversible without investment and the creation of a new environment might result in a significant fall in land value.

While conventional farmers might accept a low IRR the risks are understood and for owner-occupiers capital appreciation (land value) has been substantial over the last 20 years.

IRR may alter after development is complete but we do not know. Development is always ongoing, even for established crops, but even the front runners appear unlikely to develop a sustainable production system within the next five years. For some of the introduced species, gene editing technologies may help to narrow the gap relatively quickly with conventional crops where even the newest crops have been subject to intensive breeding programmes for over 100 years.

Since many of the outputs are new to the market the market reaction is an estimate. Buyers need to decide what volume of production can be sold at any particular price and know that the purchase (or production) cost is lower than the sale price. This is a complex interaction and notoriously difficult to estimate. Where the outputs are established, such as biomass (cellulose and others), sale requires the buyer to consider the material to be better value either via a lower price (possibly a lower transport cost) or for a technical reason (such as timing of supply, higher calorific value or it is easier to handle).

2.10. Crop choice

The crop choice is not purely a costing exercise since the profitability will depend on management, the rate of agronomic development, the choice of site and the market development. For this reason, we have not scored profitability in the table below since profitability is potentially similar. All options have the potential for high profitability under expert management but in practice, return is most likely to be low and risk high. An important factor is site investment and this will depend on site selection.

All of the 123 crops assessed have previously been identified in other studies as paludiculture crops[8][9]. Paludiculture crops are diverse even in terms of their water requirement. For example, T. latifolia (bulrush) and Mentha aquatic (water mint) will grow while submerged while the Vaccinium species (Blueberries, Cranberries, etc.) require the roots to be aerated with the water table raised only to within 20cm of the soil surface and sphagnum within 2cm of the soil surface. Another significant distinction is between plants suited to bog areas (which are largely rain-fed, have a low nutrient status and are slightly acidic) and fen areas (which are largely groundwater-fed, have alkali subsoil and a higher nutrient status). Some of these distinctions can be overcome via appropriate husbandry although the ability to transfer to more conventional systems (celery, blueberries) makes production in a wetland situation unviable.

Metrics used in the following tables are explained below:

- **Market advocate**: Is there an organisation that will manage the market on behalf of the estate?
- **Development advocate**: Is there an organisation that has an interest in improving production, providing guidance on cultivation and coordinating agronomic development for the growers?
- **New demand drivers**: All paludiculture crops are attractive because of the potential association with carbon reduction and positive environmental management but are there other drivers such as legislation or technical development that provide particular benefits to the product?
- **Market entry**: This is assessed in three ways: 1) Is there an established supply chain for a similar good? 2) Is there an organisation (such as Ponda or BeadaMoss) that has actively developed the market? 3) Can sales be made through existing estate facilities?
- **Market displacement**: Are there other products already meeting the market need that would have to be displaced?
- **Potential market competition**: Would the successful establishment of the market attract others to enter perhaps using a product from a wild site?
- **Price sensitivity to supply**: How easy would it be to overproduce leading to a price collapse? Is there some supply management or major barriers to entry?

[8] https://greifswaldmoor.de/files/dokumente/GMC%20Schriften/2022_Abel%20&%20Kallweit_2022_DPPP_Holarctis.pdf Potential Paludiculture Plants of the Holoratic - Greifswald Mire Centre. Abel, S. & Kallweit, T.

[9] https://repository.uel.ac.uk/item/88348 Defra Project SP1218 An assessment of the potential for paludiculture in England and Wales – 2020 Defra, ADAS, CEH, University Leicester, University East London, Bangor University

- **Environmental threat**: Does the plant/crop have the ability to invade neighbouring environmentally sensitive areas or genetically contaminate plants with a high genetic value?
- **Site suitability**: How easy is it to create conditions for production?
- **Agronomic development**: Has agronomic development taken place either through commercial production in other countries, via research organisations in this crop, or via established similar crops?
- **Cultivation machinery**: Can existing machinery be used or does specialist machinery need to be developed? (Assuming there is the ability to manage the water table).
- **Harvesting machinery**: Can existing machinery be used or does specialist machinery need to be developed? (Assuming there is the ability to manage the water table).
- **Machinery for processing**: Can existing machinery be used or does specialist machinery need to be developed?
- **Centralised processing of bulky material**: Transport costs are significant for some materials. Is transport cost significant relative to product value and can transport cost be readily reduced by onsite processing? The biomass score takes into account the nearby biomass consumer.
- **Expertise required**: Is the management complex and is there support available?

In the table below the main attributes have been scored from 1 to 5 where 5 is desirable/positive.

Table 2: Main attribute analysis

	Sphagnum	**T. latifolia (Bulrush, Reedmace, Cattail)**		**Vaccinium e.g. V. oxycoccos (Cranberry, Marsh cranberry, Small cranberry)**
Uses	Potting compost	Down	Biomass	Fruit
Market advocate	5	5	2	1
Development advocate	5	4	2	1
New demand drivers	4	3	2	1
Market entry	4	5	3	2
Market competition	3	3	2	2
Potential market competition	2	3	2	1
Price sensitivity to supply	2	3	1	2
Environmental threat	3	2	2	4
Site suitability	4	3	3	2
Site investment	1	3	3	2
Agronomic development	5	4	3	2
Machinery cultivation	4	5	5	5
Machinery harvesting	4	3	5	5
Machinery processing	5	4	5	5
Centralised processing of bulky material	3	4	5	3
Expertise available	3	3	3	1
TOTAL	57	57	48	39

Several of the Vaccinium plants (e.g. blueberries, cranberry) are already commercialised and others in the group should be much easier to develop as a consequence. While the commercialised Vaccinium species are produced on a large scale during development, local sales may be made via the Vitagrass Farms (Holker) Ltd shop as a novelty product. Attempts have been made to develop Vaccinium myrtillus (Blaebury) largely through enhancing wild production but yields are currently low and erratic. Even less work has been completed on V. oxycoccos (Marsh cranberry, Small cranberry**).** Scoring takes into account work already undertaken on other Vaccinium species.

While Vaccinium macrocarpon (American Cranberry) and Vaccinium corymbosum (Blueberry, Highbush Blueberry) are already established crops it would be difficult for Vitagrass Farms (Holker) Ltd to compete. V. macrocarpon is already produced on a large scale, has been subject to considerable investment and has an established marketing route via the farm Cooperative Ocean Spray. In contrast, V. corymbosum is produced on an even larger scale and while grown on a similar soil type in the USA it is already grown extensively in the UK using table-top systems and artificial media. Management costs are lower and there is less production variability. In addition, neither of these crops are native to the UK.

To secure a competitive advantage either the cost of production needs to be lower than for competing suppliers or there needs to be a premium. It is unlikely that production costs can be lowered but a premium may be securable via the supply of a novel, better-flavoured berry such as V. oxycoccos (Marsh cranberry, Small cranberry) or even V. myrtillus (Blaebury). Sales are initially perceived as being local, building on the existing estate presence.

The following options are expected to start with an artisan operation with the entire process in-house on a domestic scale making the most of the estate's existing branding and retail operation to sell directly to buyers and online. Once established the objective would be to expand to sell larger volumes through the flavouring and aromatics industry. Mentha aquatic is similar to other Mentha plants (spearmint and peppermint) that have similar requirements. These are established and widely used as flavourings. Small botanical stills are available for processing the plants to create flavourings and aromatics for under £2,000 (although larger stills can cost over £60,000). The manufacturing process can become an additional visitor experience.

Table 3: Main attribute analysis

	Myrtle Gale (Bog Myrtle)	**Mentha Aquatica (Water mint)**	**Angelica archangelica (Angelica)**
Uses	Flavouring	Flavouring oil, herb	Food, flavouring (oil), decoration
Market advocate	1	2	1
Development advocate	3	3	2
New demand drivers	1	2	1
Market entry	2	2	2
Market competition	2	1	2
Potential market competition	1	1	1
Price sensitivity to supply	1	1	1
Environmental threat	3	4	4
Site suitability	3	3	1
Site investment	3	2	3
Agronomic development	2	3	2
Machinery cultivation	4	4	2
Machinery harvesting	3	4	2
Machinery processing	3	4	3
Centralised processing of bulky material	4	4	4
Expertise	1	2	1
TOTAL	37	42	32

2.11. Trials

With appropriate site preparation and management, there should be little difficulty in establishing the selected plants although site preparation might take several years. The establishment should not be a gamble.

For the trials to be credible, treatments need to be capable of statistical analysis and designed with clear objectives. Preparation requires reading of existing research work to avoid duplication of effort. Since the objective is commercialisation the trials should be aimed at commercial production rather than restoration.

The sphagnum trials carried out by Moors for the Future[10] provide good examples of the use of quadrats to provide valuable statistically valid results. It is important to note, these trials are for restoration rather than commercial production but trial design is to a high standard.

3. Sphagnum Moss

3.1. Summary

Sphagnum moss is the only paludiculture crop where a potential change in legislation and change in consumer preference combine to increase demand and consequently raise the price of the output to create a new grower opportunity.

While sphagnum moss production to supply potting compost in horticultural markets provides one of the best returns of the options considered for rewetted sites, the return is still low and risk high based on the published data. The significantly higher yields quoted by BeadaMoss from unpublished trials may allow a better return.

The cost is overwhelmingly influenced by the cost of creating the appropriate infrastructure for commercial production and this is strongly influenced by scale of operation. Where scale is increased the structural cost is reduced and more of the tasks can be mechanised. The cost of processing is also likely to require a different scale of operation from that available for production.

- For competitive commercial production without irrigation, water levels need to be consistent at around 2cm from the soil surface and capable of control at low cost. BeadaMoss promote production entirely using above-ground irrigation infrastructure which, while expensive, has fewer potential containment and off-site implications. Whether water is required to raise the water table, or for irrigation, a reservoir may be necessary to maintain the security of the water supply to ensure the optimum growth rate needed for production (allowing for at least three years from planting until harvest).
- Irrigation should be available to reduce the risk of crop loss and to maintain growth in periods of adverse weather during the three years from planting to harvest. The high rainfall in the area suggests that the quantity of water required can be small.
- Land must be flat to allow mechanical harvesting and consistent water table, and soil sufficiently structured to drain for the periodic planting and harvest (despite the use of low-ground pressure vehicles).
- The land needs to be restored to a low nutrient status and low pH.
- Ideally weed levels need to be minimised at establishment and use of frequent cutting.

Costs are particularly high in the research projects but may be capable of reduction if:

1. Sites are used where the water table can be controlled so that land can be dried for key operations such as planting and harvesting.
2. Crop production is restricted to land with a stable subsoil that can withstand tractor movement. Since the land at Vitagrass Farms (Holker) Ltd has been used historically for arable cropping this should be possible.

[10] https://www.moorsforthefuture.org.uk/

3. Land is already level and does not require levelling (such as ex-arable land).
4. Production is on sites where irrigation is available to reduce risk and optimise production.
5. Weed-free planting material is used to minimise the weed burden.
6. Planted mechanically. Both plant blocks and gel can be mechanically planted on suitable sites. Under good management, the gel planting should be cheaper.
7. If the site is managed to consistently harvest at three years. This should be possible under management to optimise establishment and subsequent growth without compromising yield. Maintaining sufficient water for germination at establishment and adjusting plant density at planting are crucial components.
8. Harvesting machinery is developed such as that used for root cropping (or stone separation).
9. Areas harvested are replanted (rather than allowed to regenerate) to reduce recovery time.
10. Processing is centralised to enable the use of capital assets throughout the entire year.

There is still considerable agronomic research that needs to be undertaken particularly into the variety and even species selection before commercial production is realistically an option.

Reworking the published figures using the above proposals shows a low return of about £1,300/ha and a modest internal rate of return of about 5% (before the opportunity cost for the land). In commercial terms, the return for the risk is far too low to make commercial production a viable prospect but is as good as might be expected from an undeveloped crop with little or no entrepreneurial input. However, the exceptional yields quoted by BeadaMoss for their overhead irrigation system and micro propagules have the potential to generate a return of over 20%. The high return is likely to be received by BeadaMoss through payment for the technology needed. The benefit for the grower needs to be only slightly above that achieved from any competing crops replaced to secure the production. The infrastructure for overhead irrigation is not available to Vitagrass Farms (Holker) Ltd.

Profitable commercial production differs from planting to achieve restoration objectives. Considerably more development work is needed in machinery, design and agronomic optimisation for paludiculture crops than for conventional crops.

Additional income streams such as environmental payments, under the Countryside Stewardship Higher Tier (CS) scheme and carbon credits are available for peatland rewetting and restoration. These are received without the need to expose the business to the risk of growing a crop. It is appropriate that the CS scheme is modified 1) to make an additional one-off payment where the objective is to restore the flora to allow the peat to develop and increase biodiversity and 2) to make annual payments where the objective is the development of paludiculture (production should eventually be self-supporting). The CS guidance is at present undefined and it is not clear that the payments will be compatible with all types of paludiculture production.

The ban on the use of peat (including for use as a peat compost in the shorter term and in the longer period in commercial horticulture) will not be implemented until 2030. However, the use of peat in plant compost has fallen dramatically, particularly since 2020.

It appears unlikely that the harvest of sphagnum moss would be prevented by the ban on the use of peat and measures to protect peat reserves. Without additional legislation, this would potentially still allow large-scale harvest of sphagnum on restored sites or even harvest of sphagnum from virgin peat bogs. The parties currently harvesting peat would be well placed to transfer activity to these areas using established supply chains and equipment. It is possible that if, as seems sensible, restrictions are placed on the areas that can be harvested for sphagnum, some areas occupied by Vitagrass Farms (Holker) Ltd may become ineligible.

We understand that BeadaMoss intends to offer a contract production service for the production of sphagnum as well as restoration material. BeadaMoss is also in a position to coordinate agronomic development to improve growing efficiency and market management to avoid the risk of oversupply.

If the Vitagrass Farms (Holker) Ltd site were deemed suitable for growing sphagnum an arrangement with BeadaMoss would be appropriate.

3.2. Introduction

Sphagnum moss consists of over 300 species. It forms the bulk of the organic material in raised bogs (not fens which are groundwater-fed). Growth requires regular atmospheric moisture (rain and mists) with low levels of nutrients and slightly low pH. While sphagnum is found on wet soil the wet ground conditions are a consequence of the conditions and not a requirement for growth (high rainfall or overhead application of low nutrient marginally low pH water is essential). The moss holds large moisture reserves within its tissue. Cultivation is more demanding than restoration and requires the creation of conditions to optimise growth.

Where the objective is cultivation conditions for growth can be created in areas without a history of sphagnum. Irrigation is likely to be a necessary component. The pH of the water might need to be lowered and any nutrients in the water, particularly nitrates, reduced.

In contrast to other paludiculture crops, not only is the loss of organic matter prevented (removing/reducing the emission of greenhouse gas) but if it is retained (and not harvested) carbon capture is also increased. This possibility introduces additional policy complexity since (any) support payment should differ between the two options. It also introduces the potential for conflict between the sale of sphagnum produced on non-peat land and sphagnum produced on peat or restored peat. The policy difficulty is increased when peat production recovers on peat that has historically been “mined” allowing semi-wild harvesting.

The main use of sphagnum is as a peat substitute for horticulture although other markets exist such as in reptile enclosures and where highly absorbent material is needed.

Trials have been carried out on sphagnum moss establishment in several countries (including Germany, Finland, the UK and Canada). Most of the work, but not all, focuses on establishment for restoration purposes rather than commercial production.

Interest in sphagnum production has risen in response to:

- Introduction of payments for raising water tables and peatland restoration[11].
- The Autumn 2024 Budget has pledged £400million for fund peatland restoration and tree planting. This follows the previous governments target to restore approximately 35,000 hectares of peatland in England by the end of this Parliament[12] although the Climate Change Committee recommended this figure should have been increased to about 67,000 hectares.
- Payments under the peatland code for peat restoration.
- Interest in nature recovery (Environmental groups are major landowners).

[11] https://defrafarming.blog.gov.uk/2024/01/04/environmental-land-management-in-2024-details-of-actions-and-payments/

[12] https://www.gov.uk/government/news/thousands-of-hectares-of-peatlands-set-to-be-restored-to-help-tackle-climate-change

- A proposed ban on the sale of “fossil” peat by 2030. The concern is that different rules in different UK nations would allow sellers to challenge the ban based on “market access principles” preventing discrimination in the UK. Regardless of the exemptions, the ban increases demand for sphagnum moss as a substitute for peat.
- Developing consumer preference and demand for peat-free compost materials.
- Identification of new and revived uses for sphagnum such as for insulation, preservation, wound dressings and sanitation.

While multiple income streams may be generated from the same area the productive options potentially conflict with the environmental objectives.

3.3. Market

Since sphagnum moss gives rise to peat it is assumed to be a direct substitute for the use of peat as a growing medium. Its characteristics are similar and the trials carried out in plant nurseries support this substitution[13]. There are differences, for example, sphagnum usually has a neutral pH in comparison with peat and is lower in tannins.

Table 4: Peat v’s Sphagnum comparison

	Peat	Sphagnum
Bulk density Kg/m3	60-75	11
Water holding capacity %v/v	50-55	64
Air volume %v/v	35-42	35

Source BeadaMoss

Currently, sphagnum is not a mainstream substitute for peat as a growing medium, arguably due to lack of availability. Peat substitution is mainly with relatively low-cost waste materials (current substitutes include spent mushroom compost, soil/loam, coir, wood-based, bark, composted green waste and other (mineral or organic)). The main substitutes are wood-based materials (both sectors) and mushroom compost in the professional sector. It is perhaps surprising that anaerobic digestion waste has not been developed more. Many of the materials are wastes although there can be additional treatment and logistic costs associated with their use. For niche uses (such as orchid production) sphagnum is the most effective substitute. Replacement of the other peat substitute materials is likely to be more price-sensitive. Expansion of the use of coir (extracted from coconut husk) might also impose a sustainability risk.

Sphagnum has been thoroughly trialled as a potting material (including by the RHS at Wisley) and is an effective peat substitute.

Of the paludiculture products identified, sphagnum has the most new profitability drivers and thus one of the higher chances of success in suitable areas. While theoretically consumer preference and legislative requirements might change it is considered unlikely.

[13] http://mires-and-peat.net/media/map21/map_21_17.pdf Physical growing media characteristics of Sphagnum biomass dominated by Sphagnum fuscum (Schimp.) Klinggr. A. Kämäräinen, A. Simojoki, L. Lindén1, K. Jokinen and N. Silvan

For most commodities (including sphagnum) the product price is determined by the buyer paying the least to secure supply. The product itself may be worth more to some buyers but they will not need to pay that premium if others are paying less. Retailers put a lot of effort into differentiating supply to secure the return at each potential market price (e.g. via branding and packaging) but the impact is limited. This price variation is important for the sale of sphagnum moss and means that the price will vary considerably with the volume made available.

The price also influences supply. If there proves to be a viable market, more produce potentially becomes available unless there is some form of barrier preventing a supply increase and the price falls. The price is determined by the highest-cost producer who can supply at that price.

Thus:

- While some markets may be more valuable than others it does not mean that a supplier can achieve the premium price.
- The price is likely to fall once producers are in full production.
- Long-term commercial viability requires a low cost of production i.e. competitive advantage achieved by technology, expertise or site characteristics. Irrigation will be needed to reduce variability or even crop failure.

Several countries already harvest sphagnum moss from the wild and claim to do so sustainably. Many more areas could do so if it was worthwhile often on sites following historical peat harvesting. Investigation of the legislation examining the ban on the use of peat appears not to prevent this practice.

It cannot be overemphasised that the ability to grow a plant is not a determinant of whether it is a commercial option, although growth alone may be sufficient to secure environmental targets.

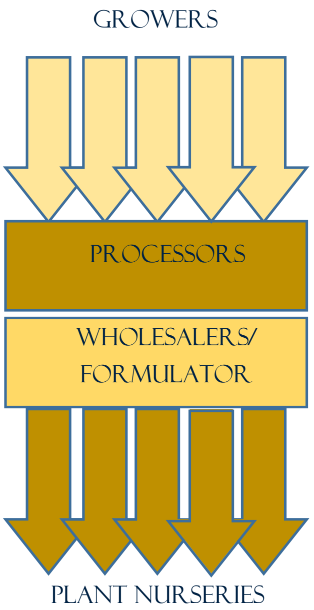
Market barriers to prevent oversupply and price falls can be as simple as the locality where transport cost is high or the association with a region is strong. A regional association may have value beyond the immediate area and may be reinforced by Protected Designation of Origin (PDO) status (e.g. stilton cheese) but this does not apply to recently developed paludiculture crops. Stronger barriers can be introduced via the development of processes and machinery particularly where the development can be patented.

There is the threat that “natural” sphagnum moss will be harvested. It is not at present clear whether any distinction will be made between sphagnum growing wild, sphagnum growing on restored peat or sphagnum established on arable land. It would seem at least possible that sphagnum production might be restricted to the third category and this might rule out some areas occupied by Vitagrass Farms (Holker) Ltd.

According to BeadaMoss, their process would allow the production of sphagnum on most soil types where suitable water supply was available. Thus there is the potential to oversupply leading to a price drop. While this does not differ from any other crop, BeadaMoss claims to have undertaken sufficient research to impose other important barriers.
BeadaMoss (strictly Micropropagation Services (EM) Limited) holds several patents[14] concerning the propagation of sphagnum moss. Although these do not prevent other parties from growing sphagnum, they do make it more difficult for other competitors to produce pure stands of sphagnum at scale at a low cost. BeadaMoss are also developing specialist seeding and harvesting machinery. These developments make it possible to manage the majority of the supply chain (Figure 2).

[14] https://patents.justia.com/assignee/micropropagation-services-e-m-limited

Figure 2: Supply Chain



In this illustration, BeadaMoss acts as the processor taking supply from several growers for supply to blenders of growing media. The growers benefit from BeadaMoss technology, expertise, lower marketing costs and are provided with an additional output to help manage risk. The wholesaler/formulator receives material in bulk of a known provenance in competition with other growing media. BeadaMoss controls supply and consequently price within a defined band determined by supply. To ensure supply BeadaMoss has to pay the grower a price that is competitive with that of any alternative crop.

BeadaMoss propose a fairly standard contracting arrangement to share risk and ensure collaboration (see also 2.10).

BeadaMoss intends to supply professional growers who require material in bulk and where any differences in output will be quantified and thus assessment of the value of sphagnum compared with other materials (in contrast to most amateur gardeners). Differences in professional grower output provide the price for the supply of sphagnum from BeadaMoss. No doubt if there were high-value amateur use some of the supply would leak to meet this requirement. However, by controlling supply the price is also defined (albeit since the elasticities are unknown and unknowable there is still no certainty of absolute price at any level of supply in such a changing market (see following statistics)).

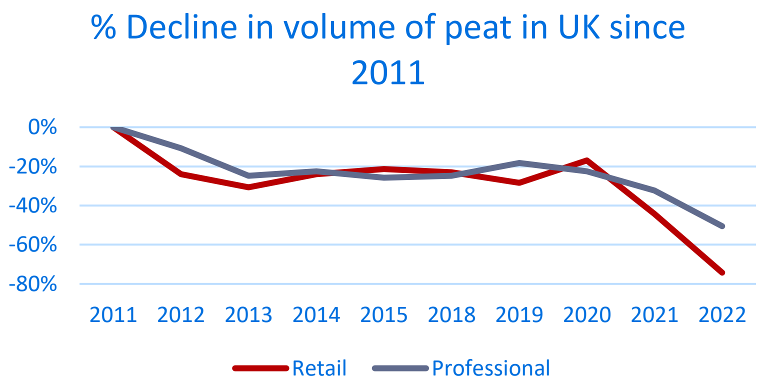
There is still a large risk to all parties and without government support, for what appears to be a leading process with significant export potential, the project may still fail. Grower uptake is high risk and for many growers the sphagnum replaces high-value crops (although not at Vitagrass Farms (Holker) Ltd).

There are other potential markets for sphagnum such as sanitary towels, bandages and other uses requiring highly absorbent materials these markets are currently met by other materials.

3.4. Market Statistics

As a result of the change in consumer preference and the threat of a legislative ban, sales of peat have declined[15].

Figure 3: Peat as a growing medium



[15]https://projectbluearchive.blob.core.windows.net/media/Default/Research%20Papers/Horticulture/CP%20203_Final%20report%202011-2022.pdfGrowing Media Monitor Report HTA/AHDB/GMA & DEFRA

Figure 3 shows that, as concern over peat use and threat of ban has increased, both retail and professional sectors have reduced peat use at an increasing rate. Indeed, the trend would suggest that the use of peat would disappear entirely within the next few years even without legislative change. This is improbable since for a few uses the substitutes are unlikely to be as effective and the decline is expected to slow. Against this, the technology within the growing media production sector is also improving.

While the decline in peat use is dramatic, the volume consumed in 2022 is still substantial at 950,000 m^3. The entire market is much bigger and growing at around 4 million m^3 (including peat). However, many of the substitutes are relatively low cost and there is a complex trade-off between quality and price making the extent of the substitution difficult to assess.

There is no consistent conversion between m^3 and weight since it depends on packing and moisture content. BeadaMoss claims to produce more than 3,000m^3 per ha per year. This suggests an area of only a little over 300ha (950,000m^3 divided by 3,000m^3/ha) to replace the remaining peat used as growing media. This is about the same area as estimated by the University of East London. Where the peat substitutes are also replaced, the area required is 1,200ha. This is a small area for a crop that can be produced at the scale needed to lower cost sufficiently to compete with the other substitutes. To put into perspective it is well below the UK area of even minor field crops such as linseed (20,682 ha) or about the same area as raspberries (1,312 ha). Raspberries require a large labour input which would not be the case for sphagnum.

This estimate is sensitive to assumptions. Other substitutes based on wastes may be developed as the pressure for change increases and as importantly expertise is developed in using the alternatives that have been introduced. Many of the nursery plants grown on peat are valued for their aesthetic properties and thus prone to change as fashion changes and may be price sensitive. Conversely, it is likely that for some uses, sphagnum would be a better medium than other substitutes and attract a price premium.

Ultimately, the control of supply will determine both the size of the market and the price of the product.

At this point of rapid change and given the sensitivity of price to supply, it would be expected that the budgeted price for sphagnum should match that of a premium substitute. The price is likely initially to be higher since supply will be particularly tight but fall as the market develops. There is also a likelihood that there will initially be the opportunity to supply niche markets.

The risk is illustrated by the rapid change in peat use since 2020. The small change before that date suggested a more positive view of sphagnum use than post 2020.

3.5. Pricing

Pricing is dependent not just on the cost of supply but also on the value to the buyer. Despite differences in the cost of materials the prices of different materials tend to be similar and the price variation appears to relate to logistics and purpose. Bulk discounts tend to be large, for example, Evergreen Moss Peat retails at £20/bale for a single 100l bale but £15.28 for purchases over 280 bales or the equivalent of £200/m^3. Coir can be purchased in bulk in the UK at £130/m^3 albeit in the country of origin the cost is as little as £2.00/m^3. There is a suggestion that pricing is based on the cost of any replacement rather than the cost of the material.

Products tend to be blended to meet particular market requirements, baled and branded.

Sphagnum moss products such as those supplied by Evergreen (‘Moss Peat’ 100% sphagnum moss) and LBS (‘LBS Potting and Bedding ‘LBS Low N Potting and Bedding’ with 70% sphagnum, and ‘LBS Nursery Stock Ericaceous’ with 80% sphagnum) tends to achieve a premium over other materials.

The sphagnum used in these products is likely to be collected from the surface of peat bogs. This is understandably contentious.

If Vitagrass Farms (Holker) Ltd were to grow, blend and bag, the output would be in the order of £1,700 to £2,500 per ha per year (i.e. before costs and other subsidies) and adopting traditional water table technology. As discussed in section 2.5 grants are largely irrelevant as far as paludiculture crop production is concerned but not to peat restoration.

This return is comparable with those that might be obtained from similar land but does not recognise the additional risk or damage to existing infrastructure (such as loss of field drains). If the project works as expected, the return should be sufficient to allow sphagnum farming. However, until there is widespread practical experience of sphagnum management and evidence of return, most landowners are likely to accept the subsidy income (for restoration) and not aim for the much higher risk from crop production. Government funding is likely to be necessary initially to provide sufficient commercial confidence to establish the enterprise (as it was, for example, to encourage the adoption of renewable energy production).

3.6. Threats and Competition

The recognition that peat is to be banned in horticultural use, and the reduction in consumer demand for peat composts, has stimulated the investigation and development of other materials. Many of the alternative materials are low-value wastes and, as an understanding of how to use these materials increases, the development of higher-cost materials such as sphagnum is likely to become less important. Other potential materials can still be developed, such as the waste from anaerobic digestion. While primarily providing mulch rather than growing media Apsley Farms is one amongst many anaerobic digestion operators selling increasing volumes of processed waste to meet similar objectives with the benefit of trial evidence[16]. In contrast, sphagnum production is relatively expensive to produce (albeit a better product).

As the precursor to peat, the harvest of sphagnum reduces the rate of peat formation. It also becomes difficult to distinguish the harvesting of peat from natural sources from farmed sources particularly where material is imported from neighbouring areas such as Ireland. Consumer choice could move against the use of sphagnum as it has done from the use of peat. The difficulty of preserving peat while allowing sphagnum to be harvested threatens additional legislation that would make sphagnum harvesting more difficult, particularly where planted on restored land.

Existing producers of peat (particularly in the UK and Ireland) will not only look for new income streams if peat sales are no longer possible but would be able to use some of the same machinery to harvest sphagnum produced on worked peat sites[17]. These producers would already have appropriate supply chain relationships to market this material. In some areas, such as Canada, the land value is also low allowing a longer, and thus cheaper period, for the moss to develop. At best these low-cost producers, largely making use of historic capital, would be able to undercut new producers and at worst could lead to oversupply and a collapse in price followed by price volatility.

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[16] https://mulch.apsleyfarms.com/apsley-mulch-independent-growth-trail/

[17] https://www.youtube.com/watch?v=6sVJ3oaNEQk and https://www.youtube.com/watch?v=MnY553THUR0

While there is no indication that this will be the case, it would seem reasonable that commercial production of sphagnum moss should only be permitted in designated areas that could not easily be restored to peat. This would prevent the harvest of areas already in the process of restoration and allow these areas to increase carbon stocks, and not just maintain carbon levels.

3.7. Environmental Issues

While ultimately wetting organic land (fen and peat) as proposed reduces greenhouse gas emissions the variation is large[18] and the initial impact can be a release of methane contributing to global warming[19]. While sphagnum supports methogones[20] in the anaerobic area which oxidises methane to carbon dioxide, reducing the impact, there can still be an initial release of greenhouse gas. Time scale becomes a factor in terms of impact assessment.

While sphagnum appears as least as effective as preserving peat as other paludiculture crops, the harvest of sphagnum harvesting reduces the potential for long-term accumulation compared to restoration projects. In contrast to even the production of trees, sphagnum has the potential to maintain and extend carbon capture for a very long time. Where peat is replaced as a growing medium by sphagnum (or any other non-fossil substitute) there is a further saving in greenhouse gas emissions from the peat preservation. However, in contrast to most other substitutes, if the peat had not been harvested the carbon would continue to accumulate (potentially restoring bog where grown on denuded sites).

The cost and difficulty of assessing greenhouse gas emissions of methane and nitrous oxide means that there is unlikely to be any certainty on the benefit of a system that harvests most of the additional dry matter produced and creates an environment of wetting and drying for some time. The peat grows slowly so for a lot of the time ground cover is likely to be incomplete. It is, however, likely that existing carbon levels will be maintained more effectively than under conventional arable production and far more effectively than where fossil peat is consumed. There is some evidence that under a system that does not wet the land to the surface methane emissions are lower.

Given the environmental sensitivity of peatland and the proximity of the neighbouring SSSI, there may be a concern that genetically distinct strains will be brought into the area despite being of the same species. These will have the potential to spread into neighbouring areas either vegetatively or via the spread of spores. While legally unnecessary there may be an argument for maintaining a buffer from the SSSI to prevent genetic contamination. This might be funded via the Sustainable Farming Incentive (see section 3.8.2). If not for the presence of the SSSI this would not be considered even as a remote concern – and probably is not even with the proximity. However, there is no genetic typing available for the widely distributed species.

3.8. Sphagnum Cultivation

It is relatively straightforward to create the appropriate conditions to establish and eventually achieve full ground cover of sphagnum. For commercial production, it is essential to minimise risk and optimise growth.

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[18] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5513236/ Emissions of methane from northern peatlands: a review of management impacts and implications for future management options. Abdalla et al and https://environmentalevidencejournal.biomedcentral.com/articles/10.1186/2047-2382-3-5 Evaluating effects of land management on greenhouse gas fluxes and carbon balances in boreo-temperate lowland peatland systems Haddaway et al

[19] https://onlinelibrary.wiley.com/doi/10.1111/gcb.12580 A synthesis of methane emissions from 71 northern, temperate, and subtropical wetlands Merritt R. Turetsk et al.

[20] https://amb-express.springeropen.com/articles/10.1186/s13568-020-00994-9 Microbial nitrogen fixation and methane oxidation are strongly enhanced by light in Sphagnum mosses Martine Kox et al.

Several sources have been used in the following assessment but the principal source is provided in the footnote[21]. The evidence suggests that sphagnum growth is primarily determined by water availability with temperature also influencing the growth of specific species.

While the Canadian industry is primarily concerned with peat harvesting (it is described as mining in the same way as the extraction of coal), the re-establishment of sphagnum moss in harvested areas is now considered to be part of the process by many operators. The videos[22] describe the harvesting and sphagnum reestablishment process managed at a commercial scale. It is highly likely that if, as expected, harvesting of peat is banned the replanted sphagnum areas will be used to supply sphagnum. While the cost of transporting a low-density product is high, low-cost production is likely to make a larger cost saving. Mining of peat has reduced carbon reserves but once depleted the production of sphagnum will conserve any remaining material although in common with other sphagnum farming will not restore peat.

Machinery use is discussed under the relevant operation. While conventional, modified or specialist machinery for harvesting can be used, this depends on the ability to travel on the land (control of water levels) and a relatively flat surface (as would be the case for land previously in arable production). The specialist nature of the machinery makes it unlikely that there would be available contractors in the area and purchase uneconomic unless the scale was over say 80ha (i.e. corresponding to the area justifying a potato harvester). Realistically, machinery is likely to be developed on behalf of all growers and operated on a shared basis.

While the 'Moors for the Future Partnership' is concerned with restoration it has produced a considerable body of replicated trial evidence. Similarly, papers from the review Mires and Peat are also valuable.

3.8.1. Site Preparation

To grow sphagnum moss it is essential to have a manageable water supply. Water may be applied via raising the water table or via overhead irrigation. In all likelihood, both will be needed. Flooding, and thus levees, is unlikely to be necessary although they were a feature of the Greifswald experimental site. At Greifswald, a long-reach excavator was used for harvest. This had a particularly slow work rate and required the construction of tracks for vehicle movement. Commercially this does not appear to be a long-term option.

Sphagnum is a bog plant. In the natural environment, it is rain-fed and thus receives slightly acidic water with a low nutrient status. The subsurface in peat bogs is sometimes significantly more acidic. The sensitivity to pH and nutrients varies with species. Water with a high pH, for example from a groundwater source running through a calcium-rich soil, is unsuitable. Where this water is used for irrigation the addition of an acidifier is an additional management input. Storage of rainwater harvested over winter months when there is a surplus provides another option to meet water demand.

[21] https://pure.rug.nl/ws/portalfiles/portal/71535635/map_20_13.pdf Sphagnum farming from species selection to the production of growing media: A review. Mires and Peat, 20, Article 13.Gaudig, G., Krebs, M., Prager, A., Wichmann, S., Barney, M., Caporn, S. J. M., Emmel, M., Fritz, C., Graf, M., Grobe, A., Pacheco, S. G., Hogue-Hugron, S.., Holztraeger, S., Irrgang, S., Kamarainen, A., Karofeld, E., Koch, G., Koebbing, J. F., Kumar, S, Joosten, H. (2017). https://doi.org/10.19189/MaP.2018.OMB.340

[22] https://www.youtube.com/watch?v=6sVJ3oaNEQk and https://www.youtube.com/watch?v=U1XCtqvC8uE

BeadaMoss promote the use of arable land and overhead irrigation without raising the water table although they also report that the water table is raised as a consequence of the moss and irrigation. This implies that sphagnum can be grown as a conventional crop and on many soil types including those with field drainage systems intact. While still requiring infrastructure and irrigation water it is a much simpler and for many growers it is a cheaper process without the threat to drainage infrastructure.

Irrigation is not available to Vitagrass Farms (Holker) Limited so this method is not available. The cost of infrastructure for irrigation might be as high as for raising the water table although the damage to existing drainage infrastructure is reduced. In dryer areas, it also puts pressure on water resources.

Given the arable history of the proposed site, it is vital to test soil and water for nutrients and pH and remedy if nutrients or pH are high. The neighbouring sphagnum suggests that the site is suitable and it is only recent management that may require correction. There is a possibility that the destruction of existing plant matter in preparation for planting will lead to a flush of nitrates that may be particularly damaging to moss establishment.

BeadaMoss has argued that for cultivation, suitable conditions can be created in areas that do not have a history of sphagnum. Surface vegetation needs to be removed and competition with other plants minimised. Grassland would at least need to be inverted.

Given that much of the work on sphagnum is for restoration it is important to adjust findings to take into account the differing objectives between restoration and commercial production as described in 2.1.

Cost varies enormously with the site and the work needed. As a capital, the cost should be written off over the anticipated production life which would hopefully include at least three harvests. The long write-off period increases risk and would mean a higher discount rate would need to be applied to the future income stream.

3.8.2. Water

Maintenance of a high water table is repeated throughout the literature both to maximise establishment and optimise growth. Plant fragments are sensitive to water (and being washed away). Water for plant growth is only appropriate where rapid cover and yield are viewed to be important. There is variation in the optimum level quoted between sources. 5cm to 10cm below the surface is typical although some sources suggest 2cm for optimum growth.

The importance of the water table level is likely to vary with the amount of water applied from above (e.g. rainfall or irrigation). Established sphagnum stores water in the plant tissue and this buffers the other sources so soil moisture becomes less critical.

Germany's work at Rastede[23] reports the use of 160mm of water per unit area (i.e. 1,600m^3 per ha) in an area with rainfall of 849mm. The rainfall at Holker is higher than the combined irrigation plus rainfall at this site. However, while the average may be more than adequate this does not mean that rainfall is adequate all the time. There is still a risk of water availability at critical times such as establishment.

[23] https://pure.rug.nl/ws/portalfiles/portal/71535635/map_20_13.pdf Sphagnum farming from species selection to the production of growing media: A review. Gaudig, G., Krebs, M., Prager, A., Wichmann, S., Barney, M., Caporn, S. J. M., Emmel, M., Fritz, C., Graf, M., Gro

The high rainfall should be sufficient to dilute high nutrient content in the groundwater in the medium term. However, if neighbouring fields are to remain in arable cropping, the establishment of buffer zones on these fields to prevent any risk of drift or seepage into the watercourse would be sensible precautions at least until experience is gained. The reduction in leakage increases rapidly with increasing buffer strip width. We do not have data on the current nutrient level in the watercourse let alone specific leakage. However, a 6m margin funded through Defra's Sustainable Farming Incentive at £515/ha (on widths from 4m to 12m) is likely to be sufficient and unlikely to hurt the farming return where costs can be reduced proportionately (although this should be assessed for the specific situation).

3.8.3. Material for planting

In common with other bryophytes, sphagnum has two distinct generations of plants and two distinct methods of multiplication via spores and fragmentation.

Spores

Theoretically, spores are the favoured method of propagation because there is little risk of contamination with other plants and there is a high volume of spores released (a single capsule may contain over 200,000 spores although this is species-dependent). As described in the authoritative reference book Bryophyte Ecology by Janice M Glime[24] spores will germinate given moisture, sunlight and nutrients particularly phosphate to form a short thread. There is variability between, and within, species. Spore survival varies with depth, the colour of the spore (for some species), whether the soil was aerobic or anaerobic and whether the spore was refrigerated. The establishment from spores is erratic.

There is a chance that if appropriate conditions are created spore release from neighbouring sphagnum will populate the site. This is not, however, sufficiently reliable for commercial cultivation.
Cultivation from spores has been achieved with a 30-fold increase in dry weight reported in four weeks[25].

Vegetative production

Sphagnum spreads from pieces of stem. While water at planting is important, it is less important than it is for the spores. In addition to reducing the percentage of plants established, too much water can wash away fragments into hollows reducing the population consistency.

The process starts with a donor site. This may be any site with a population of the appropriate species and for reclamation would usually be taken from a neighbouring site with similar sphagnum species and genetic provenance. This material may be used directly or following multiplication.

The donor sphagnum moss will regenerate after cutting providing the whole plant is not removed. Establishment from neighbouring populations is the most satisfactory method of establishing sphagnum for restoration because the species selection is appropriate and contamination with other species may enhance the formation of the target habitat. This is not suitable where the objective is just the sphagnum component.

[24] https://digitalcommons.mtu.edu/oabooks/4/

[25] Rudolph, H., Kirchhoff, M. & Gliesmann, S. (1988) Sphagnum culture techniques. In: Glime, J.M. (ed.) Methods in Bryology – Proceedings of the Bryological Methods Workshop, Mainz, Hattori Botanical Laboratory, Japan, 29–34.

In Canada, this method is employed on a very large scale to restore vegetation following peat harvest. Sphagnum moss is scraped from the top 25 cm surface of virgin peat areas with a mechanical digger when the ground is frozen. The collected material is transferred to a muck spreader to spread across the denuded harvested peat before the thaw. Straw is spread on the top to provide some frost protection and a little fertiliser (largely phosphate) is applied. Drains are blocked (created to assist with the peat harvest) and the water table is raised. The donor site and reclaimed site are considered fully recovered in 15 years although the species mix is restored within two years. The period taken to achieve full cover is not a concern where the objective is regeneration.

In Europe, collection may be by digger attachment, raking or cutting from sites that can be easily accessed. The maximum depth of sphagnum harvest for reestablishment is considered to be 10cm. The availability of suitable sites may limit this method and multiplication (planting and re-harvesting after a period of growth) may become an additional step. The method also allows undesirable species to be removed.

Multiplication has been achieved from sphagnum fragments:

- On a suitable field site. The multiplication achieved depends on the area, planting density and the period from planting until harvest. The period until harvest varies but should be under five years if conditions are suitable.
- In a glass house using horticultural fleece and irrigation. Multiplication rates are reported to be 10 times faster and weed contamination lower.
- Submerged. Contaminants (algae, fungi, bacteria) resulted in a growth rate no faster than where peat blocks were used.

In the UK BeadaMoss is the main, if not only, source of commercially available propagule material. The plants are multiplied in a controlled environment and the sphagnum is pure and thus free from other competitive plants. The species of moss can also be selected for multiplication for any delivery system. Products are:

- Beads: (‘BeadaMoss’). Clay-encased propagules. These are no longer available.
- Gel: (‘Beadagel’). Longer strands are held in a gel. The gel provides some protection from desiccation and BeadaMoss reports that they have developed machinery for mechanised planting. It is the standard BeadaMoss product where the objective is commercial cultivation.
- Clumps (Not a BeadaMoss product): These are handfuls of stems harvested from existing sites. BeadaMoss do not harvest from the wild although presumably wild harvesting provided source material. Trials[26] with sphagnum palustre showed that the donor areas recovered within 5 years and potentially more quickly where managed and conditions are favourable (warm and wet). In these trials, large (> 5 mm) vegetative fragments initially produced more biomass, than smaller fragments (1-3 mm) and more capitula[27]. The need for a high water table is again emphasised. A low mulch was found to be more effective than no mulch or high mulch.
- Plugs (‘BeadHumok’): These are plugs containing 15-20 species that can be tailored for the site (they can contain up to 30 species). The product is aimed at restoration projects presumably because plants are likely to be planted by hand (although plug planting machinery is available for other crops) and at a low density. The cost per plant is relatively high so optimum plant density, and consequently cover, is low. BeadaMoss expects the moss to grow to eight times its original size within 18 months.

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[26] https://www.moorsforthefuture.org.uk/__data/assets/pdf_file/0026/96317/2019-NE-Sphagnum-Donor-Site-Monitoring-Pilot-Study-Report.pdf Harvesting Sphagnum from donor sites: pilot study report. Benson, J. L., Crouch, T., Chandler, D. & Walker, J. (2019) Moors for the Future Partnership, Edale.

[27] http://mires-and-peat.net/media/map13/map_13_08.pdf

BeadaMoss has found that their products produced via micropropagation, from the species tested, grow more rapidly and achieve ground cover more quickly than wild-sourced material or material multiplied from wild-sourced material. For restoration, Moors for the Future found that plugs and clumps were the most successful means of establishment trialled. This appears to be because the planting can be carried out by hand into unprepared (uneven) land in the presence of other bog species. While the objective is to achieve good ground cover there is no attempt to maximise output as there would be if the objective were cultivation.

Their replicated trial work shows a less clear picture. The cover achieved from plugs and clumps was much higher than from beads or gel. However, the cost per percentage cover was lowest for gel and clumps. It appears that the larger biomass of clumps and plugs is more robust in an uncultivated site. There is a suggestion that the gel may have washed outside the sampled area (plants were found outside the planted area but it was not certain where these originated). In a managed site the considerably low cost of gel would allow a higher seeding rate, and higher percentage establishment, narrowing the difference in cover achieved.

Difference between species was found and the agronomic environment was not managed as it would be for production. Differences between species suggest that some may not be equally as suited to production or the intended use. This is not considered in the research although there is some work suggesting that mixed species may be more robust.

3.8.4. Planting method

Planting usually takes place in March after the risk of prolonged frost has gone.

Most Sphagnum is planted by hand by volunteers and since the planting only occurs once for restoration, the cost is less significant than for cultivation where planting is repeated. Speed, and thus cost is unlikely to be optimised. Hand planting of natural areas also allows targeting of plants in hollows where they are more likely to survive. Any of the seeding materials may be planted by hand.

With only modest adjustments, the sphagnum plugs could be planted using a plug planter as used for other crops such as lettuce. This would still be relatively expensive because of the cost of the plug (commercial producers of plant plugs can lower the cost to well below 50p per plant where produced at scale. However current cost includes the multiplication of plant material and is between 50p and £1 per plug).

Commercial planting in Canada for restoration, using material harvested from mature areas of sphagnum makes use of muck-spreaders. The now discontinued beads could have been broadcast by fertiliser spinner or even helicopter. In trials, the gel was spread via a syringe in part to ensure that it was placed directly on the ground and not left suspended on other residual vegetation. BeadaMoss has developed a planter (drill) to allow the gel to be applied at commercial speeds. Gel seeders have been available for over 40 years[28].

3.8.5. Straw mulch

European and Canadian work supports the use of straw mulch. The thickness should be no more than 3cm (3t/ha). The mulch is argued to provide benefits both from reducing water loss and temperature reduction.

[28] https://www.jstor.org/stable/23432647 Effect of Planting Equipment and Techniques on Seed Germination and Emergence: Review Michael Orzolek, Donald Daum

3.8.6. Fertiliser

A fertiliser is unlikely to be essential. However, at least two sources suggest that the addition of a little phosphate may be beneficial. There is some evidence to suggest that the addition of phosphorus may counter high nitrogen levels[29][30].

While nutrient demands are low, if the harvest of sphagnum is to be sustainable, nutrients will need to be replaced. In Canada, restoration often includes the addition of phosphorus. Phosphate in the water from the application of phosphate fertiliser is unlikely to present a problem (although the higher concentrations in livestock manures and greater run-off might pose a threat). Nitrates in the water from artificial fertiliser or manures might damage the sphagnum although uptakes of 35-56 kg/ha by vigorous sphagnum moss with full ground cover have been estimated. Small plants may be more sensitive.

3.8.7. Weed control

The site should be clear of weeds at planting. This can most effectively be achieved with the application of glyphosate. Asulox has also been used for rhododendron control.

Once established, regular mowing with low-ground pressure machinery, and removal of cut material, is likely to be necessary to remove competitive vegetation. Hand weeding may also be necessary during the establishment period. Most of the research is primarily concerned with restoration and consequently, weed control is less important since diversity is the objective. Herbicide use is not considered in the research papers although it is likely that materials would be available for selective control. For herbicide use see 2.4.3.

3.8.8. Fungal Disease

Sphagnum moss can suffer from fungal attacks. Myclobutanil (a triazole fungicide sold as Systhane and under many other product names) and the antagonist Trichoderma virens (a beneficial soil-dwelling saprophyte effective against some plant fungal diseases) have been used in the glasshouse. Systhane is approved for use in soft and top fruit production and has been used in Canada successfully on sphagnum moss. However, it is being withdrawn after the end of this year.

Other triazole fungicides are likely to be effective although there is no approval for use (see 2.4.3).

3.8.9. Pests

Animals and birds damage sphagnum largely as a result of the nitrogen content of their droppings. Birds are unlikely to be in sufficiently high numbers to cause damage although there have been occasions for other crops when control of birds has been necessary. For example, Brent geese can cause considerable damage in some areas of the country and as a protected species cannot be easily removed. Grazing animals can pose a threat although grant funding for fencing is available under the environmental schemes. The scale of fencing will depend on the threat.

Bird-scarers may assist with repelling birds although this might be inappropriate given the proximity to the SSSI.

[29] https://www.sciencedirect.com/science/article/pii/S2351989421003413#:~:text=Phosphorus%20application%20can%20alleviate%20the,of%20Sphagnum%20to%20nitrogen%20deposition.

Sphagnum response to nitrogen deposition and nitrogen critical load: A meta-analysis Yinying Zhoua, Yuxin Huanga, Xiaoxue Penga, Junfeng Xua, Yuekai Huc

[30] https://peatlands.org/document/sphagnum-propagules-from-spores-first-experiences/

3.9. Yield and harvesting

The available data shows variable yields of sphagnum with most variation related to water table, variety, period of growth and management. Very little of the work by BeadaMoss for sphagnum cultivation (in contrast to restoration) using above-ground irrigation is published despite being strongly promoted. Where very high yields are quoted this is usually based on the period from when full ground cover is achieved at least three years after planting.

A further complication is the depth of harvesting. Some investigators anticipate recovery post-harvest while others (such as BeadaMoss) expect to replant. Where recovery is expected the recovery period can be seven or more years. Regrowth appears to depend on the depth of moss harvested and once again on the height of the water table (a water table of 4cm below the harvested surface was present in the trials quoted below).

In the paper 'Paludiculture on former bog grassland: Profitability of Sphagnum farming in North West Germany'[31] the first harvest is assumed to be at the end of the fifth year and every five years subsequently. Yields are estimated to be the same for each harvest. Yields quoted are an average harvested dry mass yield of 16t per ha (range 10t- 22t), i.e. 3.2t per ha per year (range 2.0-4.4t/ha/year). The costings presented assume the same yield at the remaining five-year intervals. In another paper, Gaudig proposes 'a conservative yield of 65m^3 of Sphagnum biomass per ha per year (corresponding to 2t dry biomass per ha per year)' Canadian yields are no more than two-thirds of these while Chinese yields are reported to be higher.

BeadaMoss claims to produce more than 3,000 m^3 per ha of sphagnum in three years suggesting 1,000 m^3/year. There is no consistent conversion between m^3 and weight since it depends on density and moisture content. However, even using a relatively conservative conversion of 1m^3 = 0.02 tonnes dry matter, (S Wichmann et al propose a range of 0.038 to 0.02 tonnes dry matter per m^3) a dry matter yield of 60t/ha at harvest and 20t/ha per year is suggested. This is similar to a conventionally managed cereal crop but significantly higher than achieved in the cultivation trials at Greifswald in Northwest Germany. The use of micropropagation and more precise husbandry makes this a possibility. Yield is also likely to vary with planting density and percentage establishment.

Precision cultivation is not a possibility for Vitagrass Farms (Holker) Limited where overhead irrigation is not available. Most work is undertaken for restoration purposes and consequently 1) conditions are not optimised 2) ground cover is more important than yield 3) plant establishment density and time taken to full cover are less important given that the cover is expected to be permanent.

It is reported that the natural productivity of Sphagnum varies between species. Global average dry biomass production is 2.6t/ha/year, while the maximum measured value is 14.5t/ha/year. Various sources report average varietal yields recorded.

Table 5: Average varietal yields

Species	Yield t/ha/year
Sphagnum falcatulum	7.70
Sphagnum subnitens	5.90
Sphagnum fuscum	8.00
Sphagnum magellanicum	7.90
Sphagnum rubellum	9.60
Sphagnum palustre	5.75

[31] https://www.researchgate.net/publication/339788614_Paludiculture_on_former_bog_grassland_Profitability_of_Sphagnum_farming_in_North_West_Germany Paludiculture on former bog grassland: Profitability of Sphagnum farming in North West Germany S. Wichmann, M. Krebs, S. Kumar2, G. Gaudig

The Moors for the Future data[32] shows differences in growth between species. For restoration choice of appropriate species for the situation is more important than the rate of growth.

Table 6: Varietal yields

Sphagnum species	Growth over 16 months*
S. capillifolium	X 7
S. cuspidatum	X 14
S. denticulatum	X 6
S. fallax	X 9
S. fimbriatum	X 7
S. medium	X 7
S. palustre	X 8
S. papillosum	X 8
S. squarrosum	X 7
S. subnitens	X 7
S. tenellum	X 6

*nearest whole number

The range of yields experienced, the divergence in harvest interval and even whether replanting is necessary, demonstrate how risky crop production still is. For cultivation, the first selection is the higher-yielding varieties.
Expert opinion even varies on harvesting methods. German trials are based on using an excavator with a long reach arm and bucket. This is painfully slow, and not suited to commercial harvesting, although it does allow harvesting where sites cannot be dried out, or freeze (as it does in Finland) to allow machinery to run across the surface. Depth control must also be demanding and drying of sphagnum after harvest is more difficult than where the material can be severed and left on the surface for a period.

In Canada, to harvest peat, the surface is rotavated or tined to loosen to the required depth and material is collected with a vacuum harvester. This machinery is not currently available in the UK although common elsewhere and could be imported if scale were achieved. The cost is a fraction of that achieved in Europe. While this is intended for restoration and there is no intention to harvest, there is no barrier to harvest if it becomes economically attractive. It would be expected to meet the objective of preservation of peat although not of restoration (much as BeadaMoss promote for their cultivation product).

As discussed BeadaMoss grow sphagnum much more like a conventional crop using irrigation.

Where the land is suited to cultivation, as at Holker, it should be possible to use a more conventional harvester, albeit modified to collect sphagnum, developed from machinery used to harvest turf, lift onions or separate stone/clod in preparation for planting root crops. The sphagnum crop may need to be turned after separation from the ground and broken up, before collection to reduce moisture content and lower drying cost. It is unlikely that suitable machinery would be available to Vitagrass Farms (Holker) Ltd given the local crop types. This lack of basic machinery also pushes towards a joint venture with BeadaMoss or other producers in the area.

[32] https://www.moorsforthefuture.org.uk/__data/assets/pdf_file/0022/387031/D1-single-species-Sphagnum-report-final.pdf Monitoring single-species Sphagnum plug growth on blanket bog Benson, J. L., Crouch, T. & Chandler, D. (2021) . Moors for the Future Partnership report

Where drying is not possible in the field (the material does not need to be completely dry where it is to be blended for potting compost) a conventional ventilated floor drier should be suitable as used for grain or even hay drying. The need for drying at a different time of year from grain or grass drying might allow the use of an existing facility (if it exists).

3.10. Costings

The cost of growing sphagnum is exceptionally variable depending particularly on the site, scale and infrastructure needed. In practice power units, irrigation water and distribution mains are likely to be available already and can be operated at marginal cost. Specialist machinery would expect to be shared between growers even if the power units were supplied by the farm business. None of the published costings are entirely satisfactory and are largely produced for small-scale operations or to implement systems that may not be considered suitable for more recent technologies (such as those proposed by BeadaMoss).

The return is even more uncertain given the scale of production that might be possible and the large reduction in peat use since 2020. There are also indications that the price of at least some of the substitutes is set by the cost of using other more expensive materials.

The costings below are as provided by ‘Paludiculture on former bog grassland: Profitability of Sphagnum farming in North West Germany’.

The most appropriate means of assessing an investment is via calculation of the Internal Rate of Return (IRR). This shows the expected return on an investment thereby allowing comparison with other investments.
The data used to compile the calculation is taken directly from the paper and is summarised below. The paper includes two scenarios based on actual data and a scenario based on an estimate of future costs. For this costing, we have looked at the ‘medium cost’ scenario. The costs were specific to the site, scale and prevailing conditions but provide a relatively rigorous starting point. The paper was published in 2021 and the Euro values have been converted to Sterling using an exchange rate of €1=£0.8547. The IRR is not influenced by the exchange rate.

Table 7: Cost analysis

Establishment cost			
Item	**Description**	**Scenario 1**	**Scenario 2**
Site preparation		€36,287/ha	£31,015/ha
Investment in water management		€22,334/ha	£19,089/ha
Sphagnum shoots		€34,779/ha	£29,726/ha
Seeding		€5,046/ha	£4,313/ha
Annual management costs			
Water management	Cleaning of irrigation channels	€2,330/ha	£1,991/ha
Site maintenance	Weed control - mowing 6-8 times a year Mulching of causeways 4-6 times a year	€6,336/ha	£5,415/ha
Harvesting and processing costs			
Harvesting	94 hours per ha for machine operators 50 hours per ha for harvesting and loading 12 hours per ha field transport Processing cost	€5,880/ha (Mowing) €6,722/ha (field transport)	£5,026/ha £5,745/ha
Loading		€0.35/m³	
Road Transport		€0.32/m³	
Cleaning		€3.24/m³	

Screening		€0.64/m^3	
Output			
Production	24 t/ha (15-34 t/ha)		
Yield	16 t/ha (10-22 t/ha) 35% of above		
Density	20 or 38 g/l		
Price	€25/m^3 (£21/m^3)		

While Wichmann et al use the incurred management costs for the first five years in their estimates of profitability, in the table above the average over the period per year is shown (the difference is small but it removes spurious fluctuation brought about by seasonal influences).

Saddled with these costs the project is unviable and the production loses approximately £11,000/ha per year and gives rise to a strongly negative return on investment. There is a loss even at the above-average production level achieved in the highest-yielding plots in the project. The loss takes no account of the opportunity cost for the land which is likely to be in the order of £700/ha where previously cropped.

A price increase for the output is possible and the project claims that “a breakeven price of around €100/m^3 seems achievable”. This price still results in a loss (even if the infrastructure costs are considered to retain their value). The paper suggests a price of €165/m^3 is needed to allow some scenarios to break even and a price of €750/m^3 for all the reported scenarios to make a profit.

While there are niche sphagnum products with a high price, and the ban on peat will provide upward price pressure, it appears extremely unlikely that a high price could be sustained (other than perhaps during a transition period while commercial production is being established and is still to come on stream). Consumers valuing the crop more highly are unlikely to pay a premium over other consumers for the same product.

Care-Peat[33] provides a different basis for the costings although their costings include very long-term discount periods for the investment (50 years) and a low discount rate. Neither of these assumptions would be acceptable to a commercial operator. The costings help to demonstrate the potential value of flooding peatland but not the productive use of peatland other than via (inappropriate) cross-subsidisation. The Care-Peat costs do not differ significantly from those quoted above: £74,700/ha set up costs for their pilot study and estimated costs of £15,000/ha “typical” and £6,000/ha “low”. The costs quoted for the pilot are for a 2 ha site but are shown below per hectare.

Table 8: Care-Peat cost analysis

	£/ha
Ground preparation capital works (topsoil removal, 2ha Sphagnum beds, irrigation ditch system, 1 ha water retention area/sump).	17,800
Supply & installation of low-energy solar pumps used for the irrigation system (solar pump for a carbon farm, a float control system, a remote telemetry option, solar panels)	4,650
Provision of Beadahumok™ moss plug plants (budgeted figure)	41,250
Contractor planting of the Sphagnum plugs (75,000/ha)	11,000
	£74,700

[33] https://vb.nweurope.eu/media/21534/care-peat_main_output_model_carbon_farm_wpt2.pdf Validating the bespoke model for the social and economic impact of Carbon farming and developing a theoretical model for the impact of Paludiculture Care-Peat: Niall Ó Brolcháin • University of Galway Christopher Field • Manchester Metropolitan University Konstantinos Tzoulas • Manchester Metropolitan University Sarah Johnson • Lancashire Wildlife Trust Jo Kennedy • Lancashire Wildlife Trust.

These costings can also be criticised, as Care-Peat suggests, by providing “typical” and “low” costs although there is no breakdown of the revised figures. BeadaMoss would no doubt expect to use their low-cost Beadagel product and argue against the need for so much expense in land preparation. Nonetheless, the two actual establishment costs, as distinct from theoretical data, at least suggest that the costs could be very high.

As a combination of the high yields reported by BeadaMoss and the lower establishment costs claimed, a significantly higher IRR of potentially over 20% is possible making production feasible for an entrepreneur. Since the technology needed to achieve the higher yields is held by BeadaMoss, the return to the grower needs only to be comparable with other crops with the margin retained by BeadaMoss.

The overhead irrigation, as proposed by BeadaMoss, would allow the dual opportunity to retain peatland and crop. There are other income streams such as the CS scheme and potentially carbon credits but these would be received irrespective of whether sphagnum moss were grown (see 2.5).

The system described is specific to the trial site where the set-up costs were particularly high and inefficient planting and harvesting systems were adopted. To some extent, the high cost is a consequence of a small site. As we have proposed using a plug planter and modified onion harvester (or similar) allows a much lower cost of production providing soil type, water level management and adoption of techniques (tracks and tyres) to lower ground pressure allowing mechanised operation from within the growing area. It is possible where peat is harvested.
In the 2017 report ‘A feasibility study on the usage of cattail (Typha spp.) for the production of insulation materials and bio-adhesives’, Colbers et al compares the profitability of T. latifolia with Sphagnum production building on work by Riet et al in 2014. This report suggests a higher profit is achievable than T. latifolia and much higher than reported at €2,625/ha/year. There is a significantly lower initial investment for the project but the outcome is still a modest 8% IRR which is slightly higher than we have estimated.

The scale of the growing operation makes a large difference in cost. Where scale is increased the structural cost is reduced and more of the tasks can be mechanised. The cost of processing is also likely to require a different scale of operation although this will depend on national and international volumes available.

Costs are particularly high in the research projects and may be capable of reduction where:

1. The water table can be controlled so that land can be dried for key operations such as planting and harvesting as would be possible under an irrigation system.
2. Crop production is restricted to land with a stable subsoil that can withstand tractor movement. Since the land at Vitagrass Farms (Holker) Ltd has been used historically for arable cropping this should be possible.
3. Grown on land that is already level and does not require levelling (such as ex-arable land).
4. Produced on sites where irrigation is available to reduce risk and optimise production.
5. Weed-free planting material is sown and the land has a low weed burden reducing weed competition (this is not appropriate where the objective is restoration) and the need for multiple cutting throughout the year to control weeds.
6. Sphagnum is planted mechanically. Both plant blocks and gel can be mechanically planted on suitable sites. Under good management, the gel planting should be cheaper. The Moors for the Future report (Kinder Scout Sphagnum Trials: 2018 Update Report, concerned with restoration not cultivation but focussed on establishment which is common to both objectives) provides a price per m^2 ranging from £1.04/m^2 for gel to £10.44/m^2 for plugs. The study above is based on a cost of about £4/m^2. The peat blocks in the Moors for the Future project are expensive compared with other plants supplied in peat blocks (£6.30 per m^2 or £0.70 per plug) and were hand planted (costing an extraordinary £4.14/m^2 or £0.46/plug). By way of comparison

planting trees (with the addition of guard) by hand is about £0.12/m^2 although planting density is less. Nonetheless, machine planting of large volumes of plugs (plants and planting) should be comfortably under £3.50/m^2. The high cost in the trial presumably reflects the legitimately higher price for the low volume and the experimental production of the plant material. Hand planting on a small trial site targeted at restoration rather than production is also appropriate. The trial showed a lower establishment of the gel plants but this is likely to be a feature of the management in a restoration site.

7. The period from establishment until harvest is reduced e.g. from a five to three year production cycle. This should be possible under management to optimise percentage establishment, planting density and subsequent growth without compromising yield. Ultimately planting density is determined by the cost of planting material, land rent and the cost of planting against the value of the product (in technical terms the point where marginal cost equals marginal return). Maintaining sufficient water for germination at establishment and adjusting plant density at planting are crucial components.
8. Machinery is used for harvesting. Machinery used for root cropping (or stone separation) or even vacuum harvesting would significantly lower harvesting costs if machinery can be used at scale.
9. Areas harvested are replanted to reduce recovery time (rather than rely on regeneration).
10. Centralise processing to enable the use of capital assets throughout the entire year.

There is still considerable agronomic research to be undertaken particularly into variety and even species selection. Reworking the figures using the above proposals shows a low return of about £1,300/ha and a modest internal rate of return of about 5% (before the opportunity cost for the land). In commercial terms, the return for the risk is far too low to make commercial production a viable prospect but is as good as might be expected from an undeveloped crop with little or no entrepreneurial input. Adopting the approach taken by BeadaMoss and the very high yields they quote the IRR may be increased to over 20% although for the grower the returns are likely to be only slightly higher than the return from current cropping i.e. the payment needed to secure production.

BeadaMoss is expected to introduce a risk-share arrangement with growers. BeadaMoss would supply planting material, contract services for planting, undertake harvesting and receive all production. The grower would manage the growing crop, apply irrigation and control weeds in exchange for a return comparable with other high-value crops that might be grown on the land and a performance-related profit share. This has the major advantage of de-risking the system for the grower and managing supply to reduce the chances of oversupply. Initially, until the process is established and accepted, BeadaMoss recognise that additional government subsidies linked to production may be needed at least until production is established. Additional assistance is not unusual where there is a lack of experience of the production system, there is a high degree of market uncertainty and commercial confidence is low (and other options are available to the grower).

The fear remains that sustainable production from higher quality planting of sphagnum moss on previously harvested peat in Canada or particularly Ireland (using existing processing plant (albeit supported with new specialist machinery for planting), processing capacity and supply chain) would, within a short time, undermine UK production. The opportunity cost for the land compared to those areas in England historically using the land for high-value cropping would be much lower.

There is also an internal threat where UK arable producers produce sphagnum. While suitable areas for production are limited, manipulation of the water supply makes it possible to grow more widely (as horticultural producers do for other crops) and the potential economies of scale are significant.

4. Typha latifolia (Bulrushes, Reed Mace, Cattail)

4.1. Summary

Typha latifolia (T. latifolia) (Bulrushes, Reed Mace or Cattail) already grows on the estate in abundance as a wild plant. There is considerable research work available into its use and some research into optimisation of production. There is at least one high-profile specialist (Ponda previously SaltyCo) that has: developed marketing links; is developing a production system; and is interested in shared contracts to de-risk production.

The most important income stream, at present, developed by Ponda is the down from the seed used as an insulating material in quilted clothing. The market is built on the association with sustainability. In contrast to cotton, pesticide use is low and water consumption is in an area of excess rainfall. In contrast to duck and goose down it is not an animal product and does not have welfare issues. In contrast to bioplastics (which could also be produced from the T. latifolia biomass residue), it would not be considered to have involved a chemical process. However, other fibres, such as kapok, have very similar marketing attributes and there are other plant downs available.

To remove the need for investment in processing equipment, to quickly gain expertise and to establish a route to market, Vitagrass Farms (Holker) Ltd should enter into a contract with Ponda[34].

The bulk of the biomass (following down extraction) is consequently unused. The proximity of a plant combusting biomass provides a market output for the biomass. This should provide a low-value return to maintain income while higher-value products are developed. Use as animal bedding provides another simple, if low-value, output that would not require specialist machinery. However, it is likely that if the biomass is to be used it will need to be stored and dried.

While this biomass should be profitable as biofuel, at least in the short-term, it would be appropriate to work with Ponda to develop higher value outputs such as fibre from the stem and fibre board where the plant has some unique characteristics. Biochar is also a potential product currently attracting a premium in recognition of its ability to capture carbon. The biochar also has some intrinsic value as a “growth promoter and/or resilience enhancer” although experimental work on temperate soils is inconclusive. T. latifolia has been used as a source of cellulose for bioplastics. Development of these options requires substantial investment and could most effectively be achieved via a shared initiative.

For most biomass uses the cost of transport is high relative to the product. Bulk density of bulrush is estimated as 52kg/m^3 (Mills) which means that transport is likely to cost in the order of £120/t in an unmodified lorry without compaction and potentially up to twice the value of the biomass. However, with purpose-built transport or the use of farm trailers, it should be possible to reduce the cost to £10/t if distances are only a mile or two. This forms a barrier to competition where development is early but means that central processing of large volumes is expensive if product value is low. Investment in processing equipment may allow profitable harvest from semi-natural sites although this might help to achieve scale.

[34] Note. There is a similar business “FluffStuff” based in Finland

To ensure long-term viability, cost of production needs to be lowered. There are three key ways that this can be achieved:

1. Select and manage fields to enable the use of conventional machinery ideally for planting but particularly for annual harvesting. This would necessitate the ability to lower the water table temporarily and the selection of suitable soil types that drain following the lowering of the water table.
2. Form arrangements with other growers to develop appropriate machinery. This would lower the cost of development and the same machine could probably be used by several growers until the appropriate scale was achieved (Ponda are working on a solution).
3. Be prepared to operate on an area of at least 40ha once development is complete.

While floating machinery to cut reads is available, throughput is low and development to harvest seed head and straw is needed. Thus, tracked machinery or machinery with suitable low-ground pressure tyres is likely to be necessary (paddy rice is harvested with conventional tracked harvesters in central southern Europe). Unmodified swathers and balers have been used to harvest Typha for biomass but this is unsuitable for managing the straw and seed heads as separate crops. A modified reaper binder looks likely to provide a simple solution. The reeds could be harvested with the heads bunched at one end of the stook for subsequent drying and separation. This would still be slow, and expensive, compared to just cutting and baling the biomass so would have to be justified by the value of the down. A more exotic option would be to develop a pared-down version of a dual-cut hemp harvester to separate and collect separately the seed heads and straw.

The production is subject to competition from sites that already have a high wild population of Typha spp. e,g. in the USA and Canada where Typha is considered an undesirable invasive weed. Many environmental sites (e.g. The National Trust site at Wicken Fen in Cambridgeshire) cut the Typha spp. annually for environmental reasons and payment for the seed heads becomes a means of subsidising an operation that is taking place in any case. The payment for the Typha would be treated as a contribution to the cost of managing the environmental sites and not for full cost recovery or generation of profit.

Long-term crop profitability requires a commercial advocate to manage and invest in development.

4.2. Introduction

T. latifolia, T. augustifolia and a hybrid between the two grow in the UK and are native species. The distinction between the species is relatively small although slight differences in form and conditions for growth have been identified. Both plants can provide similar outputs although T. augustifolia is considered to have a slightly less desirable seed head. T. latifolia is slightly more widespread and there is a greater body of research available for its use and management. For this reason, T. latifolia has been identified as the subject of this report.

T. latifolia is a common plant growing in fresh and brackish water throughout the northern hemisphere and is often invasive elsewhere. It is a perennial plant generally growing in shallow water. It is not restricted to fenland or bog and will grow anywhere with sufficient water. In contrast to sphagnum, it prefers nutrient-rich sites. Importantly it will survive for short periods out of water and thus allow harvesting and establishment to be carried out with conventional machinery. It is found at Holker and would almost certainly be easy to establish more widely in a cultivated form. Plant biology is discussed in detail in the reference supplied in the footnote[35] and this source is referred to throughout.

[35] https://www.cabi.org/isc/datasheet/54297 Typha latifolia (broadleaf cattail) David Clements CABI

4.3. Market

The major features of T. latifolia are the ease with which it grows and the plethora of uses.

For all biomass uses it is likely that storage will be necessary to allow processing throughout the year. It is also likely to need drying to 15% to preserve it. An obsolete drive-over drying floor would be ideal. Some of the biomass could be used to provide the power for drying. Sophisticated drying floors are unlikely to be necessary and second-hand equipment for an existing shed would be suitable[36]. Since biomass is the secondary crop this is not critical initially.

The seed heads do not deteriorate rapidly and Ponda is prepared to accept undried material at a discount. Thus drying of the seed heads is not crucial at least in the short term. In the longer term, this might change once volumes increase.

4.3.1. Fibre – down from the seed head

While the fibre from the seed head has historically been the Cinderella output and the subject of very few trials, SaltyCo, now Ponda, has established the output as mainstream for use in quilted clothing. This is a consequence of Ponda's excellent marketing skills and the creation of the "BioPuff®" brand. The fashion industry is under pressure to improve its environmental footprint and the environmental connection of bulrushes to carbon retention (and/or sequestration), plant-based materials (goose down is an alternative) and the avoidance of cotton with its high water and pesticide input provides market leverage.

The specific use as insulation is also less vulnerable to competition with the lowest cost materials. However there are competitive materials available either other plant-based, such as kapok, or biodegradable fibres produced from plant cellulose (refer to appendix).

In common with most products and demand, price elasticity is likely to be high. Thus while supply is restricted price is high. If the supply should increase the fall in price is likely to be significant.

Yields of fibre are reported to be about 600kg/ha dry weight reducing to around 350kg for the processed end product (e.g. seed and contaminant removal). Processing is likely to be carried out centrally or using mobile equipment available to all producers.

4.3.2. Fibre- extraction from the stem[37]

The paper 'Extraction Efficiency, Quality and Characterization of Typha latifolia. Fibres for Textile' referenced in the footnote demonstrates that T. latifolia leaves and the core spongy tissue could be transformed into fibres under controlled experimental conditions in an aqueous alkaline solution giving a yield range of 15% to 60%. The diameter of the T. latifolia fibre is much higher than cotton and wool while the moisture regain (%) and thermal resistance are comparable.

Storage and drying on a ventilated floor are likely to be necessary to allow material to be delivered for processing throughout the year. Without significant investment in infrastructure and the development of expertise it is unlikely that Vitagrass Farms (Holker) Ltd would be in a position to pioneer the development of this output.

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[36] https://www.welvent.com/used-equipment/

[37] https://mspace.lib.umanitoba.ca/bitstream/handle/1993/33616/Final%20MSc%20Thesis.pdf?sequence=1&isAllowed=y Extraction Efficiency, Quality and Characterization of Typha latifolia L. Fibres for Textile Koushik Chakma, University of Manitoba

4.3.3. Fibre - weaving

The broad fibrous and durable leaves of cattails make an excellent weaving material. However, this is in practical terms a craft use and not suited to commercial use on the estate.

4.3.4. Phytoremediation[38]

T. latifolia is an effective plant for removing phosphate and nitrates in contaminated water courses. The process is largely, but not entirely, physical. When water is made to flow through a reedbed the speed of flow is slowed reducing the ability of the water to hold materials in suspension. These are precipitated and sink to the floor of the reedbed. Phosphate, in particular, is held within the suspended organic matter and is removed in this way. The growing reed also takes up nitrogen and phosphate and annual cutting will allow removal from the water catchment. It is necessary to clean the reedbeds to remove the sediment-captured nutrients and replant about once every five years.

Other reeds may be used but there is at least some evidence to suggest T. latifolia is more effective at removing phosphate and potash than Phragmites australis (common reed) although Phragmites or mixed populations may be more effective at removing other nutrients.

The ability of T. latifolia to grow in brackish water means that it is also effective at salt removal for example from treated roads or runways.

The high uptake of nitrogen and phosphorus makes it a useful transition crop for lower nutrients in cultivated land in preparation for environmental restoration[30].

This use is specific to the site and unlikely to be of value to Vitagrass Farms (Holker) Ltd.

4.3.5. Biomass for energy

Given that there is demand for combustible biomass in the area this output is a relatively straightforward, albeit low-value output for the crop. The low value of the land and proximity to the point of consumption is likely to make it more cost-effective than other forms of biomass such as miscanthus (if it can be harvested dry with conventional machinery as should be possible). There is also increasing concern that the time taken to reabsorb the carbon released from mature trees is longer than the reduction time horizon, increasing demand for crops that can be harvested annually. While combustion of trees for energy is carbon neutral if replanted the time taken to recapture the released carbon can be over 100 years meaning targets for neutrality would not be met.

In Canada, T. latifolia has been harvested using a swather and baler from unmanaged marshland areas although not without machinery becoming stuck. If the water levels can be controlled and appropriate low-ground machinery can be used harvesting with equipment already available would make the operation worth exploring.

Floating machinery is also used for reed cutting but a low work rate is likely to make this an unviable option.

[38] https://mspace.lib.umanitoba.ca/bitstream/handle/1993/23564/Grosshans_Richard.pdf?sequence=5&isAllowed=y Cattail (Typha spp.) Biomass Harvesting for Nutrient Capture and Sustainable Bioenergy for Integrated Watershed Management Richard Eric Grosshans, University of Manitoba

Combustion trials have revealed an average calorific heat value of 17 MJ/kg to 20 MJ/kg, comparable to commercial wood pellets. Dry weights of up to 22t/ha have been reported in Canada and 30t/ha DM in Europe[39]. However, average yields of 8-13t/ha DM[40] are more likely. Phosphorus content is about 13kg/ha. T. orientalis, in Australia grown in small trials, has achieved 43.79 t/ha.

Phosphate and potash minerals in the biomass will be preserved in the ash and will have potential fertiliser value. Typha can also be used as a feedstock for anaerobic digestion[41]. When cut young.

Table 9: Characteristics of Mixed Tall Fen in Anaerobic Digestion

	Dry Matter %	Moisture %	Total Gas Yield m^3/t	Methane %
Mixed tall fen	31.9	68.1	165	52.4

The output is similar to poor-quality grass (which is not generally considered a good feedstock) and below that of maize silage. Data presented show the moisture content varies throughout the year with the lowest moisture content of 20% reached in February. Additional value might be obtained from compressing the biomass into pellets or briquettes. This would also lower the cost of distribution.

4.3.6. Biomass for biochar

In common with other woody sources, it can be converted into biochar (a form of carbon) which is one of the few long-term methods of storing carbon. The process involves burning the material with insufficient oxygen to produce a stable high-carbon material. Carbon credits are potentially awarded. The Lapwing Estate in Lincolnshire has developed a new model for ‘rethinking peatlands’ including the production of biochar.

In tropical soils application to the land is thought to increase productivity but the trial evidence for application to temperate soils is uncertain.

Table 10: Conversion of materials to biochar[42]

	The net calorific value of input MJ/kg	Moisture %	The net calorific value of charred biomass MJ/kg	Moisture content %
Rush/grass	14	20	20.7	3.7
Willow	12.5	30	23.6	2.7

[39] https://www.sciencedirect.com/science/article/abs/pii/S0048969720346313 Nutrient removal potential and biomass production by Phragmites australis and Typha latifolia on European rewetted peat and mineral soils Jeroen J.M. Geurts, Claudia Oehmke, Carla Lambertini , Franziska Eller, Brian K. Sorrell, Samuel R. Mandiola, Albert P. Grootjans, Hans Brix, Wendelin Wichtmann, Leon P.M. Lamers, Christian Fritz

[40] https://www.iisd.org/system/files/publications/cattail-biomass-to-energy-commercial-scale-harvesting-solid-fuel.pdf Cattail Biomass to Energy: Commercial-scale harvesting of cattail biomass for biocarbon and solid Richard E. Grosshans, IISD and Lorne Grieger, PAMI

[41] https://res.mdpi.com/d_attachment/resources/resources-09-00057/article_deploy/resources-09-00057-v2.pdf "Biomethane Yield from Different European Phragmites australis Genotypes, Compared with other Herbaceous Wetland Species Grown at Different Fertilization Regimes" Franziska Eller , Per Magnus Ehde, Claudia Oehmke, Linjing Ren, Hans Brix, Brian K. Sorrell 1 and Stefan E. B.Weisner

[42] https://ecosystemsknowledge.net/sites/default/files/wp-content/uploads/DECC%20Biomass%20to%20Bioenergy%20End%20User%20Report_0.pdf

Equipment is available in the UK for example as supplied by ONNU[43]. The price paid for biochar is volatile although Terra Preta quoted a price of £400 to £800/t. This is a longer-term option for Vitagrass Farms (Holker) Ltd.

4.3.7. Cellulose for bioplastics

Typha leaves are a rich source of cellulosic fibre tows. The fibres are relatively easy to extract with chemical retting (sodium hydroxide and other materials are used). The bioplastics created are biodegradable and environmentally friendly.

There is considerable growth in the use of bioplastics (although very often the materials created are the bioplastics such as rayon and lyocell developed at the end of the 19th century) and a source of readily available cellulose is needed.

It is unlikely that Vitagrass Farms (Holker) Ltd would be able to generate the volumes needed for this industrial process or be in a position to lead on development. There are manufacturers producing products similar to rayon that already make use of cellulose. Unless the T. latifolia can be demonstrated to provide benefit over other sources the risk is that transport cost would prove a barrier.

The starch from the roots is also an excellent source for the biochemical industry although the difficulty of harvesting means that the source is likely to remain maize, wheat and potatoes.

4.3.8. Construction and Insulation Materials[44]

T. latifolia is suited to the manufacture of bio-laminates. The composite fibres can be prepared without any addition of a binder system due to natural constituents that act as an intrinsic binder. Research is advanced in the Netherlands and Germany. The yield of suitable fibre is higher per ha than from forestry. The market for using T. latifolia as an insulation material is established in Germany and Austria.

The Fraunhofer Institute for Building Physics in Germany[45] has developed Typha-based insulation panels based on magnesite-bonded Typha leaf particles. The manufacturer claims that there are no products of comparable quality on the market for use as a building material. They have a high load-bearing capacity, provide good insulation and are fireproof. In Thailand, cattail has been also used as insulation material by binding the leaves with methylene diphenyl diisocyanate (MDI) and hot pressed to produce thermal insulation boards (Luamkanchanaphan, 2012).

Typha Technik established over 20 years ago specifically to develop Typha products, has multiple types of insulation boards with different thermal conductivities available for sale.

[43] https://www.onnu.com/

[44] https://edepot.wur.nl/429929 A feasibility study on the usage of cattail (Typha spp.) for the production of insulation materials and bio-adhesives Colbers, B.; Cornelis, S.; Geraets, E.; Gutiérrez-Valdés, N.; Tran, L. M.; Moreno-Giménez, E.; Ramírez-Gaona, M.

[45] https://www.fraunhofer.de/en.html

Hanffaser Uckermark, another German company[46] claims that Typha has potential as a blow-in insulation material. One hectare of Typha is sufficient to insulate the roofs of four houses. Naporo also produced both boards and blow-in insulation using leaves, stems or the whole plant although they appear to have been absorbed into Capatect a company now more involved with producing building materials from hemp[47].

In Estonia Typha chips are mixed with clay to produce safe and cost-efficient building blocks. The material is light and has good thermal insulation properties. Fibre material from cattail spadixes is used as clay plaster reinforcement. The fibre is an ideal material to avoid cracks in clay plaster. Ready-made dry fibre and clay mixtures and cattail chips and clay blocks are produced and sold on the market[48].

The production of blow-in insulation and potentially insulating boards should be a secondary development for Vitagrass Farms (Holker) Ltd. Blow-in insulation is a reasonably practical application although it would be necessary to demonstrate effectiveness. BRE (Building Research Establishment)[49] may be interested in helping to develop the product in the UK.

4.3.9. Feed and food source

Typha is sometimes grazed but is not considered particularly nutritious. Young shoots are also eaten. The root is rich in starch and is sometimes consumed by people. According to one source, the crop will provide 8t/ha of flour although replanting would be needed to maintain production. The root contains about 80% carbohydrate and 6-8% protein.

4.3.10. Other

Historically T. latifolia has been used for thatch (it is inferior to Phragmites and no longer used in the UK for this purpose), paper and weaving. The pollen has occasionally been used as an attractant for insects and mites to protect other vulnerable plants[50]. The pollen is used as a flour substitute and colours baked products in a similar way as saffron.

4.4. Market Statistics

The biomass industry is established for incineration in electricity generation in response to the emissions trading scheme (ETS). A Defra paper analysing data from the 2019 June Agricultural Survey found that 49,000 tonnes of miscanthus, 28,200 tonnes of short rotation coppice and 625,166 tonnes of straw are used for electricity generation. According to BEIS 7.8 million tonnes of wood pellets were imported into the UK in 2018. The intention is to phase coal out of the mix this year (2024) which (if replaced by biomass) would require approximately 80,000 ha more biomass.

Biomass is an undifferentiated commodity with the value determined by the relative ease of handling and the energy value.

[46] https://www.hanffaser.de/

[47] https://www.hanfdaemmung.at/

[48] https://www.researchgate.net/publication/223872753_The_humidity_buffer_capacity_of_clay-sand_plaster_filled_with_phytomass_from_treatment_wetlands Martin Maddison, Tõnu Mauring, Kalle Kirsimäe, Ülo Mander

[49] https://bregroup.com/

[50] https://www.canr.msu.edu/news/applying_pollen_over_a_crop_as_an_alternative_food_source_for_predatory_mit

4.5. Pricing

The current ex-farm price for biomass is between £60 and £80/t or about £750/ha for a managed crop. The top price is imposed by the cost of straw and the value for combustion.

The down is worth about £2/kg fresh weight or about £2,000/ha for a managed crop. This payment is likely to be extremely volatile, reducing as supply increases.

The outputs quoted are for an established crop from (say) the third year after planting. However there is income even in year one and while this is speculative, it is likely to be in the order of £275/ha.

The other outputs are more valuable. For example, the Wageningen University feasibility report quotes a profit of €100-200/tonne pre-processing and €300-500/tonne where processing is carried out for fibre production.

The cost of transport is an important component of profitability and processing needs to be close to production. However, the area of production also needs to be large enough to justify the processing plant.

Several studies confuse product output with the sale of carbon credits. To receive payment for the carbon it is only necessary to change the land management and not to produce an output so this income is not part of determining crop profitability. The same is true of the Sustainable Farming Incentive (and as it currently stands would also impose restrictions on paludiculture management).

There is already an opportunity to sell the down and possibly biomass from the areas where Typha spp. grows wild on the estate. This will provide experience of the market. However, production in a managed environment should be much higher.

4.6. Threats and Competition

Most of the outputs are delivered into commodity markets that are already supplied by other materials. In many cases, the other supplies are easier to manage and can be delivered at lower cost.

The down has semi-unique properties although there are alternative materials based on recycled plastics and bioplastics. Kapok is similar and produced in parts of the world with a lower cost base. It is harvested from both wild and cultivated sources. While demand for products not derived from oil with a positive environmental footprint is increasing there are other substitutes.

T. latifolia covers large areas of the natural environment and annual cutting is usually considered to be positive for environmental enhancement. If the fibre does become commercially viable, wild harvesting could undercut managed production. If the T. latifolia is to be cut for environmental gain regardless of commercial justification, any additional income, such as from the sale of the seed heads, is desirable and only needs to contribute to the cost. Yew clippings were sold in this way in the UK until about five years ago.

4.7. Environmental Issues

T. latifolia is an indigenous plant suited to many areas of the UK where the water table can be raised. It is an aggressive species and will out-compete other plants and in parts of the world such as Canada and USA much of the research focus is on its removal.

The fibre is harvested together with the seed (and then separated) reducing the risk of spread. In practice, the seeds can travel long distances and, if there is a threat, it is already established.

In the UK several environmental sites aiming to increase diversity actively cut the plant or introduce cattle or water buffalo that will create mud pools within the T. latifolia beds to provide suitable areas for other flora and fauna. There is evidence showing that methane emissions are lower under T. latifolia than where the wetted land is left fallow[51]. There is also some evidence that greenhouse gas emissions are lowest where the ground is wetted to below the surface.

4.8. Cultivation

There is considerably more research available for optimising the growth of Typha[52] than for many of the other paludiculture options.

4.8.1. Site Preparation

In common with other paludiculture crops, site preparation depends on the initial condition of the site and scale (larger areas are usually significantly cheaper to prepare). It is assumed that the site selected was in arable production before drainage so will be level and capable of withstanding vehicle operation. Thus the main, and possibly only, task is to block drainage systems. Optimisation of conditions for cultivation (versus restoration) is easier than for sphagnum but still requires the land to be level and for drainage to be controlled.

Water depth should be in the order of 10 cm to 30 cm, with recent research suggesting that to optimise efficacy (carbon sequestration and reduction of methane emissions), wetting of peat should be within 10 cam of the soil surface. Whilst T. latifolia will survive dry periods and periods where the water depth is deeper, the impact on crop yield (as distinct from survival) is not known. There is no requirement for overhead water.

4.8.2. Planting method

Establishment is straightforward and can be achieved via seed, planting of plugged plants or distribution of rhizomes. Seeds can be spread aerially, in water or via animals and new sites adjacent to established reed beds will usually populate within a few years without human intervention. However, for cultivation, there needs to be more certainty over the plant distribution and speed of establishment since both influence yield and period from establishment until harvest. Temperature, temperature fluctuation and water depth impacts on seed germination.

An individual inflorescence is estimated to produce between 20,000 and 700,000 seeds. To produce the down the main processing input is seed removal so an established producer, such as Ponda, is likely to extract large quantities of viable seed. Seed is also available from companies such as R P Seeds. Recommended planting density is 20-100 seeds per m^2 which is equivalent to 1kg/ha.

[51] https://www.sciencedirect.com/science/article/pii/S0304377022001103 Wetland plant development overrides nitrogen effects on initial methane emissions after peat rewetting Coline C.F. Boonmana, Tom S. Heutsa, Renske J.E. Vrooma, Jeroen J.M. Geurtsa, Christian Fritz

[52] https://d-nb.info/102048487X/34 Population biology of Typha latifolia L. and Typha angustifolia L.: establishment, growth and reproduction in a constructed wetland, Sabine I. Heinz

To reduce risk, the seed is usually planted in blocks to ensure that plant populations have been achieved. If planting is delayed excess growth (preventing machine harvesting) may be removed. If the number of plants required is over about 10,000 a professional grower of nursery plants will usually supply established plants in blocks on contract for under £0.50 each. Purchased as individual plants the cost may be as much as £3.00/plant. It is almost as easy to collect down from an existing wild site and plant in seed trays (ideally following the guidance in 'Light, oxygen, and temperature requirements for Typha latifolia seed germination'[53] and others including R P Seeds) and plant out.

Plant establishment is also consistent where harvested rhizomes are planted. Plants from the donor bed will usually recover where harvesting is partial.

Planting density is poorly explored and will depend on survival rate, plant size and vigour under specific weather conditions. Ecoinvent is reported as establishing a T. latifolia reed-bed at a density of 2 plants/m^2 (20,000/ha) using a two-row planter while remediation planting is usually half of this (Also reported in 'Paludiculture pilots and experiments with a focus on cattail and reed in the Netherlands'. This report quotes German populations down to one plant every 2 m^2). The report states that shoot numbers can multiply to 10 in two months and 30 in a growing season.

For research purposes, planting is usually by hand or superimposed on established reed beds where populations for some Typha species have been as high as 140 plants/m^2. However, the components of yield, and the relationship between them (e.g. plants. Stems and fluff per head, and consequently maximum yield) are not well understood although some data is available[54].

Irrespective of planting density, providing the distribution is relatively even across the site the plant will occupy the entire area within one or two years.

4.8.3. Fertiliser

Nitrogen and particularly phosphate fertiliser have been shown to increase the yield of some components at least in small-scale trials. However, the efficiency of application to water is likely to be very poor with a high risk of pollution and is not appropriate. Bulrushes (in contrast to sphagnum moss) tend to grow best in high-nutrient sites.

In common with any crop, nutrient is lost in any part of the plant harvested. Where nutrient is depleted biomass yields will decline. Both sphagnum and T. latifolia are good scavengers of nutrient (they will extract nutrient from sources with a low nutrient content) and have relatively low uptakes. Consequently they will grow where there is only a low level of replenishment from the water supply. Reeds such as T. latifolia slow water movement resulting in the deposition of any organic particles in the water. The captured organic matter supplies nutrients for subsequent up take, sphagnum, T. latifolia and all other paludiculture crops are likely to produce a higher product yield where nutrient levels can be managed.

[53] https://cdnsciencepub.com/doi/abs/10.1139/b83-140 :Light, oxygen, and temperature requirements for Typha latifolia seed germination: V. Bonnewell, W. L. Koukkari, and D. C. Pratt

[54] https://www.researchgate.net/publication/277648709_Anatomy_and_physiology_of_Cattail_as_related_to_different_population_densities Anatomy and Physiology of Cattail as Related to Different Population Densities Corrêa, F.F.2, Madail, R.H.3, Barbosa, S.4, Pereira, M.P.2, Castro, E.M.2,Soriano, C.T.G.2, And Pereira, F.J

4.8.4. Weed control

Since T. latifolia is competitive and tolerant of flooding and occasional drying out, weed control is not usually a problem because few other plants can tolerate such diverse conditions particularly where good coverage is established at planting. Phragmites australis can co-exist and would need to be removed by hand to maintain a pure stand.

4.8.5. Pest and Disease

While T. latifolia is attacked by several pests (such as Eldana saccharina (African sugarcane borer) and Pomacea canaliculata (invasive apple snail)) these are not known to be damaging in the UK. The Royal Horticultural Society reports that T. latifolia is generally pest and disease-free although ducks and grazing animals can damage young plants.

4.9. Yield and harvesting

Several of the referenced reports provide information on yield. There is good consistency between the sources suggesting an above-ground dry matter yield generally of 15-17t/ha where actively managed although yields of up to 40t/ha and down to 4t/ha have been reported. While the variation is high most of the sites were unmanaged and production was incidental to the study. The output is competitive with other biomass crops such as miscanthus. While there is some production in the year following planting, or even in the same year where sown in early spring, the yield may be one-tenth of the established crop yield.

Yield of down is estimated at around 1 t/ha fresh weight, 0.6t/ha dry weight and 0.35t/ha processed weight. However, T. latifolia is not determinant (growth stages are not fully synchronised) so to maximise the production either the area has to be harvested on several occasions or judgement is taken on the time when the maximum quantity can be harvested. Fortunately, there is a relatively long period between when the seed is fully developed and when it disperses.

Rhizome yield is estimated at 30t/ha although there is relatively little data available.

For most uses the principal harvest is the above-ground production. Even where the fields are selected as proposed (water level can be dropped and soil type allows travel) vehicles will need low ground pressure or tracks. In common with miscanthus, which is also harvested when the ground is saturated, it would be expected that unharvested biomass material will make it easier to collect than on a fallow site.

Sally Mills provides an excellent review of harvesting methods[55] for energy production. However, her report is aimed at harvesting natural reed beds and focuses on floating cutting devices (Truxor) or low-ground pressure purpose-built vehicles (Softrak, The Pisten Bully Greentech, Seiga Harvester, Olympia mower binder). The existence of a range of harvesters illustrates that managing T. latifolia for biomass uses is advanced compared to sphagnum production even if the development is primarily for environmental management. The small equipment has work rates of around 40 hours per ha (and a cost of £2-300/ha) making the crop unviable compared to dry land production systems such as those based on miscanthus or cereal straws. Larger machines are available that will harvest 1 ha in about two hours and these are closer to being comparable with conventional machinery in terms of work rate and cost.

[55] https://ecosystemsknowledge.net/sites/default/files/wp-content/uploads/DECC%20Biomass%20to%20Bioenergy%20End%20User%20Report_0.pdf Wetland Conservation Biomass to Bioenergy End User Report Sally Mills for RSPB funded DECC

Where the material is taken entirely for biomass (heads might be harvested by hand beforehand or not harvested) it would be usual to chop the material with a towed forage harvester or collect cut material with a baler.

The practical difficulty is the local availability of specialist machinery when the area cropped is suboptimal. Local wildlife organisations may adopt cutting machinery for environmental reasons that might be contracted out although the tendency appears to be the use of the smaller floating machinery.

The Olympia mower binder differs from the other devices in that rather than being a simple biomass harvester it bundles the material making it easier to separate the higher-value seed heads post-harvest. This is a small device with the operator walking behind to steer intended for reed harvesting for thatching. It will work in 20cm of water and is estimated to be capable of harvesting 0.75ha per day. Tracmaster in the UK sells similar devices for £12-14,000 (price correct at January 2024).

While the Tracmaster or Olympia are not a long-term harvesting solution they provide a practical short-term solution while the business is being established allowing both outputs (biomass and down) to be retained. Another solution would be to obtain a vintage reaper binder.

Longer-term it would be expected that a dual harvesting device would be developed such as that developed for harvesting seed and fibre from hemp (refer to: John Deere https://www.youtube.com/watch?v=_M6iDyRl2H0 or Hyler https://www.youtube.com/watch?v=7EgUfQyE0P0). The former is far more sophisticated than needed (and heavier) because it also separates the seed, while for Typha harvesting involves only the separation of the seed head in the field.

In Canada, conventional machinery (swather) has been used with a following baler. This is likely to be too dependent on conditions where the ground does not reliably freeze but it does provide an idea of the scale that is possible for competing biomass providers.

Once cut the material needs to be moved from the field and some thought needs to be given to the use of low-ground pressure trailers and/or balers. Suitable conventional trailers should be acceptable if tractors and trailers are fitted with low-ground-pressure tyres or tracks. If necessary small trailers pulled by ATVs can take the material to the nearest firm ground.

Timing of harvest is critical both in terms of yield optimisation and moisture content. Harvest of the down is likely to be between September and December. Narrowing of the harvesting period may be achieved via plant selection (even by gene editing) and agronomic development. Sealants are sometimes used for other crops (a spray of gum) and it is possible that this would be effective in managing the down harvest. Hair sprays are used to prevent the spread of down where bulrushes are used in floral displays.

Harvest for biomass for insulation/combustion/etc. is usually in the winter which has the advantage that nutrients are transferred back to the rhizomes.

It is unlikely that the biomass will be needed as harvested so storage will be necessary. The biomass will also need drying to prevent deterioration and allow combustion. An existing ventilated grain store would be ideal since cut material could be dried. It should be assumed that the moisture content would be 50%.

4.10. Costings

The major variables impacting on profitability are:

1. investment needed to create suitable conditions.
2. crop yield determining output at the pervading price.
3. area under cultivation determining the cost of production.

Costings quoted in 'A feasibility study on the usage of cattail (Typha spp.) for the production of insulation materials and bio-adhesives' produced in 2017 based on updated figures suggest that T. latifolia makes a modest profit of €1,630/ha (£1,393/ha). Reassessing the figures, over 20 years, for the basic biomass output and down output and associated costs has derived a similar profit. However, this produces a modest 7% IRR after a £10,000/ha initial investment in the site to raise and manage water levels, level the land and provide basic infrastructure for access. The proposition works if the cost of conversion is low.

The grant funding through the Countryside Stewardship Higher Tier (CS) and any carbon credits reduces the apparent risk although for many sites, the CS scheme rules might make compliance with cropping difficult to achieve.

5. Local opportunities

While the following options, Myrica gale (Bog-myrtle), Angelica archangelica (Angelica) and Mentha aquatic (Water mint) provide the opportunity to scale production, the initial competitive advantage is via the creation of a range of products for local and internet sales building on the estate's established brand and the environmental attributes of the product. Crop production and product manufacture might also provide part of the visitor experience further enhancing the overall visitor value.

The provision of relative novel goods sold by association with the estate provides some protection from competition. Sales are also likely to be seen as luxury goods with the price (within a reasonable range) dependent on the outlet and branding as much as the product.

These are entrepreneurial options without external support and would require more detailed research, including into compliance. Risk is consequently even higher than for sphagnum and T. latifolia and there is no external advocate. All three products have been grown commercially and there is some research into use and cultivation. None are mainstream products in the UK despite being native plants (and in the case of Myrica gale a large Scottish project with the objective of commercialisation). However, they are versatile and can be incorporated into other products or form multiple products for retail at little cost. They are all attractive and provide a good source of pollen and nectar for insects.

The plants do not have an active advocate to develop the agronomy, processing or marketing opportunity and would consequently be demanding in terms of management.

If essential oil extraction were developed it would be worth considering the production of other plants (including non paludiculture crops) that might be suitable and broaden the range and spread the cost of the botanical still.

The three crops considered illustrate a particularly wide range of site requirements.

6. Myrica gale (Bog-myrtle or Sweet Gale)

6.1. Summary

While the essential oil from Myrica gale is sold, and therefore has a market price, like other essential oils and perfumes the price range is large. The price achieved depends on the marketing expertise available and marketing as an adjunct to other public-facing activity on the estate. The distillation process itself might be used to enhance the visitor experience. In the longer term, if the venture proved a success and could be scaled to lower cost there is a large market in the cosmetics industry. The oil has been subject to human safety evaluations and efficacy testing and included in cosmetic products[56]. It is also a natural insect repellent.

At expected production levels of 0.75l/ha, retail sales at about £5 per 10ml, would gross in the order of £3,750 per ha (see following sections for references). This is not large (output is higher, and growing costs are lower than for wheat but the management, processing, packing and retail costs are likely to be much higher when grown at a small scale) and would rely on the marginal cost to be worthwhile. Profitability might be improved via expansion of area or introduction of other similar crops with the expectation of lowering the cost of processing.

In contrast to sphagnum and T. latifolia, there would be no sharing of risk and success would depend on the available interest and expertise provided by Vitagrass Farms (Holker) Ltd to pursue an entrepreneurial opportunity. However, the cost of site preparation to establish Myrica gale will usually be lower than for sphagnum or T. latifolia. If Myrica gale were unsuccessful it would also be much cheaper to replant with another crop option.

Myrica gale has been subject to agronomic trials run by the University of the Highlands and Islands, Inverness, Scotland slightly over 10 years ago. While far from complete, the trial evidence obtained is at least equal to that undertaken for T. latifolia and sphagnum commercialisation and much of it is to a higher standard. However, there is no “advocate” promoting and developing the crop or investing in the market.

The most important areas for investigation are the optimum harvest date and the extent of the material available for harvest without damaging future production. The annual loss of established plants in the trials is also not understood and needs to be explored.

Initially, it is likely that the harvest will have to be manual but if it is determined that harvest at a fixed height is possible there is scope for harvesting with a forage harvester. The harvest of different parts of the plant in a single process is unlikely to cause contamination, given that the marketed product is the extracted oil. However, the area grown is likely to remain small making the benefits of mechanisation less significant than for the sphagnum and T. latifolia where lowering cost is likely to become more important if the market is to grow.

6.2. Introduction

Myrica gale is a nitrogen-fixing deciduous shrub from the Myricaceae family growing up to 2m tall. It grows in light or shade and favours acidic, low nutrient, moist or wet soil in high rainfall areas. It is an obligate wetland plant almost always occurring in moist, peaty soils in bogs, fens, coastal and inland swamps, and along the borders of lakes, ponds, and streams. It can become a dominant shrub species in these habitats.

[56] Galley E, Simpson M. 2007. From Scottish bog to international beauty counter – the story of sweet gale. Cosmetic Science Technology 2007: pages 63–67.

It flowers in spring, with catkins appearing before the leaves from April to May, and fruiting later in the autumn season. It is usually dioecious. On pollination, female flowers produce clusters of yellowish-green knobbly fruits. It is not self-fertile and is wind-pollinated.

Myrtle gale is wild-harvested in Scotland and Finland. It has a sweet scent and is used in perfumery, soaps and cosmetics. It is also used as an insect repellent. Traditionally it has been used as a beer flavouring, tea, candle wax, dye and a condiment. More recently it has been used as a gin flavouring. The Highland Soap Company produces a premium soap containing the essential oil extracted from the plant.

Myrica gale (Bog-myrtle) was the subject of considerable investment to establish the crop as a commercial entity in Scotland. The identified market was the cosmetics industry. At that time the market was reported as worth £5m per year and the crop area needed would be 5,000 ha. It was anticipated that 500 jobs would be created and farmers would receive £700/ha. The project eventually collapsed ostensibly as a result of a takeover of one of the main partners in the investigation (the partners in the project were Highlands and Islands Enterprise, the Boots Company, Highland Natural Products Ltd, Essentially Scottish Botanicals Ltd and Technology Crops International Ltd). The project ran for three and a half years until May 2011.

The essential oil from Myrica gale was considered to be similar to the widely used Tea tree oil but was found to be better suited to sensitive skin. Tea tree oil is produced in Australia and according to 'The Brainy Insights' the forecast global tea tree oil market will reach $91.0 million by 2030 and have a CAGR (Compound annual growth rate) of 6.9% during the period from 2022 to 2030.

6.3. Extraction of oil

Oil is extracted from the leaves and stems and various extraction methods have been trialled[57]. Another paper reports a leaf oil yield of 0.05–0.29% and, a flower oil yield of 0.97%. The main components were α-pinene [20.1–38.9%], 1, 8-cineole [2.5–23.9%], germacrene [0.4–13.2%] and γ-cadinene [8.4–21.0].

Steam distillation is the preferred extraction method. Extraction is a fairly simple process. There is a large range of stills, with prices depending on the scale and sophistication of the control systems. Thus stills start from under £200 for an Alembic copper and glass distiller rising to £60,000. To maintain versatility equipment should be suited to steam or alcohol distillation.

6.3.1. Market

The Highland Soap Co illustrates the opportunity by stating on their website "*It's been 18 months since we last able to buy the essential oil …we tried to buy some but just couldn't, for love or money (we tried both). We believe we are now the only company using real bog myrtle (myrica gale) essential oils to make soap and skincare products in the UK…So, this summer we purchased a copper pot still, sustainably wild-harvested some bog myrtle from hill and glen, and distilled the oil from the leaves and voila! We created our own bog myrtle oil for the first time*."

[57] https://www.mdpi.com/2297-8739/10/2/128 Effect of Extraction Methods on Essential Oil Composition: A Case Study of Irish Bog Myrtle-Myrica gale L Shipra Nagar, Maria Pigott,Sophie Whyms,Apolline Berlemont, Helen Sheridan

Table 11: Examples of retail prices

Supplier	Web address	Pricing information as presented by supplier
Hermitage Oils	https://hermitageoils.com/product/sweet-gale-essential-oil/	€8.00/10ml (about £8.40)
Powells Aromatherapy	https://www.powellsaromatherapy.co.uk/acatalog/Bog-Myrtle--Myrica-gale--44.html	£42.50/100ml £5.85/10ml
Blooming oils	https://www.bloomingoils.com/product/bog-myrtle-organic/	Range of products and dilutions £56.85/10ml (undiluted)
Highland Soap Company	https://www.highlandsoaps.com/collections/key-ingredient-bog-myrtle-essential-oil/scottish-bog-myrtle?sort_by=title-ascending	Range of products: soap, hand wash, night cream, body lotion
The Wonky Broomstick	https://thewonkybroomstick.co.uk/Bog-Myrtle-Essential-Oil	Out of stock
Luminescents	https://www.luminescents.net/shop/oils/essential-oils/bog-myrtle-essential-oil-myrica-gale/	£12.50/10ml
Bog Myrtle from Scotland	https://www.bogmyrtle.com/	Dried herbs £3.99/10gms

6.4. Environment

Bog Myrtle is a flowering plant and thus a source of pollen and nectar. It supports almost 70 species of leaf-eating insects, and several mammals including beavers, feral goats (Capra hircus), the mountain hare (Lepus timidus), and domestic sheep (Ovis aries). In common with other paludiculture crops the peat reserves are protected under cultivation.

6.5. Threats and Competition

Sales are initially expected to be local and branded via association with the estate as well as production methods. Sales are expected to be opportunistic with initial sales to curious buyers rather than those seeking the specific product. In the longer term, it may be possible to build on the Scottish development project and materially increase the market size.

The main threat remains that the product simply does not sell and if it does sell other producers set up and the oil loses its cache as a novelty item. If the market develops and production grows there is a possibility that others might leapfrog technically to establish a more efficient production system. There are very few other producers but supply appears to be erratic.

6.6. Cultivation

As part of the Scottish research project into the commercialisation of Myrica Gale cultivation trials were carried out by the University of the Highlands and Islands in Inverness. Much of the data is taken from "Production potential and crop agronomy of sweet gale (Myrica gale L.)" in the north of Scotland[58] and other papers by Martin and Chang forming part of the Scottish investigation.

The species forms a symbiotic relationship with certain soil micro-organisms that form nodules on the roots and fix atmospheric nitrogen. Some of this nitrogen is used by the growing plant but some can also be used by other plants. This habit allows the plant to succeed in water-logged soils.

Flowers are produced mainly on one-year-old wood. All parts of the plant are aromatic.

[58] https://www.sciencedirect.com/science/article/abs/pii/S0926669013000022 "Production potential and crop agronomy of sweet gale (Myrica gale L.) in the north of Scotland" Peter Martin, Xianmin Chang

The trial plants were cut back to 20-30cm to encourage lower branching in March one year after planting out. This was also to provide a baseline for the trials. The evidence for this length appears weak with no justification given. While speculative, the cutting regime might have influenced the plant's survival.

Established plant numbers appear to fall annually irrespective of other factors although poor weed control accelerated loss. There was also an unusual degree of skew between the yields of plants within a treatment, with the most productive 50% of plants within the treatment contributing 76%-85% of the shoot production. The reasons for the decline in survival and yield variation are not known and are important areas for further research. The skew in production would appear to suggest there is scope for fairly rapid improvement in yield.

6.6.1. Planting method

Propagation can be by seed, by layering in spring, or by softwood cuttings. Some sources suggest that the seed should be sown as soon as ripe and planted in a cold frame and then planted out in the following spring. Plant nursery advice is to sow seeds outdoors in August or September. Other sources suggest that germination is still good after three months. Layering should occur when the plant is dormant. Cuttings of half-ripe wood (5 - 8cm) can be planted in July/August in a frame. Cuttings of mature wood in November/December in a frame. Layering in spring.

A Canadian paper[59] explored several factors contributing to germination. Light was essential: seeds failed to germinate in the dark and required four 16-hour photoperiods (one per day) for maximum germination. There was no absolute requirement for pre-chilling, but pre-chilling increased germination by 75% in two-month-old seeds and by 164% in 4.5-year-old seeds. Leaching did not affect germination and 500 ppm gibberellic acid enhanced germination only 20%. The seeds were long-lived: there was no decrease in percent germination during six years of dry storage at 5 °C and germination remained high after one year of wet storage at 5 °C. Because Myrica gale seeds often germinate on water-worked substrates, the requirement for extended exposure to light for germination may serve as a mechanism to prevent unsuccessful germination of seeds that are reburied after brief exposure to light as sediments are worked by water.

Many online plant nurseries sell Myrica gale seeds (e.g. https://www.magicgardenseeds.com/Bog-Myrtle-Myrica-gale, https://www.poyntzfieldherbs.co.uk/) and plants (e.g. https://celticwildflowers.co.uk/products/bog-myrtle-myrica-gale, https://www.agroforestry.co.uk/product/myrica-gale/). However, these supplies are intended for garden use and volumes are unlikely to be large enough for commercial production.

Where seed and/or plants are required for commercial production pre-ordering is likely to be necessary allowing nurseries to produce cheaply on a large scale.

Planting of seeds would be possible using a conventional drill and planting of modules by a conventional block planter. Male and female plants must be grown if seed is required.

In the trials, plants were raised in modules and planted by hand at three years on a 0.5m x 0.5m grid suggesting a population of around 40,000 per ha. The field was prepared following conventional ploughing and power harrowing. Planting of the trials was carried out on 9 March 2009 using plants of two heights, i.e. 7-9 cm (from BritishFlora, UK) and 20-40 cm (from Quercus Garden Plants Ltd, UK).

[59] https://cdnsciencepub.com/doi/abs/10.1139/x89-167?journalCode=cjfr Factors affecting germination of Myricagale seeds Christa R. Schwintzer and Andrea Ostrofsky, Canadian Journal of Forest Research

6.6.2. Fertiliser

The trials showed a positive response to nitrogen fertiliser (despite the plant's ability to fix nitrogen). While phosphate, potash and nitrogen did not affect shoot yield, nitrogen doubled shoot yield and tripled oil yield compared to the phosphate application and control. Unfortunately, the modest nitrogen rates tested (30kg/ha N and 60 kg/ha N) were not sufficient to establish the optimum application.

Phosphate application resulted in the largest number of plants changing gender from female to male.

6.6.3. Weed control

Weed control was shown to be a vital input in determining yield and plant longevity. Active management is likely to be necessary. In one trial, use of a mulch and herbicide showed the highest plant survival compared with the untreated control and herbicide alone (at 63%), fresh weight shoot yields of 0.75 t/ha and oil yield of 1.38l/ha. This is around four times higher than where harvested in the wild.

Weed control protocols were included in the trial. Treatments included glyphosate, diquat (no longer approved for use) and propyzamide. The glyphosate and propyzamide were applied in December. A 5cm woodchip mulch was also applied to some plots. The herbicide plus mulch was effective on most sites. Minor use approval would be required for the herbicide use.

6.6.4. Fungal Disease and Pests

The Royal Horticultural Society has not identified any pests associated with the plant. It is damaged by grazing animals and would need to be protected from these larger pests. Plants in this genus are resistant to honey fungus.

6.7. Yield and harvesting

Trials were harvested in August with all stems cut back to 3cm above the initial cut in March. Optimum harvest timing and harvest management (cutting point) require further research.

The trial data shows that there can be considerable seasonal variation with no clarity on the cause of the variation. Thus yield data appears to vary between around 0.6l/ha and 1l/ha. This corresponds to a shoot harvest of around 0.5t/ha. Wild stands have produced twice this biomass and while the oil yield is unlikely to increase proportionately with increased yield, it is likely to increase as biomass is increased.

The skew between plants (50% of the plants yield 75% of the biomass) provides a significant opportunity for development.

7. Mentha aquatica (Water mint)

7.1. Summary

Mentha aquatica (water mint) is a perennial plant that grows in flooded environments with a neutral or alkaline pH. High pH is unlikely on the Holker site without liming and the history of arable cropping may already have raised the pH. Mentha aquatica is rhizomatous so once established it will spread. It will grow to approximately 90cm and produce an attractive pink flower. Other cultivated Mentha spp. are replanted every three years and this may prove necessary. Mentha aquatic is cultivated in other countries (France and USA) despite being native to the UK.

Mentha species tend to hybridise and, for example, M. aquatic crossed with M. spicata (spearmint) has given rise to peppermint which is globally the most widely cultivated mint. There is also considerable variation within the M. aquatica species. Work on other very similar mints means that agronomy, in many respects, is more developed than for other paludiculture crops.

Mentha spp. are widely cultivated as edible herbs (sold fresh or dried), for herbal teas, to produce citrate oil for use in perfumery and as a flavouring. The cultivated species giving rise to eau de Cologne mint (also known as bergamot mint (and not the same as bergamot oil)) is considered to be a variety of Mentha aquatica. There is renewed interest in using the essential oils from mint species (which have disinfectant properties) as natural food preservatives and antioxidants. There is some evidence for anti-inflammatory and cardio-protective effects.

The proposal is to grow the mint for its essential oil (all parts of the plant contain the oil) making the most of the opportunity to build on the local branding and footfall to promote a local, attractive, environmentally friendly product. Additional sales should be developed online. If successful, production can be expanded for the wider perfumery, flavourings and cosmetic industry where the unusual native plant may provide a distinct product and thus value. It differs from the commonly produced spearmint and peppermint oils.

Peppermint and spearmint are cultivated widely (in Europe, USA, and South America). While husbandry is not identical (spearmint is grown on conventional arable land with irrigation) spearmint and peppermint have been extensively researched and the plants are similar in many respects. As a hybrid vegetative propagation is necessary. Spearmint will survive short periods of waterlogging. The best soils are found to be deep, well-drained, and rich in humus, with good moisture retention.

There is considerable information on the commercial production of these very similar species. It is likely that the relative difficulty of managing paludiculture crops compared to more conventional crops, and the relatively unusual environment needed, means that the benefits of Mentha aquatica have not been fully explored and thus represent an opportunity.

Control of the water table is important to reduce the cost of harvest and ensure plants are evenly distributed at establishment. Plants can be established from seed or by cloning but because of the variation it is usual to clone by planting short lengths of stem. Since the objective is to extract the oil, harvesting could be managed via a domestic lawn mower with a collection box or on a larger scale forage harvester. The significant plant variation might allow selection and then cloning of desirable types.

Extraction of oil is generally carried out by steam distillation. Steam distillation can be undertaken at a small artisan level (at a capital cost of under £200) or on an industrial scale (with a capital cost of over £60,000).

By analogy with other Mentha spp., it would be expected that yields of at least 100kg/ha of oil could be obtained (oil content of leaves around 40%). While it would be hoped that a premium might be obtained, peppermint oil retails for £1.89-5.30/10ml and in bulk at £30/kg. This should gross at least £3,000 per ha. Lower volume sales at a premium price should be targeted until the plant is established as a viable option.

A branded product 'Allplant Essence Organic Mint' is organically cultivated in Northern California (1 kg Allplant Essence® Organic Mint contains the essence of approx. 200 g fresh plants.). Klorane specialises in aquatic mint products and cultivates water mint organically in South West France.

7.2. Market

Table 12: UN Data shows world production of peppermint and spearmint

	2020	2021	2022
Production (tonnes)	48,435	38,008	51,081
Yield (kg/ha)	16,085	18,359	30,939
Harvested area (ha)	3,011	2,070	1,651

While these mints are not Mentha aquatica, the data shows the production of a closely related Mentha species and, if a distinct flavour variant can be found, the data indicates the potential market substitution possible. It also shows that increasing yields are making up for reduced harvested areas and in all likelihood a falling cost of production. There is very little production in Europe although Morocco is one of the major producers (accounting for around 80% of the production recorded by the FAO).

Table 13: Price analysis

Supplier/product	Web address	Pricing	£/l
Lavera (organic water mint)	https://www.lavera.com/uk/products/ingredients/organic-water-mint	Products only	
Scents, Soaps & Candles. Wild mint fragrance oil	https://scentssoapsandcandles.co.uk/	50ml £6.90 5l £266.46	138 53
Cosy owl. Wild mint fragrance oil	https://cosyowl.com/fragrance-oils	10ml £1.95 500ml £32.64	195 65
Mystic Moments. Peppermint essential oil	https://www.mysticmomentsuk.com/	10ml £3.95 200kg £7,086.95	395 35
Ingredients Store. Peppermint essential oil	https://www.theingredientsstore.com/	100ml £8.11 5kg £107.52	81 22

The variation in price suggests that marketing is a particular determinant of price.

7.3. Threats and Competition

The genome of Mentha species has been explored and gene-edited versions are likely to be developed targeting specifically favourable combinations of oil. This is not necessarily a threat since the development could be used to emphasise the "purity" of the production.

Where the oil is ingested, the EU has a maximum tolerated daily intake (TDI) of menthofuran and pulegone of no more than 0.1 mg/kg of body weight (European Medicines Agency, 2005).

7.4. Environmental Issues

Mentha Aquatica meets many environmental targets without subjecting the neighbouring SSSI to the threat of invasive species or genetic contamination. The plant is already common through-out the UK with the exception of the Scottish Highlands.

Since water mint grows fully submerged and is a perennial crop, preservation of soil carbon is likely to be good. It is also particularly attractive and provides a useful source of pollen and nectar for pollinators.

7.5. Mentha Aquatica Cultivation

Several papers (and references included in these papers) have been used to compile this section[60] and several US production guides provide useful guidance on spearmint and peppermint production[61] [62] [63].

7.5.1. Site Preparation

Most Mentha species are sensitive to water stress so water levels need to be capable of being maintained. This means the soil surface needs to be level and any ditches capable of filling and emptying as required. Even for spearmint, the advice is to use furrow irrigation and water at least three times per week.

Mint is tolerant of a wide range of pH and soil types but ideally requires a pH of 5.5-6.5 and organic soil. Mentha aquatica is a vigorous rhizomatous perennial that grows in permanently moist soil or shallow water up to 15cm deep and with the top of the plant and flowers emerging above the water line.

7.5.2. Plants and planting

Mentha species will grow from seed, lengths of stolon and shoots taken when actively growing. Seeds can be purchased retail for £3.00 for approximately 3,000 seeds (https://www.naturescape.co.uk/product/water-mint/). Naturescape also produce plugs and pots and is amenable to contract production.

While seed allows relatively cheap and easily mechanised planting there is likely to be a high variability and establishment is less assured. Thus despite the availability of viable seed (except where hybrids are grown), it is more usual to plant from 3cm lengths of green shoots, underground stolons or root turions (buds). It is estimated that 1ha of plant material will produce sufficient fragments for 7-10ha. In the appropriate environment, it establishes well and grows quickly to colonise the area planted within one year.

Viable plant material for Mentha aquatica is unlikely to be available for purchase and it is suggested that a dual approach is taken to establishment in any trial: 1) a contract is agreed to establish the plant in peat blocks for manual or mechanised planting 2) seed is planted accepting the increased variability. This would allow the two options to be explored in terms of percentage establishment, period until harvest and relative variability. Realistically the cost of peat blocks could be a prohibitive £40,000/ha (depending on plant density – see below) while seed would cost, at most, £1,000/ha. Seed should be pressed into the soil but not covered.

Once established this material could be used for populating any expansion of production.

Seeds are usually planted from January until the end of April. For most Mentha species plant fragments are planted 7 to 10 cm deep in a shallow fallow with a row-to-row distance of 45–60 cm either manually or mechanically. Water is needed at planting to maximise establishment.

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[60] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6161068/ Plants of Genus Mentha: From Farm to Food Factory Bahare Salehi, Zorica Stojanović-Radić, Jelena Mate, Farukh Sharopov, Hubert Antolak, Dorota Kręgiel, Surjit Sen, Mehdi Sharifi-Rad, Krishnendu Acharya, Razieh Sharifi-Rad, Miquel Martorell, Antoni Sureda, Natália Martins, and Javad Sharifi-Rad

[61] https://ag.purdue.edu/department/arge/_docs/ppp-103.pdf Mint Production and Pest Management in Indiana Steve Weller, Ralph Green, Jr., Cheri Janssen, Fred Whitford,

[62] https://agsci.oregonstate.edu/coarec/peppermint-0 Peppermint (includes research reports) Central Oregon Agricultural Research and Extension Center

[63] https://coststudyfiles.ucdavis.edu/uploads/cs_public/98/24/9824704c-852f-49e2-9f0c-fc78c330d0d3/peppermintim2011.pdf, Sample Costs to Establish a Mint Stand and Produce Peppermint Oil, Rob Wilson, Daniel B. Marcum, Karen M. Klonsky Richard L. De Moura

Peppermint density was reported to optimise at 75 cm × 45 cm[64]. This would suggest a plant density of around 30,000 plants per ha. This trial was carried out in a very different climatic regime. Wikifarmer[65] suggests a planting density of 70,000 to 90,000 plants per ha for peppermint. This higher density, intuitively, appears to be more appropriate for a potentially higher-yielding site such as Holker where land value is high.

7.5.3. Fertiliser

Nitrogen fertiliser (potentially as manure) is likely to be needed with guidance from Bahre Salehi et al suggesting 100-120kg/ha nitrogen for Mentha aquatica (the US production guides for peppermint show an application of well over 200kg/ha). Typical replacement rates of 40kg/ha potash, 50kg/ha phosphate and 20kg/ha sulphur are also suggested for some Mentha species. Trials have also shown the benefit of organic manures and lime[66].

7.5.4. Weed control

It would be expected that the water environment would reduce the need for weed control although water-based weeds such as Typha spp. are likely to colonise over time.

Work on spearmint and peppermint has shown that pendimethalin, oxyfluorfen and linuron have provided excellent control of annual weeds[67]. These herbicides are approved for use in the UK although approval for minor use may be required.

7.5.5. Pest and Disease

There are a large number of pest and disease threats to Mentha spp. - fungi, insects, nematodes, bacteria, viruses and phytoplasma. Although it is not clear how the distinct conditions for growing Mentha aquatica influence the disease spectrum. Puccinia menthae (rust), Alternaria alternata (leaf spot); Verticillium dahliae (wilt), Phoma stasserti (stem rot), Rhizoctonia solani (root and stolon rot) and Erysiphe cichoracearum (powdery mildew) are recognised threats and can be controlled most reliably with fungicides although botanicals and biopesticides are also available. As discussed in other sections minor use approval may be required.

7.6. Yield and harvesting

The number of cuts and the timing of cuts are both variables. The work is not complete for Mentha aquatica but for other mint species, the crop is harvested when plants are in full bloom, in the late morning on a dry sunny day. One or two crops may be taken depending on growing conditions. There is variation in oil content and yield between cuts but generally the plant gives the best crop in the second and third year after planting.

According to the production guide peppermint is usually swathed and left to dry for up to three days before being collected for distillation.

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[64] https://www.sciencedirect.com/science/article/abs/pii/S0926669012005262 Improving production potential and resources use efficiency of peppermint (Mentha piperita L.) intercropped with geranium (Pelargonium graveolens L. Herit ex Ait) under different plant density Rajesh Kumar Verma, Amit Chauhan, Ram Swaroop Verma, Laq-Ur Rahman, Anand Bisht

[65] https://wikifarmer.com/library/en/article/peppermint-planting-distances-and-number-of-plants-per-acre

[66] https://www.researchgate.net/publication/273716408_Biomass_and_essential_oil_production_from_menthe_is_influenced_by_compost_and_lime Biomass and essential oil production from menthe is influenced by compost and lime Patricia Alves Casaes Alves1, Eduardo Gross, Larissa Corrêa do Bomfim Costa, VerônicaCordeiro Silva, Fábio Mathias Correa and Rosilene Aparecida de Oliveira

[67] https://pubmed.ncbi.nlm.nih.gov/28503740/ Weed interference with peppermint (Mentha x piperita L.) and spearmint (Mentha spicata L.) crops under different herbicide treatments: effects on biomass and essential oil yield Anestis Karkanis, Christos Lykas, Vasiliki Liava, Anna Bezou, Spyridon Petropoulos, Nikolaos Tsiropoulos

There is a large variation in oil content with site and no doubt plant clone and this would form an important part of any research work. Mentha aquatica possess 26 essential oil chemotypes isolated from aerial parts, leaves, inflorescences, seeds or stolons. In addition, linalyl acetate, piperitenone oxide, pulegone, menthone, elemol, caryophyllene oxide, α-terpinene, isopinocamphone, linalool, menthol, menthyl acetate, germacrene D, dihydrocarveil acetate, menthyl esters and α-pinene are also found in Mentha aquatica essential oil.

Trials on spearmint suggest that the highest oil yield is obtained at full flower[68] although the highest biomass yield occurred after this. This seems to be the recommended harvesting period for other Mentha species. In this Turkish trial, dry matter yields were over 10t/ha DM and oil yields were a little over 80l/ha cut at the optimum time. There was a high annual variation.

The highest oil yields of peppermint oil are associated with the environmental conditions of long days and cool nights. This trial reported oil yields of 118.9 kg ha−1 in 2003 and 119.2 kg ha−1 in 2004 for harvest dates of July 29 and August 13, respectively[69].

The plant is ready for harvest in late July or early August. It is mowed and then collected with a forage harvester. The extracted oil is stable for at least two years.

8. Angelica archangelica (Angelica)

8.1. Summary

Angelica is a 2-3m high biennial, flowering in the second year (although there are cultivated perennial types and removal of flower heads will extend the plant life). The roots, leaves, seeds and young stems are edible and have a flavour similar to liquorice. The leaves can be mixed into salads, the shoots used as celery or turned into candy, and the leaves, seeds, and roots can be used for making tea. Angelica root is used as a dry flavouring in most gins (with juniper and coriander) so demand has increased in response to the growth of gin sales. Traditionally it was candied for cake decoration.

The major market is an essential oil distilled from the plant's roots used in perfumes, colognes, fragrances, cosmetics and liqueurs such as including in Benedictine and Chartreuse. It is a traditional medicine although its benefits are unproven[70][71]. The oil is found in other parts of the plants but is strongest in the roots. Roots contain 0.5−1.0%, the fruits 0.6−1.5% and the leaves contain 0.2−0.3% of essential oils (Galambosi, 1994[72]).

[68]https://www.researchgate.net/publication/264698620_Influence_of_different_harvest_times_on_the_yield_and_oil_composition_of_spearmint_Mentha_spicata_L_var_spicata/link/53ec7f620cf250c8947cbd87/download?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoicHVibGljYXRpb24ifX0. Influence of different harvest times on the yield and oil composition of spearmint (Mentha spicata L. var. spicata)" Süleyman Kizil and Özlem Tonçer

[69] https://www.sciencedirect.com/science/article/abs/pii/S0378377405003045 Effect of irrigation and harvest timing on peppermint oil yield in California Daniel B. Marcum, Blaine R. Hanson

[70] https://www.ema.europa.eu/en/documents/scientific-guideline/final-reflection-paper-risks-associated-furocoumarins-contained-preparations-angelica-archangelica-l_en.pdf Reflection paper on the risks associated with furocoumarins contained in preparations of angelica archangelica l European Medicines Agency Committee on Herbal Medicinal Products (HMPC)

[71] https://www.efsa.europa.eu/sites/default/files/topic/ndaart13ref04.pdf

[72]https://www.researchgate.net/publication/231545076_Characterization_of_volatile_composition_and_odor_of_angelica_Angelica_archangelica_Subsp_archangelica_L_root_extracts Characterization of volatile composition and odor of angelica (Angelica archangelica Subsp. archangelica L.) root extracts Kaisli Kerrola, Bertalan Galambosi, Heikki Kallio

Angelica can potentially be a strong local brand with the opportunity for wider sales. The whole plant stem, leaves and root can be sold through the retail outlets on the estate.

While it is considered a paludiculture crop, it grows best in saturated organic soils adjacent to water rather than on flooded land. This should assist in maintaining water levels in the neighbouring SSSI but not as effectively as where the land is flooded (e.g. for Mentha aquatica or T. latifolia). Soil should be slightly acidic.

The harvest of the roots is particularly demanding in a paludiculture situation although possible on an appropriate freely draining soil type if water levels can be managed. The action of harvesting the root is also likely to reduce the carbon preserved in the soil although hopefully maintaining levels at a higher level than conventional arable cropping. The leaves can be harvested once or twice but the roots, the main harvest, only once in the crop's life.

The harvest of the roots makes it particularly important that the soil is light-textured and free from stones. It might be possible to grow on ridges which would maintain proximity to water while making harvesting easier. It is likely that in this situation modified drilling equipment would be needed for planting. Control of the water level is crucial.

In contrast to most of the other crops, Angelica is likely to benefit from rotation and would need to be integrated with other crops such as those described. Given the potential area, this might help manage risk. Agronomic advice is particularly variable and would need to be developed.
The commercial gross return is dependent on the price and volume that can be marketed via the current estate outlets. In contrast to other crops, there is also a choice of sales stream: dried herb (including for the manufacture of gin), dried seed, viable seed, pot plants, dried root, candied angelica and essential oil. The sale of the dried root would potentially gross (1.6 tonnes/ha dry weight by £70/kg) over £100,000 per ha and conversion to essential oil would realise around £75,000 per ha. It is emphasised that this would be for a relatively small production volume and it would be relatively easy to flood the market. However, the growth in the gin market means that there is scope to sell larger volumes albeit at a lower price.

As with other paludiculture crops commercial success also depends on the cost of creating an appropriate site and, in the future, agronomic development and plant selection.

This review makes particular use of the undergraduate thesis by Madeliene Klein "Angelica archangelica"[73].

8.2. Market

According to 'Proficient Market Insights' the global angelica root oil market is expected to reach $873.74m in 2024 and is projected to reach $1,251.62m in 2031 with an annual growth of 5.3%.

There are some key players: Albert Vielle (France), Berje (USA), Elixens (France), Fleurvhem (USA), Interdonti (France), Ungererer and Co (USA), Penta Manufacturing (USA) and Robertet Group (France).
The top exporting countries are China, India and Belgium. Several European countries produce angelica oil including Hungary, Switzerland and Poland.

[73] https://stud.epsilon.slu.se/818/4/Kylin_M_100128.pdf Angelica archangelica L. 2010 Madeleine Kylin69.3

8.3. Pricing

An important aspect of the crop is the number of products that can be produced on a small scale. As seen for other proposed products the price is variable and dependent on the packaging and targeting. The products are mainly imported so price gains from the cost of transport.

Comparison is consciously with the retail price since this is seen as the route to market for Vitagrass Farms (Holker) Ltd.

Table 13: Price analysis

Supplier/product	Web address	Price	£/l
Oils4life	https://www.oils4life.co.uk/product-page/angelica-root-essential-oil-angelica-archangelica-1	2ml £10.00 100ml £250	5,000 2,500
Oshadhi (root) ORGANIC	https://oshadhi.co.uk/angelica-root-organic-essential-oil/	1ml £21.49 3ml £56.25 3ml £40.99 (not organic)	21,490 18,750 13,663
Amphora Aromatics Limited	https://www.amphora-aromatics.com/speciality-pure-essential-oils/angelica-root-essential-oil-10ml-info	10ml £48.60	4,850
Essential oils online	https://www.essentialoilsonline.co.uk/acatalog/Angelica-Root-Essential-Oil--Angelica-Archangelica--858.html	2.5ml £10.80 10ml £30.00	4,320 3,000
G Baldwin & Co	https://www.baldwins.co.uk/baldwins-angelica-angelica-archangelica-essential-oil	5ml £28.85 50ml £185.59	5,770 3,710

Dry Angelica root		Price	£/kg
G Baldwin & Co (dried root)	https://www.baldwins.co.uk/baldwins-angelica-root-angelica-archangelica	25g £3.75 500g £34.65	150 69
Just Ingredients	https://justingredients.co.uk/products/angelica-root-cut	100g £9.19 17.8 kg £3,585	92 201
DG Store UK	https://dgstoreuk.com/products/angelica-root	25g £3.29 1kg £33.29	132 33

Dry Angelica herb		Price	£/kg
G Baldwin & Co (dried root)	https://www.baldwins.co.uk/baldwins-angelica-herb-angelica-officinalis	25g £4.25 500g £39.19	170 78
Woodland Herbs	https://www.woodlandherbs.co.uk/acatalog/Angelica_dried_herb.html	50g £3.40	68
Love Brewing	https://www.lovebrewing.co.uk/	100g £3.75	38

Candied Angelica		Price	£/kg
Buy Whole Foods	https://www.buywholefoodsonline.co.uk/	50g £2.60 4kg £76.24	52 19

Angelica seed (for cooking		Price	£/kg
G Baldwin & Co	https://www.baldwins.co.uk/baldwins-angelica-seed-angelica-officinalis?queryID=b43c8016eceeacc2a668ac9faf63ecc1&objectID=13387&indexName=baldwinsdefault_products	25g £4.95 500g £46.15	198 92

A New Zealand paper[74] estimates that New Zealand gin distilleries are importing 1.5 tonnes per year of angelica root at €300/kg (about £150/kg). UK demand is likely to be even higher.

8.4. Threats and Competition

Similarly to sphagnum moss, there is a threat that suitably equipped farmers with access to irrigation would produce at a considerably lower cost. However, in contrast to sphagnum the local branding and retail should mean that the price is more robust.

The major threat is an increase in pests or diseases, damaging production with consequent loss of consistency needed to develop the market.

There are areas where more research is needed. For example, consistency of establishment needs to be improved and basic agronomic inputs for the site need to be understood (e.g. plant density, weed control, and pest/disease management.

8.4.1. Site Preparation

Soil pH should be between 4.5−7.3 while some sources suggest an optimum of a slightly acid 6.3 in keeping with a largely rain-fed site. The site should be stone-free. Ideally, the soil should be free draining once the water table is lowered. A fertile high organic matter soil type is likely to be most suitable.

Soil preparation should remove impedances to root growth. Ideally, this will mean ploughing or deep subsoil cultivation such as provided by winged tine implements.
While not discussed in any of the research viewed, the plant might be best suited to planting on ridges in otherwise flooded soil. This would ensure the plant was adjacent to water but would also make it easier to harvest the roots following the lowering of the water table.

8.4.2. Planting

Seed management can prove a challenge. Seed rapidly loses viability if not stored under cold conditions and should be planted in the autumn of the year it is produced. Advice on optimum conditions is variable but the consensus seems to be that: 1) The seed needs light for germination 2) A cold shock may be beneficial either pre-planting or once the plant is in the ground 3) Soil temperature for growth needs to be around 20^{o}C. Some sources suggest heat treatment at around this temperature before planting to break dormancy following soaking and before drying. The RHS (Royal Horticultural Society) and several seed suppliers suggest (only) that the seed requires light to germinate but mention no other factors. It appears that germination may be variable but once established (despite being a biennial) it is likely to prosper.

[74] https://www.venture.org.nz/assets/Uploads/Gin-Blueprint-Final.pdf Gin Botanicals THE OPPORTUNITY FOR TARANAKI, NEW ZEALAND Venture Taranaki

Seed rate guidance varies between sources[517552]. On balance, the data suggests a target population of around 5-6 plants per m^2 from applying a seed rate of 10-12kg/ha (some sources suggest that the seed rate may be as low as 4kg/ha and as high as 20kg/ha). Thousand grain weight appears to vary enormously with one source suggesting a thousand grain weight range of around 2.0g to 8.5g. The typical rate appears to be around 5gm (approximately the same as oilseed rape). Germination is low at 60-70% and relatively long at 4 weeks. Several sources suggest wide rows of 50cm or more.

Small seed drills are available that would allow mechanised sowing but the seed must remain on the soil surface.

Transplanting may also be used but this is comparatively expensive and risks damaging the long tap root.

Some sources suggest that the stand may be maintained by leaving some rows unharvested to seed the area to maintain production. Otherwise, flowering heads should be pruned.

8.4.3. Fertiliser

A relatively high nutrient level is required such as appropriate to an organic soil.

The papers reviewed provide inconsistent fertiliser recommendations. There is agreement that fertiliser demand, particularly potash, is high and that high nitrogen application increases stem production at the expense of root growth. Given the relatively small area grown and the range of locations, it is highly unlikely that the recommendations are rigorous.

Peter Jakab et al[76] are fairly typical in recommending 50-70 kg/ha of nitrogen, 80-100kg/ha of phosphate and 120-180 kg/ha of potash. If the site is relatively fertile the premium for organic production might make application unnecessary.

Trace element deficiency (e.g. boron and manganese) is a threat to crops grown on organic soils but can be treated on identification of the symptoms.

8.4.4. Weed control

The slow rate of initial growth means that weed control is particularly important. The weed burden is likely to be particularly high on the organic soil type. In practice, the best results are likely to be achieved from a pre-planting application of glyphosate. This may be followed by inter-row cultivation.

Jovan B. Lazarević tested several mulches[77] and found that an agro-textile waterproof foil was 100% effective (and more effective than herbicide).

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[75] https://www.lbtu.lv/sites/default/files/files/lapas/Manual_Entrepreneurship_in_rural_areas_2018.pdf "Entrepreneurship in Rural Areas through the production and exploitation of medicinal and aromatic plants" "Dana Maria Bobiț, Mariana Ciufu, Viorica Ghinea, Anna Kiss, Lāsma Līcīte, Aina Muška, Līga Paula, Dina Popluga, Lorena-Andreea Urse, Lucian Urse"

[76] https://core.ac.uk/download/pdf/229449263.pdf Production and use of angelica in medicine and environmental protection Péter Jakab, Júlia Hupuczi, Yoshitaka Wachi, Tímea Süli-Zakar

[77] https://www.researchgate.net/publication/348700255_Weed_control_in_angelica_Angelica_archangelica_L/figures?lo=1 Weed control in angelica (Angelica archangelica L. Jovan B. Lazarević, Ana Dragumilo, Tatjana Lj. Marković, Dragana Bozic

8.4.5. Pest and Disease

Unusually, the crop appears to suffer from a large number of pests and diseases despite a low area. Some of the pests such as bean aphids (aphis fabae) and diseases such as sclerotinia are mobile and have a common host that already occupies a large area. Many of the insect pests are also hosted by other umbellifera plants such as hogweed and celery. It would be hoped that the relative lack of the mainstream crop near Holker would reduce the risk at least in the short term. Not all the pests and diseases listed are common in the UK.

Table 14: Disease and pest analysis

Site of attack	Disease	Pest
Root	Rhizotonia crocorum Fusarium	Dysaphis (was Yezabura) angelicae (aphid also found on hawthorn) Scarabaeoidea subfamily Arvicolinae (beetle) Dasypolia templi (Brindled ochre moth found SW UK, hogweed) Ephestia elutella (Cacao moth tropical but occasionally found in the UK) Stegobium paniceum (biscuit beetle, common UK) Plodia interpunctella (Indian meal moth, food warehouses) Hepialus sp. (Ghost moth larvae (etc.))
Leaf	Erysiphe umbrelliferarum Plasmopara nivea Puccinia engelicae Phyllachora angelicae	Orthops (was Lygus) campestris (Capsid Bug) Empoasca (was Chlorita) flavescens (Leaf hopper)) Eupteryx atropunctata. (Bug, southern England) Philophylla heraclei. (celery or hogweed fly) Cnephasia asseclana (was wahlbomiana) (flax tortrix moth) Bourletiella sulphurea. (misspelt in some references. springtails) Papilio Machaon (swallowtail butterfly) Tetranychus urticae (red spider mite) Apodemus sylvaticus (wood mouse)
Stalk/ Leaf stalk	Sclerotinia	Dysaphis (was Yezabura) angelicae Aphis fabae. (black bean aphid) Dasypolia templi
Fruit		Le(u)canium (was pulchrum) rufulum (scale insect) Papilio machaon Phaulernis fulvigutella. (moth) Apodemus sylvaticus

Angelica is also vulnerable to grazing animals and these need to be excluded.

The extensive list of diseases and pests probably overstates the threat at least in the initial years. There are non-chemical treatments for some such as the use of mesh and/or planting companion crops (several of the papers referenced, refer to the insect pests by names that have been superseded).

Where the crop is considered a long-term prospect it becomes important to rotate and by analogy with other crops grow no more than one year in five.

Most of the pests and diseases are controllable with insecticides and fungicides but it is unrealistic to carry the cost in isolation. Ideally, a mutually supportive group to share cost should be formed with the common interest of commercialising the crop (as is potentially available for the sphagnum moss and T. latifolia options).

8.5. Yield and harvesting

Leaves are harvested both manually and via machine harvesting. Leaf harvesting can start when the first true leaf is visible. Harvesting at scale can be via using a forage harvester or on an artisan scale domestic lawn mower and grass box. Harvesting of leaves will almost certainly reduce the root harvest but need to be harvested immediately before harvesting the roots. Where grown as a vegetable the young leaves are most suitable but later harvested plant may still be used as a herb flavouring.

Seed harvesting can be managed with a combined harvester or by hand in the second or third year. Harvesting of some seed is likely to be necessary for ongoing establishment if the crop is rotated as proposed. If the crop is not rotated it appears that rows may be left to reseed the area naturally.

Root harvesting can take place from the first year when the roots reach 50cm in length in the autumn (or in the following spring). Root harvesting follows the removal of stems and shoots. Potato harvesters can be used or it can be harvested manually with garden forks. Once harvested the roots may need to be washed with a jet of cold water. All harvested materials will decay if not used immediately and they are usually dried. To increase the area for drying, roots are usually sliced. The temperature has to be relatively low at a maximum of about 35ºC to avoid loss of oil and can be dried using ambient air.

There is quite a lot of data but the range of reported yields is high, reflecting the relatively few trials carried out and the number of environmentally different locations. If the site can be managed well (for example growing the plant on ridges between wetter troughs and achieving a high establishment through care with planting) the site should produce high yields.

In the early experimental stage manual harvesting is likely to be most appropriate so that harvesting and processing are aligned with minimal investment in drying.

Table 15: Output analysis

	Fresh weight t/ha		**Dry weight t/ha**		**Oil %**		**Oil yield kg**
	Estimated	Range	Estimated	Range	Estimated	Range	Estimated
Root	12	8 to 22	1.6	0.6 to 2.5	0.5	0.2 to 1.0	8.000
Leaf	20	20 to 60	0.7	0.6 to 0.8	0.25	0.2 to 0.3	1.750
Seed	2	1 to 3	1.8	0.8 to 2.5	0.6	0.01 to 2.0	10.800

Many methods for extracting the oil have been tried. The conventional method is steam extraction at 107ºC over at least three hours. Extraction with carbon dioxide, solvent or vacuum distillation, possibly in a multistage process, might become necessary if the enterprise were scaled.

9. Vaccinium species

9.1. Summary

Removal of land from conventional production is likely to have a massive impact on the UK supply of food crops, particularly vegetables. There is potentially an imperative to develop paludiculture food crops. The Vaccinium crop plants provide one of the better opportunities for producing high-value food on paludiculture sites.

There are few successful paludiculture crops and even fewer that supply (market-acceptable) food. However, the Vaccinium genus is one of the few groups of plants that not only originated on wetlands but contain species that have grown in importance as food crops such as Vaccinium corymbosum (Blueberry. Lowbush Blueberry) and Vaccinium macrocarpon (American Cranberry).

Both of these crops are established and produced by growers with crop-specific expertise making it unlikely that a novice grower would be able to compete, and without the infrastructure and established route to market. While this is probably also true of the other Vaccinium plants there is scope to create a new widely available fruit plant (in a similar way to the Blueberry or Kiwifruit). This is likely to be a long-term project but small-scale production and farm shop sales would help fund development.

Vaccinium species are generally perennial, woody, dwarf shrubs producing edible berries that grow on acidic soils on heath, bog or woodland. They tend to have a surface root system that throws up growing stems. There are over 450 species worldwide.

Those plants of interest produce edible berries that are often high in antioxidants and other medically active components. They are described colloquially as “superfoods”.

The USA has successfully established two internationally recognised Vaccinium crops: Vaccinium macrocarpon (American Cranberry) and Vaccinium corymbosum (Blueberry). These are both native to Canada and the Northern USA. They are considered to have been developed relatively recently as commercial crops but both have detailed agronomic information and a range of varieties. Market growth has been exceptional.

Both require a high water table. Vaccinium macrocarpon is flooded twice a year: 1) over winter to protect from frost and 2) for harvest where the combed berries float to the surface for collection. In contrast, Vaccinium corymbosum requires a water table of around 20cm from the soil surface. Where this is not achieved there can be a dramatic difference in growth and yield and even plant failure. Both crops are irrigated when grown commercially. Vaccinium corymbosum is increasingly an established crop grown in polytunnels (often on coir) in the UK.

Both crops could be grown in the UK on suitable sites but require a high level of investment and expertise that is unlikely to be available to a novice grower. Product differentiation to obtain a premium is difficult to identify although there may be a premium from local production and in the case of cranberry, a market for fresh berries. Agronomy, including mechanisation, is developed and the route to market is developed.

The other crops are currently a long way from commercialisation (as are most potential paludiculture crops) but are appropriate to a research project aimed at exploring commercialisation.

9.1.1. Vaccinium myrtillus (Bilberry, Whortleberry, Blaeberry, European blueberry)

Vaccinium myrtillus (Bilberry, Whortleberry, Blaeberry, European blueberry) in Europe and Vaccinium angustifolium (Lowbush blueberry) have been developed in a hybrid form where wild plants are nurtured (herbicide, fertiliser, pest and disease control, etc.) to enhance yield. There is limited cultivation but yields appear to be erratic.

V. myrtillus is a native, calcifugous low shrub that is locally dominant with Calluna vulgaris in well-drained heathlands and moorland, especially in upland areas, and as an understorey in birch, pine and oak woods; it is also common in peat bogs in northern and western Britain. It rarely regenerates from seed.

In contrast, to the other undeveloped Vaccinium species, V. myrtillus (bilberry, whortleberry, and European blueberry) is common in peat bogs although also growing alongside Calluna vulgaris (heather) in well-drained heathland. It can form plant stands suggesting suitability for cultivation. There is a large existing body of research work although most relate to the cultivation of wild stands (Norwegian papers by Rolf Nestby, et al) and some research is negative about the prospects. The main barrier is the inability to reproduce from seed. The fruit has a higher antioxidant content than the lowbush blueberry. It is the best plant-based source of anthocyanins, other phenolic compounds and carotenoids. Researchers at the James Hutton Institute will identify cultivated varieties of blueberries suited to commercial production in the UK although low and variable yields at present make the plant unsuitable for immediate commercialisation. Norway reportedly produced 100,000t from wild plants in 2005.

9.1.2. Vaccinium uliginosum, Bog Bilberry

A low shrub, locally abundant on podsolic or peaty acidic soils in upland dwarf-shrub heaths and blanket bog, occasionally in Nardus stricta–Carex bigelowii heath; also, rarely, in calcareous Dryas octopetala communities on montane ledges. From near sea level at Fara (Shetland) and 40 m at Loch Awe (Main Argyll) to about 1,130 m on Cairngorm (Easterness), but predominantly an upland plant and so unsuited to the coastal area without major agronomic development. It is a British native.

9.1.3. Vaccinium vitis-idaea Cowberry, Lingonberry, Partridge berry

A calcifugous shrub of heaths, both dry and montane, on siliceous upland crags, in the understorey of birch, pine and oak woods on acidic substrates, and on drier hummocks in blanket bogs. It ascends from close to sea level to 1,095 m on Ben Lawers (Mid Perthshire). It is native.

V. vitis-idaea is cultivated to a small extent in the US, Netherlands and elsewhere in Europe. Varieties are available suggesting considerable development. It is also harvested wild. It is a calcifugous shrub of heaths, both dry and montane, on siliceous upland crags, in the understorey of birch, pine and oak woods on acidic substrates, and on drier hummocks in blanket bogs. Cultivation requires light, well-drained soils such as sand or silt loam with 2 to 6% organic matter and a pH range between 4.3 and 5.5. Thus not compatible with maintaining a high water table.

9.1.4. Vaccinium oxycoccos (Cranberry, Marsh cranberry, Small cranberry)

Vaccinium oxycoccos (Cranberry, Marsh cranberry, Small cranberry) is particularly interesting because it is found locally in Holker and is often found in association with sphagnum moss suggesting the possibility of a dual income stream. It is a slender, trailing dwarf shrub of hummocks in bogs, in peaty flushes and transition mires. It is found creeping amongst and over sphagnum moss raising the possibility of inter-row cropping. This would have the advantage of retaining areas in the sphagnum that could seed harvested areas that would also be productive.

The berry is considered to be one of the tastiest native fruit (and superior to V macrocarpon (American Cranberry)). V. oxycoccos has a high nutritional content and provides wide-ranging health benefits. It is particularly high in disease-fighting antioxidants, outranking almost every other fruit and vegetable (including spinach and broccoli). It is rich in vitamins C, A and K as well as flavonoids, which helps to lower the risk of heart problems. It provides other medicinal benefits and can be used to clean silver.

It could be retailed through the existing estate infrastructure as fresh or prepared fruit on a small scale (as jam, or juice) while agronomic expertise and husbandry skills are developed to enable larger-scale production. It is also likely to be in direct competition with V. macrocarpon (American Cranberry) until better established in its own right.

It prefers moist or wet, lime-free soil, rich in peat or a light loamy soil[78]. It also forms a dense ground cover which should make it suited to cultivation.

Grows best in acid soil with a pH of 4.0 to 5.5 with low nutrient levels and a high water table. It is an indicator of coniferous swamps. It grows in bogs and fens in moist forest habitats. The plant's mycorrhizae help it obtain nutrients in this situation. The plant can often be found growing on hummocks of sphagnum mosses.

The plant is not developed agronomically and primary research would be needed to develop it commercially and multiply planting material. It can be grown from seed or cuttings. It fruits from the third year in September and then continuously. Yield declines with age and pruning or periodic burning to maintain vigour and reduce competing vegetation is necessary.

There is very little development work but represents one of the few opportunities where long-term government funding would be justified to kick-start development. This opportunity is too far from commercial development to be a viable short-term opportunity but might provide a useful long-term project.

9.2. Summary of Vaccinia Species identified as potential paludiculture

Table 16: Summary of Vaccinia spp.

		Cultivated commercially	Competitive advantage	Water depth	Native	Vitagrass Farms (Holker) Ltd market strengths	Agronomic strengths
Vaccinium macrocarpon	American Cranberry	Yes	No	Bog	No	Established US crop, Promoted as UK-grown, Fresh	None. Material historic investment. Research within existing producer group
Vaccinium corymbosum	Blueberry. Highbush Blueberry	Yes	No	Heath	No	Established international crop Promoted as UK-grown, Fresh	None. Grown on artificial media. A large body of research.
Vaccinium myrtillus	Bilberry, Whortleberry, Blaeberry, European blueberry	Wild	Yes	Heath	Yes	Higher levels of antioxidants than blueberries. Demand high	Found locally. Enhanced wild production trials. Generally found in forested upland areas
Vaccinium oxycoccos	Cranberry. Marsh cranberry Small cranberry	No	Yes	Bog	Yes	Reported to have a better flavour than American Cranberry. Demand may need to be created	Found locally. Often found in association with sphagnum moss creating the possibility of double cropping

[78] https://temperate.theferns.info/plant/Vaccinium+oxycoccos Vaccinium oxycoccos Useful temperate plants

Vaccinium uliginosum	Bog Bilberry	No	?*	Heath	Yes	Largely novelty only	None although development might uncover un realised strengths
Vaccinium vitis-idaea	Cowberry, Lingonberry, Partridge berry	No	?*	Heath	Yes	Largely novelty only	None although development might uncover un realised strengths

*There is no current commercial production and consequently no established market. However, the current enthusiasm for more exotic berries is likely to provide a niche opportunity both as a novelty product and in top end restaurants where locally sourced, unusual native berries may receive a premium, In contrast Vaccinium oxycoccos (Marsh cranberry) and Vaccinium myrtillus (Bilberry) would be supplied as a premium product into established markets.

The largest barrier for the new Vaccinium crops is a low and erratic yield. This is likely to be all or in part due to the lack of development.

9.2.1. Environment

The proposed Vaccinium species are all native plants. V. oxycoccos and V. myrtillus the two favoured plants for development are already reported on the neighbouring site.

Low yields are likely to make the fertiliser demand low. As for any crop, nutrients removed ultimately need to be replaced to avoid a decline in yield and to maintain a sustainable system. At the site of application there is no material difference in environmental terms, whether the nutrient is obtained from mineral deposits or organic sources. Organic sources tend to lead to more run-off and application less targeted. Conversely, mineral deposits are not renewable. In contrast, nitrogen, whether organic or manufactured, can be renewable. Artificial nitrogen fertiliser at present has a high carbon footprint (equivalent to that of livestock producing manure). This was not traditionally the case and may not be in the future. Artificial nitrogen fertilisers are subject to less run-off and better nutrient targeting (where applied appropriately than their organic equivalents).

9.2.2. Other species

V. angustifolium and V. myrtilloides were excluded as non-native species from northern North America. Both are important horticultural crops grown on land not suited to other crops. These were domesticated in the 19th Century and there were 1,000 producers in 1990, growing 113,000 ha and producing 12,700 tonnes[79]. Much of the development was from the cultivation of plants growing on abandoned farmland.

9.3. Cultivation

There are a large number of excellent guides published in the USA and Canada that describe in detail the management of V. macrocarpon (Cranberry) and V. corymbosum (Blueberry). These guides provide a framework for developing other Vaccinium species such as V. macrocarpon and V. oxycoccos the species of most potential interest. There is no point in regurgitating the guides but key points have been summarised below to explain some of the potential complexities of production and provide an indication of the development that might be applied to the undeveloped UK Vaccinium species. The references also provide some insight into the scale and sophistication of development that is needed to develop other potential paludiculture crops.

[79] Kinsman GB (1993) The history of the lowbush blueberry industry in Nova Scotia 1950 – 1990. Blueberry Producers' Association of Nova Scotia, March 31 1993, 154 pp

There are many common features. All the Vaccinium species considered require organic soils with a low pH. They require a free draining topsoil, ideally of sand, and a high water table. The genus tends to benefit from irrigation. They can withstand short periods of flooding. Fertiliser is usually applied at establishment and to replace nutrients lost in the harvested fruit. Fertiliser may also be required for acidification.

The establishment can be from plant fragments or in some cases seeds. In general plant plugs are used. The plants form a large root mass in the surface layers of the soil. Flowers are insect-pollinated and they may not fruit for three years.

Longevity where plants are managed (preventing excessive root mass and removing the oldest growth) can be many years and in the case of commercial American Cranberries some plant stands are over 100 years.
Yield varies between years and there is a large genetic variation and thus big potential gains from plant selection.

9.4. Vaccinium macrocarpon (American Cranberry)

9.4.1. Sources of information

These YouTube clips show the scale of production, the precision required and the established expertise. While they all relate to Cranberry production they are also illustrative of issues that need to be addressed by many paludiculture crops if they are to become commercial opportunities.

- https://www.youtube.com/watch?v=pGWP86dZ-_0 (planting, varieties, pollination)
- https://www.youtube.com/watch?v=H8NMzQns3xw
- https://www.youtube.com/watch?v=XZPXQ7nw_9Y
- https://www.youtube.com/watch?v=zFpwGBjhB2g (dry harvesting machinery, wet harvesting machinery, grading, low tech)

These production guides provide a useful introduction to the agronomic aspects of production.

- https://ag.umass.edu/cranberry/publications-resources/cranberry-production-guide Cranberry Production a Guide for Massachusetts University of Massachusetts Cranberry Station College of Natural Resources and the Environment East Wareham, MA
- https://www2.gov.bc.ca/gov/content/industry/agriservice-bc/production-guides/berries/cranberries Cranberries British Columbia. This site includes a large number of links to sources of information on Cranberry Production including fertiliser, herbicides, pests, diseases and varieties.
- https://www.cranberries.org/how-cranberries-grow
- https://blog.firsttunnels.co.uk/how-to-grow-cranberries/#details-about-cranberries UK gardening advice

9.4.2. V. macrocarpon (American Cranberry) overview

The water table needs to be capable of management, the site should be unshaded and the soil must have a very low pH of 3.3 to 6 maintained with applications of ammonium sulphate fertiliser and low pH water. Cranberry growing areas are known as bogs. These areas range from 5 to 40ha and are surrounded by ditches to provide water and allow drainage.

Soil is usually alternate layers of sand and organic matter. Sand is applied every 3-5 years to a depth of about 25mm. This stimulates organic matter decomposition (nitrogen release and relief of root congestion) and suppresses several pests and diseases. Sanding improves soil drainage and may physically strengthen peat soils so that mechanical operations are easier. Below the layers, there should be over 0.75m of peat but also a hard pan at about 2m. The water table should be capable of maintaining at 150mm to 45mm below the surface to ensure adequate water while maintaining aeration.

Cranberry production in the USA involves enormous volumes of water. Water used to flood the sites in winter, to reduce frost damage, and for harvesting, is not consumed and there is usually a large storage area. Water used for irrigation and plant establishment is lost.

Once established the plants will last at least 50 years. Replanting takes place when better varieties are available or following disease loss. Planting is expensive, the production guide quotes $10,000 to $25,000/acre (about £20,000 to £50,000/ha) in 2008 for traditional planting of cuttings. These are obtained either from severe pruning of existing beds or bought in. These may be up to 450mm long. Allowing for inflation, costs are potentially double this although new beds will not require clearance and fumigation. The planting rate is suggested at 2.5 tonnes per ha of cuttings. The material spread on the surface and disced in.

Plants are also available as rooted plugs and planted at around 110,000 to 125,000 per ha. The use of plugs (likely to be around 50p/plug) is also considered to reduce the need for weed control. Planting is with a modified strawberry planter. Micropropagation is also used to produce disease-free planting material.

Full harvest is usually reached three years after planting. Yields are variable with quoted state yields varying from 10 to 25 t/ha.

Irrigation is considered vital. Some systems are sophisticated with internet-enabled automated irrigation systems using sensors placed within the cranberry vines to monitor temperature and other weather conditions.

Fertiliser is applied to replace nutrients lost from harvest and initially to assist plant establishment. Ammonium sulphate is applied to help maintain acidic conditions.

There are several herbicides used and hand weeding is also practiced particularly in the early establishment years. Crops are occasionally pruned to remove excess runners and old, long upright shoots and to facilitate the use of dry harvesting equipment.

Insect pollination is vital at flowering and while not essential, most growers bring in honey bees or bumble bees to improve success rate. This can have a material impact on yield.

There are two types of harvesting. Around 5% of the US area is dry harvested and the remainder is wet harvested. Dry harvest is for fresh sales. Mechanical harvesters are used that comb the pushes without flooding. The fruit is then conveyed into a burlap bag (or historically a wooden box). Combing is used for harvesting some of the other Vaccinium species.

The wet harvest is made into juice, sauce, dried cranberries and nutraceutical products. Cranberries have pockets of air inside the fruit and, as a consequence, float. The bogs are flooded and the vines are beaten with mechanical devices, to free the berries from the vines, allowing them to float to the surface. Wooden or plastic "booms" are used to round up the berries, which are then lifted by a conveyor or pumped into a truck to take them to the receiving station for cleaning.

Ocean Spray, a farmer cooperative with over 700 members and 2,000 employees, dominates the marketing of Cranberries in the USA. Ocean Spray undertakes processing, advertising and the development of new products. They do not appear to have a role in plant breeding or agronomic development. Work is carried out by universities on behalf of growers.

Table 17: FAO estimate of World cranberry production

	Tonnes
2020	533,514.39
2021	491,737.31
2022	582,923.64

Source: FAO[80]

The variation shows the impact of weather changes, a feature of many of the Vaccinium crops. Most production is in the USA.

9.5. Vaccinium corymbosum (Blueberry. Highbush Blueberry)

9.5.1. Sources

The following YouTube videos provide useful information:

- https://www.youtube.com/watch?v=aB9U1wTsx2c History and industry creation and planting.
- https://www.youtube.com/watch?v=zzOGutpJb1M Site selection and preparation.
- https://www.youtube.com/watch?v=XarFNbN04Io Planting.
- https://www.youtube.com/watch?v=tDk6Ex95Cbc Site preparation and establishment.

The following sources provide useful production guides:

- https://extension.psu.edu/highbush-blueberry-production#:~:text=Highbush%20blueberry%20plants%20require%20annual,fruit%20buds%20are%20easily%20recognizable .
- https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/horticulture/commercial-fruit-production/NRAES-055_LowRes.pdf
- https://extension.umaine.edu/publications/2253e/#:~:text=Selecting%20and%20Preparing%20a%20Planting%20Site,-Choose%20a%20planting&text=Blueberries%20prefer%20a%20well%2Ddrained,sawdust%2C%20and%2For%20compost

[80] https://www.fao.org/faostat/en/#data

9.5.2. V. corymbosum (Blueberry) overview

Vaccinium corymbosum (Blueberry. Highbush Blueberry) is a common fruit in the UK noted for its high level of antioxidants. It can be juiced or converted to jam. In the US it is grown as a 'Pick Your Own' crop.

While V. corymbosum were first cultivated in 1908 they only took off as a crop from the 1950s (there were about 80ha in the 1930s). They are now grown globally, including in the UK, where they are grown often on coir in polytunnels. There are many varieties and different management systems developed.

Table 18: FAO estimate of World blueberry production

	Tonnes
2020	1,032,358.87
2021	1,153,233.78
2022	1,228,595.98

Source: FAO[81]

V. corymbosum grows best on very acid, organic (above 3%) sandy-loam soil with an optimum pH of about 4.5 (and tolerate +/-1 point). Five to six samples of bulked soil are recommended per 4 ha with separate topsoil and subsoil samples. Sulphur (as elemental sulphur or aluminium sulphate) can be applied for acidification. These soils were historically considered to be of very low quality. Soil should be friable to allow root growth.

The plant produces a bush of 2 to 2.5m. Vernalisation is required for fruiting. Most roots are close to the surface but some will go down as far as 1m.

V. corymbosum is sensitive to both stress from drought and from too much water. Blueberries can be flooded when dormant but when growing the soil should be aerated. Where soil floods they are often grown on raised beds. Drainage from the surface needs to occur within about 24 hours.

Irrigation is normal and water may require acidification. The water table should ideally be around 30 to 60 cm from the soil surface. Drainage channels may be cut between the plant rows. Site preparation may require levelling so that the water table is at a constant depth from the soil surface.

Propagation is from softwood or hardwood cuttings. Hardwood cuttings taken in the spring before growth starts may be planted as 30 cm whips. Softwood cuttings are usually shorter at 20 cm and taken when leaves begin to sprout but before bud growth. Planting is at the onset of spring.

Propagation of the shoot tip in agar can be used to produce disease-free plants. Planting may also be via seed (after cold treatment and in high light levels) or by budding. Plants may be provided as nursery stock or micropropagated plants.

Planting density is around 2,000 to 2,500 plants per ha at a row spacing of a little over 1 m. Plants have a reputation for dying and may need to be replaced so additional plants may be planted between the rows that can be used for restocking.

[81] https://www.fao.org/faostat/en/#data

Weed control is important (plastic sheets have been used). Fertiliser will also be necessary to help with the establishment and subsequently replace nutrients lost in the harvest. Pruning is required to create an open structure to maintain vigour. Bushes reach full maturity at around six to 10 years with the first crop three to four years after planting. Insect pollinators are required. Birds and grazing animals need to be excluded.

Table 19: Typical yields

Year	**2**	**3**	**4**	**5**	**6**
t/ha	0.04	0.18	1.79	3.59	5.38

Machine harvesting is possible but only suited to fruit for processing. The bushes are shaken to loosen the ripe fruit, collected and cleaned after harvesting with a colour sorter. Most growers hand harvest initially (ripening is over some time so plants are picked multiple times). Table-top production, as used for strawberries, appears to offer several advantages. The guides contain a costing template that could be updated for other Vaccinium production.

10. Vitagrass Farms (Holker) Ltd grass drying analysis

This analysis aims to understand why, in 2006, after more than 50 years of business, the company elected to cease grass-drying operations.

10.1. Understanding the business

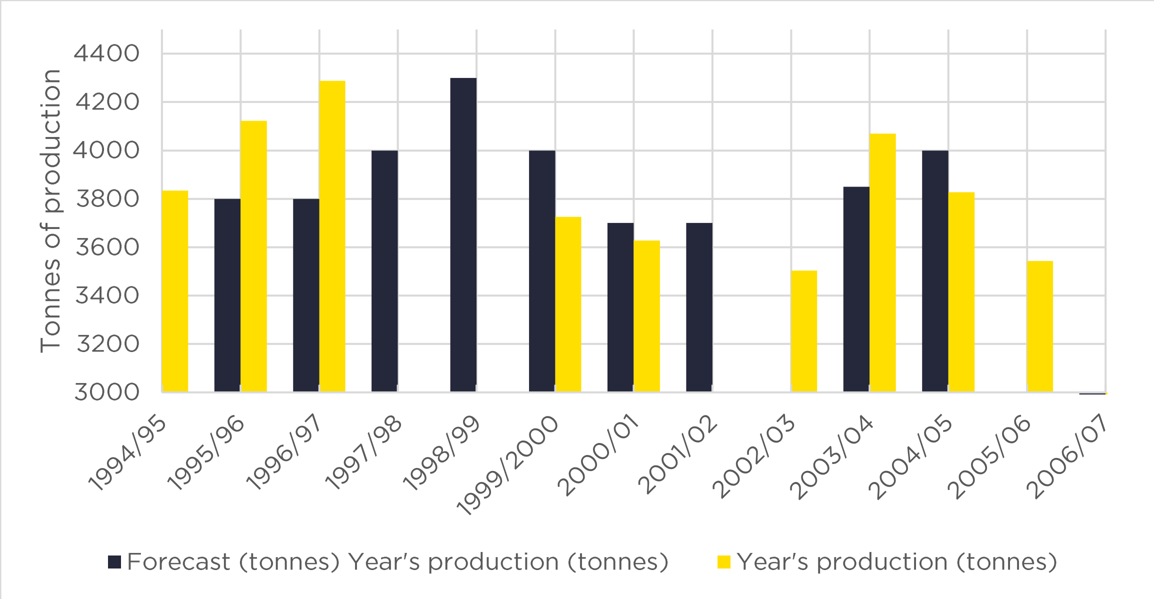
Vitagrass Farms (Holker) Ltd was first incorporated on 20th August 1954. The Declaration of Compliance with the requirements of the Companies Act 1948 declares firstly that the business was established to produce, manufacture and trade dried grass.

Agriculture Survey data submitted in 1994 indicated a total holding area of 351.4 acres. This was an increase of approximately 50 acres on what was regularly submitted for the 10 years previous. 323.6 acres were "long-term sown". This area is approximately 42 acres above the figure submitted in multiple years prior. Survey records regularly indicate four acres of woodland and the occasional planting of cereal crops.

10.2. British Association of Green Crop Driers (BAGCD)

As part of its membership of the British Association of Green Crop Driers (BAGCD), Vitagrass Farms (Holker) Ltd submitted regular declarations of production volume and production forecasts for the year ahead. While the evidence is incomplete, it is sufficient to indicate how production varied over the crucial period before the cessation of business.

Figure 4: Production analysis

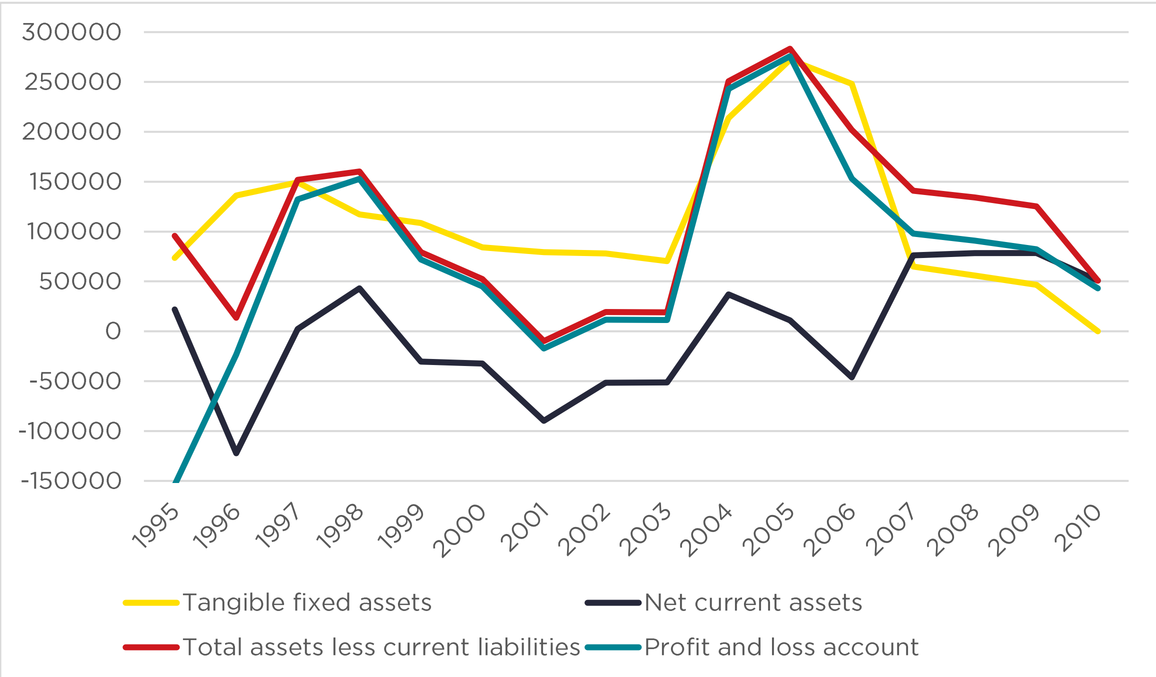


10.3. Cessation of grass drying

The grass drying operation ceased in early 2006 and is attributed to four primary factors:

- Fuel costs
- Local conditions
- Scale
- Waste Incineration Directive

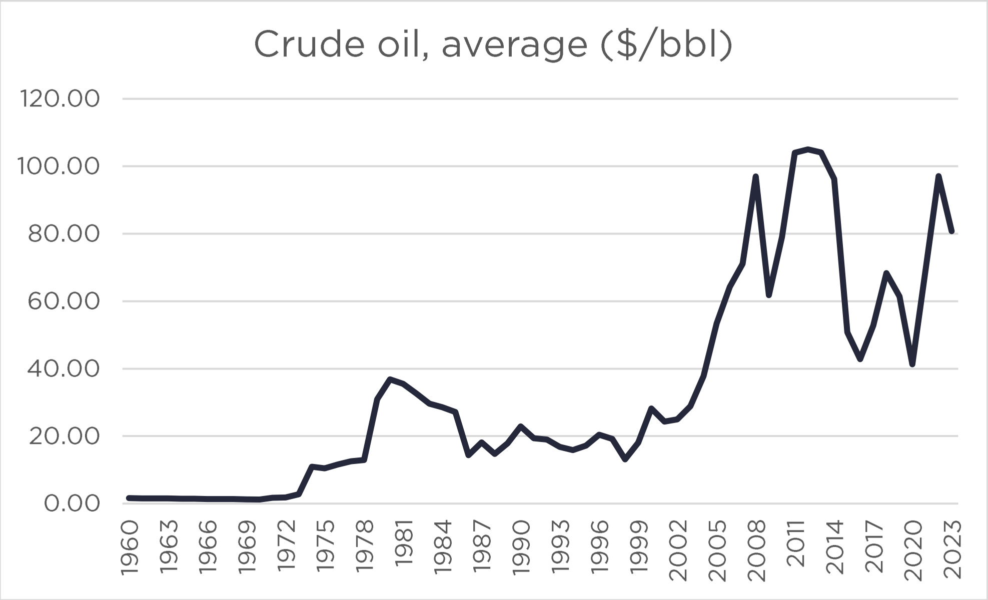
Figure 5: Grass drying enterprise performance



10.3.1. Fuel costs

Fuel prices rose steeply from the turn of the millennium. There are numerous indications that the Vitagrass Farms (Holker) Ltd operation attempted to mitigate against these changes but was ultimately unsuccessful in doing so. For example, an “operational heating cost comparison of alternative fuels” compares virgin fuels (gas oil and MFO, presumed to be medium fuel oil) and natural gas to the existing fuel type, recovered fuel oil (RFO). In this document, the fuel operating cost per tonne of dried product for those alternatives is notably higher than the existing fuel costs. A separate communication also indicated that Vitagrass Farms (Holker) Ltd switched RFO supplier in 2004, possibly as an attempt to mitigate against these cost increases.

Figure 6: Crude oil price analysis



10.3.2. Local conditions

Historic Met Office records indicate the Vitagrass Farms (Holker) Ltd operation has had to compete with less favourable conditions than similar operations elsewhere in the nation. In comparing prevailing weather conditions between the North West with those in the South East, a notable difference is found. An average difference of 1.4°C across annual average temperatures is seen across the 20 years. Similarly, the South East must contest with 515mm less rainfall each year on average.

Both of these measured factors induce additional costs for the Vitagrass Farms (Holker) Ltd operation, particularly in relation to the fuel volume. Conditions would have resulted in additional unwanted impacts too. For example, harvest will likely have been delayed on multiple occasions, both to produce drier grass and to take advantage of lower fuel prices. In this delay, a deterioration of product quality would have occurred. Thus a constant balancing act between costs and prices paid.

Figure 7: Annual rainfall

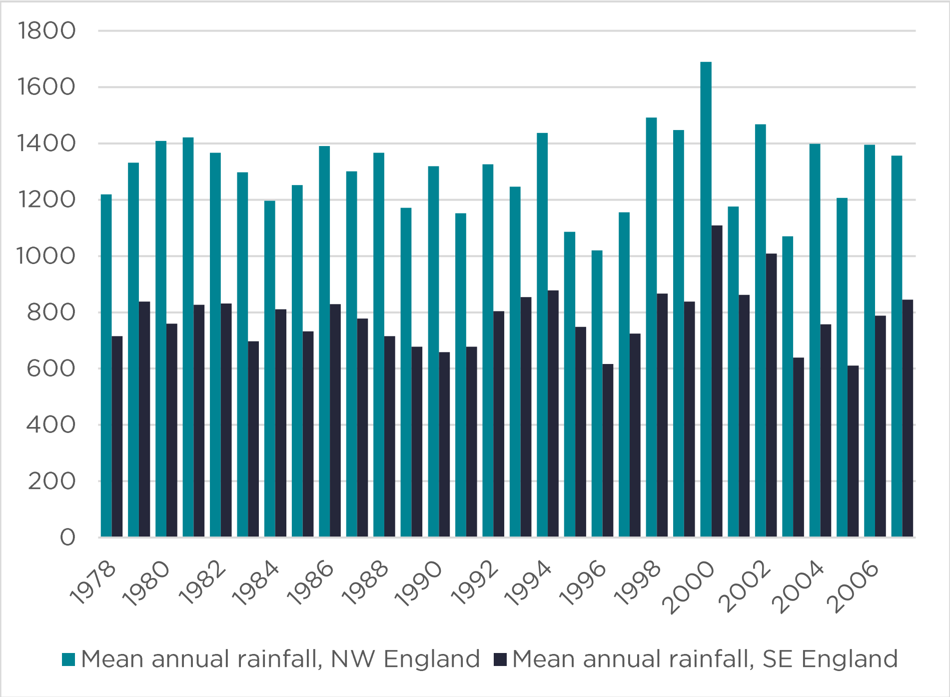
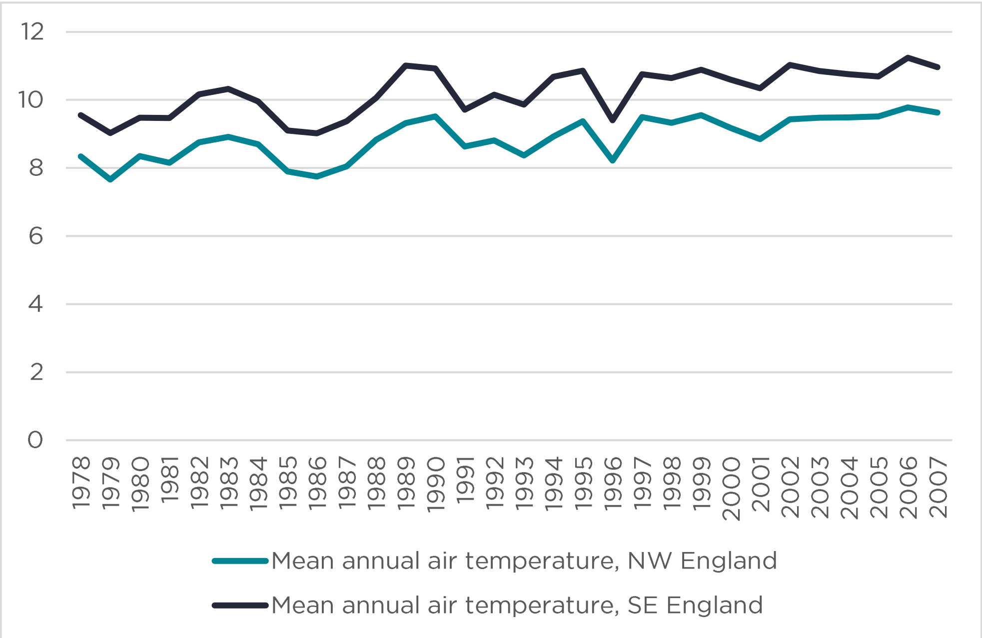


Figure 8: Annual air temperature

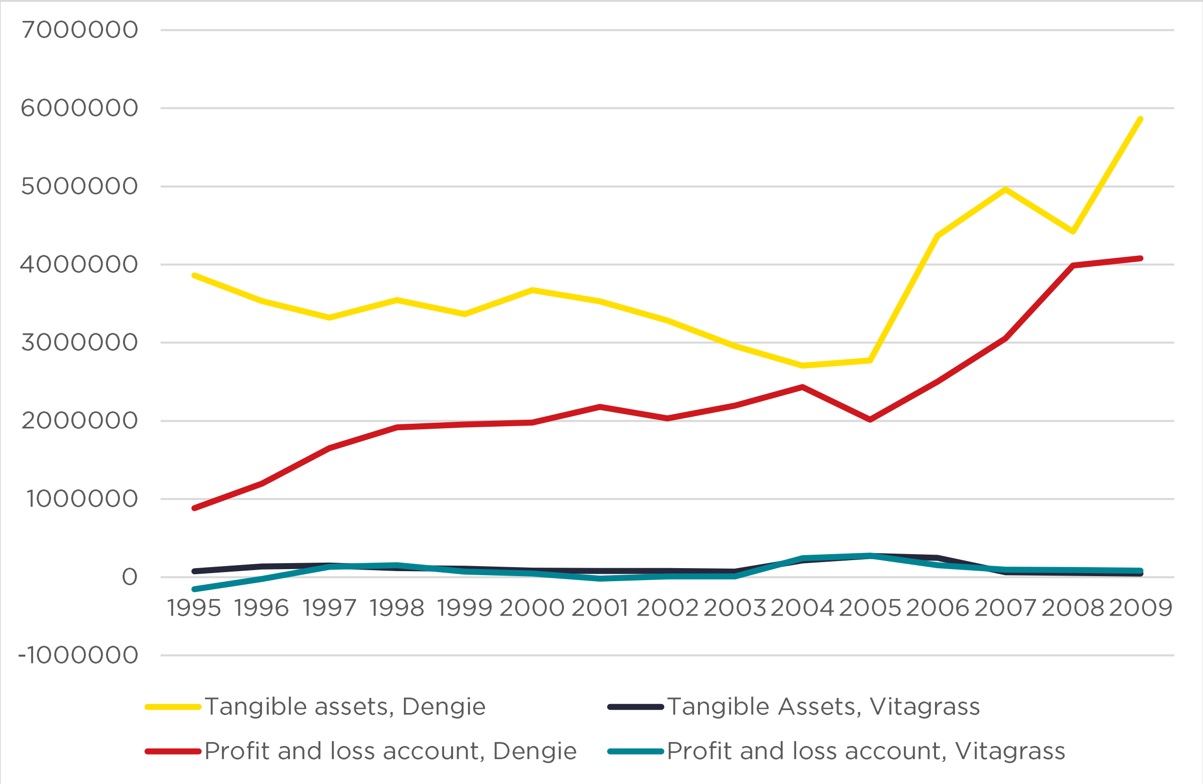


10.3.3. Scale

Other crop drying operations also encountered difficulties at a similar time to Vitagrass Farms (Holker) Ltd and anecdotal evidence suggests several other operations ceased operations. Dengie Crop Driers, a grass-drying operation based in Essex, continues operations to the present day and was seemingly able to endure the change in market conditions. Analysis of both Vitagrass Farms (Holker) Ltd and Dengie company accounts indicates notable differences in scale, likely contributing to its ability to endure.

Dengie's profit and loss accounts indicate a slight downturn between 2004 and 2005 though this was followed by more rapid growth than the previous years. Ensuing years also indicate a rapid growth in asset value, potentially a consolidation of assets from elsewhere in the sector made available by the downturn in market conditions.

Figure 9: Financial analysis comparison



10.3.4. Waste Incineration Directive

In the same communication that announces the cessation of grass drying, the introduction of the Waste Incineration Directive (WID) is cited as one of the main reasons behind the decision. The WID is a European law which aims to prevent or limit the negative effects of waste incineration on the environment. To do so, the WID required compliance with much tighter limits than the previous regime. The regime also operated on the principle that installations must operate using the best available techniques for reducing pollution.

The Directive prevented the burning of Recycled Fuel Oils (RFO), the primary fuel used for the grass-drying operation. The communication states that alternatives, such as "heavy, medium oil or even gas oil", were investigated in the aforementioned "operational heating cost comparison of alternative fuels" document, however, such alternatives were "considerably more expensive" and "would have created substantial losses for the company".

Below we discuss other cost factors, particularly those considered around 1998 and 1999. Within these communications, attention was paid to whether the additional levies would apply to RFOs, which they did not at the time. This attention to the regulation around RFO is regular and expected given the central role it played in the operation.

10.4. Other factors

It should be noted that while the factors listed above might be considered the major contributors, there is evidence that other factors challenged the business over its 50-year lifetime.

10.4.1. Changes to aid

Also of concern were proposed changes to the Dehydrated Fodder Scheme. Council Regulation (EEC) No 1067/74 established the common market organisation (CMO) for dried fodder from 1 April 1974, to increase the domestic supply of protein-rich animal feed. A uniform level of aid was introduced, with the marketing year starting on 1 April and ending on 31 March each year. To qualify for aid the dried fodder produced had to meet quality standards.

Production rose steadily throughout the 1980s, simultaneously causing increases in total aid expenditure as no limit had been placed on the quantities for which aid would be paid. In 1995, Council Regulation (EC) No 603/95 was adopted. A Maximum Guaranteed Quantity (MGQ) of 4,412,400 tonnes for dehydrated and 443,500 tonnes for sun-dried fodder was introduced. In the same period, the Chairman of the BAGCD described the "worst crisis ever" faced by British dehydrate producers. It appears likely he was referring to these changes.

It was suggested that the total amount of aid paid to member states in any given year not exceed the national guaranteed quantity (NGQ). Any member state exceeding its NGQ would benefit from the NGQ of other nations that did not utilise the entirety of its NGQ. The primary concern was other EU member states would utilise the UK's unused allocation. In turn, prices would be affected downwards.

Vitagrass Farms (Holker) Ltd was able to sell its 1997 production, however, it was noted that "some fairly unpleasant prices" were accepted to do so. The Holker agent of the time agreed that the future would inspire "much greater concern" due to "strong resistance by purchasers for any increase in price". The agent also agreed there may be merit in reducing production accordingly. Indeed, forecasts fell from 4,300 tonnes of product in 1998/99 to 4,000 tonnes in 1999/2000 and fell again to 3,700 tonnes of product in 2000/01. Minor recovery was seen between 2003 and 2005 where both forecasts and production recovered to approximately the 4,000 tonne mark, but swiftly declined as the operation was wound down. It appears that, while changes in aid were significant, they were not fatal.

10.4.2. Single farm payments

At the same time that increasing costs made the grass drying operation less viable, Vitagrass (Farms) Holker Ltd felt the introduction of the Single Farm Payments meant alternative land uses became more attractive. From 2005, payments were fully decoupled and based on historic payments earned by the farmer from 2000 to 2003.

10.4.3. Climate change levy

A series of communications between 1998 and 1999 expressed concern at the potential for additional expenses due to the Climate Change Levy. Ultimately, communications indicated that the extra cost per year would be equivalent to £4,300 per year of £1.20 per tonne of product.

10.5. Conclusion

Vitagrass Farms (Holker) Ltd, like much of the grass-drying industry, ultimately encountered severe cost increases at the beginning of the millennium. Costs were already elevated due to the local conditions (wetter and colder than those of more southern operations) and the relatively small-scale nature of the operation reduced its ability to counter these cost increases. Other factors, such as the Waste Incineration Directive and single farm payments likely accelerated the decision to cease operations against this backdrop of adversity.

11. Stakeholder engagement

This research project reviewed trials and investigations which have taken place by other stakeholders. This has been, in the main, restoring peatland rather than understanding the viability of growing commercial crops. Table 20 outlines the visits, webinars, face to face meetings and telephone calls which have taken place to help inform this research project and information from the stakeholders listed has been included throughout this research report.

In addition, Savills have contributed to a number of press articles; Farmers Guardian in December 2024 and earlier in the year (April), a rewetting article for Crop Protection Magazine (https://www.cpm-magazine.co.uk/sustainable-farming/paludiculture-wetter-farming/).

Table 20: Stakeholder engagement analysis

Project	Location	Partners / Contact	Contact Date	Comment
Winmarleigh Moss	Garstang, Lancashire PR3.	Lancashire Wildlife Trust	26th January 2024 teams call. Visit was rearranged to a teams call by the Wildlife Trust.	
Chat Moss and surrounding sites	Manchester	Sarah Johnson Site managed by The Wildlife Trust for Lancashire, Manchester and North Merseyside,	1st February 2024 teams call. 14th March 2024 visit was cancelled by organisers rearranged for 13th June 2024.	Includes trial crops of celery, blueberries and bulrush.
BeadaMoss	Micropropagation Services (EM) Ltd, East Leake, Loughborough LE12 6NZ		15th January 2024 face to face meeting.	Supplier of sphagnum https://beadamoss.com/
Harper Adams	Shropshire	Julia Casperd	26th March 2024 Conference / Workshop event. November 2024 Conference / workshop. Savills presented this project.	Savills attended and met the Lancashire Wildlife Trust. Unfortunately site visit was cancelled on the day. Good engagement following the presentation (e.g. Natural England, a drone company, a farmer who had recently planted typha). Site visit undertaken. They're testing various crops and planting densities and GHG flux but no results yet. They have used clay barriers instead of compacted peat.
NIAB	Online		7th March 2024 online webinar.	Followed up with a review of this research report.
IAgM (Institute of Agricultural Management)	Fens		9th January 2024 meeting.	Sphagnum moss focus with discussions on nuance of fenland v's bog.
Ponda (Salty Co)		Fin Duncan (production lead) and Julian Ellis-Brown (MD)	29th March report review on continued discussions. Follow up call November 2024.	Typha Project. Ponda can provide plugs and advice on planting density. First harvest in year three. 6-10 years before replanting needed Hydrology is the essential thing to know and control. Handy to

				know about nutrients as well as typha is nutrient hungry. Ponda are looking into machinery. August harvest and it seems that it's then best to leave the biomass in order to get good harvests in the future. Deer can be a pest. Phragmites can invade and compete. Ponda can provide a sample contract.
Fenland Soil	Fens	Megan Hudson	29th January 2024 call.	Paludiculture v's commercial crop production and horticulture doesn't yet stack up. The markets are not established and not guaranteed for the future yet for paludiculture. There are lots of projects currently looking at the economics which will help inform the future. This is all still very much in its infancy.

Savills Rural Research conducted four site visits in 2024 as part of this project. The aim of the site visits were to understand the successes and challenges of paludiculture. A number of the site visits had trials in place which would further increase the knowledge for Vitagrass Farms (Holker) Ltd and this project.

11.1. Winmarleigh Site visit

11.1.1. Summary

Information on the Winmarleigh Farm was initially provided through a virtual presentation offered by Mike Longden and Sarah Jackson of Lancashire Wildlife Trust which was then followed by a site visit.

In summary, the site is 2 ha of sphagnum moss which was established in September 2020 with full coverage being recorded in June 2023. The crop will not be harvested as, the main purpose of the site is restoration and carbon sequestration/capture which has seen a decrease in emissions from the land by 91.5%. Sphagnum was chosen due to consideration for the neighbouring SSSI and was locally sourced.

- The topsoil was very nutrient rich and had to be stripped. Mechanical means is not advised due to capital and carbon cost, on an alternative site, celery was used to strip the nutrients – this trial is ongoing.
- Weed wiping was carried out before establishment.
- 150,000 plugs used over 2 ha site and planted by hand.
- Rush grasses controlled by mowing and left.
- Reservoir erected to enable water to be provided through irrigation when needed.
- Previous land drainage blocked with plugs.
- Banks created to separate from neighbouring fields (2 x 200 m banks).
- Funding from the Wildlife Trust Precious Peatlands.
- Will look at the CS options, green finance and the peatland code (topsoil removal not compatible with peatland code).

11.1.2. Site information

Winmarleigh Farm is a 2 ha paludiculture site established on land formerly grazed by livestock. It neighbours a SSSI and other agricultural fields. The objective of this site was to restore the site and establish a carbon farm; a site which ultimately sequesters more carbon than it emits.

11.1.3. Site preparation

Sphagnum is averse to nutrient-rich soils, such as those that were initially present on the site due to historic land use for grazing. The topsoil was therefore stripped using mechanical means before planting. Mechanical means were used owing to time limitations on the trial and ultimately resulted in a carbon-positive operation, though a significantly lower carbon cost than previous operations. Had mechanical means of removing the top soil not been used, a carbon negative result would have been possible.

Manual labour was used to construct irrigation ditches as the site was not constructed to permit the use of mechanisation. In hindsight, the facilitation of small mechanised units would have been advantageous as ditches require ongoing clearing due to ongoing changes in the peat according to weather conditions. Banks were constructed to separate from neighbouring agricultural fields.

A water reservoir was constructed, though behind schedule, which ultimately led to it being underfilled during propagation. Water is kept within a closed system and recycled into the nearby SSSI. There is no manual control of water though this would be achievable and has been pursued at other sites with weirs, pump systems and remote monitoring.

11.1.4. Cultivation and ongoing management

Planting of sphagnum moss took place in September 2020, with full coverage achieved in June 2023. Approximately 150,000 sphagnum plugs were established over the 2 ha site using volunteer labour. Species were grown in accordance with what complimented the neighbouring SSSI and so are locally sourced. A "chunky mix" was used, growing upwards and then laterally in order to maximise carbon farming. This is acceptable however, this would not be the case for crop production.

Few weeds were encountered during propagation other than rushes which were controlled with mowing. In this instance, the structures created by the mown rushes supported the ‘clumping’ of the sphagnum moss which was desirable in this context but would not be in instances of commercial production of sphagnum moss. In the future, cotton grasses could be used to create similar structures to promote this upwards growth of mosses in a carbon farm context. The mowed rushes were not removed but instead formed rudimentary protection for the sphagnum it covered.

The establishment was affected by a dry spell, requiring water to be purchased to aid establishment and growth. Some bleaching of the sphagnum did occur during this period and later growth was slowed. Ensuing years were wetter promoting growth and permitting a reliance on rain-fed irrigation. Purchased water was only utilised for a short period of time meaning no modification to account for pH changes was required. Ultimately, no harvest was conducted due to the intention to establish the Winmarleigh site as a carbon farm and so the organic matter must remain in place.

11.1.5. Conclusion

This site targeted the propagation of sphagnum moss for carbon capture, regeneration and sustainability of peatland, rather than the ongoing output of a commercial product. Nonetheless, lessons in the cultivation of sphagnum moss and site preparation can still be learned for Vitagrass Farms (Holker) Ltd.

Site preparation at Winmarleigh was intensive, incurring a significant carbon and economic cost in order to remove historic nutrients from the area and therefore enable sphagnum propagation. As we will see with later site visits, this intense method of nutrient control may not be the only option for nutrient mitigation depending on the site. Should other options prove to be available, less carbon and cost intensive measures should be considered.

11.2. Manor Farm

11.2.1. Site details

Manor Farm is a 6.5 ha site of formerly grade 1 land near Irlam, Greater Manchester and is managed by a local farmer. Though categorised as grade 1, the land demonstrated poor drainage and was regularly waterlogged and underproductive. The field is known to have a gentle slope towards a trainline at the perimeter of the field.

11.2.2. Site preparation

Extensive earthmoving was undertaken to enact close hydrological control across the site. The perimeter drainage ditch was blocked and pre-existing field drains cut through with bunds. Bunds are lengths of compressed peat which prevent the flow of water. A perimeter bund was created to create a closed hydrological site. Smaller bunds are used to divide the field into cells. Weirs and solar-powered pumps are used to control the water level in each cell. Two water storage cells were created at the bottom of the slope. While these are primarily to provide a reserve water supply, they are also present to protect the train line from flooding. Despite the extensive changes, site reversion is expected to be easy if necessary and may improve the site over original characteristics.

11.2.3. Cultivation and ongoing management

Typha was sown in June 2024 using a drone system operated by Autospray Systems. Owing to the ordinary nature of Typha seed dispersal (via wind), the seeds were encapsulated within a clay pellet and dispersed from the drone. Though evidence of germination was seen, some concerns emerged over the ability of the seeds to escape and grow from the pellets.

Another option is a cellulose gel spray containing the seeds. Though this avoids the issue of breaking out from the clay pellets, Typha appears to grow better when seeds are in close proximity, as with the clay pellets. Transplantation of wild Typha that grew spontaneously in a neighbouring site is being explored as another planting option.

The water level was raised to 10 cm above ground level for planting and then lowered again to 10 cm below ground for ongoing cultivation. No nutrients have been applied but this will be monitored until harvest. Ongoing water and nutrient sampling is being taken.

The first harvest is expected in September 2025. The characteristics of Typha mean an annual yield could then be anticipated, with no need to replant for six to 10 years. This assumes no utilisation or destruction of the rhizome in between harvests. The precise method in which the Typha will be harvested is still debated. Options being explored include a digger with a reciprocating saw, a reed chopper or a tracked tractor.

In this instance, the Typha is being grown to produce a commercial crop of fibre from the seed head. This fibre is to be utilised by Ponda (formerly Salty Co.) for their Biopuff clothing. Though not being explored, other uses and markets for the remainder of the crop beyond the seed head were noted, including reincorporating stems to increase carbon sequestration and derive income from carbon credits. Stems may also be utilised for materials such as thatch or fibreboard. Markets will require future development and all must compete against established products. An estimate of £30,000 per hectare of income was provided, alongside a production cost of between £6,000 and £15,000 per hectare.

11.2.4. Conclusions

The visit to Manor Farm reaffirmed the need for good site preparation which includes both soil and water operational considerations. Establishment of Typha is interesting using a drone and not yet confirming the most effective method. Whilst transplantation from another site has not yet been carried out, this is being considered which would also be available to Vitagrass Farms (Holker) Ltd with the neighbouring SSSI. Manor Farm are working with Ponda for the commercial output and this is being recommended at this stage. This site visit confirmed that commercial markets are still in their infancy and need developing.

11.3. Rindle Farm

11.3.1. Site details

The site at Rindle Farm was previously used to grow potatoes, though yields had been in decline due to regularly waterlogged soils. The 2 ha site is broadly split into three inter-reliant sections; a bog, a field and actively farmed trial plots.

11.3.2. Site preparation

Each section is isolated from the next via bunds with infrastructure in place to allow the downward movement of water (from bog to field to farm). Pumps could theoretically reverse this flow if necessary though none are kept on site permanently. Within the field, several ponds were dug to penetrate a compacted layer approximately 30 cm down. This was done to counteract the compaction issue but ultimately created small areas of enhanced biodiversity.

11.3.3. Cultivation and ongoing management

The bog and field are planted for restoration and biodiversity. Farming plots are split between crops, with each crop having two plots with different target water levels (50 cm and 30 cm) below the surface. Researchers here are seeking to determine the ‘sweet spot’ between achieving the lowest emissions and the most profitable crop, though the lower water level appears to have performed better in terms of crop health up to now. June 2024 was the third year in which crops were trialled, with 2024 also seeing the widest variety planted. The crops planted between 2022 and 2024 are as follows:

- May 2022 - celery
- May 2023 - celery and blueberries
- June 2024 - celery, lettuce and blueberries.

Celery was planted using plugs and existing machinery to replicate existing 'business-as-usual' methods. These plugs were noted as suboptimal during the site visit and other means of planting should be considered.

No crop has yet been successfully harvested. In the first year, the celery crop utilised remnant nutrients from the previous potato crops but ultimately failed two weeks before harvest due to lack of nutrients. In the second year, the celery was outcompeted by weeds. There is an acknowledgement that business-as-usual practices, such as the application of nutrients or pesticides will be necessary to ensure reliable crops in the future. Organic fertilisers have so far been used alongside the third crop as well as manual weed control due to the small size of the plots. The first blueberry harvest is expected in 2025.

It should be noted that celery's ability to strip nutrients is considered as a means of returning topsoil to an appropriate nutrient level after agricultural use and should be considered as part of a rotation. Nutrient flow can also be controlled via control of the flow of water between plots on the site. Water from the restoration area can be used to transport nutrients down to the farming plots. Similarly pumps could be used to reverse flow of water from farming plots in event of excessive rainfall. Solar pumps are not currently maintained on-site due to anti-social behaviour issues nearby.

Carbon dioxide and readings of other greenhouse gas emission levels from across the wetter farming trial and a local business-as-usual farm are taken monthly and whenever any interventions take place, such as ploughing, sowing, fertiliser application, and harvesting. This is done to demonstrate the impact of the alternative farming method.

Supermarkets had initially agreed to buy produce, however this was not fulfilled due to the failure of the crop. No other markets are being explored though it is acknowledged that natural capital income streams could be obtained from the field and bog sites.

11.3.4. Conclusions

Any paludiculture site needs to have a management programme in place whether the site is restorative or commercial. Three years into this trial site and no harvest has taken place due agronomic reasons; nutrition and weed control. An interesting point for this trial is that Supermarkets had been liaised with and were willing to buy the produce. If output can be achieved, this could be a viable opportunity.

11.4. Harper Adams University

While no visit to an active trial site was undertaken during the first visit, a site visit was conducted during the second visit, later in 2024. Other topics such as enabling technologies and theories that may support successful wetter farming in the future were discussed.

Harper Adams University conducted a Crops and Engineering Solutions workshop on Tuesday 26th March 2024.

This day included, amongst others, presentations on:

- Crop production on rewetted peat by Professor Jim Monaghan
- Practicalities of water management across a lowland peatland landscape mosaic by Dr Mike Longden
- The role of autonomous vehicles in the farming of wet peat by Mr Kit Franklin

Practical demonstrations were also provided, including:

- A carousel of equipment and machinery demonstrations, accompanied by Aldert van Weeren of Wetland Products.
- A demonstration of the capabilities of drones for managing farming on rewetted peat by Autospray Systems

- A demonstration of alternative tyre technologies by Tom Saunders, Beyond Road Account Manager at Michelin.

It should be noted that many of the lessons learned here were later confirmed during the aforementioned site visits. For instance, the Rindle Farm site made use of the drone capabilities demonstrated by Autospray Systems. Much of the water management at the various sites has been overseen by Professor Mike Longden. Other elements of the research undertaken by the Savills Rural Research team have also been affirmed by discussions had at the Harper Adams Workshops, including the suitability of crops such as Typha and the final markets it may serve.

11.5. Additional projects

There are known projects being undertaken where contact from Vitagrass Farms (Holker) Ltd and Savills will continue:

- Peatland Action with the aim of restoring peatland across Scotland.
- Cumbria Wildlife Trust. A recent purchase of agricultural land to restore wetland with sphagnum already growing.
- Sphagnum Farming UK Project is an Innovate UK funded project with BeadaMoss a partner along with Manchester Metropolitan University, The University of East London and Natural England.

11.6. Overall conclusions

Trial sites are an important part of research and provide a method to disseminate information, transfer knowledge and share practices. The main areas of interest from the site visits and, which Vitagrass Farms (Holker) Ltd need to ensure due consideration is made are:

- Site preparation. Sampling of soil and water is essential.
- Water management. Ditch management, bunding required and reservoir construction to provide resilience of water supply.
- Nutrient and pesticide considerations through the establishment and growing of the crop.
- Output markets. Work with existing markets as others are still very much in their infancy.

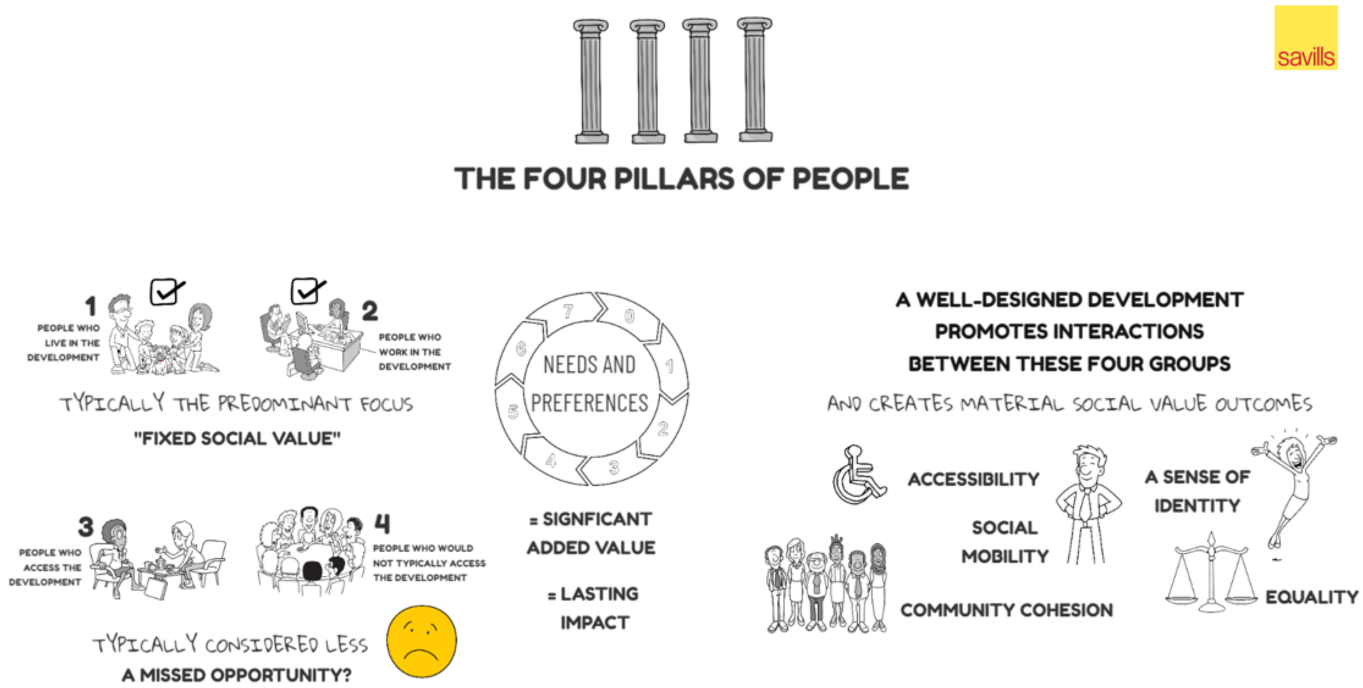
12. Social value

Social value is all about people. In a rural context these are people who live, work, visit a farm or estate as well as people who currently don't. It's about making decisions that meaningfully consider the social impact on all these people – their health and wellbeing, their quality of life and longer term, the creation of positive life outcomes. Savills has developed the Fours Pillars of People to help navigate through the decision making process to take everyone into account.

When delivering social value it is essential to identify all associated stakeholders and people impacted both within and outside of the business. Savills analyses who these stakeholders should be through its four pillars of people. These represent the different levels of interaction and allow businesses to assess the social value an asset is providing and work out ways it could be amplified.

Typically pillars one and two (people who live and work on the estate or farm) are the main focus of social strategy and will be directly impacted by any improvement in social value. These groups of people are termed as "fixed social value" because their engagement with the asset is a given. The third pillar focuses on people who access a farm or estate through public routes and the fourth pillar focuses on people who would not typically access the farm or estate. The people within the latter two pillars are often given little consideration, but when the needs of the people within pillars three and four are considered this sends a clear message that a business is actively working to improve its social value. The scope to improve social value for people within pillars three and four is often greater than for those in pillars one and two.

Figure 10: Savills social value analysis



Source: Savills

Since the rise of ESG (Environmental, Social and Governance), through which businesses consider their impacts upon the world, the audience for social value has changed considerably and so has its purpose. It is clear that there are many opinions of what social value is, but equally there is an acceptance that a singular definition is unimportant. What is important, is that what we are measuring, monitoring and reporting and that these are transparent and understood by the audiences.

In terms of the social value opportunities for Vitagrass Farms (Holker) Ltd and paludiculture, it must be centred around the journey that paludiculture plays in the wider estates ambition of protecting and enhancing the environment for future resilience and sustainability, thus protecting people and planet. The first step would be to undertake a baseline assessment of assets and activities on the estate and then apply the Four Pillars to understand the level of impact and potential to each category. Each category can be engaged with before the paludiculture project is undertaken to provide their thoughts and ideas. The concept of 'bringing people on the journey' and conveying the great messages of environmental protection through peatland restoration and carbon emission reduction.

a) People who work
The ability for the people who work on the estate to be involved in the project and understand its importance for the estate and overall environmental ambition.

b) People who live
It is likely that people who live in the area may not appreciate the importance of the environment in their catchment. The ability to increase awareness and raise knowledge levels could promote greater understanding and more engagement with the estate.

c) People who visit
There are accessibility routes which snake around the site. Information boards could be developed following the setting up of the trial and the establishment of paludiculture. This could be interactive seeking comments. The boards would certainly increase awareness and knowledge.

d) People who don't visit
These are often the most difficult category but by liaising with the three categories above and other stakeholders such as local councils, wildlife trusts, visits could be arranged to bring people to the site / estate / area.

The RSPB[82] reported that societal value is delivered through the restoration of peatland through benefits such as increased carbon storage and sequestration with one case study reporting over £500,000 worth of societal benefits per year by avoiding c9,000 tonnes of carbon loss from soils. Additionally, it was felt that further restoration involving the entirety of the case study site could increase the value of public benefits to £1.2 million per year through additional carbon emission reductions

As well as reducing carbon loss from soils, peatland has the ability to improve water quality and reduce flood risk alongside increasing biodiversity and habitat improvements and, providing public health benefits through more people getting greater access to nature which is where our Four Pillars of People feature.

[82] https://community.rspb.org.uk/ourwork/farming/b/farming-blog/posts/valuing-our-peatland---environmental-and-societal-benefits-delivered-through-peatland-restoration#:~:text=The%20restoration%20has%20delivered%20over,through%20additional%20carbon%20emission%20reductions

13. Conclusion

There is a clear driver from government to restore peatland across the UK, reduce carbon emissions and contribute to meeting net zero targets. In the Autumn 2024 Budget, the government have pledged £400m for peatland restoration and tree planting across the 2024-25 and 2025-26 period.

Whilst many of the trials and research are focused on peatland restoration, for business viability, the commerciality of growing crops on peatland needs to be explored further as this area is very much in its infancy. It cannot be overemphasised that the ability to grow a plant is not a determinant of whether it is a commercial option, although growth alone may be sufficient to secure environmental targets.

Savills research, through this project, reviewed 123 crops that could have potential for paludiculture and through a metric assessment, Savills derived six champion crops to review in further detail for Vitagrass Farms (Holker) Ltd. The following areas are absolutely critical and need fully understanding before pursuing:

- Site selection. For Vitagrass (Farms) Holker Ltd, the proposed site sits alongside a SSSI which could have a considerable impact on the crop grown both positively and negatively.
- Site preparation. It is important soil and water sampling is undertaken and remedial action carried out if appropriate for the crop chosen.
- Markets. Many are in their infancy and time is needed to allow markets to develop and for advocates to emerge to drive production. Apart from Ponda and BeadaMoss, the other crops are not established at scale in the UK. Ponda and BeadaMoss have demonstrated the potential for scale - identified routes to market and are evaluating production methods. The remaining champion crops need advocates to support development to provide commercial confidence to justify investment with an IRR of less than 10%. The importance of collaboration at this stage is paramount to reduce costs and risk. It is recommended Ponda and BeadaMoss are liaised with in the first instance for Vitagrass Farms (Holker) Ltd to understand the opportunities.
- Collaboration. The aim is to control costs and therefore collaborating with others to share machinery and potentially, irrigation equipment would be beneficial.
- Water management. This is one area where compromises cannot be made and where cost may be incurred to ensure it can be managed effectively.

A summary of the six champion crops is provided below:

Sphagnum moss production is being driven by the legislation change of the proposed peat ban and thus to supply potting compost as a peat substitute. It is one of the few crops that allows continuous carbon capture. Sphagnum moss already grows on the neighbouring SSSI site. Species selection is important that does not threaten the established population in the SSSI. Sphagnum moss could be produced under the umbrella of BeadaMoss. BeadaMoss recognise that the site is unlikely to be a favoured commercial site without irrigation and a history of sophisticated horticultural production. The key to success is to optimise output and manage costs. The rate of return is about £1,300 per ha and IRR of 5% however BeadaMoss yield data could see this increase to over 20% - this is for commercial production with sophisticated irrigation and weed control.

T. latifolia already grows on the estate and initial research would suggest that provided water levels can be managed, this crop would be able to provide a favourable route to the commercialisation of existing reed beds. However, recent research suggests that, to optimise carbon capture and reduce methane emissions, the wetting of peat needs to be within 10 cm of the soil surface. This does not make the crop ideal for production and requires further investigation. It is likely Ponda would be willing to explore a collaborative venture with Vitagrass Farms (Holker) Ltd. In addition to the down from the seed heads which are used as fibre for clothing, biochar could be created from the biomass which is another way to capture carbon for the long term.

With regard to the other champion crops; Myrica gale, Mentha aquatica and Angelica could offer Vitagrass Farms (Holker) Ltd an opportunity to create a novel good with estate branding. They would need more research and trialling on the site and currently, there is less government interest in their development. They would require active entrepreneurial input by Vitagrass Farms (Holker) Ltd and they would require an industry advocate to support the development and marketing of the niche crop, such as that already established for sphagnum moss and T. latifolia. Many of the outputs are the same from Myrica gale, Mentha aquatica and Angelica; oils, edible herbs, flavourings and the cosmetic industry.

Of the Vaccinium spp. crops, this is the only one which offers a food crop. V. oxycoccos (cranberry, marsh cranberry, small cranberry) have established commercial markets and Vitagrass Farms (Holker) Ltd is unlikely to compete with the existing producers however there is a European cranberry found in the neighbouring SSSI which is said to have distinct properties which could be promoted to create a unique market position and premium. Additionally, V. oxycoccos could be intercropped with sphagnum moss.

The three key takeaways from this research for Vitagrass Farms (Holker) Ltd are:

1. Know the site.
2. Know the market.
3. Know the numbers.

In order to progress this work, it is recommended that Vitagrass Farms (Holker) Ltd:

1. Undertake a trial with a strong statistical analysis which is designed with clear objectives.

2. Review the payments available under the Countryside Stewardship Higher Tier scheme and carbon credits within the Peatland Code to begin the journey with peatland restoration and carbon sequestration.

3. Liaise with BeadaMoss regarding the production of sphagnum moss, specifically questioning the irrigation demand.

4. Liaise with Ponda regarding the production of T. latifolia, specifically questioning the management of the water table to 10 cm of the soil surface.

14. Appendix 1

14.1. Selection of Favoured Paludiculture Options

14.1.1. Selection process

The interest in paludiculture is not driven by the demand for new materials but by the desire to find a means of contributing to the cost of preserving land with a high organic matter content, reducing greenhouse gas emissions and maintaining biodiversity. This objective contrasts with the development of most products where the demand for a material is identified and product development is to explore whether this demand can be met at a price that supplies more profit to the producer than other options.

The initial selection of potential paludiculture crops involved a detailed literature review and the compilation of an extensive list of temperate climate plants already recognised as paludiculture plants.

The commercial advantage for paludiculture production is largely dependent on secondary income (grants/subsidy, sales of carbon credits, biodiversity net gain) and positive branding to add value and distinction, building on any desirable trait identified (for example, Ponda has branded 'BioPuff® ', a material produced from Typha latifolia (bulrush), on its environmental attributes compared with animal products (down) or cotton). The only product that might be considered to result from more conventional drivers is the production of sphagnum moss where consumer preference and (potential) legislation change create an opportunity for a new plant-growing medium to replace peat. The objective of the report was to narrow the selection to identify the potential plants that were most likely to be commercially viable specifically for Vitagrass Farms (Holker) Ltd.

Conventional crops have been subject to genetic and agronomic improvement, in many cases for over a century (or arguably over 3,500 years in the case of wheat). Substitution of these crop outputs with paludiculture crop outputs is unlikely except in a few specific situations. Positive selection was based on attributes such as:

1. Identification of an attribute not previously recognised as valuable (e.g. the seed down from bulrushes (T. latifolia)).
2. Legislative change creating a new opportunity (substitute of peat with sphagnum).
3. Technical change, changing the relative production cost (resistance of blackgrass to herbicides raises the cost of grain production).
4. Positive consumer view of the paludiculture version such as a positive environmental association leading to a premium sufficient to offset the higher production cost.
5. Harvest of multiple income streams. While conventional crops can also give rise to multiple uses (wheat provides grain and animal bedding) some paludiculture crops provide more unusual uses such as bulrushes supply fibre for clothing, material for insulation and adhesives.

Conversely, rejection was likely where:

1. The crop was unlikely to attract a premium via association with environmental attributes. This included forage crops where value is determined almost entirely by feed value (e.g. the grasses Agrostis spp. (Bent grasses), Echinocloa sp., and Carex sp (reeds)). The exception is biomass crops (for incineration or potentially raw material e.g. for bioplastic) where production is potentially as high as alternative materials and the estate is close to a large consumer (e.g. Arundo donax (Giant cane, elephant grass), Phragmites australis (common reed) and others).
2. There were reported pharmaceutical benefits but inconclusive evidence and no current commercial production (e.g. Agrimonia eupatoria, Equisetum arvense). Rejection was extended to plants with a proven pharmaceutical value but was no longer cultivated for this purpose because better methods of synthesis

were available (e.g. Digitalis purpurea) or where there was no obvious co-partner to develop the product. Pharmaceutical use is also likely to migrate to controlled environment production, where the active ingredient cannot be synthesised.

3. There is a long interval between planting and harvest and only weak distinguishing attributes. These plants are exposed to additional risk i.e. by harvest the attributes might no longer be valued (e.g. various trees).
4. Where the plant grew equally well in areas that were not flooded. For example, plants growing in damp places but not in waterlogged areas (e.g. Stellaria media (chickweed), Linum usitatissimum (flax), Apium graveolens (celery), Ribes sp (redcurrant and black currant)).
5. Posing a threat to health either via intrinsic characteristics (Agrimonia eupatoria (Agrimony, sticklewort)) or via the proposed production method (Nasturtium officinale (Watercress or yellowcress) – parasite).

Other barriers to production were identified that could be overcome where there were also strongly positive characteristics.

1. A distinct regional habitat for existing “wild” plants such as salt marsh, low rainfall area or altitude. (e.g. Crithmum maritimum (Samphire) (this is potentially an important plant for other sites but requires a high salt environment), Chamaemelum nobile (chamomile) (favouring the South East), Rubus chamaemorus (cloudberry) (found largely over 600m)).
2. Plants already widely available that could be made available at little cost if a market were established (e.g. Phragmites Australis (Common Reed)). This is an important paludiculture crop but adoption requires the identification of a new product (direct or indirect) that can be branded by association with environmental benefit and not the ability to produce. T. Latifoli (bulrush) is a similar plant in this respect but Ponda have developed a specific aspect of the plant, a good environmental brand and controls the market for fibre supply via its links and brand, and via processes to extract the seed contaminant.
3. The need for a new complex supply change with large-scale processing. Sphagnum moss is a good illustration of how this barrier can be overcome since BeadaMoss has taken on the responsibility for planting and harvesting equipment that can be used on a contract basis by several growers (while recognising that large sites are still needed) and is supply to established blenders. In contrast, Linum usitatissimum (Flax) requires the construction of a dedicated mill to service many growers.
4. Established cultivation and infrastructure that would be difficult to compete with (e.g. Nasturtium officinale (watercress), Vaccinium corymbosum (Blueberry), Vaccinium macrocarpon (American Cranberry), Apium graveolens). These plants can prosper as niche products emphasising the environmental benefit but will be more expensive to produce than established sources.
5. Plants that could potentially be processed at scale and automated in controlled environment production, such as Lemna minor (common duckweed or lesser duckweed).
6. Plants producing starch or other material suitable as a food crop but lacking a distinct flavour or identification in the UK e.g. Glyceria maxima (Reed Grass, reed sweet grass, giant manna grass).

Some crops are “bog” plants (i.e. rain-fed and slightly acidic) while other plants are suited to the “fens” where the water is ground-fed and potentially subject to a different mineral balance. Discussion has shown that this can be overcome through management. Similarly, some plants require specific site conditions such as shade (Allium ursinum (ramsons, wild garlic)) or a fairly precise watering regime where production is commercial and consider that these are infrastructure costs. The selection took into account plants reported present on the neighbouring SSSI.

There is concern that new strains or even species could be introduced into a biologically sensitive area. Some of the selected species may cross with strains in the SSSI or occupy a similar market niche and thus spread over time. This concern was increased where plants were not of local provenance and were not native and potentially invasive.

For most selections, there is already a body of research showing that there is some likelihood of success. This reduces the investment and exposure to risk although might exclude some options that might prove the most viable in the long term. Vitagrass Farms (Holker) Ltd may not have the resources to undertake detailed agronomy work, develop specialist machinery for growing and/or processing or investment to introduce and establish a new market product. Therefore options that fit into existing supply chains or where specialists in the crop can manage the marketing and supply of any specialist machinery have been favoured.

Other factors were taken into account following more detailed research to derive the final six from the shortened list. Most potential crop plants failed the selection on more than one characteristic.

The focus has been on the priority area adjacent to the existing SSSI where the lower water table on the estate poses a threat to the SSSI and there is environmental gain from raising the water level.

14.1.2. Selection

The complete list of potential plants identified extends to 123 candidates. This was refined to 30 potential plants although this included some similar plants (Vaccinium and Typha spp.) where the distinction is not great. This has been refined to the six champion crops.

Management is likely to have a major influence on profitability and development is incomplete so there is inevitably an area of risk. For this reason, it is suggested that the most appropriate development for Vitagrass Farms (Holker) Ltd is via the production of sphagnum moss on a contract basis with BeadaMoss. To be successful infrastructure via use of overhead irrigation is essential to minimise risk and maximise yield. This would not be necessary where production is for reclamation only. The threat to the neighbouring SSSI from introducing genetically different sphagnum moss (even if of the same species) with the potential for ingress needs to be understood.

Typha Latifolia offers a similar means of reducing risk through Ponda. However, the particular site (although we understand that there are neighbouring suitable sites) makes sphagnum a preferable option.

The other options listed would have to be developed in isolation and thus impose greater risk. There is also less government interest in their development through the lack of a “advocate” to promote.

They all require different water management regimes so this should also be taken into account. Sphagnum and bilberry have a long interval from planting until harvest and thus require additional funding in this period.

The lowest risk is to introduce the most recent Sustainable Farmland Initiative options and sell any carbon credits that might be produced. There is a reasonable chance that the site would support similar vegetation to the neighbouring SSSI at much less cost (or no cost if the period until establishment was not a concern). This would require much less investment. There is a reasonable chance that the net income would also be higher.

Table 21: Paludiculture species summary

Latin name/ Common name	**Comment**
Sphagnum spp./ sphagnum moss	• Market demand created via a change in consumer preference and potential legislative change banning the use of peat. • History of crop development (as well as for peatland regeneration) particularly in the UK (BeadaMoss) and Germany (Greifswald University). Machinery development takes place in harvesting and planting to achieve commercially acceptable work rates.

	• Supply-side management to establish a brand and prevent price collapse if commercial production becomes a reality. • Some agronomic knowledge available (disease control, weed control and fertilisation). • Marketing route clear but not established. • Expectation of low-risk contract ensuring viable income. • Active breakdown of methane during wetting of peat. • Local wild production (and production suited to the site). • Need for water infrastructure to ensure commercial viability. • Harvest approximately every third year requiring large area to maintain continuous production and potential income voids. • Although a perennial for commercial production replanting is necessary after harvest. • Control of the water table necessary under the Greifswald system (but not Micropropagation). • Substantial divergence between sources on cultivation method and cost. • Potential threat to genetic purity via the spread of spores and fragmentation.
Typha latifolia/ Bulrush	• A newly created output with strong branding and a developed route to market (via Ponda). • Crop development (Netherlands, US, UK and elsewhere) although limited in terms of fibre optimisation. • Secondary outputs with market value (biochar, biomass for incineration or cellulose, building materials). Roots can be harvested for starch. Published research into new uses. • Extremely fast-growing and robust perennial crop that does not need reseeding. However, changes in production over production life and variations between seasons are unknown. • Relatively insensitive to the condition of water although requires land to be flooded (and not just a high water table) although it will withstand short dry periods. • Machinery available for harvesting stems but not fibre (hand-harvested). Establishment by machine (pre-flooding) or hand via seed, tubers or transplants ("peat" blocks). Drying may be necessary but can use a drying floor. • Agronomy not developed. • Contracts available for fibre output (seed heads) from Ponda. May be possible to negotiate longer-term supply contracts. • A fen or salt marsh plant rather than suited to acid peat bogs although production at Holker (not recorded on neighbouring SSSI). • Considerable area of Typha available for "wild harvesting" that might depress the market if Ponda fails to establish sufficiently strong links with the buyer or commitment is not established with the suppliers to them. • Other Typha species with similar outputs available and slightly different management requirements (e.g. depth of water).
The following opportunities are less developed and Vitagrass Farms (Holker) Ltd would need to take greater responsibility for development and marketing. This would consequently expose the estate to more risk. They are ideal artisan opportunities although all have the potential to expand beyond this.	
Myrica gale Bog-myrtle	• Demand from the cosmetics industry (essential oil). Oil is extracted by steam distillation and can be carried out on a small scale with low investment. • Quality agronomy trials in Scotland (Published trials are at a higher level than above). • Soil moist to wet. • Failed Scottish plan to commercialise. Parties involved included Boots Company, the Agronomy Institute at Orkney College UHI, Highland Natural Products Ltd and later, Essentially Scottish Botanicals Ltd and Technology Crops International Ltd. • Manufactured currently in France and Canada for export to the UK. • Wild harvesting in Scotland and Finland. • Legume.
Angelica archangelica Angelica	• Leaf salad, vegetable and essential oil from root. • Yield varies between sources. Root yield ranges from 1.7 to 6 t/ha DM and 0.35 to 1.2% essential oil. • Soil moist to wet. • Propagation from seed.

<table>
<tr><td>Mentha aquatica
Water mint</td><td>
Proposed use of cultivated varieties ‘eau de Cologne mint’ or ‘bergamot mint’ to maximise the market potential to produce citrate oil (note this is not bergamot oil). Leaves can also be eaten and are sold dry. There is some evidence for anti-inflammatory and cardio-protective effects.
Other mints (peppermint and spearmint) are cultivated widely (in Europe, the USA, South America, Far East) in all probability because the soil requirements are less demanding. While husbandry is not identical there is considerable information on the commercial production of these species. Mentha species cross widely and peppermint is a hybrid of water mint and spearmint.
By analogy with other Mentha species it would be expected that yields of at least 100kg/ha of oil could be obtained (oil content of leaves around 40%).
A branded product ‘Allplant Essence Organic Mint’ is organically cultivated in Northern California (1 kg Allplant Essence® Organic Mint contains the essence of approx. 200 g fresh plants.). Klorane specialises in aquatic mint products and cultivates water mint organically in South West France.
Spearmint is a hybrid between Mentha aquatic and spicata suggesting an opportunity for developing a strain with wider uses. Cultivation of spearmint has been extensively researched although this plant is grown on conventional arable land with irrigation. As a hybrid vegetative propagation is necessary. Spearmint will survive short periods of waterlogging ‘The best soils are deep, well-drained, rich in humus, with good moisture retention’[83].
Market local, online and wholesale.
Steam distillation required. Small-scale stills are available. Essential oil yield about 0.8%.
Perennial.
Grows from seed and spreads via rhizomes and is thus capable of scaling. Seed is available from several UK suppliers. Harvesting potentially by forage harvester (or lawn mower). Can also be propagated vegetatively which reduces the threat of hybridisation. For commercial production control of water levels would be necessary.
Soil wet to shallow water.
Specific paludiculture production is not developed but it is grown as a garden plant and commercially for essential oils.
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<tr><td colspan="2">Internationally the most successful paludiculture crops have been berry production such as Vaccinium macrocarpon (American Cranberry) and Vaccinium corymbosum (Blueberry). These are both potentially suitable crops with a strong history of agronomic development. The selected plant is less widely grown allowing a niche opportunity although also suffering from lack of development.</td></tr>
<tr><td>Vaccinium e.g.
V. oxycoccos
Cranberry.
Marsh cranberry
Small cranberry</td><td>
Currently wild-harvested and considered to be nutritionally superior to the alternative Vaccinium berries. Commercial viability initially is likely to hinge on securing a premium market and streamlined supply chain such as possible via internet sales and local markets. Poland historically exported wild harvest bilberries to Germany. Wild harvesting (for Baxters of Speyside) occurred in Scotland in the 1950s. Also sold as a health food (e.g. Bristol Botanicals and many others Limited) and has some evidence of benefit (see European Medicines Agency).
Grows on wet, but not flooded, peatland. It is found on the neighbouring SSSI.
Perennial plant that can be established from hardwood cuttings or seed. Some data on nutrition, weed control, pests and water requirements. Mycorrhiza association is viewed as particularly important.
Harvest can be hand or with combs followed by separation of other matter. Yields are likely to be low until plant breeding and agronomic expertise are gained at around 0-550kg/ha. Yields are also reported to be erratic although this should be less of a problem in areas in the west of the UK that are not subject to severe frost. Mechanical harvesters are available for similar species.
Production suits an established producer of similar fruit with appropriate machinery and an established route to market.
The main threat is the variability of production and lack of selection.
</td></tr>
</table>

[83] https://library.buplant.da.gov.ph/images/1641885697Peppermint%20Production%20Guide.pdf

14.2. Other shortlisted crops

Table 21: Other shortlisted crops

Latin Name	Common Name
Allium ursinum	Ramsons, wild garlic
Althaea officinalis	Marshmallow
Apium graveolens	Celery, celeriac
Armoracia rusticana	horseradish
Arundo Donax	giant cane, elephant grass
Eriophorum angustifolium	Common Cottongrass
Glyceria fluitans	Floating sweet-grass, water mannagrass
Linum usitatissimum	Flax, linseed
Persicaria hydropiper	water pepper, marsh pepper knotweed, arse smart or tade

The selection has some precedent as shown in the quotation "the process of domestication of useful wild species continues to this day with bilberry (Vaccinium myrtillus) domesticated in the 20th century, and bog myrtle (Myrica gale) in Scotland and Arctic bramble (Rubus arcticus) in Finland being domesticated within the last few decades"[84].

[84] https://efi.int/sites/default/files/files/publication-bank/2019/efi_wsctu_10_2019.pdf