Cranberries, are the UK's lowland peat farmers missing an opportunity?

Global perspectives on the productive restoration of lowland peatland using sustainable wet farming systems.

Figure 1 Julia Casperd in a cranberry bog at the Habelman Brothers Cranberry Farm, Wisconsin, US with Shirley Acedo (USDA) & Tom Tiber (Farm Manager, Habelman Brothers Ltd.).

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'Intelligence without ambition is a bird without wings'

(Salvador Dali)

Figure 2 Shirley Acedo, Bob Wilson & Tom Tiber on the Habelman Bros Ltd. cranberry bog.

Abstract

Current practices of farming on lowland peat in the UK are causing unsustainable soil losses. This impacts on One Health and the societal and natural capital opportunities provided by this land. In some areas degraded peat soils, currently used for agricultural production, will no longer exist in 10-20 years' time (Worrall, 2024). It is clear that in order to reduce this loss and the impact of agricultural practices on the environment and its ecosystem services, there needs to be innovation and adaptation by the farming industry to adopt more regenerative farming systems in support of food security.

Figure 3 Cranberries (*Vaccinium Macrocarpon*) grown on sand over peat, Wisconsin (September 2023).

Exploring alternative forms of productive wet farming, paludiculture, have become pivotal in the race against climate change and the emission reduction targets set by the UK Government. This is reflected by the current financial support in the farming sector for research and development. This report responds to the call by the FAO for a long term a water-food-ecosystem nexus (Food and Agricultural Organization of the United Nations, 2014). It explores the feasibility of growing a novel high value crop, cranberries, which is already successfully grown elsewhere in the world (Figure 3). It is considered that cranberries may also have a role to play in reinstating critical ecosystem functions relating to climate change, biodiversity, water quality and availability and nutrient mitigation which will be required to meet the UK's Sustainable Development Goals. Initial desk-based research, along with interviews, various meetings in the UK and visits to the US and Netherlands indicate that it may be feasible to grow cranberries in the UK, but research and development is required from the outset.

The social, economic and environmental sustainability of current global models of growing cranberries are reviewed and four models are proposed for trials in the UK. These include a large scale farming system with no inputs or low inputs which may be appropriate to farms in the Norfolk and Cambridgeshire fens (*Model 1 NIC/LIC-Large scale*); a no input or organic model suitable for small scale cultivations as part of a mosaic on mixed farms looking to diversify and exploit subsidies and private finance opportunities (*Model 2 NIC-Small scale*); a high inputs, high yielding isolated farming system requiring precision farming techniques (*Model 4 HIC-Isolated precision*); and a final model which proposes the use of cranberries and sphagnum in the farming of wetland margins ('wetlandscape' margin mix: *Model 3 NIC-Margins*). This report identifies a number of areas of cranberry agronomy for further research which include the use of sphagnum as a means of ameliorating soil pH and restoring degraded agricultural peat. It is proposed that this could be achieved by incorporating it into a long-term crop rotation or through the use of inter-cropping, or planting cranberries directly into sphagnum. The main barriers identified in the implementation of these models of cranberry farming relate to eradicating the weed burden which is significant (Figure 4), frost protection, pH amendment, water management, consumer demand and profitability for larger scale farms and the reliance on Government subsidies (Countryside Stewardship, ELM, SFI) and/or private finance.

Figure 4 Cranberries (*Vaccinium macrocarpon*) growing on the polders as part of a farming for 'Natur' enterprise in the Netherlands.

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7.7 – Pdf with English translation of Nancy Wiltink’s report: Opportunities and difficulties for the cranberry – can there be a role for cranberry picking or cultivation in the intended Amsterdam wetlands (attached)

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1. Aims and objectives

The overarching aim of this research was to draw on insight from around the world, particularly in the US and Europe, to explore the feasibility of farming cranberries in the UK. The motivation behind this research was driven by UK Government and Robert Caudwell's Lowland Peat Task Force Report (Defra, 2023) to seek alternatives to current farming practices on degraded lowland peat as a means of reducing the significant GHG emissions associated with agriculture. It was considered a priority to characterise the different forms of cranberry production that exist across the globe which could feasibly be adopted by the UK. These were identified as a high intensity farming system involving high inputs, high levels of mechanisation and precision agriculture practices; a low intensity form of farming with low inputs, low mechanisation, with dry/hand harvesting; and a system which involves harvesting from unmanaged cranberry crops grown for nature and Biodiversity Net Gain (Defra, 2024). For the purposes of this study these systems have been identified respectively as 1. High Intensity Cranberry Farming (HIC), 2. Low Intensity Cranberry Farming (LIC) and 3. No Input Cranberry Harvesting (NIC). The main objectives of this research are outlined in Table 1.

Table 1 Summary of project objectives

Objective	Scope
Objective 1	To characterise global cranberry farming systems which exist: 1. High Intensity Cranberry Farming (HIC) 2. Low Intensity Cranberry farming (LIC) 3. No Input Cranberry Harvesting (NIC)
Objective 2	To perform an initial Life Cycle Analysis and evaluation of the sustainability of the farming systems.
Objective 3	To identify an appropriate farming system/s, with necessary remediations to produce cranberries on degraded lowland agricultural rewetted peat in the UK.
Objective 4	To assess the barriers to adoption of cranberry farming in the UK.

2. Introduction

There is an urgent need to restore peatlands. Only 13% are in a near natural state and acting as carbon sinks (UKCEH, no date). Much of our lowland peat is currently used for intensive agriculture, which can be highly profitable. It covers less than 4% of England's farmed area but produces more than 7% of England's total agricultural production and is worth £1.23 billion to the UK economy. These peatlands are now degraded and significant sources of greenhouse gases contributing to global warming. It is estimated croplands on peat emit a total of 7,600 kilo tonnes of carbon dioxide equivalents per year (kt CO2e yr-1) in the UK (Trenbirth & Dutton, 2019). The soils need to be returned to optimal conditions in terms of its soil abiotic profile (moisture content, pH etc.) and growth of peat forming flora. Once this is established it takes around 1,000 years for 1m of peat to build up, drainage means the land surface reduces an average (CEH). The restoration of damaged peatlands to return them to sinks and reduce their impact on climate change is a slow process.

The focus for this report was inspired by the need to find a solution to reduce GHG emissions from degraded but currently productive lowland agricultural peat on the Harper Adams University farm located in Shropshire, England. The first step in finding a solution is to understand what peat is, where it is in the UK and why it is important; because GHG emissions are a global issue threatening the outcomes of most if not all UN SDG’s and the 2030 Agenda for Sustainable Development (UN, no date) a global perspective is also taken in this report to signpost future direction.

2.1 Lowland Peat

Lowland peat is found up to 200m above sea level and within peatlands which are wetland systems comprising lowland raised bogs and fens. These are distributed across much of the UK, the most extensive of which occur in the East Anglian Fens, Somerset Levels and in the lowlands of Northern England, although they are also widespread in Scotland, Northern Ireland and Wales.

2.1.1 What is peat?

Peat is found in peatlands, transitional wetland environments (IPS, no date) that provide essential hydrological, ecological and biogeochemical functions (e.g. Krueger et al., 2015). Topographically, peatlands may be described as either lowland or upland. Lowland peat is typically found under 200 m above sea level. The wet conditions of a healthy peatland slow the decomposition of organic material and gradually allow for new matter to accumulate over timescales of centuries to millennia.

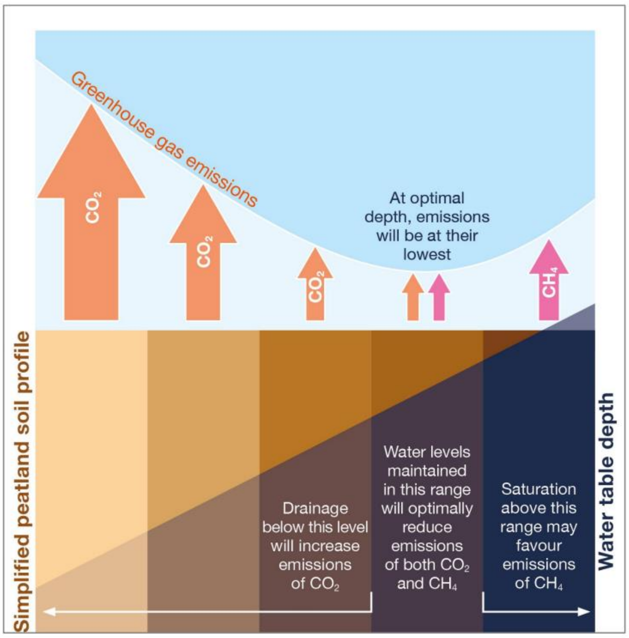


Figure 5 GHG emissions from drained peat (Defra, 2023).

Globally, peatlands are thought to include all wetlands with soils that fit into the broad IPCC concept of ‘organic soils’ with 12 percent or more organic soil carbon without a depth criterion (Hiraishi et al. 2014). This automatically includes almost all peatlands (mire, marsh, swamp, fen and bog), histosols and other organic soils, and allows the use of diverse, historically grown national or regional datasets. In a good (i.e. natural) condition, peat will contain around 90% water. However, there is currently not a globally accepted definition for a ‘peatland’.

Peat is a type of soil characteristically high in soil organic carbon which consists of partially decomposed organic matter derived mostly from plant material, which has accumulated under conditions of waterlogging, oxygen deficiency, high acidity and nutrient deficiency (see: www.peatlands.org). The actual definition of peat is much deliberated (see Lourenco, Fitchett and Woodborne, 2022) especially when it comes to the assessment of degraded agricultural peat for inclusion in the England Peat Map and financing (IUCN UK Peatland Programme, 2023). Lourenco et al. recommend that two criteria are used to define peat, depth and % soil organic content but that the actual definition is likely depending on the expected outcome.

Peat forms under anoxic, but variable climatic, conditions through the accumulation of partially decomposed plant biomass in fens, bogs, salt marshes and some swamps in various parts of the world. The peat forming vegetation varies considerably across the in different regions. In temperate biomes like the UK (but also in boreal and sub-arctic regions) where low temperatures reduce the rate of decomposition, peat is formed mainly from bryophytes (mostly sphagnum mosses), herbs, shrubs and small trees. In the lowland humid tropics, it is derived mostly from rain forest trees under near constant annual high temperatures. In other geographical regions peat can be formed from other species of plants that are able to grow in water-saturated conditions in tropical coastal fringes (e.g. New Zealand) or mangroves. New types of peat may still be found.

2.1.2 Why is peat important?

Since the Lowland Peat Task Force report in 2023 (Defra, 2023) there has been an increased focus on measures to protect the degrading carbon stores such as England's lowland agricultural peat due to the high level of GHG emissions, principally carbon dioxide, nitrous oxide and methane, being emitted from this source.

The drive to reduce GHG emissions from farming has gained pace recently as the UK Government maps out its route to Net Zero by 2050. There are also additional drivers from landscape recovery initiatives which are exploring the potential for rewetting and the re-naturalisation of these ecologically important soils.

2.1.3 What is the problem with peat?

Globally 12% of all peatlands have been drained are degraded and active sources of carbon dioxide and other greenhouse gases e.g. methane and nitrous oxide (Evans et al. 2017, see also Figure 5). Scientists estimate peatlands are emitting the equivalent of 1-2 billion tonnes of carbon dioxide, which is around 2-4% of all human greenhouse gas emissions. Keeping the carbon stored in peatlands locked away is absolutely critical to achieving global climate goals since they represent a 4% contribution to the annual global human-induced emissions.

60% of lowland peat in the UK is used for agricultural production. Of this 20% is Grade 1 and a further 19% is Grade 2. (Evans et al. 2017, see also MAFF, 1988). Farming on lowland peat contributes significantly to the UK's emissions, approximately 10% which is around 46 million tonnes of carbon dioxide equivalents per year. There is an urgent need for more regenerative farming practices reduce the loss of soil and mitigate the emissions of GHG from lowland degraded peat.

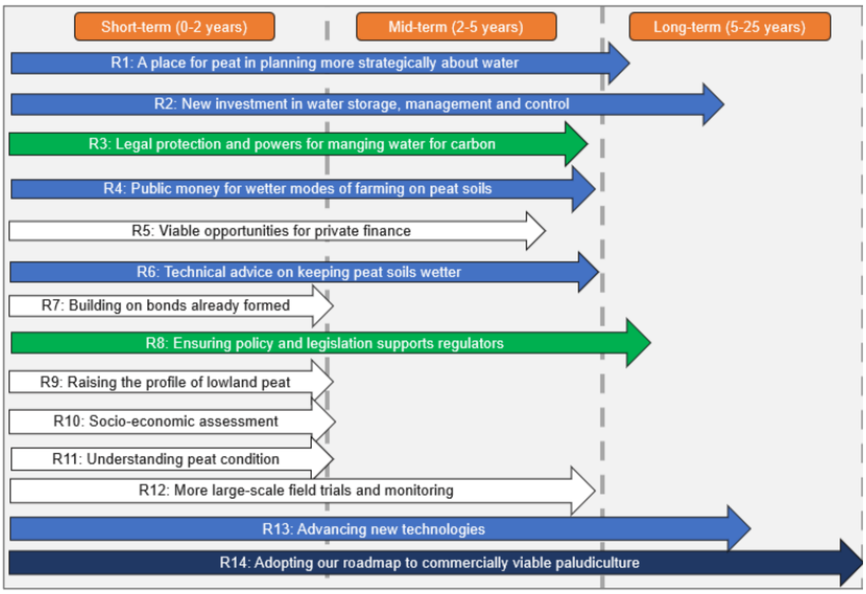


Figure 6 Paludiculture - short-term, mid-term and long-term recommendations (Defra 2023).

The level of production may be exemplified by the fact that Farming on lowland peat can be highly profitable: just in the Fens, the food chain is worth over £3 billion, and much of this is based on lowland peat (Defra, 2023).

In 2021 the Lowland Agricultural Peat Task Force identified 14 recommendations for farming on lowland peat. The fourteenth proposes adopting the roadmap to commercially viable Paludiculture by 2031 (see Figure 6)

2.1.4 Farming on peat

The distribution of peatlands in general is hotly debated due to the inaccuracies in mapping methodologies used. The most up to date estimation of this distribution has been reported by the Global Peatlands Initiative (2022), see Figure 8.

In the England Peat Map (Figure 7) is currently under review and is being baselined with active field sampling such as that being undertaken by the Environment Agency funded project Patchy Peat Solutions Project (Casperd et al., 2023). The current distribution of peat in the UK may be viewed in published material by Chris Evans et al (2017).

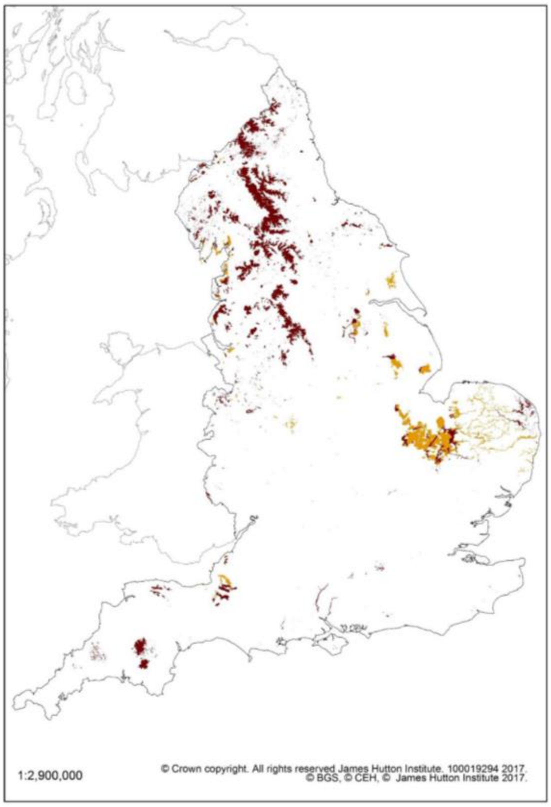


Figure 7 England peat base map (Natural England, 2023: deep peats shown in brown, wasted peats in orange).

2.1.4.1 UK distribution of lowland peatlands used for agriculture

Currently the distribution of peat in the UK is inaccurate. Natural England's (2023) England Peat Map Project has been mapping the extent, depth and condition of England's peat. GHG Emission reductions equate to carbon savings as a previously emitting environment becomes a biogenic sink. These savings from a paludicultural farming system (Figure 9) can be significant. In Finland they have been estimated at 352,000 tons of CO2 each in 2050 compared to the peat use system (Myllyviita et al., 2024).

2.1.4.2 Global distribution of lowland peatlands used for agriculture

The distribution of peat across the globe is predominantly located in the Northern hemisphere (Figure 8). The issues facing the UK are mirrored across the globe. The Global Peatlands Assessment published by the UN Environment Programme (UNEP, 2022) estimates that 500,000 hectares of peatlands are lost annually, while already drained and degraded peatlands contribute around 4% of annual global human-induced emissions. A large proportion of these GHG emissions are being produced by the tropical peatlands of Southeast Asia, primarily due to palm oil production (Evans et al., 2017).

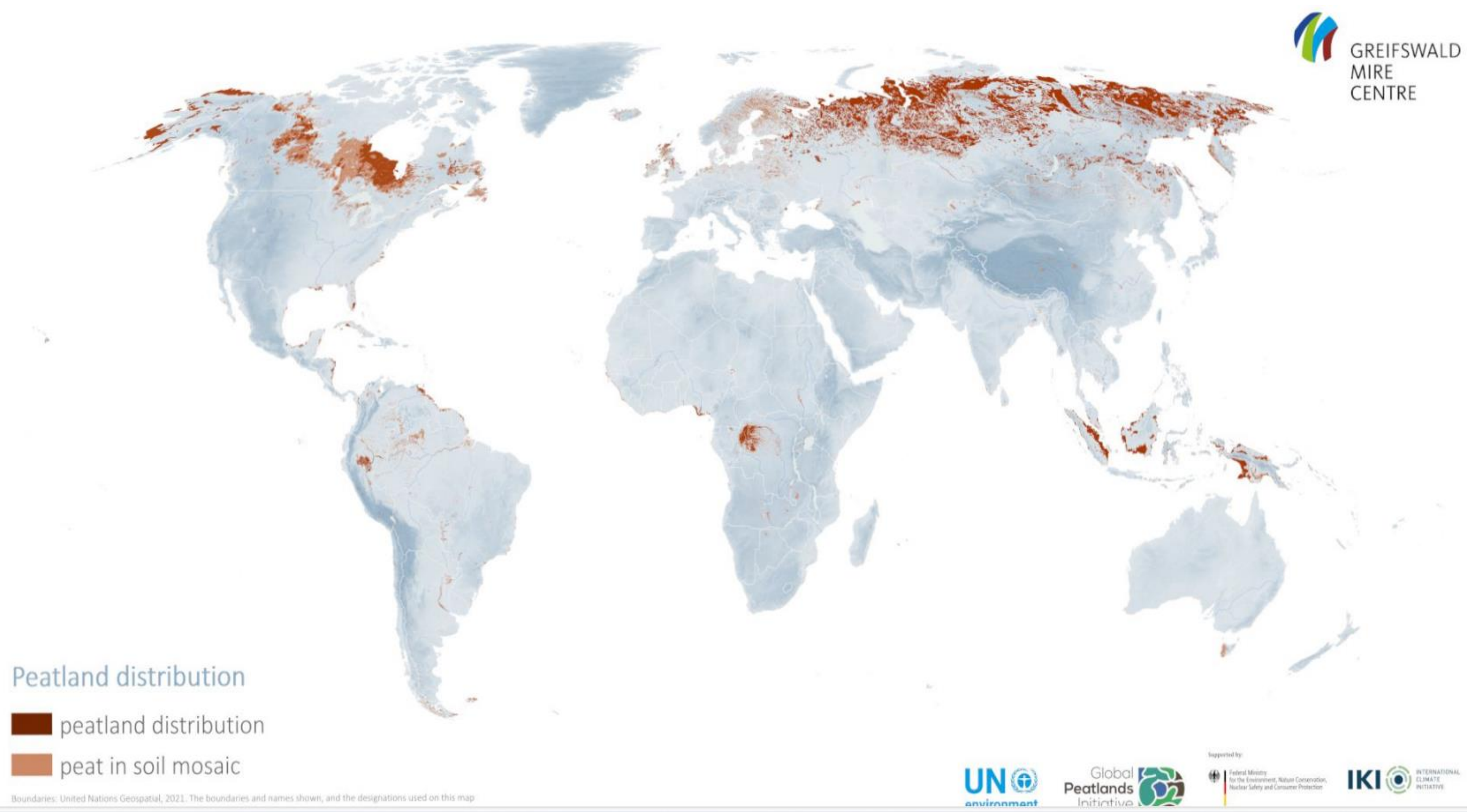


Figure 8 World map of the distribution of peat, source: Global Peatlands Initiative (2022).

2.2 Wetter farming - paludiculture

2.2.1 Paludiculture as a profitable regenerative farming system

Paludiculture, wetter farming on peat or farming on peat with raised water tables has been proposed as a productive method of continuing to use peat productively whilst reducing GHG emissions and potentially restoring these significant carbon stores to carbon sinks (see Figure 9). Grasslands and a number of crops such as broadleaf cattail, also known as bullrushes, (*Typha latifolia*) and common reed (*Phragmites australis*) have become the focus of this new farming system in Europe and much research is being produced regarding these crops in terms of their agronomy, the impact of production on GHG emissions, nutrient balance (e.g. see Vroom et al. 2022), LCA and biodiversity. Other crops are now being explored in Natural England funded Paludiculture Exploration Fund projects in England including celery, blueberries and a number of novel, high value crops (see Natalio et al. 2024) that have potential to replace conventional crops but maintain good levels of productivity without affecting food security.

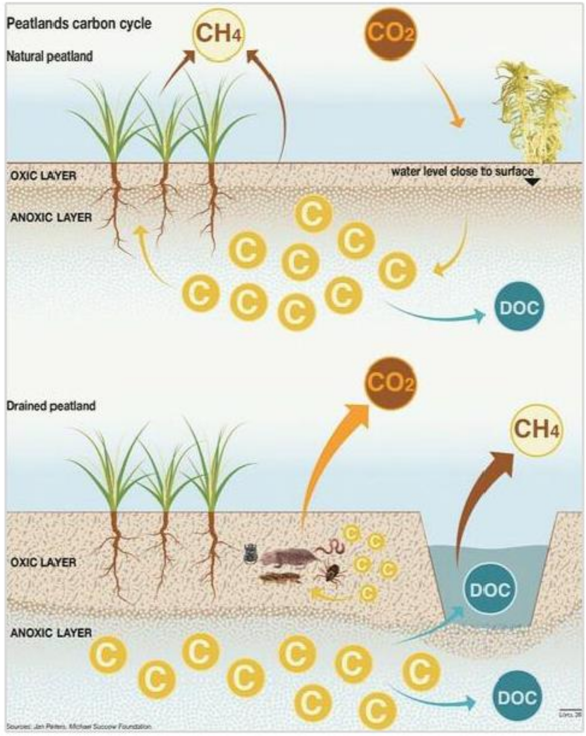


Figure 9 A natural peatland with actively forming peat (anoxic layer present) and a drained peatland which is not actively forming peat (see Izquierdo, 2017)

2.2.2 Current locations, crops, routes to market

Paludiculture is being practised across Europe and in the UK. Crops farmed in Europe include cattail (*Typha latifolia*) and reed canary grass (*Phalaris arundinaecea)* for biomass, fibreboard and insulation among other things (NIAB, no date). Grasslands are also maintained with higher water tables in paludicultural farming systems. In the UK, blueberries, celery and lettuces are being trialled on lowland peat in the North with water tables around 20 cm below the surface to the soil (Longden, 2024). There are a number of crop trials which have begun at Harper Adams University using novel high value crops as part of the Paludiculture Innovation Project and LP3 (Natalio et al., 2024).

2.2.3 Barriers to widespread adoption

The barriers to the widespread adoption of paludiculture relate mainly to the management of water in the landscape, the possible impact on food security, policy and farmer engagement. This has become the subject of a number of studies as part of a variety of lowland peat projects such as Defra's Lowland Peat 3, the Natural England funded Paludiculture Exploration Fund and the Environment Agency Lowland Agricultural Peat Water Discovery Pilot. Intuitively it does not appear that wetter farming on peat will pose a threat to our national food security (See NFU, 2019); It is more concerning that in the future our food security will be threatened by farmers not having access to sufficient water and by the loss of our fertile peat soils.

2.3 Novel high value paludiculture crops - cranberries

It has been suggested that the cranberry, which is a fruiting shrub currently farmed intensively on peatlands and sand in the US and elsewhere and which is also naturally occurring in mires and bogs in the UK, could be another possible paludiculture crop. My research and travels (see Appendix 5) indicate that cranberries have not been farmed, intensively or extensively, in the UK before. The key question here is why? Is it not profitable? Are there issues in terms of its agronomy? What are the barriers?

2.3.1 Background - Cranberry taxonomy and classification

The cranberry is named after the sandhill crane (*Grus canadensis*) due to the association of this bird with wetlands growing cranberries. It is one of a number of similar low growing shrubs with edible berries located in bogs and mires in the genus *Vaccinium*, family Ericaceae (see Figure 9). The Genus Vaccinium includes 450 species, three of which (blueberry, cranberry and lingonberry) have been cultivated as fruit crops (see Song & Hancock, 2011). There are others including bilberry and lingonberry (see Plants of the World Online, no date), the latter which is currently being explored for cultivation. These plants have a symbiotic relationship with the mycorrhizal communities in the soil to improve the efficiency of nutrient uptake from the nutrient poor soils.

Figure 10 Pure bred cranberries *V. macrocarpon*, growing in sphagnum, Central Poor Fen, Black River Falls, Wisconsin, US (Ryan O'Connor, 2023).

There are three species of cranberry (see Matthews et al., 2012), two are native to the UK, *Vaccinium oxycoccus* or the 'Northern Cranberry' and *Vaccinium microcarpus* or 'Small Cranberry'. The third species, the 'Large Cranberry' *Vaccinium macrocarpon* (Aiton, 1789) is native to Eastern Canada and Northern Central and Eastern US. Despite being difficult to transplant from the wild (Native Plant Trust, no date), the cranberry (*Vaccinium macrocarpon* – Linnaeus, 1753) was first domesticated in the twentieth century and many cultivars from this original strain are now grown.

Cranberries are an evergreen perennial plant belonging to the family Ericaceae. More details of their specific botanical characteristics are described by the Native Plant Trust (no date). Once established they continue to grow and bear fruit each year. There are reports of some plants in Cape Cod being over 150 years old. These shrubs are low growing, only reaching 6-8 inches, with trailing vines which spread horizontally over the ground for up to 7 feet long.

The distribution of native cranberries is confined to the temperate biome (Figure 11). This climate may be defined by rates of precipitation of 75-150 cm pa (but this can vary). Temperatures range from monthly averages between 0 and 18 degrees Celsius and at least one month above 10 degrees Celsius (see Berg et al., 2018 and Met Office, no date). This zone may be subdivided into 3 distinct regions (see Figure 12 and Dastrup, 2020) as follows: Mediterranean (Cs), Humid Subtropical (Cfa, Cwa, Cwb) and Marine West Coast (Cfb and Cfc). Temperate climates have four distinct seasons with a dominant winter and summer season, although this is beginning to vary as a result of climate change. Although, the UK has a different climate according to the Koppen classification, there are similarities with Wisconsin especially in terms of the dormancy temperature requirements which may mean cultivation of *V. macrocarpon* would be possible (see Appendix 3 for further discussion of dormancy and temperature requirements).

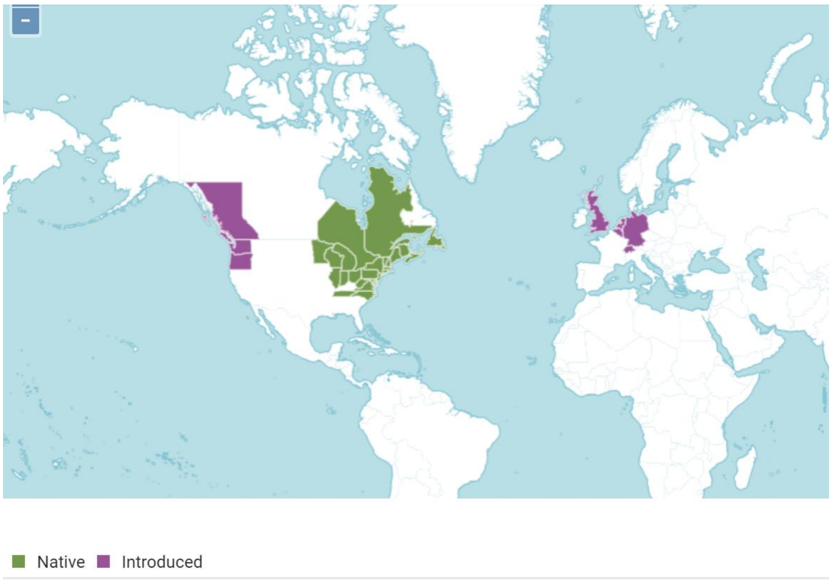


Figure 11 Map to show the native distribution of *Vaccinium macrocarpon*. Source: Plants of the World Online, Royal Botanic Gardens Kew (no date).

Vaccinium macrocarpon is the only species which has been commercially cultivated in various regions of the world due to the large size of its fruiting body. Captain Henry Hall was the first person to commercially cultivate cranberries in Cape Cod, Massachusetts in 1816. It has also been historically introduced into naturally occurring wetland habitats on the Friesian Islands of the Netherlands (Laptander, 2013).

In the UK varieties of Vaccinium macrocarpon including ‘Early Black', 'Pilgrim', 'Redstar' and 'Stevens' have been successfully grown (RHS, no date) but not on a commercial scale. In general, in low intensity farming systems or horticultural activities, cranberries (*V. macrocarpon*) are resistant to pests and diseases, but this risk increases when grown at scale (see Appendix 3).

Cranberries were widely used as food and medicine by the Native Americans who ate them fresh, ground, mashed, baked into bread as well as making tea from the leaves. By mashing them with deer meat they made ‘pemmican’, a survival food for fur traders during the winter months.
The Native Americans introduced the first European settlers to the cranberry, who initially named them crane-berries, as the flowers reminded them of the head, neck and bill of a crane. In 1667, the New Englanders sent a gift to appease King Charles II, which included ten barrels of the berries. The high vitamin C content provided a natural remedy for scurvy and barrels of the berries were once stored on American sailing ships to maintain the health of the crew. In 1796, cranberries were served at the first celebration of the landing of the Pilgrims, and cranberry sauce has remained a staple of the traditional Thanksgiving dinner ever since.

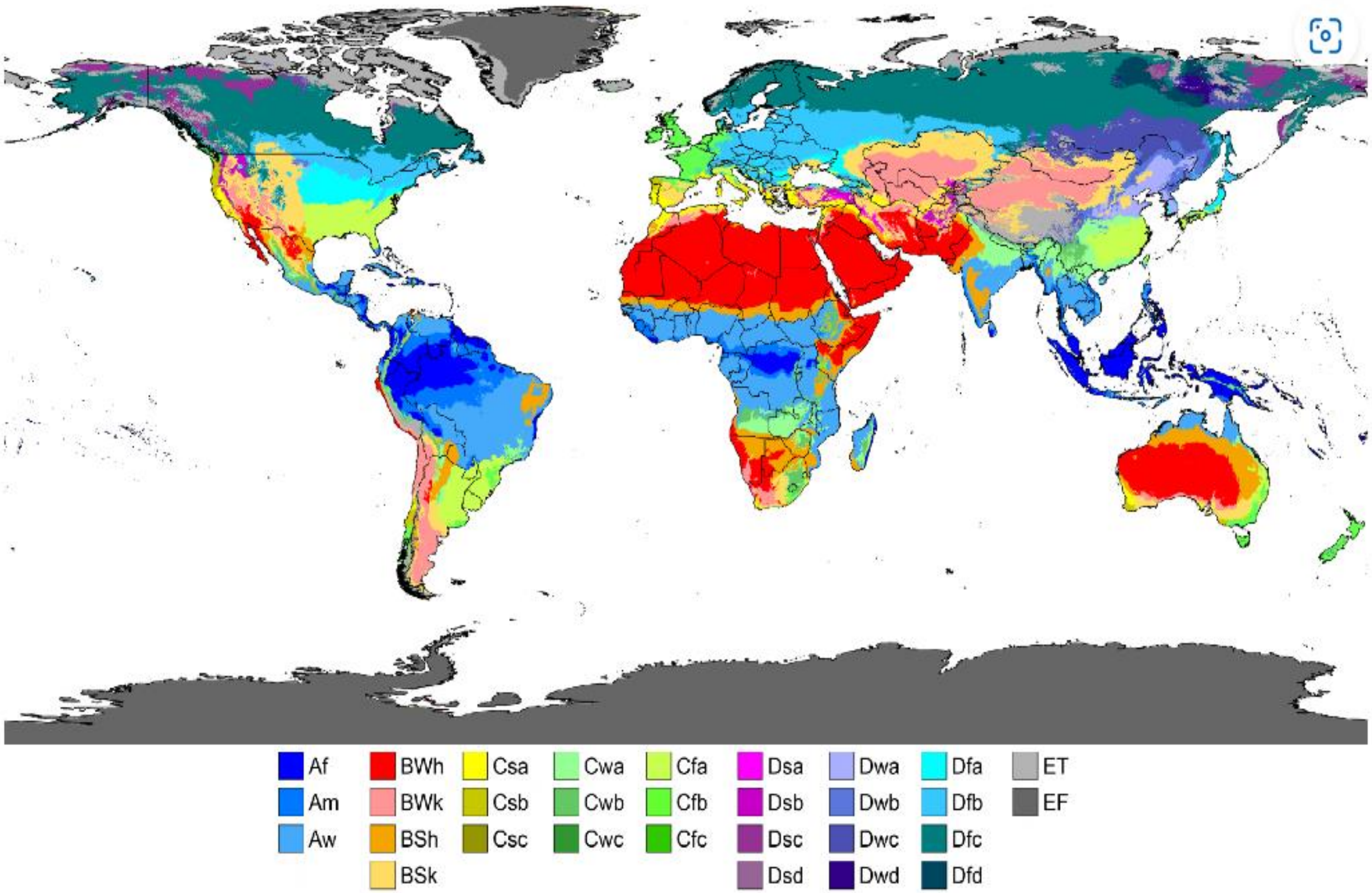


Figure 12 Map to show the current distribution of temperate climate zones (Cs, Cw and Cf codes) using the Koppen classification system (source Beck et al. 2018).

2.3.2 Cranberries in nature

Cranberries grow naturally in nature as part of wetland ecosystems such as mires and bogs. Naturally growing cranberries have been observed by the author in the UK at the Meres and Mosses, Whixall, Shropshire; in the US in Wisconsin (Figure 10), and in Europe in the Sumava National Park, Czech Republic (Figure 14). They have also been reports of cranberries growing in Haweswater in the Lake District (Figure 13, Schofield, 2024). These cranberries grow in sufficient numbers in the Lake District National Park to be harvested for personal consumption. The density of cranberry fruits look similar to that observed in the cranberry beds at Habelman Brothers farm, Wisconsin. There are also reports of cranberries being harvested in Ireland from peat bogs (see section 4.4.4.1 Case study 5).

Figure 13 Wild growing cranberries (*V. oxycoccus*) harvested from Haweswater, UK, Christmas Eve, 2023 (source: Lee Schofield)

Hybridsation of naturally occurring cranberries is a huge issue in Wisconsin. This process of hybridsation acts to modify natural habitats and reduce their resilience and will ultimately affect the genetic diversity of the wild population which may be required to call upon to target issues such as disease resistance in commercially bred varieties in the future. The Wisconsin Wetlands Association and Department of Natural Resources are mapping the distribution of unhybridized cranberries in relic bogs to safeguard against this happening. Ryan O'Connor from the Wisconsin Department of Natural Resources reported the presence of naturally occurring unhybridized cranberries in bog relics near Black River Falls (see Figure 10: Central Poor Fen: [44.343251, -90.64872](44.343251, -90.64872)). I was interested to observe the condition of these plants and the wetland assemblage in which they occurred. The cranberries I located (see Figure 15) were in low densities in a relic bog dominated by Typha. The cranberries were growing in sphagnum which was dry, indicating that the habitat had limited functionality and capacity to support the growth of cranberries and other plant species.

Figure 14 Wild growing cranberries in sphagnum in the Czech Republic with other mire vegetation including blueberries.

2.3.3 Cranberry varieties and breeding

There are approximately 100 varieties of cranberry world-wide (Jensen, Flemming & Ingram, 2024) with new cultivars being developed. Currently, *Vaccinium macrocarpon* cultivars are generated exclusively through traditional breeding approaches. Controlled hybridisation and deliberate selection has been used as the dominant technology for advanced breeding (USDA, no date). Marker-assisted selection and genomic databases are beginning to emerge that will aid in the efficiency of *Vaccinium* breeding. The US Government recognises the importance of having a wild cranberry gene pool to draw upon for the purposes of increasing the resilience of the available cultivars (USDA, no date).

Despite 50 years of breeding there is still scope for improving the genetic lines of cranberry cultivars, especially in light of the changing environment. It is recognised that to maintain production in current regions new strains will need to be developed (Hirabayashi, 2022). Recently, there has been interest in research circles to exploit the genetic traits exhibited by the circumboreal *Vaccinium oxycoccus* to improve the resilience of Vaccinium macrocarpon cultivars (Kawash et al., 2022). An initial genome sequence of an inbred line of the wild selection 'Ben Lear,' which is parent to multiple breeding programs, provided insight into the gene repertoire as well as a platform for molecular breeding. Recent breeding efforts have focused on leveraging the circumboreal *V. oxycoccus*, which forms interspecific hybrids with *V. macrocarpon*, offering to bring in novel fruit chemistry and other desirable traits.

Figure 15 Possible hybridised cranberries growing on the road verge in Black River Falls, Wisconsin (August 2023).

2.3.4 Cranberry production

Cranberries have a 16-month cycle of production from the emergence of buds to berries (Figure 14). In the Spring (April to May) buds that were developed in July of the previous year start to grow. In June stems with leaves and flower emerge. Pollination and fruit development occurs in July simultaneously with the initiation of new buds. At this point the growth cycles are overlapping (see figure 18). In late summer, around August, berries develop and become pink. Cranberry buds also develop at this time. In September to October mature berries are ready for harvest and buds developing for the following year continue to mature. In November, following harvest, buds are left on the plant to enter dormancy ready for the next year. Dormancy is an important stage in the cranberry life cycle, and it has critical abiotic thresholds, especially relating to the duration of dormancy and temperature. Abnormal dormancies may result in an 'umbrella bloom' where stems do not grow above flowers. This growth results in a 50% lower yield with only 1 or 2 fruits per stem compared to 4 or 5 on a healthy fruiting stem (see Figure 17 & 19).

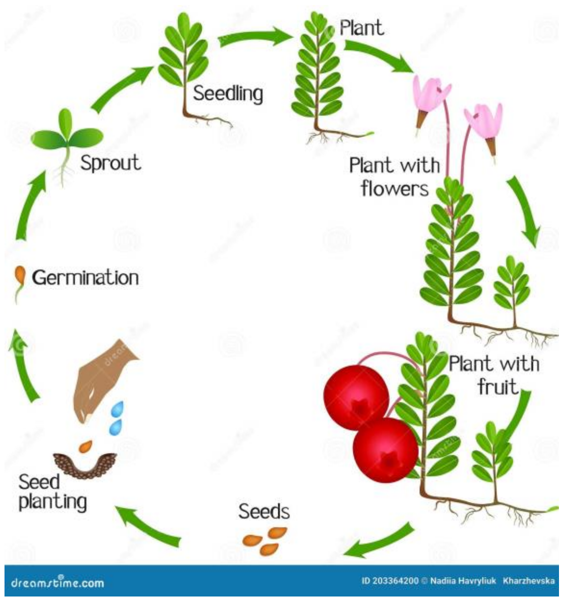


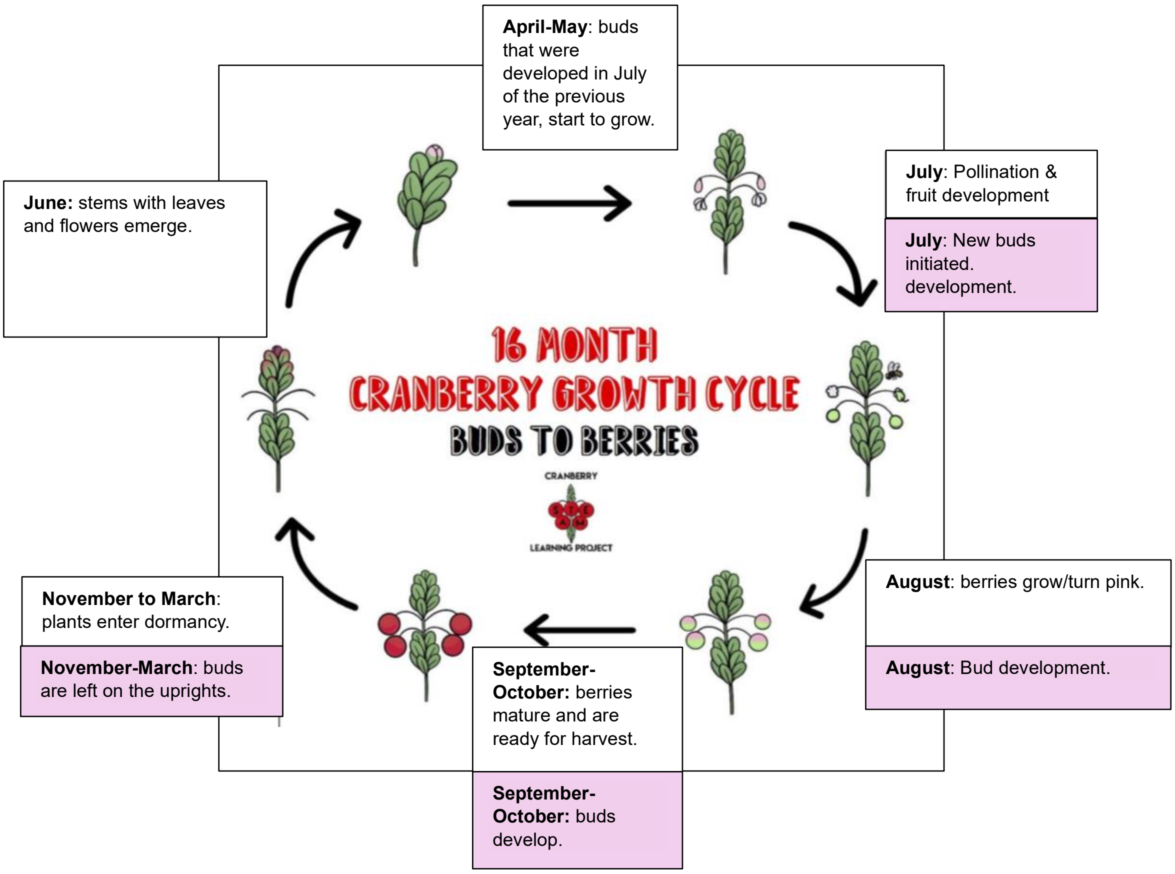
Figure 16 The life cycle of the cranberry (source: www.dreamtime.com)

Figure 17 Tom Tiber (Habelman Bros., Wisconsin) showing a healthy cranberry fruit bearing stem unaffected by frost with 4 cranberry fruits.

Harvesting

There are two methods of harvesting cranberries, wet and dry. Dry harvesting is achieved using a handheld rake like piece of equipment (see Case study 3 for more information) or possible machinery observed at Lake Nakomis (see Case study 2). Wet harvesting is very efficient producing the iconic images of berries floating on crimson lakes. This process involves flooding the cranberry bed with up to 18 inches of water to cover the cranberry plants. Water reels, known as "egg beaters," churn through the bog detaching the ripe berries from the vines. The berries float to the surface and are corralled using flotation booms and pumped into trucks or raked and extracted by hand and put into boxes. This method has allowed for intensification of the farming system allowing for large-scale harvesting of cranberries. This method is appropriate for berries destined for processing into juices, sauces and dried products but not for the fresh cranberry market because fruits are damaged, reducing quality and shelf life.

Figure 18 Cranberry growth cycle, overlap of the cycle is indicated by the mauve colouration.



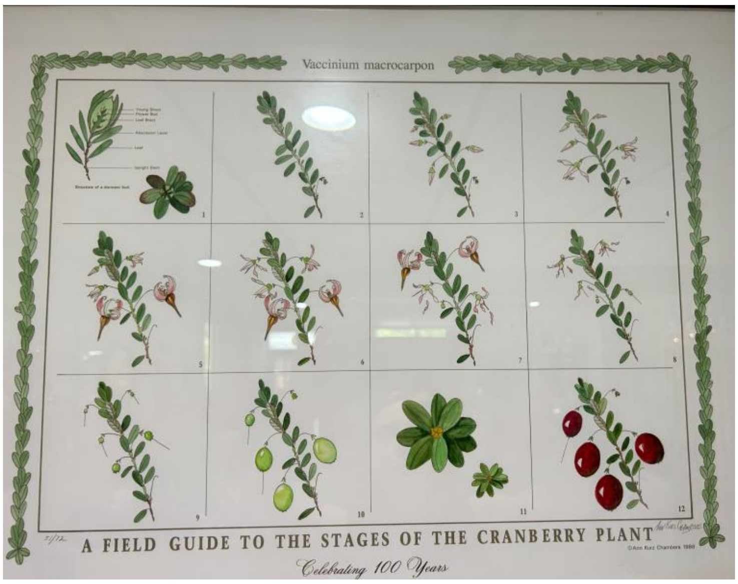


Figure 19 Field guide to cranberry plant stages demonstrating the distribution of fruits along a healthy cranberry stem (source: Habelman Brothers Ltd, Wisconsin.

2.3.4.1 Global distribution of cranberry production

Cranberries are produced all over the world (Figure 20). In America they production is focussed in Central, North Central and South-Central regions. There are new and emerging markets in Chile which are considered to be a possible threat to the US cranberry industry (Wilson, 2023).
The United States of America is the largest cranberry producer in the world with 320,870 tonnes production per year. Canada comes second with 156,575 tonnes yearly production. With 13,745 tonnes of production per year, Turkey is the third largest producer of cranberry. 3% of US cranberries harvested for fresh fruit (few farms). In Wisconsin, cranberries are farmed in pockets including Warrens, Black River, Wisconsin Rapids, Stone Lake, Eagle River and Manotowish Waters (Phillips, 2023). US Americans consume around 80 million pounds (20% of production) of cranberries every year during Thanksgiving (Berman-Vaporis et al., 2019). On average, 4000 cranberries are required to produce one gallon or 4.5 litres of cranberry juice and 200 cranberries for a jar of cranberry sauce. The cranberries market size is forecast to increase by USD 1.85 billion and is estimated to grow at a CAGR of 2.44% between 2023 and 2028 (Technavio, 2024). Cranberry plants can be prolific in their production, with one cranberry plant producing over 500g of cranberries in a year. This is comparable with other berries such as lingonberries which produces berries in the spring and summer with around 450g total harvest.

Demand & route to market

There is demand in the UK but it this could be developed further through product diversification. Cranberries are on sale either as juices, powders or dried. Demand for fresh cranberries is seasonal and coincides with Christmas. The author herself bought fresh cranberries in Lidl at Christmas which had been sourced from the Habelman Brothers farm. in the UK is seasonal. Conversations with Morrisons (Throup, 2023) suggest that if the profit margins are significant that they would stock cranberries from the UK. In the US, demand is controlled by a chain of contracts. Cranberry growers enter into multi-year contracts with a handler (company) who agrees to buy their crop. They get paid per barrel of cranberries. Additional payments are available for premium cranberries for a deep red colour or good quality.

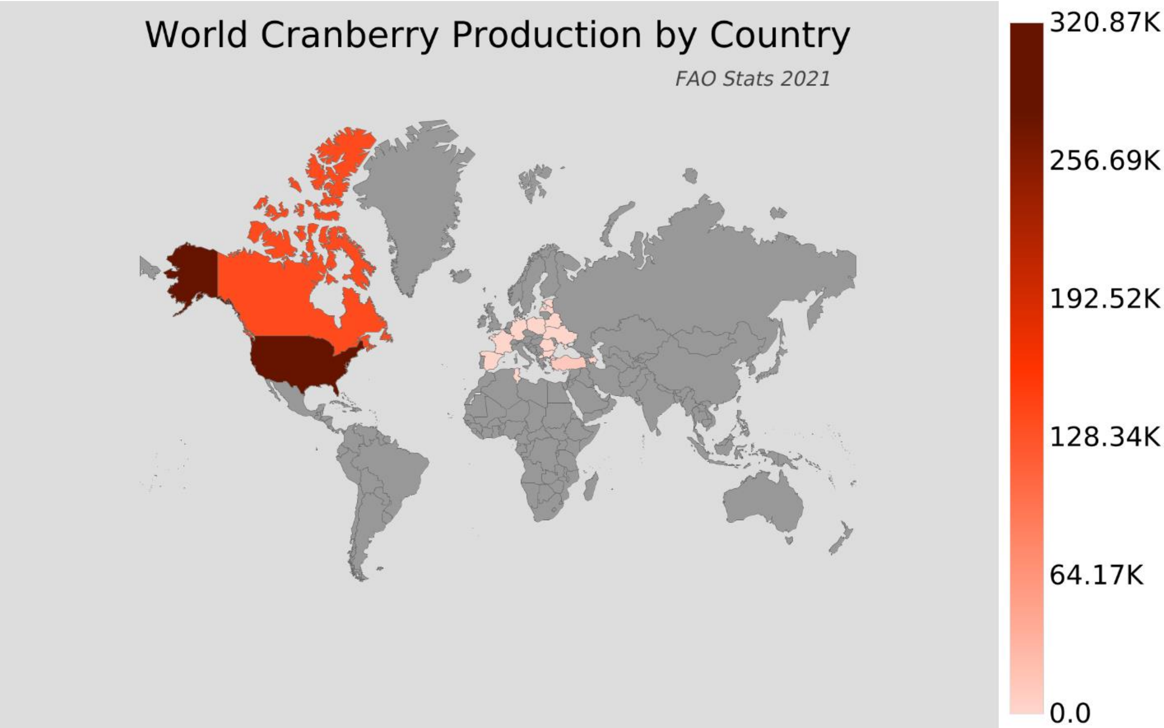


Figure 20 Map to show the global distribution of relative rates of cranberry production. Source: Defra 2023

2.3.4.2 Cranberry farming in the UK

The author's personal research. which included literature review, phone calls and questions put to stakeholders, did not provided any evidence that cranberries have been farmed in the UK.). it is believed that employees of Beadamoss, who originally ran the business as a nursery, have grown cranberries for horticultural purposes (Beadamoss, 2023). It appears that Mockbeggar Farms also attempted to cultivate them without success (Mockbeggar, 2023). It is unclear why the production of cranberries has not been successful, but it is likely to be related to the competitive imports from the US.

2.3.5 Cranberry agronomy

Agronomy relates to field crop production and soil management the aim is to improve and maintain yield in a sustainable manner. The agronomy of large-scale cranberry production is complicated and knowledge hungry. The main elements have been summarised in Appendix 3 to provide a tool for signposting. Growing cranberries in the UK needs to be informed by current practices elsewhere but there is a huge amount of information available relating to the agronomy of this fruit, e.g., University of Maine's 'Growers Services' repository (University of Maine, no date). It would be critical to establish a programme which identifies the traits required for optimal performance in the UK depending on the farming system adopted. A programme of Integrated Nutrient Management is required (Antil & Raj, 2019). The uptake of phosphorus (P) for example is directly affected by soil pH (Figure 21). For example, phosphate tends to react with calcium (Ca) and magnesium (Mg) at alkaline pH. In acidic soil, it reacts with aluminium (Al) and iron (Fe) and becomes less soluble. As soil pH increases, many nutrients, like magnesium Mg and Ca, become increasingly available, disturbing the nutrient balance and causing toxicity.

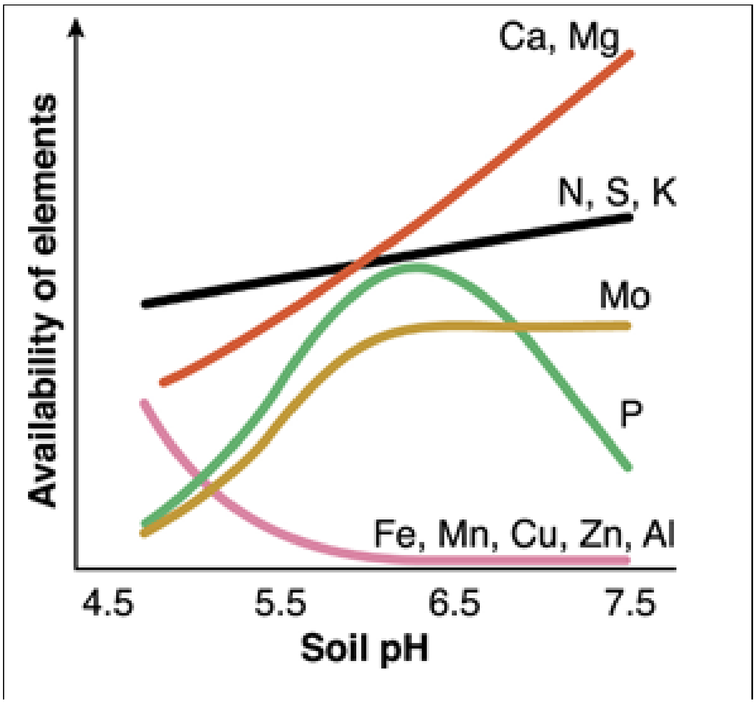


Figure 21 Soil pH and availability of the elements (source: www.agric.wa.gov.au)

2.3.6 Cranberry farming systems

There are a number of different types of farming systems which may be characterised across the globe. These include systems in which there are no inputs or where inputs are high or low. For the purposes of this report, they have been named *High Intensity Cranberry Farming* (HIC), *Low Intensity Cranberry Farming* (LIC) and *No Input Cranberry Farming* (LIC).

2.3.6.1 *High Intensity Cranberry Farming (HIC)*

The HIC system requires high inputs of fertiliser, pesticides and herbicides to be profitable. It needs to be micromanaged and highly profitable farms make use of other agronomic tools such as IPM and pollinator imports. There is plenty of research to indicate that the success of these high intensity cranberry farms is directly related to the management of the crop and the site itself (see Jones, no date). A site that has been poorly selected can result in limitations to the long-term financial viability of the operation, regardless of how skilled the manager is.


Figure 22 Tom Tiber, in a cranberry bed at Habelman Brothers showing the length of runners on the cranberry plant.

Cranberry bogs can be constructed in two different settings: natural and man-made. A natural cranberry bog is constructed on peat bogs or organic soils (Figure 23). However, peat bogs are considered wetlands and nowadays environmental approval is required before proceeding with development. This process can be very costly. This has now influenced producers to develop bogs on mineral soils, called uplands. These bogs are designed to mimic a wetland environment, including the ability to hold a flood as required for harvest and/or winter protection.

Regardless of the type of setting used to construct the cranberry bog, each site should have the following characteristics: 1. an abundant supply of fresh water, used for irrigation, frost protection, wet harvesting and winter flooding. 2. access to a reliable source of sand, used to ensure rapid water movement through the upper soil level and prevent water “ponding” on the bed surface. 3. the ability to hold flood water for wet harvesting of cranberries and winter protection of the vines. 4. the site topography should be as level as possible, with a slope no greater than two per cent.

Consequently, cranberry bog soil consists of alternating layers of sand and organic matter that cap thick sedimentary deposits of peat (see Figure 23 and Kennedy et al., 2018).

This report explores the HIC systems which in Wisconsin to determine whether a HIC system or elements of a HIC system would be appropriate in the UK.

2.3.6.2 *Low Intensity Cranberry Farming (LIC)*

LIC systems are characterised as having minimal inputs in terms of fertilisers, pesticides and herbicides. They have less impact on the environment, but they are less profitable. This report evaluates the LIC systems which are present in the Netherlands where cranberries are grown on polder reversions (c.f. The Cranberry Farm – Case Study 4) to determine whether such a system is practical.

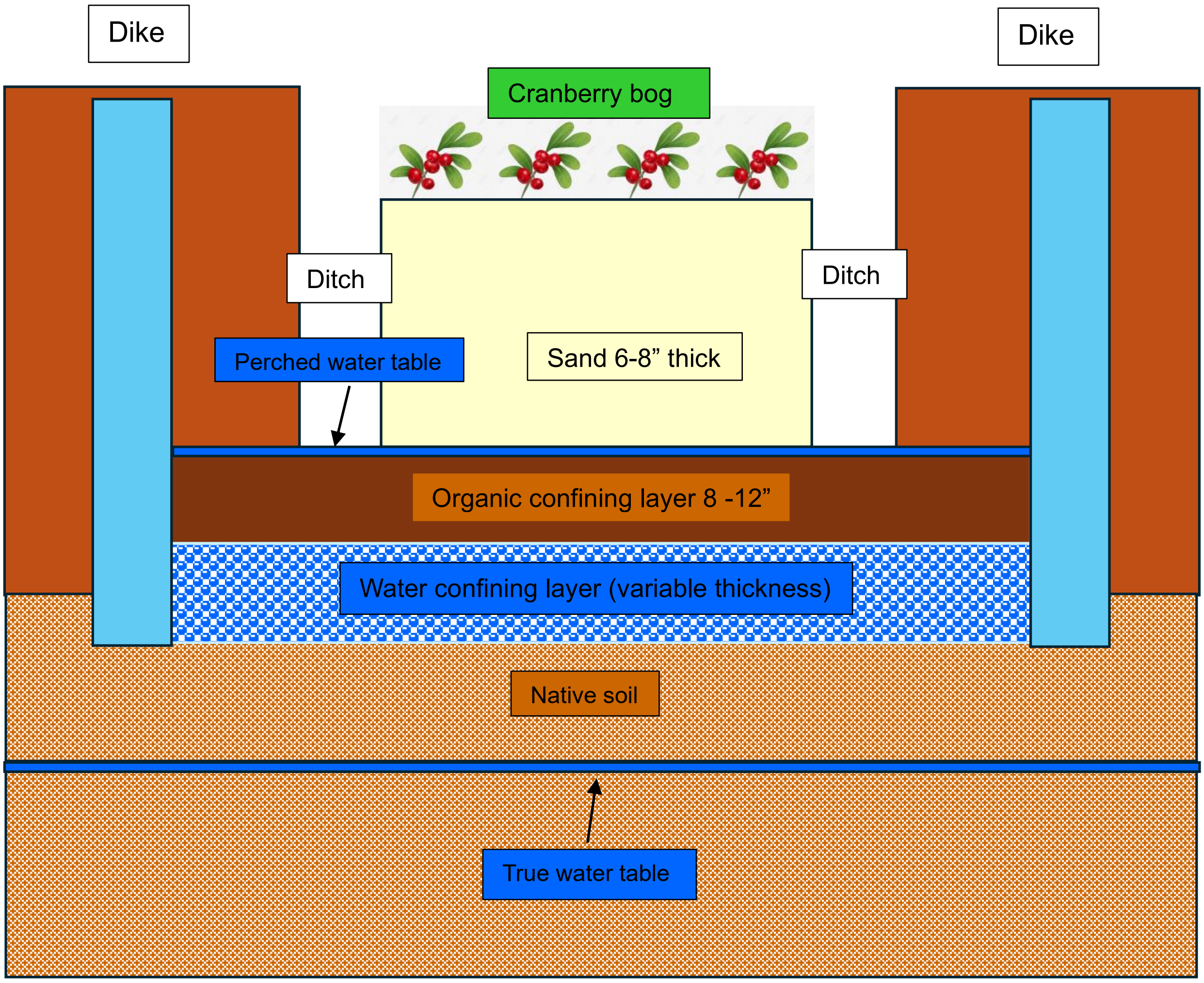


Figure 23 Cross-section of cranberry bog with location of organic and water confining layers in a perched water table design (source DeMoranville & Sandler, no date).

2.3.6.3 *No Inputs Cranberry Farming (NIC)*

NIC farming systems are similar to organic systems of farming, although the strict rules applicable to organic systems may not have been followed. Although, there appear to be some NIC or organic cranberry farming systems in Europe, e.g. in Latvia (Baltic Berry Gardens no date) where cranberries are grown within pristine peat bogs, it was not possible to look at these in great detail due to time constraints.

Although not conventional farming, cranberries are also harvested from wild peat bogs and mires in Ireland historically for sale and in the Lake District, UK (Case study 5) for personal consumption; and anthropogenically modified sand dunes such as those in Terschelling, Friesan Islands, Netherlands (see Case study 3).

2.3.7 The Cranberry market - UK/Global

Cranberries may be eaten fresh, dried and or processed as juice, chutneys, sauces, cereal toppings, cookies, wine and many other products. Drying cranberries around 50 degrees Celsius optimises nutrient density.

2.3.7.1 Fresh cranberries

Fresh cranberries are popular in America for Thanksgiving and other National festivals. In the UK, fresh cranberries tend to be incorporated into stews at Christmas or used in sauces as an accompaniment to the traditional Christmas turkey. These are a premium crop commanding good prices, this is due to the fact that they have to be dry harvested which is more labour intensive. They also require refrigeration.

2.3.7.2 Cranberry products

Cranberries are naturally low in calories, although this is not the case when dried and sold as craisans which require pre-soaking in sugar to improve palatability. Fat and sodium and considered a superfood due to their high nutritional content and wide-ranging health benefits (Gomas et al., 2024). Cranberry is used in a large number of dishes from biscuits and cakes to breads, toppings, sauces, wine, juices, jam and chutneys. Many cranberry farms in the US have their own farm shops where they sell these products following cranberry tours and during festivals.

Figure 24 Ocean spray cranberry juice stall at the Cranberry Growers Association Trade Show in Wisconsin, Summer 2023.

2.3.7.3 Health products

In addition to the numerous food products which are derived from cranberries or contain cranberries, cranberries are known to have medicinal properties (Gomas et al., 2024). They are particularly high in disease-fighting antioxidants, outranking almost every other fruit and vegetable (including spinach and broccoli). They're rich in vitamins C, A and K as well as flavonoids, which help prevent arthritis and lower the risk of heart problems. However, they are more commonly known as a popular remedy for cystitis. They are rich in vitamins A, C and K but also contain a lot of potassium, magnesium and phosphorus, antioxidants (phenolic acid and flavonoids) and proanthocyanidins. Cranberry juice drinks vary enormously in % fruit content (10% to 25%). Those with higher % of cranberry fruit are considered more appropriate for medicinal purposes. There is a growing body of evidence which suggests that cranberry juice is thought to prevent cystitis (Ranfaing et al., 2018), cardiovascular disease, Parkinson's disease and various forms of cancer. Recent research by the University of East Anglia has also indicated that eating cranberries regularly promotes blood flow in certain sectors of the brain and improves the cognitive performance of the elderly (The Cranberry Company, no date)

Cranberry is a significant example of a plant which is growing on peat soils and has a high content and a rich spectrum of biologically active substances (see Szajdak & Inisheva, 2016) . The organic compounds in the plant are responsible for its wide medical and pharmaceutical use. The beneficial impact of cranberries on human health is caused by the presence of the following substances in the berries: anthocyanins, proanthocyanidins (condensed tannins), flavonol glycosides, low-molecular-weight phenolic acids, organic acids, and sugars. Cranberry juice and fruits are reported to display a number of health benefits including potent antioxidant activity, cholesterol reduction, vasorelaxant effects, the prevention of urinary tract infections, the reduction of biofilm formation, and in vivo anticancer effects.

2.3.8 Risks and barriers to production

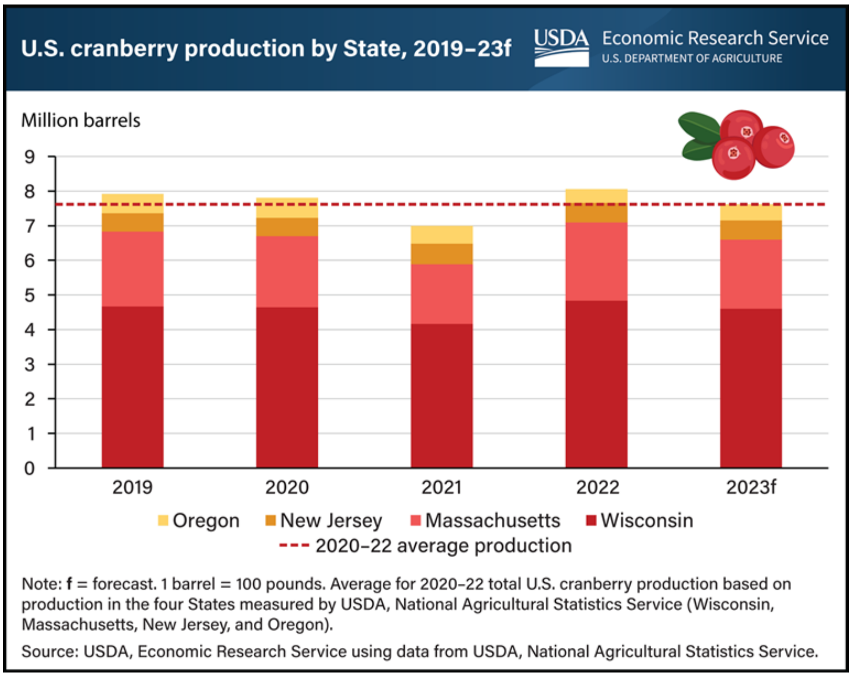


Figure 25 US Cranberry production by state (source www.ers.USDA.gov)

The risks and barriers to successful production of cranberries in the UK may be identified as issues relating to their agronomy but also to the sustainability of the farming system in terms of the 3 pillars: economic, social and environmental. The requirements of cranberry cultivars are outlined in Appendix 3. At first hand it appears that climate (especially frost), pH and weed burden would be the dominant issues to overcome initially. However, there are many others.

2.3.8.1 Sustainability - Economic pillar

The economics of cranberry production are critical to adoption by farmers. Farming is a business which needs to have sufficient profit margins to be viable either with or without subsidies. Economics is a complicated area, and this report does not go into great depth into this element of the Life Cycle Analysis but it is recognised that recommendations should be considered in light of the economic sustainability of this farming system.

2.3.8.1.1 Global & UK consumer demand

As reported by the US Cranberry Marketing Committee (CMC: www.uscranberries.com), the state of Wisconsin remains by far the most important cranberry producer in the US, now for the 28th consecutive year (see Figure 25). The USDA estimates Wisconsin's 2022 crop at 4.3 million barrels, which would represent a 3% increase over last year's figure and would also account for more than 60% of US production. Other key US growing states include Massachusetts (2 million barrels), New

Jersey (589,000 barrels) and Oregon (520,000 barrels). After the planting season was delayed by cold and precipitation in early June, warmer temperatures and better weather conditions shortly thereafter have allowed cranberry plants and berries to develop well. The USDA (USDA, no date) reports that they continue to grow well, and farmers keep a special eye on good quality.

The International Nut and Dried Fruit Council (INC, no date) estimates this year's global cranberry production at 194,836 Mt, significantly higher than the 167,493 Mt produced in the 2021/22 season. The undisputed leader remains the USA, which alone produces over 144,000 Mt of dried cranberries, followed by Canada (40,121 Mt) and Chile (10,103). The carry-over stocks are low due to last year's relatively small crop and only amount to a good 3,500 mt. According to current estimates, the USA can increase its cranberry production by more than 20,000 Mt year-on-year and thus remains the world's most important producer. Wisconsin remains the most important growing state.

Imports and exports of cranberries

The cranberry market is a significant one. In 2020, worldwide exports of cranberries from all countries were worth a total US$586.2 million (Workman, no date). Sales of exported cranberries increased by an average 4.4% since 2018 when globally exported cranberries sales were $561.2 million. However, year over year, the dollar value of exported cranberries shrank by -10.2% compared to $652.6 million for 2021.German cranberry imports have fallen significantly year-on-year, dropping by almost a third in the September-June period of the 2021/22 season. The most important supplier is Canada, which has displaced the USA from first place. Canadian shipments to Germany were increased by 31.8% in the aforementioned period and amounted to 3,572 mt. Imports from the United States plummeted by 61% and amounted to only 2,471 Mt, followed by Chile in third place with 1,545 mt. In total, German imports amounted to 7,997 mt.

Variable and fixed costs

The costs associated with establishing and operating a cranberry bog can vary from site to site and from operator to operator due to the significant cost of land preparation, labour, machinery and materials. During the initial years of bog establishment, the main costs at play are the capital costs such as the land preparation, machinery purchases/rentals, labour, vines and interest on debt. There is significant variation in the cost of land preparation depending on the need for land clearing and levelling. A new grower or someone considering entry into cranberry production must carefully consider the advantages and disadvantages of the site and variety selection because these decisions will have a significant impact on the profitability of the planting. Just knowing the establishment and production costs is not enough to make an educated decision whether to undertake cranberry production as a business or not. The individual must give consideration to the potential for profitability which is directly related to yield and price.

Variable and fixed costs relating to cranberry production will vary throughout the cranberry farming system cycle. They will also vary depending on whether the system is HIC or LIC. Adoption of cranberry farming on rewetted lowland peat is likely to incur machinery costs (Ivanovs et al., 2011; Defra 2020) in HIC systems but it will also stimulate on farm innovation as is observed on the Habelman Brothers farm in Wisconsin (see Case Study 1). This overview is derived from information provided by Jones (no date). Appendix 2 provides a detailed breakdown of the likely variable and overhead costs that would be associated with this type of system. This is a summary of the costs for the purposes of this report:

Year 1: Pre-planting Costs
In the year prior to planting the vines, the selected location will require dykes, bed and pond construction, followed by water control structures (i.e. flumes), irrigation and pump house installation. The overburden from bed levelling and the material from peripheral ditching are used in the dyke construction. It is in this year that there is a requirement for a significant infusion of cash into the bog.
Year 2: Planting Year Costs
The planting year also requires a considerable 'cash' investment in the bog. The cost of the vines is a significant portion of the cost in the planting year, making up over sixty per cent of the total costs. The labour expense will vary depending on the amount of labour required, the availability of the labour, and the wage expected by the available labour pool at the time of the planting. If the labour used is the farm owner/manager and their family, then its value needs to be accounted for in all financial projections.
Year 3: First harvest Year
In the third year of establishment, the bog will begin to yield some return. In the first year of harvest, one should expect to receive only 10 to 20% of a full yield.
Year 4 and beyond
The total costs are the same as year 3 with the exception that under the variable costs, pruning is only done every other year for the large farm and sanding is done every three years for both the large and small farm. The bog should reach a full mature yield at approximately year 7.
The price of cranberries is very volatile and unlikely to remain the same over the life of the bog. In the future it may be that this could be supported by incentives for natural capital (see Trenbirth & Dutton, 2019). The economics of cranberry production in a *High Intensity Cranberry Farming* system (HIC), and to a lesser extent a *Low Intensity Cranberry Farming* system (LIC), are critical in establishing a successful farm business. With regards to the HIC system there is interesting insight from work done in Nova Scotia (Jones, no date).

Cranberry yield is a function of site selection, sanding, and management, to name a few. The price achieved by a crop is determined by the current market and quality, therefore the price is a function of a farm's ability to grow and market a quality product. Some cranberry farmers make premium quality cranberries their priority, e.g. in Nova Scotia, and are very interested in securing the highest quality cranberries.

2.3.8.2 Sustainability - Social pillar

How sustainable cranberry farming is across the world varies with the type of system used and the community engagement and culture. In the HIC systems in Wisconsin and elsewhere in the US there is a strong cultural element associated with the harvesting of cranberries which In the Autumn ready for Thanksgiving. Over the years this has created a strong sense of community and tradition, and farmers and neighbours work together to get the crop in. However, in recent years the younger members of the community have been moving away to the cities and this has resulted in a labour shortage. The cranberry industry provides many jobs for local people and there is obvious health benefits associated with working outside. However, hours are long especially during the harvest and there are side effects from sanding on employees' health. Sanding is critical in the HIC system to control pests, to encourage new growth and protect against frost but its extraction has social and environmental implications. The fine particulates from mining sand and the exhaust from generators can cause respiratory issues and lung cancer and mining activities substrate can cause erosion sedimentation of water courses.

2.3.8.3 Sustainability - Environmental pillar

2.3.8.3.1 Climate change

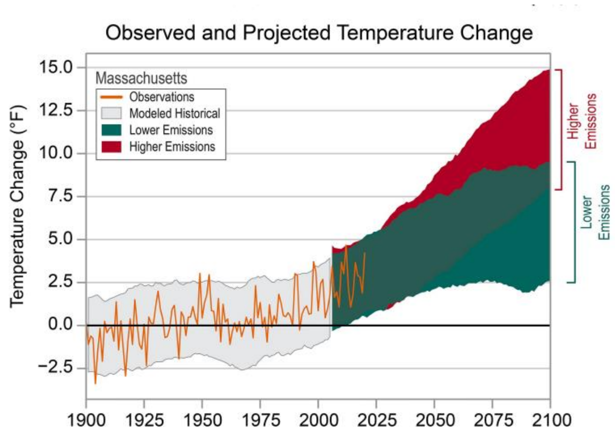


Figure 26 Observed and projected (compared to the 1901 -1960 average) in near-surface air temperature for Massachusetts (source Runkle et al. 2022).

Climate change is a huge risk to cranberry production, especially to the high intensity systems present in the US and elsewhere. There is evidence that global surface temperatures in NE states of America have increased faster (+2.08 degrees Celsius) than the global average of 1 degree Celsius since 1880 (Gareau et al. 2018). The impact of climate change such as increased weeds, water issues, e.g., heavy rainfall, water scarcity, and heat waves ruining harvests are considered important to growers in the US This has led to adaptation in farming practise as farmers try to remain optimistic. The frequency of conventional flooding and sanding in the winter (due to a lack of ice) have increased. the adoption of both conventional (e.g., increased strategic flooding, barge sanding due to lack of ice). Emerging strategies have also been adopted, e.g., smart irrigation, solar panel installations for added income (Gareau, Gao & Gareau, 2024). It is probably that climate change will increase the risk from emissions from cranberry beds.

2.3.8.3.2 Environmental policy US/UK/Europe

It was generally agreed when I was travelling in the US that there was less emphasis on environmental issues and an overall lag in environmental policy compared to the UK and Europe. In Wisconsin, there are no statutory requirements for companies/organisations to have carbon Net Zero targets. Wisconsin for example is rural and traditionally very conservative. Climate change initiatives are driven by the left-wing politicians. It is beginning to change with a focus on carbon free energy solutions.

Most growers have an ecosystem of natural wetlands which they use for flooding the cranberry beds. It is critical that they do not irrigate with water high in nutrients to avoid excessive weeds so nutrient management is key. On a cranberry farm there needs to be 5 times the area of wetlands to support the function of the bog. Cranberry farmers do not have rights to the water on the farm. It is permitted and they need to report the amount of water used. Flooding is increasingly an issue across the globe. In Northern Wisconsin ground water flooding is caused by increased precipitation, permanent and impermeable asphalt and loss of perennial vegetation which is replaced with crops. There is a lot of research around safeguarding water quality and the provision of strategies to conserve water, e.g. employing cycled frost irrigation rather than conventional frost irrigation (Jeranyama & Kennedy, 2021).

The interview with the Chair of the Wisconsin Wetlands Association (WWA), Tracy Hames, provided great insight into the challenges and barriers to environmental sustainability (see Appendix 5). The association is an NGO of 10 employees whose work is funded by charitable donations and grants. It was set up 50 years, before wetland regulations and the Federal Clean Water Act to provide information and guidance about how the wetlands could be managed more sustainably. Over 20% of the landscape in Wisconsin used to be wetlands. 50% of these, principally headwater wetlands, have been lost to agriculture or urbanisation (Figure 28). Water courses have been subject to anthropogenic change (over straightening and deepening) causing flooding downstream especially from snowmelt.

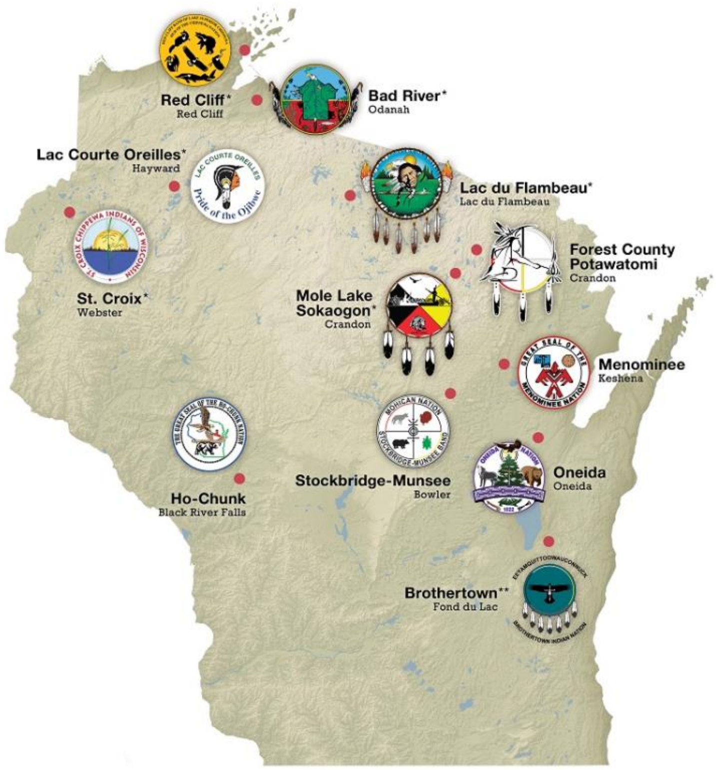


Figure 27 Distribution of the tribal nations of Wisconsin (source: www.dpi.wi.gov)

The WWA have been pivotal in driving new policy and legislation around wetland conservation and restoration and getting the Government to think about flooding and water related issues in terms of overall ecosystem function and on a landscape/water catchment scale. This is being achieved by running projects working with communities to understand the influence of Knowledge Exchange, and seek public opinion regarding how many wetlands there should be and where they should be located? They have been working with the Indian nations (see Figure 27). There are 11 federally recognised tribes in the north and have their own reservations and a seeded area for hunting fishing and gathering. They are building their capacity to manage natural resources. When the Indians take control, it has huge impact because of their understanding, the indigenous rights they have and relationship with Federal Government. The Northern wetlands are not in good condition and the Indians have called for a more evidence-based method to their management. The government has started to work with landowners to target issues such as eutrophication by regulating where new cranberry bogs may be constructed. The construction of new cranberry bogs within 200 feet of a river are subject

Figure 28 Wetland set-aside within the cranberry farm.

Figure 29 Image showing the marginal wetland areas which support biodiversity.

to the River Protection Act and new plantings constructed within 100 feet of a wetland are subjected to the Wetlands Protection Act (UMass Amherst, no date).

The populations of indigenous Indians have used their rights to drive conservation measures. They support land sharing and agricultural production.

Water resources

Cranberry wetlands systems are thought to have a role to play in recharging aquifers and flood management by controlling storm water runoff. They filter water percolating down into the ground water system. Although the fluctuation in water levels undoubtedly will cause increased GHG emissions (Natalio, 2024). Nowadays there is an issue of water retention in the upper catchment. These watersheds tend to be drier and the lowers ones wetter.

In Wisconsin, 'muck' farms, i.e. those using peat have subsided. Some as much as 6ft since the 1940's. These farms are becoming increasingly harder to drain and are returning to wetland habitats. Managing water in the landscape is becoming more difficult. This is compounded by the fact that between 75% and 85% of wetlands are located on private land. Wells near wetlands tend to have more water. Different crops impact on groundwater. Potatoes in central Wisconsin are detrimental to the environment in terms of nutrients and carbon emissions.

Figure 30 Bald eagle (*Haliaeetus leucocephalus*) at Habelman Brothers Cranberry Farm, Wisconsin.

Wildlife

Cranberry growers recognise the fact they are environmental stewards, often owning vast tracts of land and the ecosystem services they provide, such as biodiversity. For example, in Massachusetts, for every acre of cranberry bog owned cranberry growers manage an additional 3-5 acres of wetland habitat either as linear features along ditches/dykes or in surrounding areas providing refuge to a diverse assemblage of wildlife (Sandler & DeMoranville, 2008). This provides important refugia for a variety of species including the iconic bald eagle and reintroduced Elk.

Biosecurity

If cranberry farming were to be adopted a regime of strict biosecurity will need to be adopted to avoid the spread of pests and diseases via imported cultivars.

Other environmental issues related to the production of cranberries include run off and loss of sand. The protection of wetlands has focussed on plants and habitats, there has now been a shift to the hydrology. Climate change has resulted in warmer winters, earlier springs which have impacted on the capacity to protect the crop from frost. There are also more frequent localised storm events and droughts. This has also resulted in more mosquitoes and flies and a shift in the distribution of cattail.

The distribution of Narrow Leaf and Southern Cattail have moved North resulting in hybridisation with the Broadleaf Cattail. This has resulted in a weed, efficient in its nutrient uptake that establishes as a monoculture and dominates the landscape. The bogs in the lower, wetter catchment tend to be infested with Typha.

3. Methods of research

The method of researching this subject consisted of three phases. In phase one a significant amount of time was spent scoping and reviewing the literature on cranberry production. Phase 2 consisted of meetings and interviews to determine how best to use my time in Wisconsin and the Netherlands (see Appendix 5 for a log of activities). During Phase 3 time was spent travelling around Wisconsin and the Netherlands attending events and meeting key stakeholders, e.g. the academics from University of Madison and representatives of cranberry associations. The final phase was used to consolidate the knowledge acquired and to focus more on the finer detail of it was feasible to farm cranberries in the UK and what this might look like.

3.1 Networking and travel

During the period of Phase 3, 9 days were spent travelling around Wisconsin, US from the 6th to 15th August. I was based at Black River Falls but travelled extensively visiting the University of Madison, the Wisconsin Wetlands Association, two cranberry bogs (Habelman Bros and Lake Nakomis) and a variety of sites identified as having bog remnants with naturally occurring cranberries. My activity is detailed in the log in Appendix 5.

In the early Autumn (16th to 22nd September) I travelled to the Terschelling Islands and the polders of Krimpenerwaard, Netherlands where a farmer had abandoned cranberry farming with the principle aim of observing the organic farming and harvesting of cranberries. I was escorted to the site by Aldert Van Weeren who had arranged to meet the farmer who did not turn up. I did not realise until sometime after returning from my travel that the abandoned cranberry farm belonged to Bart Crouwers of The Cranberry Company (see Case study 4). I also took the opportunity to attend the European Peatland Conference 'Power to the Peatlands Conference – *For Nature, Climate and Future*' at the University of Antwerp to meet up with fellow academics from the University of Greifswald and to access scientific evidence regarding the possibility of cranberry production in the UK and the systems that may be appropriate.

Following the soft fruit growers' event in Dundee at the James Hutton Institute I continued to look for farms which were growing cranberries or had historically been involved in growing them in the UK. I travelled to Rochester Kent to visit a premium fruit grower, Mockbeggar Ltd.

(www.mockbeggarltd.co.uk) because there had been indications from online searches that they had appeared to have grown cranberries in the past but had proved impossible to contact via phone or email to discuss this further. Initial plans to travel to Estonia to observe a low intensity system of producing cranberries were cancelled due to the failed harvest.

3.2 Interviews with Stakeholders

A number of initial meetings were set up with key stakeholders to facilitate the research in the US including with the Wisconsin Cranberry Growers Association, Dr Juan Zalapa, University of Madison, Dr Casey Kennedy, University of Massachusetts, Dr Margus Arak, University of Estonia. This process was then formalised, and key stakeholders were identified for interview. A set of interview questions were formulated, and the required ethical approval and consents were obtained (see Appendix 6). Formal interviews were held with Doug McMillan (Restoration Ireland), James Brown of Pollybell Farms, Dave Cragg, NE Shropshire Hills National Landscape and Dr Margus Arak and Professor Merrit Shansky of the Estonia University of Life Sciences.

During the interview with Doug McMillan and his team from Restoration Ireland (Appendix 4) it was suggested that contact was made with Bart Crouwers of The Cranberry Company who he knew was cranberry farming on peat in the Netherlands. An interview was conducted with Bart Crouwers, this is reported in Case Study 4. During the writing up of this research it became clear that Bart Crouwer's 'The Cranberry Company' was the same farm I visited in September 2023 with Aldert van Weeren during my travels and the subject of Nancy Wiljtnik's work (see Appendix 7 part I & II). Case studies based on research whilst travelling, in person visits and interviews were compiled to provide more detail regarding the cranberry farming systems currently producing cranberries and inform the design of future farming systems.

4. Results of research

The three modes of research, literature review, interviews and travelling and engaging with stakeholders where cranberries are produced, were of equal value in producing case studies to characterise where cranberries grow in the wild and how they are cultivated using different farming systems. These are reported here, and a number of case studies have been created. This evidence has then been synthesised to provide a broad-brush evaluation of the socioeconomics and environmental impact of each farming system (see table 3) in order to determine first whether cranberry production may be feasible in the UK and whether it is worthy of a crop trial and second what it might look like in terms of its agronomy based on the knowledge derived from this study.

4.1 Summary of outputs from networking and travel

The intention of travelling in the US was to determine the techniques used for farming cranberries on peat to determine whether this could be replicated in the UK on lowland degraded peat. However, it became apparent that the majority of cranberries were grown on sand. Conversations with Bob Wilson, Wisconsin Cranberry Growers Association and Casey Kennedy, UMAS (2023) and did suggest that cranberries were grown on peat in Massachusetts and in the North of Wisconsin. Given time and budgetary constraints it was not possible to explore cranberry production in Massachusetts, so Wisconsin became the primary focus for this report.

Massachusetts is typically less productive than Wisconsin. It is responsible for 50% of global cranberry production (McGrathPR, 2024). Cranberry farms in Massachusetts tend to older and more irregular in shape and embedded within natural wetlands rather than constructed and perched on top of peatlands. The peat was formed in kettle holes and provides an acidic low nutrient substrate and a confining layer. Fertiliser is applied using helicopters. When sanding does not occur, pruning is carried out using machines. Massachusetts is also restoring cranberry beds to wetlands by removing the sand and rewetting the original seed beds to establish the floral communities. There is little nitrogen in the soil so it is thought that there would be little effect from nitrous oxide, but this is not being strategically monitored.

4.1.2 United States – Wisconsin

Wisconsin is one of the 13 states in the United States producing cranberries. It is responsible for the majority of cranberry production with Massachusetts as a close second (see Appendix 2 and section 2.3.8.1). This section gives an overview of the state in relation to cranberry production.

15,000 years ago, Lake Wisconsin and the surrounding wetlands were formed from a melting glacier. The final meltwaters cut deep narrow gorges into the sandstone creating towering cliffs over 100ft high which are know as the Wisconsin Dells today. This water eroded the sandstone providing a shallow acidic lakebed and the conditions for peat bog formation, vast amounts of sand (figure 32) and a high water table all of which are exploited by the farming system used for cranberry production in this state (Figure 31). There are a variety of different wetlands in the area, these have

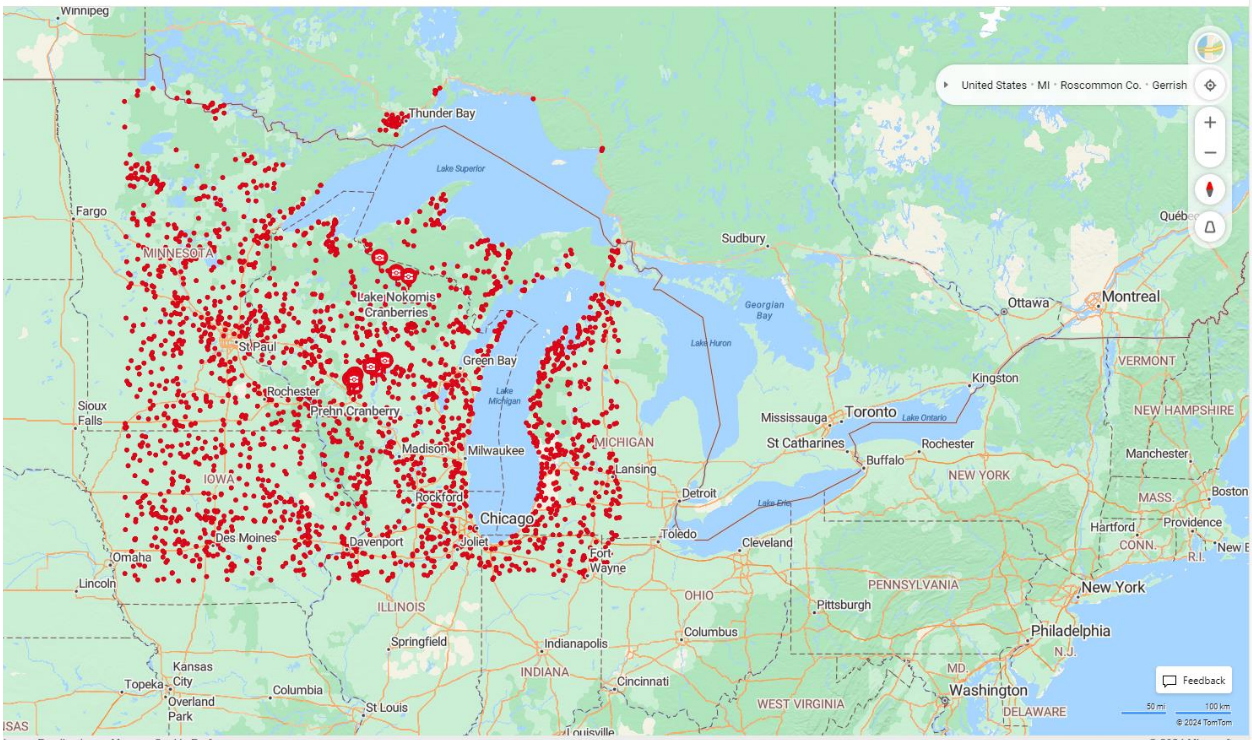


Figure 31 Map to show the distribution of cranberry farms in Wisconsin (Source: www.bing.com)

been classified by the Wisconsin Wetlands Association (2021) to further their protection.

Cranberries are principally grown on the 'Central Sands' of Wisconsin and in the peat areas in the North. In Wisconsin, cranberry beds are known as bogs. In Massachusetts they are called marshes. The US Department of Agriculture collaborates with various universities, e.g. University of Wisconsin, to support cranberry production. Biodiversity has declined in wetland areas due to habitat loss and anthropogenic and environmental factors. As a result, naturally occurring cranberries have also been lost from significant areas in the wild, e.g. the Horicon Marsh in

Wisconsin, a wetland of international importance of 44,000 acres (see US Fish and Wildlife Service, no date) where they are no longer found.

The condition of Wisconsin's wetlands and the ground water in the Great Lakes Basin are intimately connected (USGS, no date). This is of concern to the Wisconsin Wetlands Association, but they remain supportive of agriculture and cranberry production in the area. In general, they promote a land sharing approach of farming within wetlands and have teamed up with Discovery Farms (Wisconsin Wetlands Association, 2020) to explore how nutrient run off into wetlands may be prevented and how there may be a better relationship between farms and naturally occurring wetlands which the farms tend to be embedded (Wisconsin Wetlands Association, 2020). There are very few places left in Wisconsin where wild cranberries grow.

Figure 32 Sand extracted from the surrounding wetlands at Habelman Brothers cranberry farm, Wisconsin.

Travel and meetings with various stakeholders across Wisconsin gave important perspective on the HIC farming systems and the risks and barriers to production. This research has been compiled into three case studies two in Wisconsin, Habelman Bros Ltd and Lake Nokomis, and one in Massachusetts where the HIC system is more embedded in the natural wetland habitat. Further information gained from various meetings relating to the agronomy of cranberries is summarised here.

Barriers and risks to cranberry production

As in the UK, the future management of water resources in Wisconsin is a risk to the production of cranberries. Between 4-5% of all water used in Wisconsin is used for cranberry production. It is heavily regulated to ensure water resources in the ground water and their connection to the great lakes is properly managed. (USGS, no date).

Environmental Risk

Cranberries need fertiliser to maintain the high yields achieved in Wisconsin, these may be acquired through mineralisation and release from the peat or application of inorganic fertilisers. In systems where artificially constructed cranberry bogs are used and cranberries are grown in sand, perched on the water table, inorganic fertilisers need to be applied. Careful management of nutrients are needed to ensure leaching does not occur into the ground water system. However, diffuse nutrient pollution (N & P) from agriculture is a significant problem in the US causing eutrophication, e.g. Chesapeake Bay (see Redder et al, 2021). Cranberry farms are working with the Government to investigate the environmental impact of the use of inorganic fertilisers (see Kennedy 2015).

In Massachusetts the effect of the cranberry farming industry on the surrounding wetlands has been minimised in part by reducing the number of cranberry farms by 25% over the last decade. This has also been driven by a need to improve efficiency (Hoekstra, Neil & Kennedy, 2020), support climate resilience and has resulted in rewilding of 5% of all of the bogs in SE Massachusetts and Cape Cod (approx. 750 acres out of the 13,000 acres: see Smith, 2023). However, in contrast it does seem there is a role for restored cranberry bogs in nutrient buffering/removal. Findings (see Buzzard Bay, 2023) suggest that retiring and restoring cranberry bogs adjacent to these rivers could be a particularly valuable strategy, contributing to a 10% reduction in overall nitrogen pollution. To maximize nutrient removal, restoration efforts prioritise flow-through bogs, bogs closest to estuaries, and bogs that intercept water with high nitrogen concentrations from nearby developed areas. High levels of nutrients, particularly phosphorus, have caused invasions of common cattail (*Typha latifolia*) but over time *Typha* can act to lock in phosphorus and thus over 2-3 years has an ecosystem function of stripping nutrients (Longden, 2024; see also Blandford et al., 2024; Macclaren et al., 2020 and Vroom et al., 2022). In general, the lack of oxygen means that *Typha* dominates, and biodiversity is limited, so this plant needs careful management. Further nature-based solutions using Typha (*Latifolia* spp.) are employed where there are high nutrients especially phosphorus (see Hamback et al., 2023), storm water swales are vegetated with wetland species to mitigate nutrients (Arboretum Leaflets, 2013) and provide additionality in terms of biodiversity (see Ekka et al. 2021).

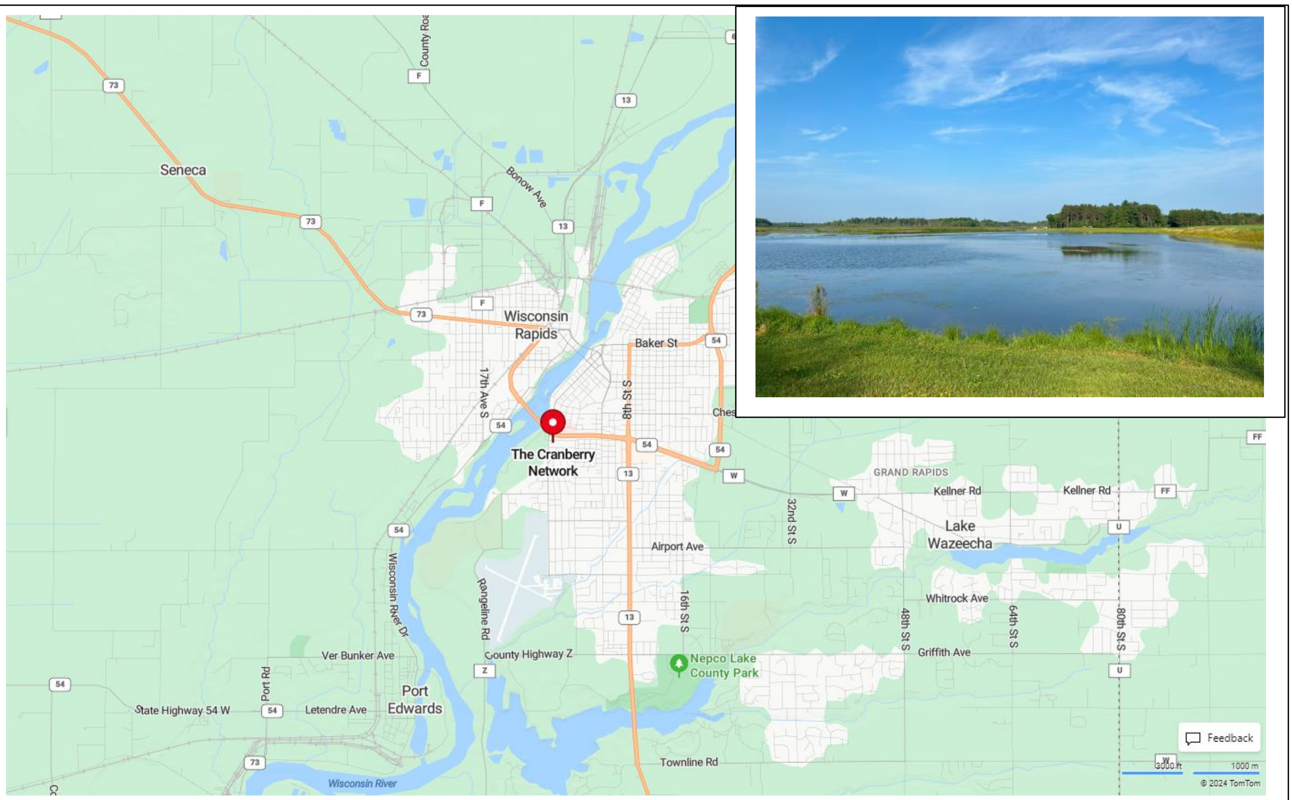


Figure 33 Map to show the location of The Cranberry Network which includes Habelman Brothers Farm on the Wisconsin River.

4.1.2.1 Case study 1 Habelman Brothers, Wisconsin

The Cranberry Network, Milestone Marsh, LLC 404 Daly Avenue Wisconsin Rapids WI 54494

The information presented in this case study has been derived from a day's visit consisting of a tour of the cranberry bog, the storage and processing facilities with the farm manager, Tom Tiber. Discussions with the Habelman Brothers and a visit to the Wisconsin Cranberry Growers Association trade fair at the Government run research station. Cranberries are grown at Habelmans on a deep bed of sand, up to 3 feet of sand. Every 3 years about 12 inches of sand is spread on the ice during the winter. When the ice melts, the sand forms a layer over the plant growth from that year and covers the runners which forces the shoots to grown upwards. Roots grow down to about 3-9 inches. The Growth from the previous year rots down to provide organic matter. In this way a bed of layers is established, sand, organic matter, sand and so on. This presents an issue with cranberry bed reversion to wetlands since the high sand contents means that the water is not retained. In order to restore the cranberry bogs, the peat has to be upturned in a similar way to bunding to improve water holding capacity. The idea of sand-based systems of growing cranberries which are not how cranberries naturally grow came about due to a storm in Cape Cod, Massachusetts which buried cranberries in sand 12 to 19 inches deep. This layer was found not to affect the growth of cranberries but to have benefits in terms of reducing the need for pruning.

Characterisation of the farm business

Habelman Brothers company is the largest producer of fresh cranberries in the world. Edward Habelman established the family farm of 25 acres in a cranberry marsh in 1914. It now consists of 3 farms with a total hectarage of approximately 700 ha, a small proportion of the 270,000 acres of cranberry vines in reported to be in production within Wisconsin (Lockman, 2017). The cranberry beds at Habelman's are rectangular and on average slightly smaller than the Wisconsin average of 5 acres. The slightly smaller sizes (2-4 acres) reflect the proportion of older and slightly smaller cranberry beds which are still present. In comparison, Massachusetts cranberry beds tend to be irregular forming part of the wetland landscape. Cranberries are perennial and may last for 30-40 years. The oldest Habelman Brothers farm has cranberry beds which are surrounded by pristine wetland and forest areas. The community of trees located in these wooded areas consist of oak, maple, Caledonian Pine, Jack Pine, walnut, birch and some ash (see Figure 34).

The Habelman Brothers grow around 13 million cranberries (130 million barrels) per year, principally for the fresh cranberry market. Tom Lochner, executive director of Wisconsin Cranberry Growers maintains most of the growers are multigenerational businesses. There is a proud history and a strong base of growers in Wisconsin with nearly 60 percent of the US's cranberry crop grown there and an estimated $1 billion per year impact on the state economy.

Labour

Habelman Brothers employ 15 full time employees. 65 seasonal staff are used for harvesting. Seasonal staff present an ongoing barrier to production due to the reliance on the local population of farmers. The number of farmers living locally has reduced significantly due to the consolidation of the smaller cranberry bogs into larger farming enterprises and they are unable to exploit the seasonal student population due to the timing of harvest. Thus, they now rely on a more costly workforce which is sourced from all over the country and require accommodation.

Figure 34 Sand cranes (*Gus canadensis*) in the marginal habitat surrounding the cranberry beds.

Marketing

The Habelman Brothers market their products using all of the conventional marketing methods as well as social media, e.g. YouTube (see Curiosity Quest, no date). They have an attractive reception which exhibits artefacts and images showing the history of the farm. Tours and educational events are held throughout the year. The highlight being the harvest which has become embedded in local and national culture.

Water management

4-5% of all water used in Wisconsin is used for cranberry production. Historically cranberry beds used the natural topography of the land to assist with drainage. This has caused issues in maintaining soil moisture, drainage of nutrients etc. At Habelman's water is manipulated as soon as it enters the site to the point at which it leaves. In the older beds they use the natural topography of the site to support this. The gradient of the land is used to manage water. The cranberry beds are distributed from North to South such that each bed is slightly lower than the last. Although this helps with drainage, it does give rise to problems of differing wetness in the beds. This has required the use of 3 irrigation lines for more precise irrigation. New cranberry bogs are constructed above the water table (perched) and water is pumped up to the beds. The management of the water is becoming increasingly controlled by tight legislation relating to the water resources provided by the Great Lakes and cranberry growers must record their water usage.

Figure 35 Satellite view of the Habelman Brothers cranberry farm embedded within the lowland bog (source Google Earth).

Habelman Brothers apply water throughout the growing period using above ground sprinklers (see Appendix 1). Historically aluminium irrigation pipes were laid on the surface of the cranberry beds due to reduce the impact of aluminium on the environment. Habelman still have a proportion of these old irrigation systems. Modern systems are made of plastic and are buried under the ground. During harvest the sprinklers are removed.

Fertilisers

The timing and quantity of inorganic fertilisers used on the Habelman farm are determined using precision technology and are informed by the nutrient needs of the crop which are assessed with observations and tissue samples, see Appendix 3 for more details on nutrient requirements. Wisconsin Cranberry Growers are beginning to use more sustainable alternatives to inorganic fertilisers such as black soldier fly derived fertiliser (Figure 36, Basri et al, 2022) and chicken manure pellets. The latter are applied at a rate of 4 times during the growing season. However, black soldier fly frass is expensive.

Pests and diseases

It was clear from the trade fair that both biological and chemical methods were used to control pests in a system of Integrated Pest Management in Wisconsin. Sanding and flooding of the cranberry beds were also used for pest control. The cranberries are grown on a bed of 3 foot of sand and further sanding, approximately 6 inches every year, is applied to assist with pest control but also to simulate pruning and encourage growth of this perennial plant. Flooding occurs ad libitum on observation of a pest invasion.

The cranberry fruit worm (Lepidoptera) is the main crop pest on the Habelman farm. It is controlled using *Altacor* (15% - FMC, no date) which is applied to coincide with egg hatching. They also use bacteria and peptides to combat this pest including *Venerate* (Dunn, 2019) and *Spear-Lep* (Vestaron, no date). The industry is looking to develop alternatives at the USDA Wisconsin Cranberry Research Station, but it was unclear how regulated the pesticides were in the US unlike here.

There are only 2 predominant fungal pathogens at Habelman's, canker and false blossom. They use *Regalia* to control these (Arbico Organics, no date).

Figure 36 Stall at the Cranberry Growers Trade Fair advertising black soldier fly derived fertiliser.

Weed control

Controlling weeds in the cranberry beds on the Habelman Farm continues throughout the season. Cranberries are in a low fruiting herbicide group and the Wisconsin Cranberry Growers are trialling 4 new weed controls. Herbicides are applied at 5 points during the growth cycle of the cranberry: 1. new planting, 2. dormant, 3. emergent, 4. full fruit set, and 5. When repairing the seed bed during bed restoration. Cranberry growers in Wisconsin use *Casaron* to control weeds in the cranberry beds. *Casaron* is a broad-spectrum herbicide providing long-lasting weed control in cranberries (UPL, no date). It forms an herbicidal barrier in the upper layer of treated soil once it is activated by water through rainfall or irrigation. Weeds rooted in, or seedlings emerging through, the treated soil are controlled when they come in to contact with the herbicidal barrier. *Casaron* is favoured since it appears to provide season-long weed control when applied in the early spring.

However, in 2008, the EU banned indiscriminate herbicides such as *Casaron* which contain *dichlobenil* (see Gross, no date) due to their negative effects on humans, animals and plants. The Habelman Brothers have adapted to this restriction by operating a system of bed rotation, whereby the cranberries produced for export to the UK are harvested from beds not using *Casaron* but each year the bed used for export changes; so that every 3-4 years every bed is treated with *Casaron*. This treatment is deemed necessary due to the intensity of production of this monocrop which means that they do not seem to be able to control the weeds otherwise and still maintain productivity levels.

Cranberry products

Cranberries from Habelman Brothers are sold fresh or for juices. Those that are used for dried cranberries are first soaked in 100% glucose solution prior to drying to make them more palatable. There is research regarding how they could be made healthier with less sugar could be used if the cranberries underwent a process of deacidification (Faucher et al. 2020) negating the need also for sweeteners.

Mechanisation

The Habelman Brothers have been pioneers of on farm innovation to improve efficiency. They have developed booms which are used for spraying herbicide and applying crystal fertiliser. These booms straddle the 5-acre cranberry beds to ensure uniformity of application. All vehicles used on the beds are light with fat tyres to minimise trafficking and compaction (see Appendix 1).

Figure 37 The author discussing cranberry agronomy in a Habelman Brothers cranberry bog.

Harvesting

Harvesting of cranberries at the Habelman Brothers begins in mid-September to continues to early November. The period of harvesting and therefore the availability of cranberries has been extended by using different cranberry cultivars that ripen at different times in the season. Fresh cranberries are harvested at the same time as those that are processed. Beds are flooded individually prior to harvesting. The fresh harvesting rate is 3 beds per day. The processed harvesting rate is faster. Fresh cranberry beds are flooded but not as much as those where the cranberries are processed for juice.

Protection against frost

Automated monitoring of all of the cranberry beds is achieved using frost sensors which predict the risk of cold temperatures. This has become more important with the unpredictability of the weather. If a frost is forecast the cranberry bed is flooded to allow icing which protects the flower bud or fruit. If icing has to occur to protect the fruit this can affect the quality of the end product and so this is avoided if possible. This measure may be rapidly applied since flooding takes around 12 hours.

The flooding of cranberry beds, in which the cranberry plants are fully submerged is multifunctional in its use. It is used for pest control, protect from storm damage, frost and for harvesting. It is important to note that cranberries do not like to be waterlogged even for a day. Sand needs to be moist to the touch but not wet. Monitoring of moisture levels is critical.

Renovation of less productive cranberry beds

When renovating a cranberry bed, the cranberries are mown, material removed. Sand is laid down and cranberries brash mown from another bed is laid down and a cutting blade from a machine is used to push the cranberry plants into the ground so that they may root.

Research and innovation.

UW-Madison researchers work closely with the cranberry growers to improve production. They are currently cultivating a cranberry-blueberry cross (‘Cranblu’, see Appendix 5) which may improve the palatability and resilience of the fruit. Chile is also looking at improving the cultivars and are developing the ‘Cranchile’ which is now available. This is being overseen by Gordon Swanson who is based in San Diego.

Improving production

Yield from cranberries is optimised by ensuring high levels of cross fertilisation. This is achieved by using bee hives (Stubbs et al. 2002). The species of bees imported varies depending on the location due to the species' requirements. Habelman's hives are a mix of bumble bee, honeybee and mason bee hives. The bumble bee (*Bombus imaptiens*) is used out of preference at Hableman's. Pollinator crops are planted to provide refuge for these insects. At the end of the growing season, bumble bees are placed near the forested edges to encourage overwintering. Interestingly, observations of the honeybees at the Habelman Brothers indicate that they are sub-optimal in their activity when located near the army base(Tiber, 2023).

Figure 38 Image demonstrating the size of ripe cranberries grown in Wisconsin (cultivar: *Malaca Queen*).

Cranberry yield

In 2023, Habelman Brothers were anticipating a price of $1.30 for fresh per pound for fresh cranberries. The price commanded for cranberries for processing into juice is about a third of that for fresh at 60 cents a pound. The difference in price reflects the need for a lower density of planting for fresh fruit production to support effective harvesting which does not damage the fruit. Fruits are considered ripe when they are red (Figure 38), and the seeds are brown. White berries are ripe but not edible, ripeness is tested by breaking open the fruit (Figure 39). A cranberry bog producing fresh cranberries has a high density of fruits (Figure 41) and typically yields 200 barrels of cranberries compared to those used for juice etc. (approximately 500 barrels produced).

Opportunities

Wisconsin Cranberry Growers Association are continually looking for opportunities to increase the market for their cranberries. Bob Wilson (2023) discussed the use of the oil from dried cranberry seeds for cosmetics. This need is beginning to drive research into the chemical composition of cranberry seeds (Gorans et al., 2024). The provision of good quality water free of nutrients whilst maintaining production is key. Stakeholders in Wisconsin are looking at more sustainable alternatives to inorganic nutrient inputs currently used these include the use of frass from black soldier flies.

Risks

Export tariffs are deemed to be a key risk to the Wisconsin growers. Cranberry growers and the USDA work together to promote all products from Wisconsin to the UK and negotiate the 15% import tariff. During my time at Wisconsin University-Madison I had discussions in various departments with a number of academics regarding the environmental issues associated with cranberry production, e.g. Kenneth Potter, Stephen Lochside, and Daniel Wright, they are similar in nature to those reported from the meeting with the Wisconsin Wetland Association.

Figure 39 Cross section of a cranberry (*Vaccinium macrocarpon*) showing the air pockets and seeds.

Research – IPM - nematodes

University of Wisconsin has a number of research programmes, and the academics there engage and collaborate with the USDA scientists which are integrated into the university and the Cranberry Growers Association using the Cranberry Research Station. Nematodes form a large component of the IPM programme for cranberries.1.5 million nematodes are needed per square acre. However, the impact of these nematodes on the cranberry's pest species, the cranberry flea beetle, is determined by the behavioural profile of the nematode. This in turn is affected by the method used to breed them and how they are applied. Commercial enterprises tend to provide a population of nematodes which is inbred and not as tenacious as those with a more natural profile. Shawn Steffan uses nematodes to target the cranberry flea beetle. His population have a more natural behavioural profile and so are more efficient compared to the commercially produced population (Foye & Steffan, 2019). They also need to be applied at low pressure in the dark or else they come out stunned and unable to hunt. In addition, it has been shown that the nematodes are more effective if the cranberry plants are irrigated with sprinklers first to wash them down on to the substrate.

Research - genetics and breeding

There is also a lot of research regarding the impact of UV stress and the cold hardiness of cranberries and the essential dormancy requirements (North et al., 2024) in an attempt to improve the resilience of the crop and limit the need for flooding. This is becoming increasingly important as water resources are limited. Amaya Atucha at the Dept of Plant and Agroecosystems, University of Wisconsin-Madison is also exploring how to improve the fruit quality of Stephens and Malaca Queen cultivars by increasing the uptake of calcium with the use of biofertilisers, e.g. mycorrhizae to mobilise nutrients.

Figure 40 Dyke and wetland adjacent to cranberry beds at Habelman farms with *Typha latifolia* in the foreground.

UW-Madison provides free services for cranberry growers in relation to a number of issues including contamination of crops by wild genotypes. Genotypes are mapped by taking samples of the crop (16-48 per 20 acre) and mapping the colour of the vine which indicates the level of wild genotypes and the point at which a bed will need renovation. There are also opportunities here. With the need for nutrient mitigation, it may be that the US explores the emerging market for products made from *Typha latifolia*. There are reports of a more dominant hybrid *Typha* species is becoming a key issue, invading cranberry beds and limiting cranberry production. This weed could be harvested and used for insulation for clothing (Ponda, no date), construction (Van Weeren, 2024) and biomass (Haldan et all, 2022).

Research - crop monitoring and precision agriculture

Wireless sensors feed information into the NEA (Network for Environmental Applications). They are linking with Cornell University and also incorporating the WISCONET (to monitor weather Dept of Civil Engineering and Environmental Science). Precision techniques, e.g. the raspberry pi 'Crancam' and drones are used to monitor crops and determine crop growth and the needs for inputs including. They are currently also developing a canopy sensor to look at leaf and soil temperature and looking at the control of irrigation based on patterns of rainfall.

GHG fluxes have not been considered a research priority in the US until recently. Literature is beginning to emerge regarding carbon emissions (Dossou-Yovo et al., 2023). Whilst travelling in the US there it was not obvious that there was a There does not appear to be a policy regarding transitioning to carbon Net Zero.

Massachusetts

I was keen to visit Massachusetts where cranberry agronomy varies and the cranberry beds are peat based and integrated into the natural wetlands. Unfortunately, time and money limited my travel. Instead, I met online with Casey Kennedy from the University of Massachusetts and so I am able to give some insight in relation to the practices in Wisconsin. Casey is also a big producer of cranberries. The Massachusetts farms tend to be older, and the cranberries are planted on peat that formed in kettle holes in a confined layer with an acidic low nutrient substrate. In Massachusetts helicopters are used to apply fertilisers. Pruning is achieved using mowing if no sanding occurs.

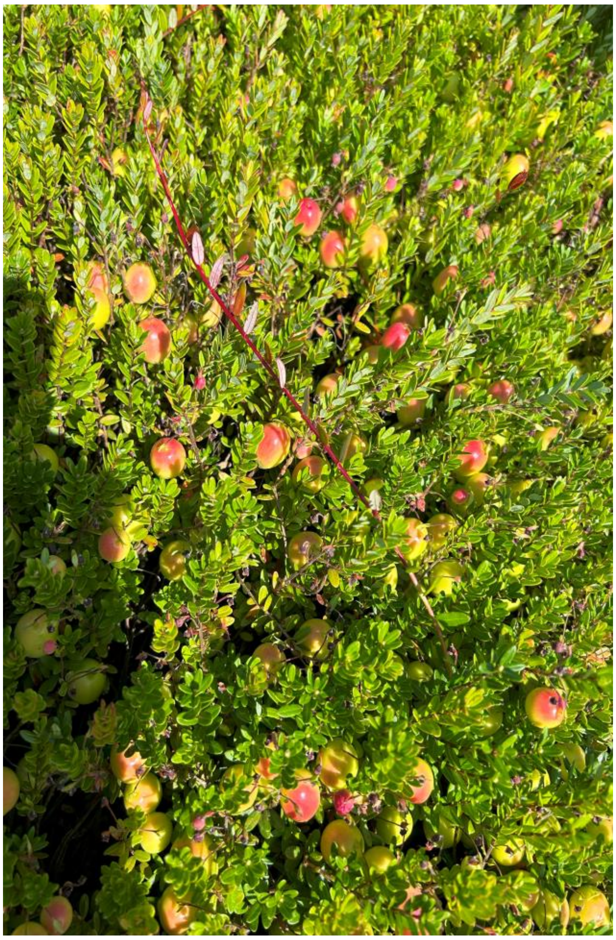


Figure 41 Image showing the density of cranberries (*Vaccinium macrocarpon*) in the cranberry bed, 1 month before harvest.

Figure 42 Cranberry bud in the snow. (Source: Massachusetts cranberries).

Massachusetts productivity is 3 times less than anywhere else partly because they use different older cranberry cultivars, *House* and *Early Black* which have smaller berries (Kennedy per. Com).

Restoration of cranberry marshes.

In 2022, there was a move to restore old non-productive cranberry beds which is part of the Massachusetts Clean Energy and Climate Plan for 2025 and 2030 (“2025/2030 CECP” or “Plan”) which has been put in place as part of the Global Warming Solutions Act of 2008 and the 2021 Climate Law (An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy, see (Massachusetts Global Warming Solutions, 2023) for more information. Removing the sand and rewetting the original seed beds allows the historic flora to establish itself again.

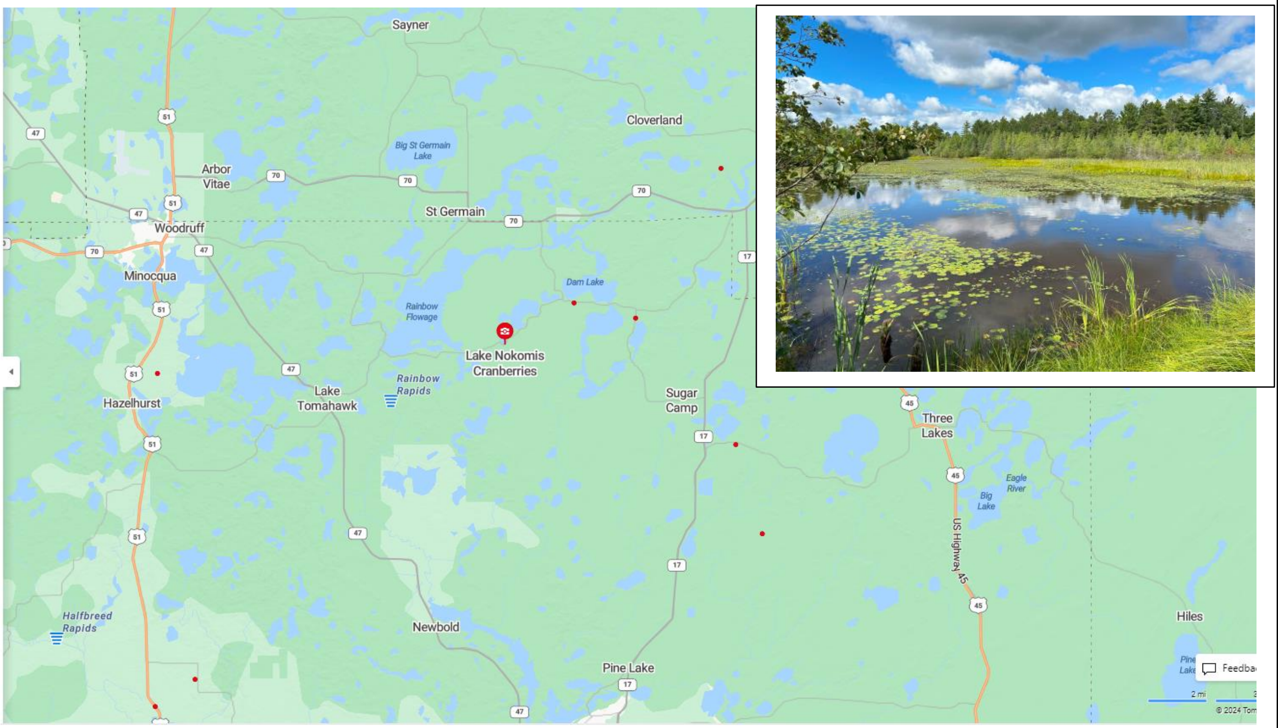


Figure 43 Map to show the location of Lake Nokomis Cranberries (Source: www.bing.com)

4.1.2.3 Case study 2 – Lake Nokomis, Wisconsin

The cranberry bog at Lake Nokomis is located in Eagle River in the North of Wisconsin (Figure 43 & 44). It is smaller than Habelman Brothers, at around 300 acres, and consists of approximately 70 beds which were created by deforesting the area. This cranberry bog was chosen for it's location with the knowledge that cranberries in the North of Wisconsin are, in general, grown on peat. The information reported here was gained from my own personal observations as I walked around the site and also from the cranberry tour given to tourists. It seemed pertinent to determine if there were differences between farming practices for cranberries grown of sand versus those grown on peat. Peat at Lake Nokomis can be as deep as 20 m and there was evidence when visiting the bog that it is still extracted for the horticulture industry. The water table is high, about 30 cm below the peat surface. Lake Nokomis grows around 10 varieties in beds that are approximately 5 acres including Crimson Queen, Sun Dance and Pilgrim. They establish beds with cuttings rather than the more expensive plugs (see Appendix 3). Their focus is fresh cranberries and cranberries for wine. They try and sell locally and have a well-stocked farm shop with a large variety of products made from or with cranberries. Historically, paddles used to be used to remove the cranberries by beating the shrubs during harvesting, but this was too destructive. Rakes are now used (see Appendix 1). In a similar way to Habelman's cranberries are corralled with floating booms. They are hoovered up and placed on an elevator to take the cranberries for sorting. They are then washed and dried using an

Figure 44 Aerial view of Lake Nokomis Cranberry Farm (Google Earth 2024)

air blower which blows off the leaves etc. The rate of harvesting is not as efficient as Habelman's at around 2 beds a day and, like the Habelman Brothers on farm innovation has been key to supporting farming practices. An example of this was the school bus which was turned into a cranberry hoover used to extract floating fruits during harvest. Sanding at the Lake Nakomis farm is a more costly operation compared to Habelman Brothers where sand is more readily available. It only occurs every 3 years and is used for levelling the bed, filling in the gaps between shrubs and for pest control. Sensors in the ground are used to monitor temperature. A temperature of 35 degrees will trigger sensor alarms which triggers flooding with water from Lake Superior for protection which then freezes for a couple of days until the environment warms. The residual heat from the cranberry acts to protect the flower, bud, fruit etc. sprinkler lines with a central drainage pipe which is buried in the peat. Little fertiliser is required due to the presence of the deep peat base layer. Deer and elk are a significant issue at Lake Nakomis and will graze the cranberries. They are excluded with 4 miles of electric fencing. There are high levels of biodiversity including bears, wolves, fish, osprey, sand cranes and porcupines. Like elsewhere in the state labour for harvesting is hard to find. Up to 30 people are required 12 hours a day, 7 days a week for one month. In order to meet this need they have had to draw on the nearest correctional centre to fulfil this need.

Figure 45 Lake Nokomis cranberry bed on peat.

Figure 46 Cranberry bed requiring renovation, Lake Nokomis.

4.1.3 Netherlands

4.1.3.1 Case study 3 – Terschelling – Netherlands

The Island of Terschelling, in the Friesan Islands of the Netherlands, has a thriving cranberry industry where these fruits are harvested from shrubs growing in the anthropogenically modified dune slacks and sold fresh as a high value organic crop (Terschelling Cranberries, 2023). However, this is not a conventional farming system. Cranberries are not naturally occurring on these sand dunes. They are a non-native species which have been inadvertently introduced as the result of a shipwreck (BEFresh Produce, no date) when barrels of *Vaccinium macrocarpon* were split open and abandoned on the sandy substrate. Soil organic matter and soil moisture levels are higher in these wetter slacks and cranberries perform well on this unconventional substrate. These areas of cranberry covered slacks may be identified in the landscape by the change in vegetation (see Figure 48). Although the cranberry does appear to be embedded in the local culture and cuisine, some locals consider them to be invasive and would like them to be removed.

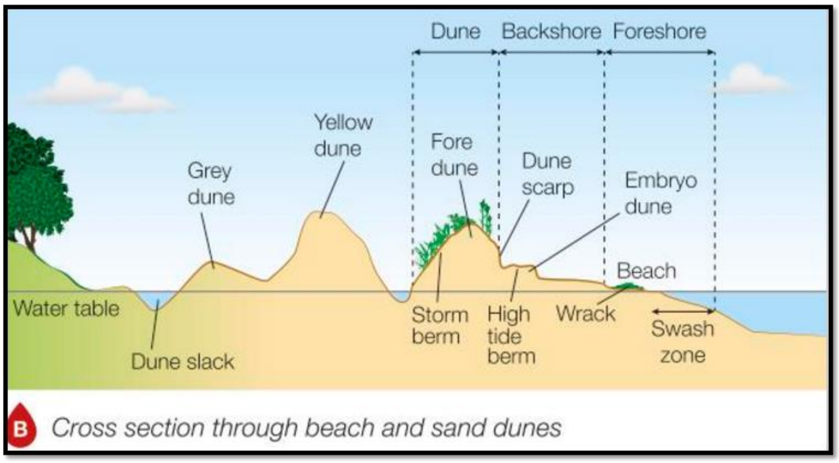


Figure 47 Diagram indicating dune slack where cranberries thrive.

A number of cranberry harvesting companies have been established, e.g. Groenhofcranberry (no date), and areas of the dunes where cranberries grow well are harvested in the Autumn. Signs are used to exclude the public or advise them not to pick the cranberries until the end of September when these companies have harvested the majority of the crop. The remaining cranberries are then available for the public to pick, and festivals take place in October when the fields are opened up to the public and a mass pick-your-own takes place. Locals then celebrate the season by cooking a variety of dishes with cranberries as the focus. There does not appear to be any particular laws in place to regulate this activity.

Figure 48 image showing that cranberries only grow in the ‘wet dune pan’ area of sand dunes, Koegelwieck, Terschelling where conditions are wetter and there is organic matter. Without it the soil is not fertile enough (source: Wiltnik, 2019).

Figure 49 Cranberry harvesting from the sand dunes Terschelling Island (BEFresh no date).

Companies harvesting cranberries on Terschelling exploit the local and international tourist trade and cranberries and derived products are sold fresh at a premium in the island shops providing an important source of income to the locals.

Figure 50 Cranberries dry harvested by hand, Terschelling Islands, Netherlands.

4.1.3.2 Case study 4 – The Cranberry Company, Netherlands

A number of growers in the Netherlands including Bart Crouwers* from the Cranberry Company and Nancy Wiltink, an urban farmer living in Amsterdam, believe that an organic (NIC farming system) is a sustainable method of cranberry production which could be adopted on Dutch polders previously used for grazing dairy cows (Wiltink, 2023). By extension, it seemed pertinent therefore to also consider this as a possible farming system for the UK, given their comparable climatic conditions.

the cranberry company

This case study is based on a number of elements including: 1. an initial interview with Bart Crouwers (see Appendix 4); 2. Communication with Nancy Wiltink (2023); 3. a visit to The Cranberry Company bogs on the Krimpenerwaard polders in the Netherlands in September 2023 with Aldert van Weeren, a Dutch born farmer living in Germany and member of the Paludiculture Community in the UK (www.paludiculture.org.uk), and 4. An interview with the Green Restoration Ireland project members in September 2023 (see Appendix 4).

Sections A and B of this case study describe the farming system as reported by The Cranberry Company (Crouwers, 2023) and available online information sources. Section C evaluates the evidence presented by Sections A and C based on the visit to the farm in 2023 and conversations with Aldert van Weeren (2023).

Bart was a pioneer in sustainable cranberry farming and spent a significant amount of time promoting his vision of organic cranberry production to others in countries such as Poland,

Measuring device in the polders of the Netherlands indicating height above sea level. Most polders are 4 m or more below chart datum.

Figure 51 Map to show the location of The Cranberry Company, Krimpenerwaard, Netherlands.

*Deceased

Lithuania, Latvia, Kaliningrad Region and Germany (see DESIRE, 2021). Driven by the effects of farming in the Netherlands on soil subsidence, around 1 cm per year, carbon emissions and loss of biodiversity, Bart and Gerard Harleman took 2000 hectares of the polder at Krimpenerwaard, located between Amsterdam and Rotterdam (see figure 51), out of dairy farming. They formed 'The Cranberry Company' in 2016 using financial support from the European subsidy system for managing 'natur' and 6-8 ha of this deep peat (2-3 m) was transformed into an area dedicated to nature restoration and cranberry farming. There was no income from this farming for the first 4-5 years.

A. Characterisation of the farming system

The aim of this pioneering project was to establish an organic system of cranberry cultivation where production and nature restoration could go hand in hand and reinforce each other. Cranberries were reported to be grown by The Cranberry Company organically on moist peat soil (at about 25 centimetres below ground level) without the use of chemical crop protection products, insecticides and fertilizers and with minimal if any disturbance to the ground & microbiology of the soil following the initial stripping of the top soil. They are grown as a mixed crop with naturally occurring wetland species such as meadow buttercup, wolf's foot, meadow grass, pipe straw and water mint also grow among the cranberry plants. This biodiversity ensures that the crop is more resilient to pests and diseases.

Figure 52 Bart Crouwers, The Cranberry Company (Crouwers, 2023)

Figure 53 Image to show the diversity of ground flora present with cranberries (source: Crouwers 2023).

The farm was designed with the cooperation of ecological advisor Rudi Terlouw of Bui-TeGewoon to provide biodiversity uplift during the project. Ecological consultant and entrepreneur, Rudi Terlouw, was initially sceptical about the possibility of growing cranberries which he considered to be an imported product requiring a lot of chemical pesticides which did not align with the Nature Management Plan for the Krimpenerwaard. But research indicated that cranberry cultivation would support the Krimpenerwaard's meadow bird objective by providing open, wetter meadows with more insects due to the wild plant species which grow alongside the cranberry for species such as snipe and the black tailed godwit (Figure 53). This also seemed to gain support from others at Radboud and Wageningen and thus this farming system was established.

The Cranberry Farm Company is a relatively small enterprise. In total, it has 18 hectares, 9 of which were established for organic cranberry cultivation (Figure 54). The beds comprise 400 m^2 polders divided evenly into quarters. The remaining 9 hectares were used to support wetland biodiversity, providing nature-friendly banks, a peat pit, a swamp zone and plots of permanent grasslands for different bird assemblages (Figure 55).

Agricultural activities were scheduled around the bird breeding season to avoid disturbance. A number of studies, mainly undergraduate dissertations, have been conducted on this cranberry farm and may be available on request (see Appendix 7 I &II and Figure 57).

Figure 54 Aerial view of The Cranberry Company's polders when planted with cranberries. The darker areas indicate presence of cranberry plants. Source: Bart Crouwers.

B. Preparing the polders and establishing the cranberries

The nutrient rich top layer had to be removed to remove the seed bed and provide poor soils required by cranberries and other wild species of meadow plant. This was achieved by removing the grass and 10-15 cm of the topsoil to remove nutrients. These were planted in September 2016 through to May 2017. Water tables were raised to 25 cm below the ground surface and a marsh corridor was created along the south side connecting all parts of the site. This zone provides refuge and food for numerous species, e.g. water shrew, grasshoppers and grass snakes etc.

Oblong in red indicates marsh corridor.

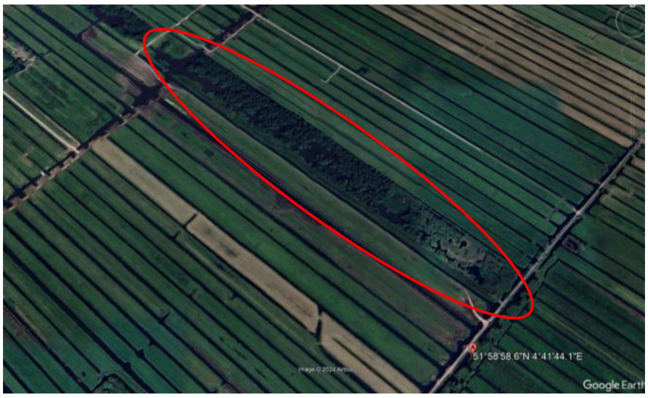


Figure 55 Google Earth image showing The Cranberry Company plots located in polder Middelblok at Lange Tiendweg 42-48, 2831 XL Gouderak, Krimpenerwaard, N 51º58'58.6" E 04º41'44.1"

Lowland peat (with clay) was rewetted and flooded in the winter and drained to 20 cm below the surface of the soil in the from April to October. Cranberry beds were established using 'Early Black' cultivars which were first introduced in 1850 and benefit from being closely related to more naturally occurring cranberries (see: Timmer & Balkhoven-Baart, 2006).

400,000 cranberry propagules were planted on half of them, and the remaining nine acres were set aside for nature development. There are five different varieties of cranberry plants planted, with small, large, bright red, or dark red berries (The Cranberry Company, 2022). Nature-friendly banks, a peat pit, a marsh zone, and plots of natural grass where meadow birds are welcome are used. During the breeding season, agricultural activities ceased to minimise disturbance to the birds (The Cranberry Company, 2022).

Since 2020, The Cranberry Company has been 100% certified organic. Weed control measures included weeding, mowing (4 times a year), grazing by sheep and maintaining high water tables. Nutrients were the biggest issue which caused dominance by weeds, Bart did not think that the pH of the soil (pH 5.5) was acidic enough to combat this competition. He maintained it should be around pH 4.5. During the interview Bart maintained that with each year of production the plots became more acidic (0.25 each year) due to the presence of the cranberries and the flooding of the fields from November to March. He also thought that this year-on-year increase in acidity helped to control the weeds.

Resilience has built into the farming system by companion growing with up to about 20 other species of plant. There have been no issues of disease to date. It is reported that within 2-3 years, 155 species have established from on the polders from the sphagnum that was transplanted (Soppe, 2023). The sphagnum did not establish itself. It is thought that this was because it was too dry. This farming system is directly over peat and no sand is used.

Figure 56 Cranberries in flower at The Cranberry Company (Crouwers 2023)

Productivity

Bart maintained that yield from this cranberry farming system was still increasing, by as much as 1.7 times each year. He anticipated a 3500 kg expected in 2023-24 and predicted that in 2-3 years this yield would be at around 10,000 kg per ha, about half of the average yield from Wisconsin's cranberry farms. However, recent reports by his son, indicate that yield was around 1200 kg this Autumn (West, 2024).

The duration of frosts are continuously monitored. Buds can withstand a drop in temperature to -1 degrees, prolonged frost and harder frosts are protected against by spraying water over the buds providing a thin layer of ice. In 2020 frost was not fully protected against resulting in smaller yields due to ice at -7 degrees in May for more than 3 nights but Bart did not consider frost to be a key issue.

Harvesting

The cranberries are dry harvested (handpicked) to be sold as fresh cranberries. Handpicking ensures they do not get bruised to allowing them to last up to 3 months. The comb harvesting of cranberries which came from the US 60-70 years ago, and is also used in Terschelling, harvests 70-80% of the crop, leaving the rest left for nature. Bart anticipates that machinery will be developed to harvest the berries in the future.

Figure 57 A number of dissertation projects have focussed on cranberry production on the Krimpenerwaard looking at growth and yield of cranberries and the biodiversity benefits of this system. These may be made available on request.

Bart maintained that this type of NIC farming system has potential to be profitable. This is due the fact that prices commanded for the fresh organic cranberries are relatively high, around 60%, compared to imported cranberries because they have an agreement to supply direct to a chain of stores providing health foods (Alnatura, no date).

Scaling up production would necessitate developing specific lightweight, tracked pieces of equipment that are able to cope with wet conditions for harvesting, pruning and weeding. It is also expected that fertiliser may be required. This will prove challenging due to its connections with the wetland environment and may require adoption of a LIC rather than NIC system of farming.

The Cranberry Company have highlighted some important points which are noteworthy in relation to the agronomy of cranberries including: the presence of *mycorrhiza ericoides* (see Appendix 3), pH, weed control and planting density. Weeds develop in parallel following the planting of cranberries. These need to be removed but may be controlled by removal of the topsoil, raised water tables and maintaining a pH of <5. Some weed plants, e.g. buttercup, commonly known as killer weeds have to be controlled by hand others by regular mowing. It is thought that full inundation during the winter may assist with weed control. It is unclear whether this was achieved since Bart reported that the polder was too dry to support sphagnum growth. In the summer they should be maintained at around -20 to -30 cm below the soil surface. In the first year, cranberry plants (cuttings) imported from America were propagated. These were planted in April at a density of 4 per m2 but it was recognised that if conditions were good only 2-3 plants would be necessary. A significant yield was obtained 3 years after planting. After 5 years the yield was significant at around 50-60 T kg/8 ha. Additional income is received by emissions reduction certificates (Desire, 2021).

Figure 58 Author with Aldert van Weeren assessing remaining marginal vegetation on the polders at The Cranberry Company.

C. Visit to The Cranberry Company (September 2023)

Since Bart Crouwers death in 2024, The Cranberry Company has been run by Bart's son, Matthijs Crouwers. He is collaborating with a company which specialises in the management of nature reserves, Agrec Zelle B.V. (Agrec Zelle, 2024) to develop machine harvesting of the cranberries whilst not impacting on the environment. In September of 2023 I scheduled a visit to The Cranberry Farm with Aldert van Weeren to meet with Bart Crouwers to discuss the organic production on the polders. At the time I was not aware that the farmer we were meeting was meant to be Bart. Unfortunately, Bart did not attend but we were able to view The Cranberry Company polders which were easily accessible from the road. The polders were clearly set out with signage indicating the different varieties of cranberry grown but the cranberry beds appeared to have been abandoned. Some were being grazed by livestock and others were managed as grassland. The only evidence of cranberry production were the polder margins which contained cranberries (see Figure 58 and Figure 59). However, these margins did have a significant crop of cranberries which were embedded in an assemblage of weeds and wetland plant species. It was surmised in discussions with Aldert van Weeren, and from communications with Nancy Wiltnik (2023), who intimated that the ‘trial’ had not worked, that the

Figure 59 cranberries at The Cranberry Farm.

farm was no longer productive due to the impact of weeds but this has not been confirmed and the company continues to report annual yields (West, no date).

4.1.4 UK

4.1.4.1 Case study 5 - Haweswater, Lake District, UK

In the UK and Ireland, cranberries (*Vaccinium oxycoccus*) have been harvested from their natural bog and mire habitats for generations. Douglas Mcmillan (2024) in the interview with Green Restoration Ireland related stories of people in the 1960's in Dublin Ireland travelling to the Wicklow mountains to pick wild cranberries which were then packed and put on the ferry to be sold at a premium at Christmas in Harrods. Although, it has not been possible to evidence historic or current commercial production or harvesting of cranberries in the UK, recent reports on the social media platform 'X' have indicated that cranberries are harvested for personal consumption in the Lake District (see figure 60). Lee Schofield's post demonstrates first that cranberries grow in the wild in the Lakes at densities comparable to those observed in the US. Second these cranberries are growing in sphagnum in a similar way to those observed growing in the wild in the US, Czech Republic and Meres and Mosses (UK); and third that sufficient may be harvested in a short period of time for the table. It was the author's intention to visit Haweswater as part of this project to meet with Lee Schofield but he took up a new position and so this was not possible. This post on 'X' provided important insight into optimal naturally occurring growing conditions for cranberries which may be adopted in the UK in a farmed environment. It is pertinent to note that, the fact that these naturally occurring shrubs were growing in sphagnum indicates that cranberry production could support additional environmental benefits including carbon sequestration and storage, carbon protection through the moisture retention achieved by the sphagnum cover if irrigation and/or water tables were high.

Figure 60 Map showing location of RSPB Wild Haweswater, Cumbria. Inset photo of harvested wild cranberries from Haweswater, Lake District, UK (Lee Schofield, 2023).

4.2 Interviews

A number of interviews were conducted to inform the scope of research for the project and to establish stakeholder opinions regarding the possibility of farming cranberries in the UK. The transcripts of these are available in Appendix 4. The interview with Bart Crouwers (see Case study 4) and James Brown were significant and are outlined in full here in this report. James Brown's interview was particularly interesting in relation to farmer perception and ambition and forms the basis of Case study 6.

4.2.1 Case study 6 – Pollybell Farms, James Brown

James Brown runs 2000-hectare family-owned, diverse, organic farming business crossing the three county borders of Nottinghamshire, Lincolnshire and South Yorkshire (see Pollybell Farm, no date). The majority of the farm sits on lowland degraded peat. It has a renewable energy and a retail division and houses three Sites of Special Scientific Interest (SSSI). James strives through sustainable farming practice to enhance the land for future generations to come. He has invested in green technology to help make the farm's cereal, vegetable and livestock farming more sustainable and is pioneering a scheme to make renewable heat, electricity and biochar, capturing and burying carbon dioxide as solid carbon. James believes the future of farming on lowland peat lies in climate-resilient, controlled environment agriculture. His farm has a well-defined natural floodplain, which is flooded regularly. The limited development on the floodplain means that the impact of the flooding is largely absorbed by agricultural land.

During an interview with James when questioned about the feasibility of growing cranberries in the UK he stated, 'If there is a business opportunity for an efficient farming enterprise we will find a way to break down the barriers to adoption'. He feels that it is possible because lowland peat management is going to change and there is now, due to climate change and the need to reduce emissions, an opportunity that was previously not available. Single farm payments (leaving CAP) have meant that there is no longer the requirement for farmers to farm in the traditional way. It is a compromise between full peatland restoration and productive farming. In his opinion, he feels that such a system should low input (LIC) since it is a more resilient model and there are questions surrounding the organic industry.

Figure 61 Pollybell Farm, an organic farm with a holistic approach.

The key barrier will be profitability. There will be a need to establish if there is a demand with careful market research, he advised using the cranberry as the star ingredient rather than the main one to limit impacts on the grower. Other key points to consider include:

1. Frost: predicting and managing crop when there are late frosts which could affect buds and fruiting. In Chile they use wind turbines in reverse to blow warm air over the crop. Fleece could also be used.
2. Equipment and machinery required and different stages in the Life Cycle. However, any technical barrier may be overcome if it is worthwhile to the farm business.
3. How do you get to a critical mass quickly enough and ensure provision 12 months of the year to make the business profitable?
4. Knowledge of how to grow it, the risk of the lead time in because it takes around 3 years to get a good crop.

5. Understanding the current supply chain and deflating the existing imported market. How may cranberries be provided cheaper. How are you going to scale up and make it viable for market?
6. Weeds, innovation would be required here with the use of laser weeders for example to replace herbicides.
7. Determining the critical mass of cranberries required by UK retailers to ensure they buy from the UK rather than abroad.

Despite calls in the North-East for flood-alleviation measures and a regulatory framework covering water resources the management of water for re-wetting is still inaccessible. This plus the variety of projects looking at this area but not coming up with any positive outcomes is impacting on farmer engagement in this area. Finally, James provided interesting insight regarding the use of private finance to support cranberry farming going forward. He perceived the private finance sector as immature and not ready to support production at scale. He was cautious at advocating the use of subsidies and green finance because when a retailer sees you are being paid via public/private finance they will negotiate hard on the price and so the system may not be profitable. He suggests that if you are going to make use of subsidies you might as well focus on ecosystem services rather than production.

5. Conclusions and recommendations

It is apparent from the findings of this report that cranberry farming could represent a sustainable change in land use on lowland peat soils, if managed sensitively. It could support a reduction in GHG emissions if higher water tables were maintained, (although the empirical evidence is still being established here, see Natalio et al., 2024), an uplift in biodiversity and an improvement in ecosystem function in terms of water quality and retention. Farming of cranberries could quite feasibly drive paludiculture (wetter farming) to provide a sustainable and productive method of protecting and possibly restoring lowland degraded peat. The scale and intensity of the cranberry farming enterprise adopted will determine whether there is a focus on large scale food production, or whether it is part of a land sharing enterprise with food production embedded in a wet landscape with associated multifactorial environmental benefits. Alternatively, it could have a completely environmental focus around natural capital opportunities, e.g. emissions reductions via carbon sequestration and storage achieved through peatland restoration.

This report has addressed all 4 objectives outlined in the introduction. The most significant outputs relating to this work for the farming industry are first the classification and characterisation of the current farming systems for cranberry production in terms of their socioeconomic and environmental risks and associated ecosystem service provision (see Table 3). Second, the easily accessible summary of cranberry agronomy (Appendix 3). Third, the capture of stakeholder opinion and perception through the interviews carried out (Appendix 4 and Section 4.2). And fourth, the discussion generated throughout the report regarding the direction of travel required to valorise cranberries to support the UK's commitment to SDG's in terms of: 1. Their application to the restoration of degraded lowland agricultural peat; 2. Their role in supporting food security; 3. Their application to mitigate environmental risks relating to carbon, water nutrients, biodiversity; 4. Their role in local community and culture; and 5. Their use as a naturally derived medicine.

5.1 Objective 1 Characterisation of cranberry farming systems

This research identifies and characterises three systems of types of cranberry farming. These were broadly classified at the outset of this project as *High Intensity Cranberry Farming* (HIC) such as those in Wisconsin, Massachusetts*; Low Intensity Cranberry Farming* (LIC), for example the farms in Estonia and the Netherlands (The Cranberry Farm) *No Input Cranberry Harvesting* (NIC) which are represented on the Friesan Islands in the Netherlands. These classifications were refined based on the findings of this report to describe 3 models that reflect current global practices of cranberry farming, the HIC Peat Model, LIC/NIC Peat Model, and the LIC Peat Model.

Models of current farming systems
The current systems used to farm cranberries include (i) the **HIC Peat Model**, a high yield, intensity and input system which may be on peat, i.e. **over-peat** such as those observed in Lake Nokomis, on **sand-over-peat**, similar to those on the Habelman Brothers farm, or on **sand-over-mineral**, which are the new generation of cranberry beds being constructed to avoid impacting the water quality of the natural wetlands, lakes and river catchments (Caron et al. 2017). (ii) the **LIC/NIC Peat Model**, a medium yield, low intensity and low or no input system similar to that on The Cranberry Farm, Netherlands (post-establishment) and possibly elsewhere in the world. This system may also be organic in nature but not necessarily certified hence the use of LIC/NIC; and (iii) the **LIC Peat Model,** it is thought this system might be present in Estonia and Latvia, but further research is required. This system differs from the LIC/NIC system in that inputs may would be higher post-establishment in order to manage the crop, yields may be similar or lower but yield, intensity and inputs would not come near those of the HIC Peat Model.

There are two other no input (NIC) methods in which cranberries enter the food chain either commercially or non-commercially. These are as a result of the harvesting of either naturally occurring native species of cranberry (*Vaccinium oxycoccus*) as documented in the Lake District **Peat-sphagnum-nature Model (NIC) Non-commercial,** and historically in Ireland although this was on a commercial basis; or the harvesting of invasive cranberries (*Vaccinium macrocarpon*) growing on anthropogenically modified sand dunes as documented on the Friesan island of Terschelling in the Netherlands (**Sand-organic Model (NIC) Commercial**).

Table 3 provides a heat map of the positives and negatives that relate to each system to provide an overall impression of sustainability of each. Dark green indicates a good sustainability outcome and light green a poor sustainability outcome. These have been explored in terms of the effect the farming system might have on the peat in terms of protection and restoration, how it would valorise the product, the environmental impact and finally the barriers to continued availability, production and adoption. The initial analysis indicates that of the 3 models, the **LIC/NIC Peat Model** is the most sustainable of the current cranberry farming system, but it may be that in a land-sparing scenario a more intensive approach with artificially constructed cranberry beds such as the **LIC/NIC Peat Model Sand-over-mineral** would be more appropriate. Further research combined with crop trials is required here to tease out the significant elements to come to a more informed recommendation but 4 models involving the farming of cranberries are proposed here for further research and development. This analysis should be explored further with future research (see objective 2 and recommendations).

5.2 Objective 2 Life Cycle Analysis and evaluation of the sustainability

Cranberry farming as a conventional farming system, e.g. the *HIC Peat Model*, just like any other type of farming, should be part of a tightly managed circular food system (CiFoS see Circular Food Systems, no date) with an aim of optimally using the available biomass and agricultural lands to guarantee a healthy, nutrient dense diet for humans while avoiding the transgression of planetary boundaries (Figure 61). A full LCA is out of scope for this research, but the sustainability of current and proposed models is mapped in general terms in Table 3 to provide insight regarding future analysis here. It is worth noting that if cranberry farming were to be adopted, yields in the UK will be low initially and may continue to be low due to climatic differences. These would need addressing early with breeding programmes and research. Valorisation will be key here to mitigate this risk to the farm business as the farmers negotiate lower priced imports from the US and elsewhere. This process of valorisation could be achieved in a number of ways including the use of produce labels which provide environmental assurance such as the LEAF marque (LEAF, no date), selling direct to suppliers of organic foods, exploiting the market for naturally derived medicines and the incorporation of this novel fruit crop into the stories currently being told by our diversifying farmers as they take ownership of their identity and enterprise.

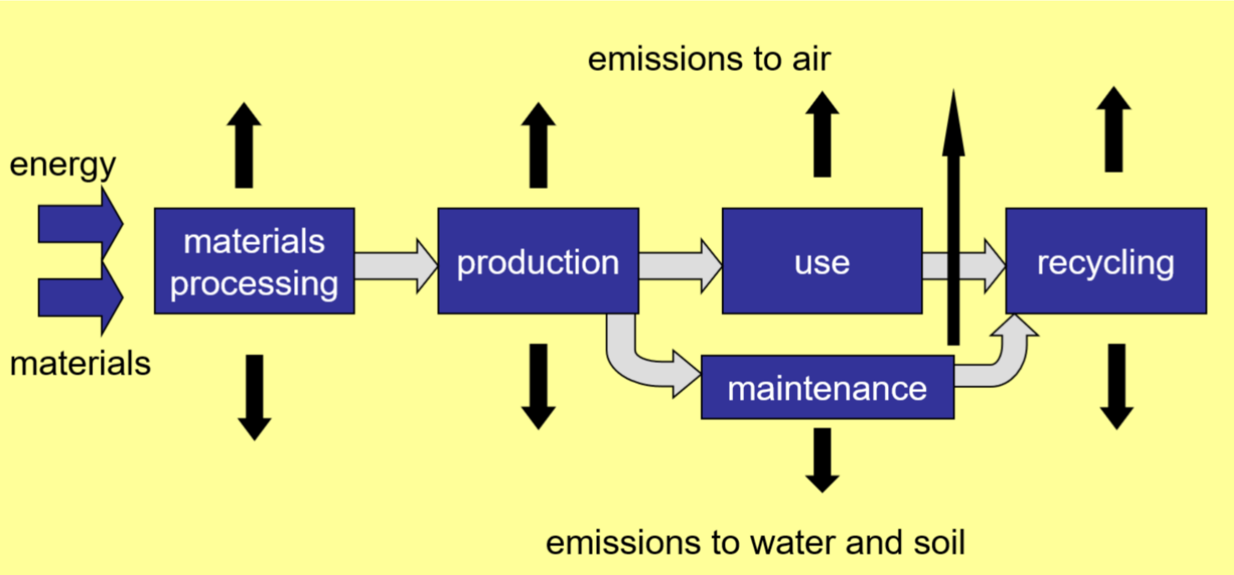


Figure 62 Circular Food System source: Cycle Chain in LCA (www.ecocosts.com, 2024)

Table 3 Heatmap of sustainability outcomes for current and proposed R&D models of cranberry farming systems/sources of cranberries.

Current models of cranberry farming systems/sources of cranberries	Sustainability: Yield/ inputs/intensity	Sustainability: Peat protection/ restoration	Sustainability: Valorisation	Sustainability: EIA positive impact (EIA +)	Sustainability: EIA negative impact (EIA -)	Sustainability: Barriers to continued availability/production/adoption
HIC Peat Model **Over-peat** (Case study 2: Lake Nokomis) **Sand-over-peat** (Case study 1: Habelman Brothers) **Sand-over-mineral** (artificial constructed bogs)	High yield High inputs High intensity	No - but organic matter incorporated every 2-3 years, cover & high water tables maintained. NB. Peat extraction continues.	**Bio** (marginal & set aside land) **C** (buried peat) **CP** (cranberries are integral part of US culture & seasonal behaviour)	**C** (partial peat protection due to rewetting & cover) **N** (nutrient stripping by cranberry & precision techniques used) Phosphorus is locked into the sand. C & N locked into peat. **Also: Pol, Bio**	**N** (nutrient loss to wetland system) **Bio** (biodiversity loss due to use of insecticides & monoculture cropping etc.) **GHG** (enhanced GHG emissions if not perched above water table due to flooding techniques used)	**CC** (climate change – especially unpredictable frosts) **Also: WQ, Y, PD, F, W, Y.**
LIC/NIC Peat Model (see Case Study 4 The Cranberry Company)	Medium yield Very low or no inputs (maybe organic) Low intensity	Yes – if water table managed sustainably (see Natalio et al., 2024)	**C** **CP** **Bio**	**Pol, Bio, GHG, N, C**	Minimal, possibly **Co**.	**CC** (rising sea levels causing flooding) **S** (saltwater ingress) **Also: N, WQ, Y, W.**
LIC Peat Model (c.f. Estonia farming systems -further research required here)	Medium yield Low inputs Low/medium intensity	Unknown	Unknown	Unknown	Unknown	Unknown- further research required.
Sand-organic Model (NIC) Commercial (see Case Study 3 Terschelling Islands, also modern artificial beds on mineral soils in the US)	Medium yield Organic/wild growing No inputs Low intensity	N/A	**CP** (tourism, community harvesting, local provisioning)	N/A	N/A except for perception of *Vaccinium macrocarpon* as an invasive non-native plant species & its impact on the native flora (**Bio**)	**CC** (flooding & temperature changes) **S** (saltwater ingress due to rising sea levels)
Peat-sphagnum-nature Model (NIC) Non-commercial (see Case Study 5 Haweswater, Lake District; & Ireland: Appendix 4)	Medium yield No inputs Low intensity	Peat protection if livestock and water managed sustainably in the landscape.	N/A	N/A	**G** (grazing from livestock) Also, human traffic and government policy.	Key risks to wild cranberries include: **CC, G** and **WQ**

Research & Development (R&D)	Sustainability: Yield/ inputs/intensity	Sustainability: Peat protection/ restoration	Sustainability: Valorisation	Sustainability: EIA positive impact (EIA +)	Sustainability: EIA negative impact (EIA -)	Sustainability: Barriers to continued production/adoption
Model 1 **NIC/LIC-Large scale** Degraded rewetted peat-large scale (c.f. Case Study 6 Pollybell Farms)	High yield Low inputs Medium/high intensity (with precision ag.)	No – unless planted into sphagnum, or sphagnum part of crop rotation or strip/intercropping with sphagnum.	Yes **C, Pv & Sub** **Bio (if strip cropping, use of margins and sensitive farming of set-aside etc.)** **Nu** **CP (would need to be developed)**.		**Management is key** **Co**? (emissions from compaction and trafficking minimal with proposed use of innovative equipment & machinery & tramlines). **GHG** (emissions negligible due to perennial crop). Use of IPM.	**W, CC, WQ, Y, PD, CC**
Model 2 **NIC-Small scale** Degraded rewetted peat - small scale	Medium yield low or no input low intensity	Possibly if use of peat forming vegetation used for a regenerative form of wetter farming.	Yes	Yes	Minimal	**CC, WQ, W, O, Po, Inf**
Model 3 **NIC-Margins** Degraded rewetted peat margins	Low yield No input Low intensity	Yes if margin includes peat forming vegetation.	Bundling of nutrient/biodiversity/carbon	Yes	Limited	**W, Po, WQ, CC.**
Model 4 **HIC-Isolated precision** Isolated precision farming system using artificially constructed beds on Sand-over-peat (degraded peat) or on Sand-over-mineral.	High yield High input High intensity	Not on sand/limited on peat unless sphagnum used due to isolated system.	Opportunities to be explored in terms of the LEAF Marque and other labels and sustainability.	**Nu**: if water used has been sourced from road run off and quality improved with the use of constructed wetlands. **Bio**: if integration of wetland margins etc.	No. If there is, the system has failed since it should be isolated and subject to precision agricultural techniques.	**Inf, WQ, Po.**

Key to sustainability outcomes

- Dark Green: good/positive outcomes
- Medium shade of green: moderate outcomes
- Light green: poor/negative outcomes

Farming systems (see Section 2.3.6): HIC - High Input Cranberry Farming; **LIC** - Low Input Cranberry Farming; **NIC** - No Input Cranberry Farming/Harvesting
Intensity - (H: high, M: medium, L: low) – i.e. requiring precision techniques
Y - yield (H: high, M: medium, L: low)
I - inputs (H: high, M: medium, L: low)
R - peat restoration: yes/no/possible
V - valorisation (**C**: carbon, **Bio**: biodiversity, **N**: nutrients, **Sub**: subsidies, **Pv**: private finance, **CP**: cultural story of provenance, **Nu**: nutrient neutrality opportunities)

Environmental Impact Assessment
EIA+ : positive impact; **EIA-** : negative impact
Elements: Co: compaction due to trafficking, **N:** nutrients, **WQ**: water management & quality, **GHG**: greenhouse gas emissions, **Pol**: impact on pollinators due to insecticide use, **Bio**: impact on biodiversity due to use of herbicides/crop diversity.

Barriers
S: salt water ingress, **GHG**: greenhouse gas emissions due to exposure of peat/flooding of peat beds, **W**: weed control, **PD**: pests & diseases, **WQ**: water management, **Y**: profitable yield, **F**: frost, **E**: overheads, **G**: grazing, **CC**: Climate Change i.e. unpredictability of weather, higher sea levels, **Po**: Government policy, **Inf**: infrastructure costs.

5.3 Objective 3 Identification of a farming system appropriate to the UK

Prior to identifying the farming system which may be appropriate to use in the UK, it is important to review the agronomy of cranberries and determine whether the UK climate will be suitable for the successful growth of these plants. This is addressed in Section 2.2.5, Appendix 3 and the various case studies. It appears that with the need for a different, wetter type of farming on peat in the UK due to the changing climate and a willingness from farmers to embrace on farm innovation and accept Government subsidies there could be strategies to overcome the main barriers likely to be associated with cranberry farming in the UK, e.g. frost, pH, water management, pest control etc. Exploitation of the potential of the opportunity presented here requires systematic crop trials and life cycle analysis to provide the necessary empirical evidence to advise the farming community regarding the viability of cranberry farming going forward.

It was evident from the outputs of my research that the high intensity, high inputs and high yielding system of farming practised in the US would not be appropriate in the UK due to the environmental impacts. However, there were elements of this system which could be adapted to support a LIC system of production at scale or an isolated HIC system. The LIC systems could also be incorporated into a mosaic of land use on a smaller scale in a similar way to that proposed, and purportedly successfully implemented by The Cranberry Company in the Netherlands. As a result of these findings opportunity models were designed based on the current farming systems for research and development (Table 3).

Models for Research and Development
Model 1 NIC/LIC-Large scale
This system would be a no input or very low input system on a large scale on degraded rewetted peat. An organic version of this was recommended by James Brown of Pollybell Farms (Case study 6). This may be appropriate in areas of the UK where there are large areas of degraded peat derived soils, e.g. in Norfolk which are currently growing potatoes, oil seed rape and lettuces. Whether the use of Government subsidies and private finance would undermine the strength of this farm business is yet to be determined.

Model 2 NIC-Small scale
This farming system suitable for small scale farming enterprises on degraded rewetted peat with no inputs. This would be part of land-sharing initiatives where productive farming is embedded in a landscape managed for ecosystem services (biodiversity, nutrient and climate mitigation etc.) in which Government subsidies could be bundled with private finance options. This system may be more appropriate where the peat is more discrete in its distribution, e.g. in Shropshire where historically cranberry bogs located in the dips and hollows were identified on farm and harvested from (Behnke, 2023). It is possible that cranberries may also be grown in sphagnum under photovoltaics as part of solar farms. Paludiculture is currently being investigated under photovoltaics in Europe (Hochschule Weihenstephan-Triesdorf, no date). It is anticipated this would involve a high level of precision farming and so may be more appropriate as part of a NIC/LIC Large-scale (Model 1) enterprise.

Model 3 NIC-Margins
Hackett & Lawrence (2014) have reported that field margins can be multi-functional in character, not only providing semi-natural habitat for biodiversity, including pollinators for crops and the predators of agricultural pests, but also reducing the effects of runoff and soil erosion. Conventional farm management for arable field margins include natural regeneration, grass sown, wildflower, pollen and nectar wild bird seed mix and an annual cultivation or conservation headland. It follows that wetter farming systems would also benefit by incorporating similar margins to improve the functionality of the wetter farmed environment especially if diversity of crop is low. There are a

number of questions surrounding the mix of species and the ecosystem service provision of these proposed margins which would require further research but it is likely that they would improve the environmental resilience of the land holding, e.g. carbon sequestration, peat restoration, retention of water, buffering of nutrients, biodiversity, provision of natural predators for pest control and others. They may also be used in the restoration of discrete wetlands such as those present in Shropshire (c.f. Harper Adams University, 2024), some of which were named 'cranberry bogs' (Behnke, 2023) but are now scrubbed over with silver birch due to land drainage, to provide connected natural wetland habitats for landscape recovery. Cranberries could quite feasibly form part of this wetland margin with a number of other wetland species. The assemblage of species is likely to vary with the predominant water table level but may look similar to those seen in the Krimpenerwaard, Netherlands (see Figure 53) and include some of the species identified by Robert Duff (see table 2, c.f. Duff no date and WWT no date).

Figure 63 Historic cranberry bog at Aqualate Hall, Staffordshire.

With the need to prevent the decline of nature and support biodiversity, and as the Government moves to support wetter farming to reduce emissions from degraded agricultural peat, use of land for water storage and flood mitigation, it seems intuitive that there would be a demand for wetland margins ('Wetlandscape') similar to arable margins farmed with bird seed and pollinator cover crops. Model 3 is provided to stimulate debate regarding whether cranberries could be part of a 'Wetland Mix' SFI option and what these margins might look like. Table 2 provides a mix of species that could be used. However, it is probable that other mixes involving meadowsweet and water mint may also be appropriate.

Relic 'moss' indicator	Common name	Occurrence (out of 100 sites)
Sphagna species	bog-moss	53
Carex rostrata	bottle sedge	7
Carex curta	white sedge	6
Carex elongata	elongated sedge	1
Eriophorum angustifolia	common cottongrass	7
Eriophorum vaginatum	hare's tail cottongrass	9
Vaccinium oxycoccos	cranberry	8
Frangula alnus	alder buckthorn	5
Andromeda polifolia	bog rosemary	1
Osmunda regalis	royal fern	4
Erica tetralix	cross leaved heather	7
Myrica gale	bog myrttle	2
Hottonia palustris	water-violet	3
Drosera rotundifolia	round-leaved sundew	1
Cicuta virosa	cowbane	1

Table 2 Table indicating possible species which could form part of a wetland margin. Source: Robert Duff (no date, www.iucn-uk-peatlandprogramme.org)

Model 4 HIC-Isolated precision

The fourth model may be appropriate on a large scale or as part of a small-scale operation. The main difference between model 1 and 4 is that farming following model 4 would be completely Isolated using artificially constructed beds using Sand-over-peat (degraded peat) or Sand-over-mineral. It would require the use of robotics and precision farming techniques to apply inputs as required and harvest. It may be possible to use this system to look at enhancing the private finance of such farming by planting cranberries into sphagnum which would support water retention and quality, carbon sequestration, peat formation and restoration to generate carbon, biodiversity and nutrient credits.

Further recommendations would include undertaking more in-depth research regarding the traits associated with cranberries which indicate the provision of ecosystem services in a similar way to that of research by Jenkins et al. (2023) to determine the full potential of cranberries when planted as (i) a monocrop, (ii) when planted into sphagnum, (iii) as part of a crop rotation with sphagnum, (iv) as part of an inter-cropping or strip cropping system with sphagnum. Finally, it would be beneficial to perform a full socioeconomic analysis using a sustainable value framework similar to that of Huang et al (2024) which evaluates the projected sustainability of cranberry farming, and the various models proposed. Research priorities will relate to the pH of the soil which will need amending, the nutrient levels which will require stripping to prevent dominance from weeds, removing or treating the seed bed in a more sustainable way, the integrated management of pests and diseases, maintaining sufficient water for optimal soil moisture profiles and finally protection from frost. If a low input system is to be achieved, then either precision techniques will be required to monitor the performance of the crop or the crop would need to be part of a diverse assemblage of species which would naturally maintain the health of the soil and farmed above ground and below ground 'ecosystem'. These conclusions align nicely with those of Nancy Wiltnik's research in the Netherlands in which she surmised that the following will be key in establishing cranberries directly on peat: (i) ensure the correct pH using amendments, (ii) maintain a high water table (10 cm below ground level) in winter and summer and (iii) avoid competition from weeds by removing reeds and using sphagnum which will also help to retain moisture. She also recommended planting in December, using only rainfall, or above ground irrigation because ditch water pH is too high.

Figure 64 Horticultural operations: cranberry plants (source: www.gifimey.com/cranberries)

5.4 Objective 4 Barriers to adoption of cranberry farming in the UK

The main barriers to the success of cranberry farming identified in this report relate to the UK climate, the nature of our degraded peat soils in terms of nutrient levels, pH and weed burden, the risks associated with rewetting, especially the impact of this on neighbouring farms, the creation and reliability of market demand, and food security due to the displacement of conventional crops. Questions remain regarding how socioeconomically viable it would be to farm in this way, what impact this would have on the farm business and what this would look like at different scales of intensity.

With climate change and increasing summer temperatures it is probable that sun and temperature requirements would not be a barrier. Successful production of cranberries in the Netherlands and personal observations of significant wild berries from the same taxonomic group, e.g. bilberry, and lingonberry, in the Shropshire Hills during the summer of 2023, and cranberries (*Vaccinium oxycoccus*) harvested from Haweswater in December 2023, indicate this should not be a barrier.

Cultivars currently used may need to be genetically modified to improved resilience to the UK climate in the same way that they are in the US as they adapt to climate change. It is not anticipated that; cold temperatures would not represent a barrier due to the methods of frost protection that are available (see section 2.3.5). Extended cold temperatures required for dormancy (but see Appendix 3 for discussion here) and germination may be a barrier. For expediency and to overcome the latter barrier cranberry plugs of hardy cultivars of *V. macrocarpon* could be imported from the US with the necessary biosecurity measures.

The higher pH of degraded peat soils would not represent a barrier. The soil pH may be amended using sulfur and acidic brash/mulches. Interestingly, it is thought that once cranberries are established, they maintain the acidic nature of the peaty soils (see Case study 4) and help to strip the nutrients which in turn provides optimal conditions for the planting of other wetland plants (Lenz, 2024). Recent reports of conservation work restoring degraded peatlands for nature in Estonia suggest that there is also a role for cranberries here as a tool to support climate change mitigation (Lenz, 2024).

Climate change has created an opportunity for UK growers. It is predicted that suitable habitat for cranberry production will move away from current growing regions (Hirabayashi, 2022). The world's interest in more ethically and sustainably sourced food which is healthy and nutrient dense represents significant opportunities with careful planning to support food security either through direct consumption of cranberries, or export to other countries as well as using cranberries to improve the ecosystem function of degraded lowland peatlands whether it be for biodiversity, carbon or nutrient and climate mitigation. In addition to the food related products provided by cranberries, the medicinal properties of cranberries have been identified as the key market drivers in the US (Technavio, 2024). There is a significant trend in the market for organically produced cranberries. This presents an opportunity to the UK due to the environmentally damaging, intense farming systems in the US and the problems they are experiencing with pests, herbicide resistance etc. The major market challenge in the US is the high cost of production but it is anticipated with the models suggested for adoption in the UK (Table 3) that these costs might be less due in all except Model 4 (*HIC-Isolated precision*) due to the low inputs required.

In summary, this body of research suggests that cranberries could be produced as a food produce in 3 ways in the UK. Firstly, if it were economically viable and the right conditions were achieved in terms of soil amendments, weed burden, water and nutrient management, cranberries could be grown at scale as part of a low input or organic farming system. It is probable that the cranberries would be dry harvested due to the negative effects of flooding on nitrous oxide and methane emissions from degraded peat and nutrient leaching. James Brown has expressed an interest in pursuing crop trials to establish the methods needed for large-scale profitable production. These trials could be pursued using grants such as the Innovate UK Smart Grants.

Second, cranberries could be farmed as part of a land sharing system in areas of low productivity in a similar way to Green Restoration Ireland, helping to connect up on farm habitats with other rural and urban land uses in the UK. This could provide a low yield which could be twinned with the restoration of peatland function and ecosystem provision in terms of water retention in the upper catchment (water quality and flood mitigation) and support for climate change mitigation, biodiversity and nutrient mitigation.

Third cranberries could be used principally as a tool for restoring lowland peat and protecting the carbon store through rewetting in a similar way to Estonia and Latvia providing fresh cranberries which could be dry harvested (see Paal, 2008). Options for protecting the peat derived soil and adding to the carbon store, e.g. strip cropping with sphagnum or planting into sphagnum, could be further investigated as viable options to optimise ecosystem services which could then be bundled and traded. This protection may also be attained in combination with other land use options currently being explored in Europe, e.g. photo voltaics (see Hochschule Weihenstephan-Triesdorf, no date). Using cranberries in this way may also have applications in the US for cranberry bed reversions to natural wetlands as smaller farms are disbanded or consolidated and in the Netherlands for polder reversions.

To conclude, are the UK's lowland peat farmers missing an opportunity in relation cranberry farming?

Very possibly.

So, in the words of James Brown of Pollybell Farms '..let's carry out a trial and find out…'.

Figure 65 Natural wetland peat forming habitat surrounding the cranberry beds on Habelman Brothers Ltd. cranberry farm, September 2023.

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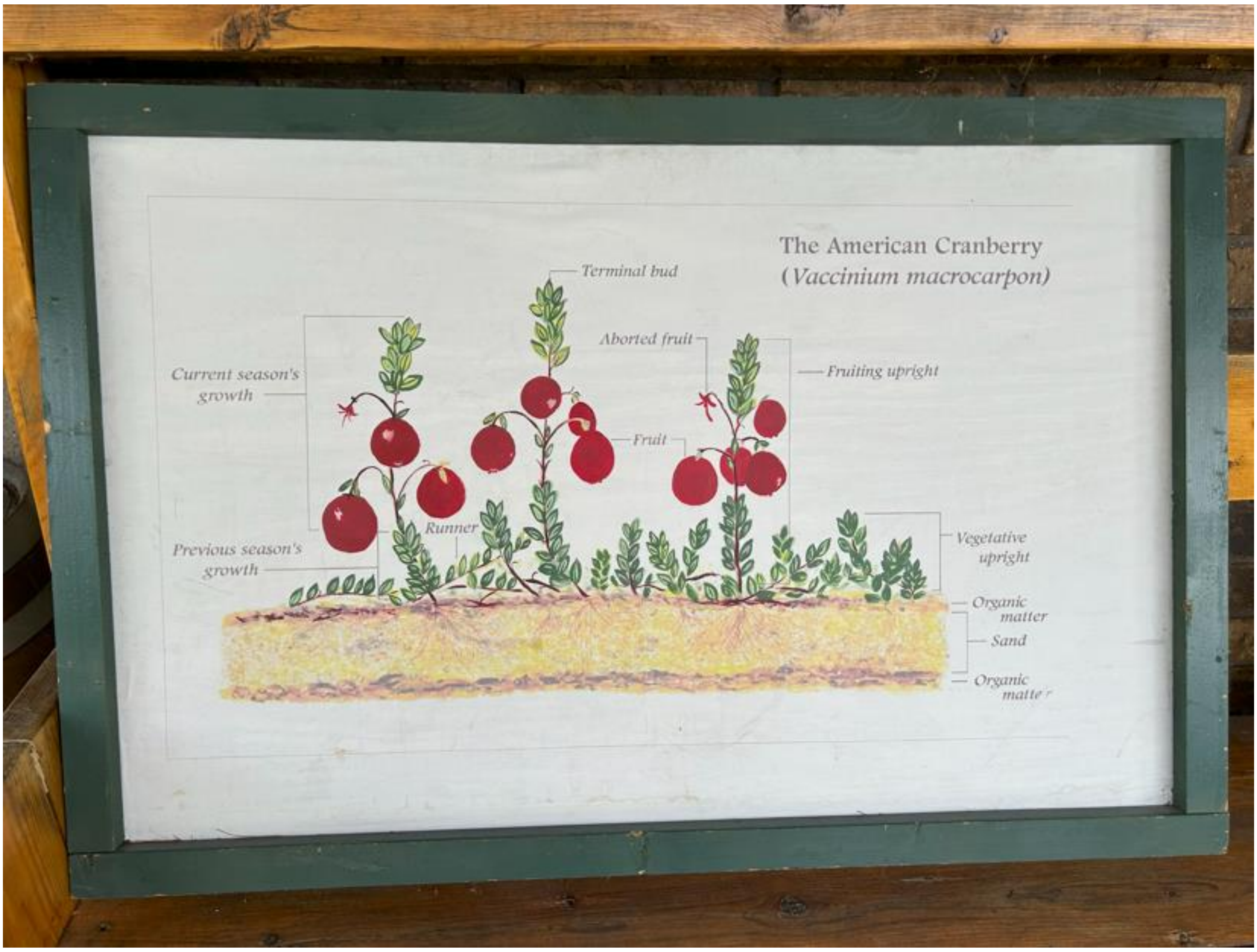

Figure 66 The American cranberry growing on sand (source: Lake Nakomis Cranberry Farm, Wisconsin)

7. Appendices

7.1 Appendix 1 - Machinery requirements (attachment)

7.2 Appendix 2 - Economics of cranberry production (attachment)

7.3 Appendix 3 - Cranberry agronomy (attachment)

7.4 Appendix 4 - Interview outputs (attachment)

7.5 Appendix 5 - Log of activities (attachment)

7.6 Appendix 6 - Interview consents (attachment)

7.7 Appendix 7 - PDF with English translation of Nancy Wiltink's report: *Opportunities and difficulties for the cranberry – can there be a role for cranberry picking or cultivation in the intended Amsterdam Wetlands?* (attachment)

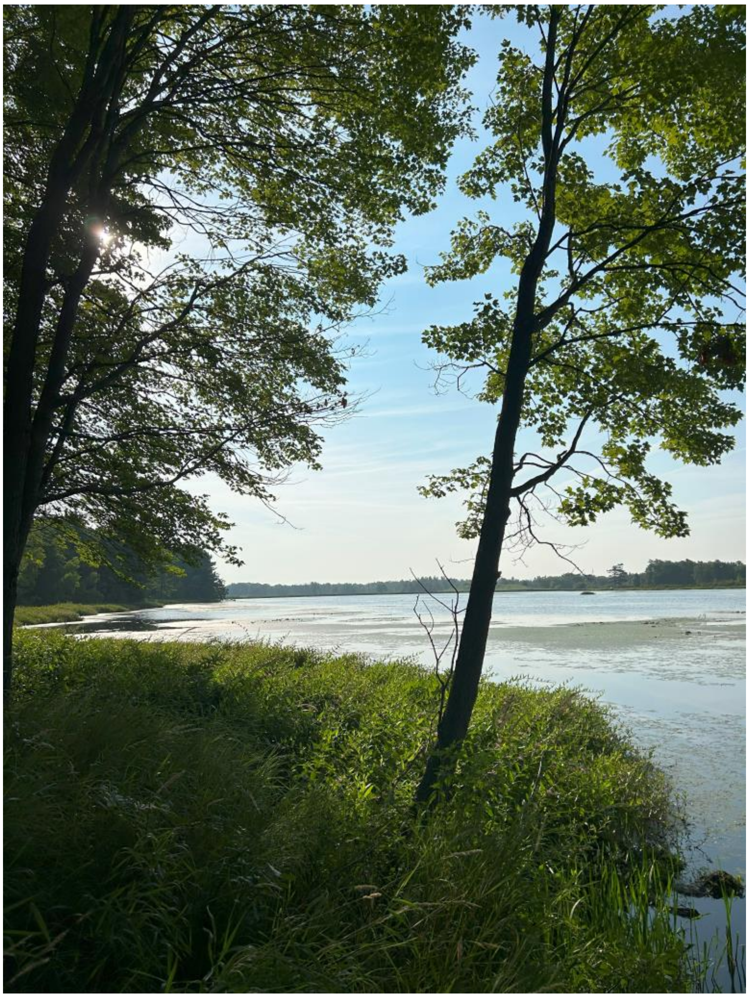

Figure 67 Natural wetland on the Habelman Brothers Cranberry Farm