Productive lowland peatlands

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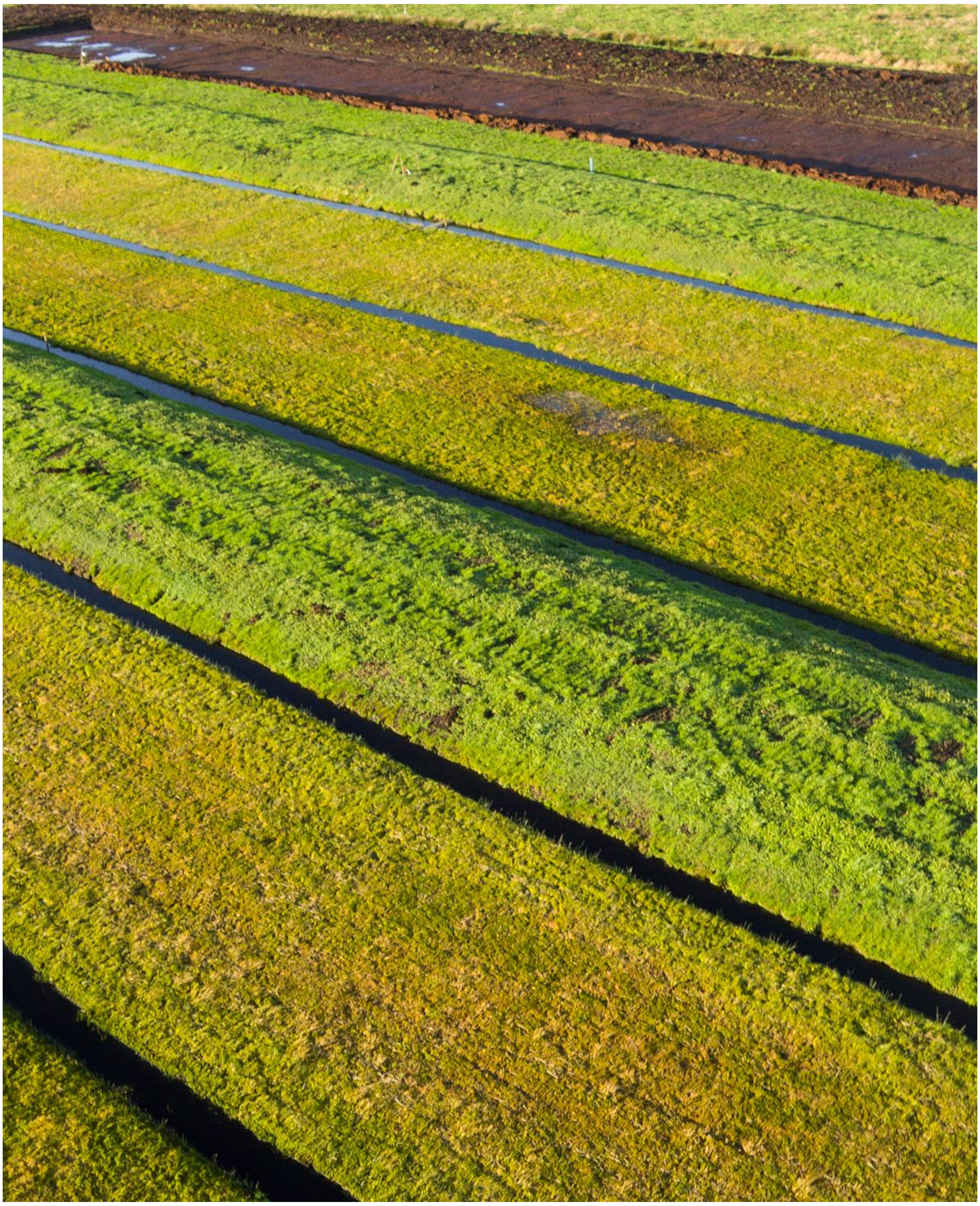

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Productive lowland peatlands

This section sets out the concept of 'paludiculture', indicates how it works and explores the benefits and opportunities, as well as the potential barriers to uptake in the UK's fen peatlands.

Introduction

With international and UK focus on managing peatlands sustainably, the role of productive farming on lowland peatlands has come under the spotlight. There is growing appreciation that maintaining the health of peat soils delivers considerable economic benefits associated with Green House Gas regulation as well as a wide range of other environmental benefits (Graves & Morris, 2013).
Yet, conventional agricultural production on lowland peatland has demonstrated that it is inherently unsustainable. The lowland fens and raised bogs of the UK have largely been drained for agriculture (Cris et al, 2014). The drainage is the root cause of many of the problems associated with peatland utilisation – see Figure 1 (Joosten, 2017). The soil degradation, compaction and subsidence that results from drainage can cause the peatlands to lose their agricultural value, while emitting thousands of tons of carbon dioxide to the atmosphere (DEFRA, 2018; Joosten et al, 2016). Agriculturally drained lowland fen and raised bog peatlands are probably the UK's largest sources of peatland greenhouse gas emissions (Evans et al, 2016; Holman IP, 2009).

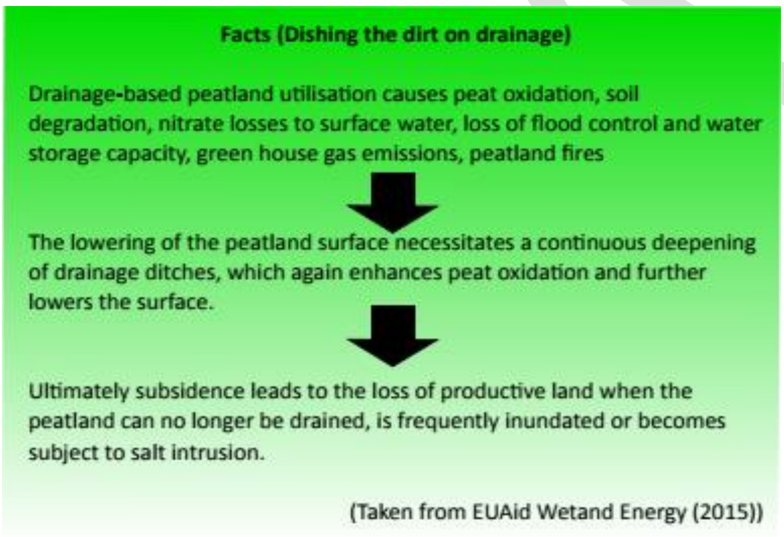


Figure 1: Process of peatland degradation following drainage

Approximately two thirds of the 325,000 ha of lowland peatlands in England are now classed as 'wasted', and there is considerable evidence – recognised by farming bodies- that current methods of arable production inevitably results in the degradation and 'wasting' of peat soils (Morris et al, 2010). In the Somerset Levels, there has been subsidence and shrinkage estimated to be 1 to 1.5 cm per year (DEFRA, 2018) and only an estimated 16% of the peat stock recorded in 1850 in the East Anglian Fens now remains (Morris et al, 2010).

There is increasing recognition that the problems caused by peatland drainage, such as Green house gas emissions, are best addressed through raising and stabilising the water level, and that climate change mitigation and adaptation strategies should include rewetting of drained peatlands (see Figure 2). For example, research shows that the overriding control on CO_2 emissions from lowland peatlands is mean water-table depth. (Evans et al, 2016).

Figure 2: FAO - climate change mitigation and adaptatio strategies for peatlands

However peatlands, once re-wetted, can no longer be used for conventional drainage-based agricultural production (Wichtmann et al, 2016). For this reason there could be some opposition against peatland re-wetting, especially since lowland peat soils, particularly on fens are of strategic agricultural importance as highly productive soils and we depend on them for growing arable crops, albeit in the short-term before the soil is depleted. But is there another choice for farmers? In practical terms, there are a range of options for agricultural production on fen peatlands, including the management of wetter systems which can protect peat soils, lock up carbon, provide other ecosystem services *and* provide an economic return. (Wichmann, 2018; Cris et al, 2014). A proposed 'inclusive solution' is paludiculture (Wichtmann et al, 2016)

Paludi-what?

> "Paludiculture is not merely a word, it is a principle, a rethinking of how to deal with peatlands in agricultural use", *Michael Succow, Chairman of the Board of the Michael Succow Foundation for the Protection of Nature (in Wichtmann et al, 2016)*

Conserving and rehabilitating lowland peatlands, so that they function fully does not have to mean that all areas become off limits to economic farming activity. Alongside restoring fens primarily for nature conservation it is possible to have areas where productive agriculture continues but based on crops that benefit from the wetter conditions. Paludiculture – from the Latin '*palus*' for swamp + '*cultura*' for care, or cultivation - is a form of agriculture that allows farmers to manage peatlands for biomass production (e.g. food, fibre and energy) without draining the habitats (Cris et al, 2014; Geurts & Fritz, 2018; Wichtmann & Joosten, 2007; Wichtmann et al., 2010). Paludiculture *is not* nature protection: it is agriculture with clear production goals. What paludiculture *is*, is a wetter way of farming on peatlands that does not degrade the peat layer and even adds to peat accumulation.

Peat is generally formed by plant material below ground; paludiculture harvests above ground biomass - from spontaneous vegetation to artificially established crops - which can be harvested without harming the peat below (Joosten et al., 2013, FAO and Wetlands International, 2012). Ideally the peatlands should be wet enough that the peat is both conserved and new peat forms (Wichtmann et al, 2010). This wetter way of farming centres around the cultivation of plants that:

- thrive under wet conditions
- produce sufficient quantity and quality of biomass
- (ideally) contribute to peat formation

(Wichtmann et al, 2010)

Aim Utilisation	Farming and Food Production	Biodiversity Conservation	Climate Change mitigation	Water storage / regulation	Water quality
Paludiculture	synergy	synergy	synergy	synergy	synergy
Conservation	conflict	synergy	synergy	synergy	synergy
Rewetting	conflict	synergy	synergy	synergy	synergy
Conventional Agriculture	synergy	conflict	conflict	conflict	conflict
Abandonment	conflict	conflict	conflict	conflict	conflict

Table 1: Conflicts and synergies of various peatland utilisation options (adapted from FAO and Wetlands International, 2012)

Paludiculture is in the early stages of development as a form of land management. Of Europe's 28.5 million hectares of degraded peatlands, less than 1% have been re-wetted, with paludiculture covering only a fraction of this area (Tanneberger et al, 2017). But sustainable management of lowland peatlands where water tables are kept high, can bring new ventures (IUCN UK peatlands strategy 2018-2040). Paludiculture offers reduced conflict and builds synergies in a way that is better than conventional agriculture (See Table 1).

There is much commercial potential in using biomass from wet and re-wetted peatlands (Wichtmann et al, 2010) – through either revitalising traditional forms of land use (e.g. reed cutting for thatching) or providing innovative products for growing market demands (e.g. biofuels) (EuAid Wetland Energy, 2015). Examples of biomass production already exist, are being trialled or developed on fen peatland in a number of countries around the world (e.g. Canada, Germany, Belarus).

Paludiculture does not have to compete with areas that are needed for food production. For example, sites that are not or are less suitable for food production (or have been abandoned since they have lost their agricultural value) can be used for paludiculture; these areas could be used to grow biomass for raw materials or for energy crops, thus taking away pressure from those areas that are needed for food production (Wichtmann et al, 2016). Alternatively there are options for food production areas to shift away from dry species to growing food crops that will thrive in higher water levels under paludiculture (see section on crops and markets).

Paludiculture is explicitly mentioned as a sustainable land use option in several global initiatives such as The Ramsar Convention on Wetlands, The Intergovernmental Panel on Climate Change (IPCC) guidelines on National GHG Inventories, on reporting of emissions and removals under the Kyoto Protocol, and by the UN Food and Agricultural Organisation (FAO) as well as in the IUCN UK Peatland Programme's UK Peatland Strategy 2018-2040. However paludiculture is underdeveloped in the UK and the scope for implementing these systems is poorly understood.

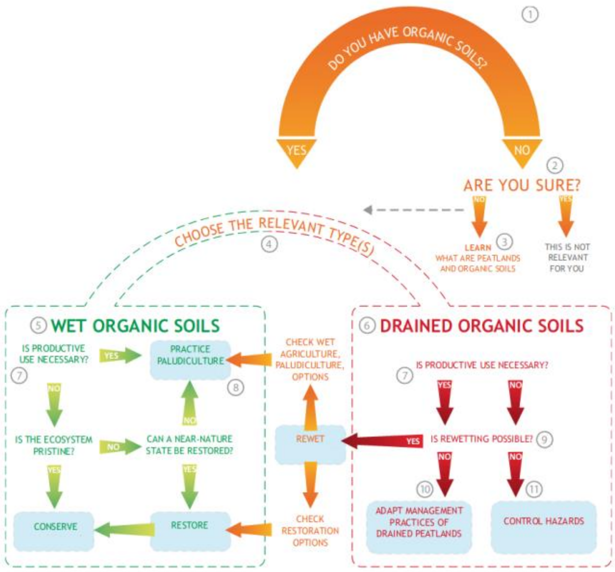


Figure 3: Decision support tree for management of peatlands. Paludiculture can be part of the farming toolbox for fen peatlands in the UK (FAO and Wetlands International 2012)

Paludiculture is not a panacea

Paludiculture is about diversifying agricultural activities rather than a complete change of land management – for example targeting paludiculture activities on marginal land.

Re-wetting may not be possible on all drained lowland peat. In that case adaptive management, which avoids over-drainage, soil tillage and the use of fertilizers is the preferable option.

However, Paludiculture offers another option in the farming tool box - instead of fighting to keep all areas drained that otherwise would be wet. It represents an opportunity to maintain farming livelihoods and generates new enterprises within UK agriculture. See Figure 3

Paludiculture covers a broad spectrum of applications, from simply changing a crop from a dryland crop to a wetland crop all the way up to wetland creation. The choice of paludiculture activity will be specific to site, current land management, extent of peatland degradation, and intended goal of any land use change. For example, it may not be appropriate to take a degraded mire and apply a cultivated wetland crop, but it may be appropriate to take a permanent pasture on peatland and restore it to mire.

The trajectory of paludiculture applied should take the peatland soils towards a more suitable wetland management (**Error! Reference source not found.**).

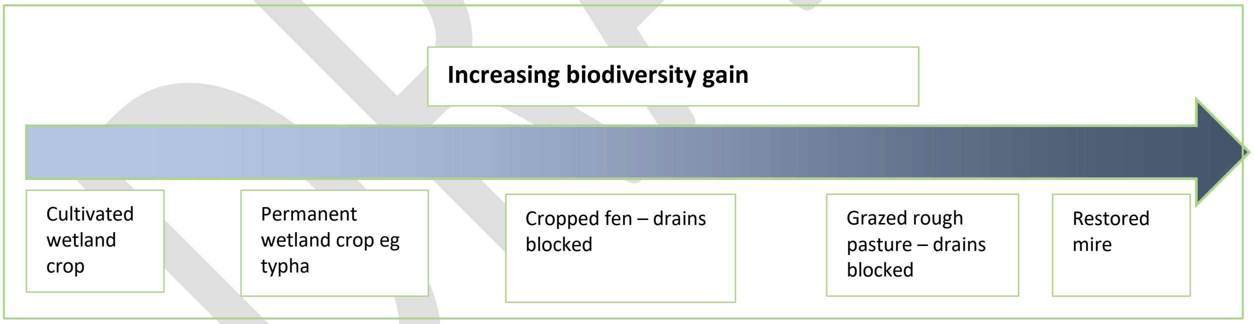
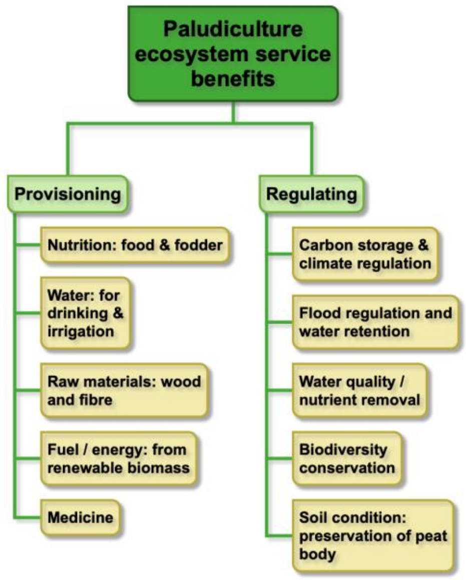


Figure 4

What are the benefits of wetter farming?

Wetlands have been described both as “the kidneys of the landscape”, because of the role they play in the regulation of water quality and flow, and as “biological supermarkets” because of the rich biodiversity they can support (McBride et al, 2011; Barbier et al, 1997).



The overriding benefit of paludiculture is that it is the only form of land use that allows the use of the provisioning capacity of peatland without substantially compromising these regulating services (Wichtmann et al, 2016). It can provide sustainable economic assets such as fibre and energy, livestock and agriculture, under conditions that maintain the peat body, and also reactivate or sustain other vital ecosystem services (Figure 5).

Paludiculture versus wetland restoration

Current re-wetting and restoration of degraded peatlands focuses on the re-establishment of mire typical biodiversity, on the improvement of water quality, on the reduction of green house gas emissions, and on the restoration of other regulating services. However restoration usually implies a stop or reduction in the production on peatlands. Paludiculture on the other hand is the only form of land use on peatlands that allows using the provision capacity of peatlands without substantially compromising the supply of regulating or cultural services.

Section	**Group**	**pristine/near natural**	**Drained land use**	**Drained & abandoned**	**Rewetted & unused**	**Paludiculture**
Provisioning	Food & fodder	+	+++	0	0	++
	Plant fibres (e.g. building material)	+	++	0	0	++
	Biomass fuel	0	++	0	0	++
Regulating	2.Climate regulation	++	---	---	+++	+++
	Water purification/ nutrient retention	++	---	---	+~	++~
	Regulation of the water cycle	+++	---	---	++	++
	Species habitat/gene pool	+++	+	–	+~	++~

Table 2: Selected ecosystem services of peatlands in dependence of water management and utilisation (take from Wichtmann et al, 2016), showing that paludiculture provides the most ecosystem benefits compared to all other land use (positive impact: +++ = strong, ++ = medium, + = existing; negative impact: --- = strong, – = medium, - = existing; 0 = no influence; ~ = changing over time)

Climate regulation – reduction of green house gas emissions

Lowland peatlands are one of the most carbon-rich ecosystems in the UK and fens under high water table management consistently act as carbon sinks (Evans et al, 2016). For example, a carbon audit carried out in 2009 showed that the Broads deep peat soils, mainly within the fens, hold 40 million tonnes of carbon dioxide equivalents, “similar to the carbon output of one of the world’s largest coal fired power stations.” (Broads Biodiversity and Water Strategy, 2013) Currently though lowland peatlands are the largest source of GHG emissions in the UK .

	Total GHG emissions ((Mt) CO_2-e per year)	
	(deep)	(wasted)
Cultivated & temporary grass	0.96	0.55
Improved grassland	0.42	-
Restored	0.02	-

Table 3: Total estimated Green House Gas emissions from fen peatlands (from Natural England, 2010, report NE257).

Given that emissions from drained peatlands continue for as long as the peatland remains drained then paludiculture could be described as low hanging fruit for climate change mitigation (Peters, J 2012). Paludiculture on re-wetted peatlands contributes to climate regulation and climate change mitigation in two ways:

By massively reducing greenhouse gas emissions from drained peatland soils. Oxidation of peat and the associated release of greenhouse gases are stopped and carbon may even be sequestered again in newly accumulating peat. Detailed research is needed in the UK, but it would be hoped that paludiculture would be close to the restored emissions factor in Table 3.

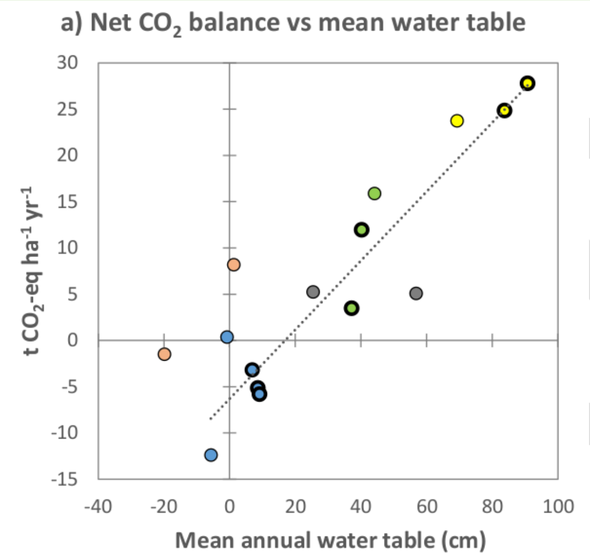


Figure 6: Observed relationship between net CO2 flux and mean measured water-table depth for study sites in (Evans et al, 2017) research. Sites are colour-coded as: blue = conservation-managed fen; orange = re-wetted raised bog; grey =extraction site; green = grassland; yellow = arable. Taken from (Evans et al, 2017)

By replacing fossil resources by renewable biomass alternatives. When the cultivated biomass is used to reduce fossil fuel emissions to the atmosphere by directly displacing oil, coal and natural gas use or by displacing high-carbon materials such as steel and cement (CCC, 2018).

Several studies of the greenhouse gas fluxes and carbon balances of lowland peatland systems in England and Wales show a clear relationship between the amount of CO2 emissions on peatlands and the mean water table, including a DEFRA-commissioned evaluation (Evans et al, 2017) in which conservation-managed lowland fens appear to be among the most effective carbon sinks per unit area, whereas lowland peats under intensive arable agriculture in England are probably the UK's largest land-use derived source of CO_2 emissions (Figure 6).

Elsewhere, trials have shown that CO_2 emission from paludiculture crops - which by nature thrive in wet conditions - are far lower than emissions from high intensity crops or grassland on peatlands (see Figure 7) .

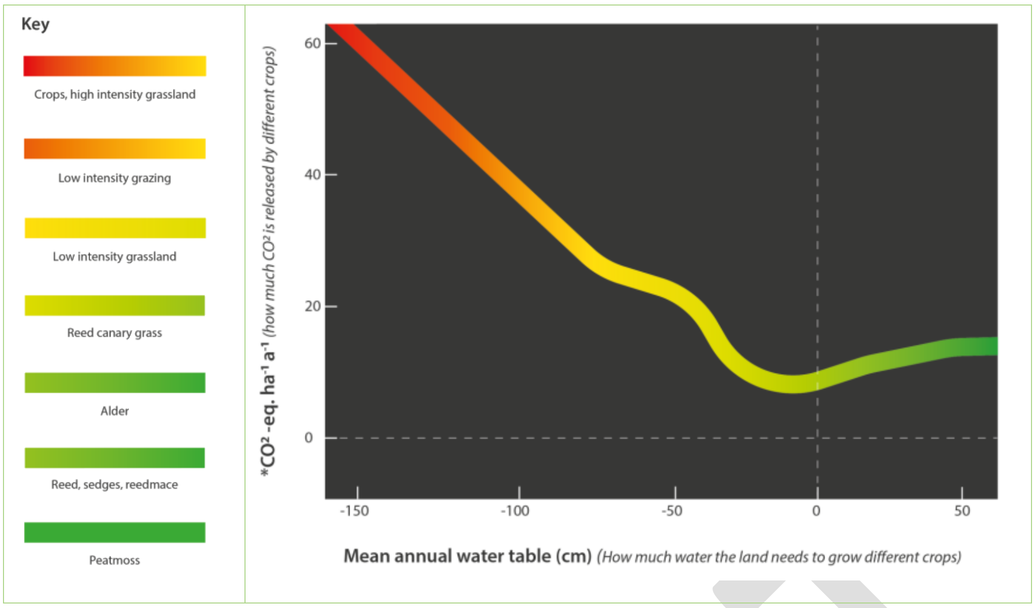


Figure 7: Relationship between CO_2 released from peatland crops, and amount of groundwater

Further research is needed to quantify the net effect of paludicrops cultivation (e.g. Phragmites, Typha, Salix, Phalaris, Sphagnum) on methane production and transport compared to flooded fields with little vegetation or easily degradable dryland/wetland plants (e.g. grasses, algae). However results indicate that converting well-drained and fertilized grasslands into paludiculture fields may result in a net reduction of some 20 t CO_2 -eq. ha^{-1} a^{-1} (Geurtz & Fritz eds. 2018).

Climate benefit of paludiculture - Common reed (*Phragmites australis*) cultivation

GHG emission reduction from re-wetting peatland:

15 t CO_2 eg ha^{-1} a^{-1}

With reed yield of 12 t DM ha^{-1} and a heating value of 17.5Mj kg DM^{-1}, one hectare of reed can replace fossil fuels in a co-generation plant that would otherwise emit:

15 t CO_2.

Total emission reduction from using reed biomass from paludiculture would avoid emission of:

~30 t CO_2 eq ha^{-1} a^{-1}

(after taking account off GHG emission from handling)

(Wichmann & Wichtmann, 2009, in Wichtmann et al, 2010)

Biodiversity benefits

Conversion of fen mires and fen meadows to drained and fertilised highly productive grasslands leads to a loss of habitat for many fen-typical plants and animal species (Joosten et al, in Bonn et al, 2017). Re-wetting drained peatland is on the whole beneficial for biodiversity conservation. An example of this is the conservation of the globally threatened Aquatic Warbler (*Acrocephalus paludicola*) in commercially-used 'reedlands' in Western-Poland (Wichtmann & Joosten, 2007).

Simply re-wetting peat soils, which have had their soils enriched with nutrients by agriculture land use and peat oxidation, can result in high productive, but species poor vegetation communities. Paludiculture activities, which both raise water tables and harvest the biomass, can help to remove the nutrients from the system. Paludicultures can also support wetland conservation sites and nature reserves, as cost effective management options for biomass removal (Wichtmann et al, 2010; Mills, 2015).

Different forms of paludiculture will have different affects on biodiversity, depending on vegetation structure and water management regime. For example, commercial bulk production of willow, reed or sedge as short rotation monoculture will be less beneficial for biodiversity (EUAid Wetland Energy, 2015; McBride et al, 2011).

Water regulation

Paludiculture can provide an improvement in regional landscape hydrology because water iwill be kept longer in the landscape (Wichtmann & Joosten, 2007). The transient water retention function of healthy fen peatlands reduces the magnitude of peak flood flows and can help reduce erosion caused by flooding (McBride et al, 2011). Paludiculture enables peatlands to retain this hydrological regulation function and, for example, safely absorb excess water without damaging their productive function. In this way, 'wetter' farmland can act as a buffer for extreme weather and contribute to climate change adaptation (Wichtmann et al, 2016).

In addition, paludiculture trials, for example with Cattail (Typha latifolia) in Canada, show that such crops can act as filters and extract excess nutrients or contaminants, helping to improve quality of both ground and surface water (Willis, 2018). The bio-filtration properties of wetlands is well known - over 1000 wetlands have been purpose constructed in the UK to mimic these functions, for example to treat road run-off, landfill leachate or domestic sewage treatment (Mc Bride et al, 2011). Plants most often used are Phragmites and Typha – both common paludiculture plants.

Economic valuation of ecosystem services

Placing a monetary value on the ecosystem services that wet or re-wetted peatlands provide would greatly and visibly enhance the economic benefit of paludiculture, however it is not an easy thing to do, especially to at the level of individual enterprises. A high-level assessment of environmental benefits by (Morris et al, 2010) suggests average benefits associated with ecosystem services from restored lowland peatlands (assumes peat-forming conditions under permanently high ground water levels and surface flooding, and excludes agriculture) range between £550 and £2,000/ha/yr, excluding the benefits of stored carbon. (Morris and Camino, 2011) have calculated values relating to individual ecosystem services provided by wetlands. The Results for inland wetlands were listed as water quality improvement (£292 – £436/ha/yr); surface and groundwater supply (£1 – £2/ha/yr), Flood control and storm buffering (£407 - £608/ha/yr), amenity and aesthetics (£227 – £339/ha/yr); and biodiversity (£304 - £454/ha/yr).

From a macroeconomic view, payments to farms that practice paludiculture and provide these wider beneficial services, are a comparatively low cost means of fulfilling UK and international commitments with respect to protecting climate, water and biodiversity (Wichtmann et al, 2010; Tannenberger and Wichtmann, 2011; Joosten et al, in Bonn et al, 2017).

Combining re-wetting of drained peatlands with biomass for bioenergy generation makes paludiculture an extraordinarily cost-effective climate change mitigation option that can bring in revenue from both carbon credits and biomass production (Tannenberger and Wichtmann, 2011; Joosten et al, in Bonn et al, 2017). A report by Natural England estimates that even using the lowest shadow carbon value, restoration of cultivated or agriculturally-improved deep peat generates net economic benefits of up to £19,000/ha after 40 years (Natural England, 2010, report NE257). Further research is needed, but it would be hoped that paludiculture would generate similar net economic benefits.

To maintain water levels required for conventional agriculture, water must be pumped out of the peatlands into the river systems through a system of pumping stations. In the Fens in East Anglia, there are 286 pumping stations with the combined capacity to pump 16,500 Olympic-size swimming pools in a 24-hour period (NFU, 2008). The average annual cost of maintaining and running just five pumping stations in the South Cumbria WLMB is estimated at over a £100,000 (Environment Agency, 2015). Costs of such pumping stations are likely to increase as land levels fall due to subsidence. Wetter ways of farming would reduce or remove the need to maintain such pumping stations (Willis, 2018).

Water quality regulation has a substantial economic value and improving the condition of peatlands is expected to improve water quality - which is why water companies in the UK are already spending money on peat restoration in their water catchments (Dickie et al, 2015).

Writing on the wall for drainage-based agriculture?

> "The current management of our lowland fen peats is already responsible for losing peat carbon faster than from any other kind of England's peat. Even without climate change, many areas will only retain a significant covering of peat for the next fifty years or so, before the soils begin to be influenced by the mineral material underneath and become wasted. Wasted peat has a lower agricultural value than deep fen peat but cost of pump drainage in these areas is likely to rise. The unabated use of our remaining deep fen peats for agriculture is therefore unlikely to be viable" Natural England report (NE257)

A report commission by Natural England (SAE03-02-325) assessed the restoration of lowland peatland in England, considering the impacts on food production and security (Morris et al 2010) within Wetland Vision 'target areas' (East Anglian Fens, The Humberhead Levels, The Somerset Moors and Levels, and the Lyth Valley in Cumbria). The report shows that under the current agricultural land use, farming on remaining deep peats in the Fens and Humberhead, is relatively profitable with net margins, of about £360 - £420/ha/year. In predominantly grassland areas of Somerset and the Lyth Valley, net margins of between £170 - 220/ha/year are achieved. However, the environmental costs, particularly associated with carbon released from arable peats and carbon emissions from farming systems result in overall negative returns from peatland farming. The combined agricultural and environmental effects of continuing agricultural production in the study areas gives an estimated net annual cost of between -£200 and -£500/ha/year (Morris et al, 2010). The estimates derived also indicate that conserving remaining peatlands could be most economically efficient compared to other farmed areas, followed by peat conservation with extensive (wet grassland) agricultural use (10% gross output of current intensive agri levels). In summary the report found that these target areas are currently productive and profitable, but that:

> "The environmental costs associated with greenhouse gas release from soils and agricultural activities are high and are likely to rise in line with increased future carbon prices. Furthermore, continued agricultural use will degrade their productive capacity, such that their comparative advantage in farming will decline. The restoration or conservation of peatlands can reduce the current environmental burdens associated with intensive use and potentially provide a range of other environmental services. The analysis here suggests that this could be achieved without a major impact on food security. Modification of the incentives and rewards so that peatland managers are encouraged to use peat soils as sustainably as possible would serve the overall public interest." (Morris et al, 2010)

Further research would be needed to see where the net margins of paludiculture would fit on the scale of the reported findings, but the data provides a useful indication of the costs and benefits of business-as-usual versus switching to wetter, more peat conserving ways of farming on lowland peatlands in the UK.

Paludiculture crops and markets

Paludiculture is at present a developing concept and market. As such there are a wide range of potential paludiculture crops, or "paludicrops"

DPPP - Database for Potential Paludiculture plants

The identification of crops suited to wet peatlands is essential for the successful implementation of paludiculture (Abel et al, 2013). A Database for Potential Paludiculture Plants (DPPP) has been developed by Susanne Abel based on her work at Greifswald University and the Michael Succow foundation (see Abel et al, 2013). It gives a global overview of conceivable paludiculture plants and their uses, helping to identify paludicrops for various habitats and climates. It is a continuously developing database and so far, has revealed approximately 300 plants with good or promising potential as paludiculture crops.

Researchers at the University of East London (Clough, J ,2019, personal comm.) have identified more than 70 plant species in the DPPP that are native to or have previously grown in the UK which have good or promising potential for paludiculture in the UK. Crop choice will be determined by a variety of factors including:

- Natural range of selected crop.
- Biological traits:
  a) Longevity of the crop species
  b) Plant capability to re-grow after cutting – i.e. woody or herbaceous which will affect the cropping rotation, machinery, biomass utilisation etc.
  c) Harvesting: timing (seasonality) and period duration (plasticity) – i.e. climatic conditions that might affect harvest, time of year needed for access
- Peat soil type – acidic/alkaline, nutrient rich/poor
- Likely water supply/potential for provision
- Machinery and infrastructure required for harvesting.
- Non-Market benefits: e.g. biodiversity, water quality, carbon removal, genetic resources etc.

Paludiculture crops for UK fen peatlands

This section gives special attention to paludiculture crops and markets for fen peatlands, although there is scope for crops and markets for lowland raised mires as well (see Table 5, Peat moss farming on lowland raised mire).

Crops that can be utilised for paludiculture fall into two categorises – wet meadows paludicultures (for fodder and grazing) - which emerge from permanent grassland just by raising the water level) and those for crop paludicultures, established by planting, seeding or adjusting the management to establish target vegetation (Wichtmann et al, 2016).

Clearly there is a need for new large-scale demonstration plots for many crops, to investigate their yields, carbon savings, harvesting requirements and financial viability. There are further considerations related to manufacturing products from wetland biomass, ranging from plant cultivation, harvest, biomass transport and storage to biomass processing and use. The growing demand for sustainable land use options will hopefully stimulate innovations in these fields (Abel et al, 2013).

There are several crops that could be grown immediately in the UK and four important examples are outlined below: Common Reed (*Phragmites australis*), Reed Canary Grass (*Phalaris arundinacea*), Cattails (*Typha spp.*) and European black alder (*Alnus glutinosa*). Through innovation and research, added value products may be developed by the processing of paludiculture crops. This is evidenced by the innovative use of *Typha* to create TyphaBoard and the potential for medical products to be isolated from wetland crops.

Paludiculture markets

The market wide research for many paludiculture species is still in its infancy; however, many of these UK suitable plants can be bought and sold on the internet and are readily available; furthermore there is evidence that many species are already used in markets. What is more wetland biomass can play an important role in the UK government's aim in de-carbonising the UK's economy through to 2050 (CCC, 2018).

Broadly, paludiculture crops can fit into the following categories:

					
Food such as blueberries, elderberry, water buffalo meat and dairy	**Fodder** in-situ and ex-situ for animal feed such as sedges, rushes	**Medicines & supplements** traditional remedies & resource for new compounds	**Raw materials** for processing – such as reed, typha, willow and alder	**Energy** such as pellets, biogas, direct combustion; biomass for biodigestion	**Agricultural conditioners** e.g. growing media *lowland raised mires

Food crops - for people

The UK food and drink industry has an annual turnover of £97.3bn and contributes 28.8bn to the UK economy (FDF, 2018). There are currently few out and out food crops identified in the DPPP database that have been trialled in the UK previously – making this a key area for research and innovations from scientists, food producers and farmers. Future food crops suitable but awaiting trials in UK on fen peatlands include:

- Salad crops: such as Celery (*Apium graveolens*), Watercress (*Nasturtium officinale*), Water mint (*Mentha aquatica*).
- Botanical: such as Angelica (*Angelica archangelica*) and Juniper (*Juniperus communis*)

Promising food crops not native to the UK have obvious food potential but need trials to ascertain ideal methods for peat preservation:

- Asian rice (*Oryza sativa*)
- Wild rice (*Zizania aquatica*)

Fodder crops – food for animals (hay, silage)

Maintaining wet meadows to produce fodder for ruminants, either by grazing or as hay and silage is certainly justified in being a paludiculture. The animal feed industry is worth about 4.4bn to the UK economy (AHDB, 2018); approximately 20% of the feed materials used in the UK are imported from outside the EU. Large quantities of aboveground biomass can be produced for animal feed on wet peatlands; crops suited to fodder paludicultures in the UK may include:

- Velvet bent (*Agrostis gigantea*)
- Creeping bent (*Agrostis stolonifera*)
- Giant manna grass (*Glyceria maxima*)
- Sweet manna grass (*Glyceria fluitans*)
- Reed Canary Grass (*Phalaris arundinaceae*)
- Marsh foxtail (*Alopecurus geniculatus*)

Grazing animals will also provide food directly as meat or milk products. Maintaining appropriate stocking densities will be essential to achieve a balance between peat preservation and grazing pressures. Grazing animals that may be suitable include Water Buffalo (*Bubalus arnee*) and Highland Cattle. Water Buffalo are hardy and are suitable for wet waterlogged sites. They are ideal for extensive grazing as they can get to vegetation that would be difficult to remove with machinery and will eat almost any riparian vegetation. They also have the benefit of keeping the wet landscape open and also provide high end products such as meat and dairy products as well as leather. In the UK for example, Mozzarella and burrata are already being produced at Laverstoke Park from buffalo milk.

Economic data on water buffalo utilisation from a farm at Gut Darß in Germany (see Wichtmann et al, 2016) suggests that water buffalo rearing has the potential to be economically feasible. The direct marketing yields per bull ranged from 3,797 – 5,298 euro (Sweers et al, 2014). Thorough market research is required as expected prices vary with regional purchasing power.

Figure 8: Water buffaloes graze on a wet meadow in the Henzeried in the valley of the Wetschaft near Roda in Germany. ©Maseltov. Creative Commons. Attribution-Share Alike 4.0 International license

Medicines and supplements

The UK pharmaceutical industry brings in around £3bn in trade surpluses each year (BPS, 2018). Supplements have a market value of £414 million (in 2015) and are set to increase with values expected at £439 - 475 million by 2021 (HFMA, 2018). There are several paludiculture products that have been used in the medical and supplement market to date that could potentially feed into this. Many are used in traditional remedies, however, they may offer an important resource from which new compounds and medicines can be created.For example, phenolic compounds (found in the cell wall of Sphagnum Mosses) are known for inhibiting growth of several bacterial species of biomedical interest; other paludiculture plants native to the UK that may be cultivated are found below in Table 4(taken from Wichtmann et al., 2016)

Latin Name	Common name	Plant parts used	Area of application
Angelica archangelica	Garden Angelica	Seed, Root, Fruit	Gastrointestinal illness, bronchitis
Drosera rotundifolia	Round-leaved Sundew	Leaves, Stem	Bronchitis, asthma
Filipendula ulmaria	Meadowsweet	Leaves, Fruit, Root	Fever, Headache, Gastrointestinal illness
Frangula alnus	Alder Buckthorn	Bark	Laxative
Lycopus europaeus	Gypsywort	Leaves, Stem	Hyperthyroidism, nervousness, tachycardia
Menyanthes trifoliata	Bogbean	Leaves	Rheumatism, arthritis, digestive issues, loss of appetite, fever
Oenanthe aquatica	Water Dropwort	Fruit	Cough, Digestive issues, Gastrointestinal illness

Table 4: Potential medicinal plants for paludicuture in the U.K

Raw materials

A range of crops can generate raw material for direct use or further processing for products in the bio-economy sector. Products from raw materials include:

- Wood for building and furniture, Mouldings, Paper , Thatch, Baskets, Construction/insulation.

Crops that may be useful are:

- Common Reed (*Phragmites australis*)
- Bulrush / Reedmace (*Typha latifolia*)
- Black Alder (*Alnus glutinosa*)
- Willow species (*Salix spp.*)

In the UK, the most developed of these crops is Common Reed (*Phragmites australis*) which can be used for thatch, fodder, fire resistant boards or insulation plaster or fuel. Yields of common reed are typically 6.5 – 23.8 t DM ha^{-1} $year^{-1}$. Monte Carlo price analysis suggests a broad range of profitability (in euros) per ha per year: -162 to +1542 for reed bundles, -287 to +677 for bales for combustion, -1036 to +179 for biogas (taken from (Wichtmann et al, 2016).

Currently the UK is a net importer of reed for thatching, importing 80% from Europe to meet UK market demand (demand is 0.2 - 0.4m bundles a year).

Meeting demand in the UK could be worth 400,000 to 500,000 euro per year (assuming bundle price of 2 - 2.5 euro) (Wichmann and Koebling, 2015).

Figure 9: There is growing demand for thatching reed in the UK ©Joseph Mischyshyn Creative Commons.

Figure 10: Insulating board 'Typha board' made from reedmace ©Tyhpa Technik

Bulrush / Reedmace (*Typha latifolia*) is also a promising species. This plant has fantastic thermal insulation values and can be refined into hollow wall insulation or insulation board (Fraunhofer, 2019).

Black Alder (*Alnus glutinosa*) can also be cultivated on wet peat, and can provide useful timber for further processing – most profitably in the joinery industry.

Biomass energy generation

The amount of bioenergy used in the UK has more than doubled over the last ten years (Figure 11) and it now provides around 7% of total primary energy demand.

This increase in bioenergy has been driven by Government policies which have incentivised the use of bioenergy across a range of sectors since 2009:

The Renewable Transport Fuel Obligation (RTFO),

The Renewables Obligation (RO) and subsequently the Contracts for Difference (CfD) scheme,

The Renewable Heat Incentive (RHI)).

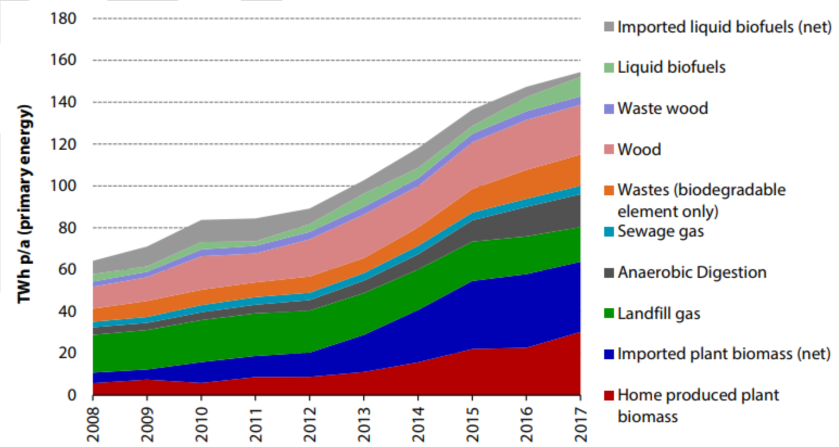


Figure 11: Bioenergy supply to the UK from 2008-2017 (CCC, 2018) The 'plant biomass' category includes straw, energy crops, short rotation forestry, other lant based biomass and wood pellets.

Net imports have increased more than threefold between 2008 and 2017, driven by wood pellet imports from North America for use in Drax power plant. This means the UK now imports over one-quarter of its bioenergy feedstocks. A recent report by the UK Committee on Climate Change recommended increasing the supply of sustainable harvested biomass from UK sources, including introducing policies to increase planting of perennial energy crops on lower-grade agricultural lands where this can contribute to increasing soil carbon and deliver other ecosystem benefits (CCC, 2018).

The use of above ground biomass for bioenergy is one of the more advanced areas of paludiculture at present, and paludiculture products can substitute fossil raw materials as perennial energy crops:

- Directly combusted as bales
- Processed further into Briquettes or pellets
- Anaerobically digested
- Bioethanol
- Biogas from fresh or ensilaged biomass

Crops that may be useful are:

- Sedge species: *Carex acuta, Carex aquatalis, Carex riparia, Carex rostrate* and *Cladium mariscus*
- Rush species: *Juncus effusus*
- Grass species; Common reed (*Phragmites australis*) and Reed Canary Grass (*Phalaris arundinacea*)
- Wet woodland made up of Birch species (*Betula pendula*). Willow species (*Salix spp.*) and Alder species (*Alnus spp.*)

Combustion characteristics of common reed (*Phragmites australis*) biomass harvested in winter, for example,show that it can economically compete with energy crops from mineral soils, even when special machinery for harvesting is required (Wichtmanm Wichmann and Tanneberger, 2010), (Joosten et al, 2016), (Schröder, CCC (2018) in (Geurts & Fritz, 2018).

Crop yields can vary. For example yields of biomass for combustion can range from 1 – 22.1 tonnes dry mass Ha^{-1} Yr^{-1}; figures for general fen biomass typically range from 1 – 2.6 tonnes dry mass Ha^{-1} Yr^{-1}. The DECC funded report on Wetland Conservation Biomass to Bioenergy by (Mills, 2016) provides more in depth figures for biomass for combustion yields in the UK (Somerset, Devon, Suffolk).

Significant, changes to renewable energy policy instruments in the UK may impact on the bioenergy sector. Multiple policy changes have created much uncertainty and have reduced the attractiveness of the UK for renewable energy investors (according to International Energy Agency, United Kingdom renewable energy policy framework summary).

Type of crop	Utilisation	Likely yield (t ha^{-1} dry matter year^{-1})	UK market prospect	Quantified use values if any?	Benefits	Reference
Common Reed (*Phragmites australis*)	Fodder: Mowing, fodder, litter, compost, pellets Material: Thatch material, paper (cellulose), chemical processing, construction materials Energy: Reed briquettes or pellets for fuel and biomass.	3.6 -43.5	UK currently imports up to 75% of its reed for thatching from Europe. (Demand is 0.2-0.4m bundles a year). Meeting UK demand could be worth 400,000 to 500,000 euro per year	Euro -1000 to +1500 ha^{-1}yr^{-1} (harvesting for thatch most profitable (Wichmann, 2017)	Highly productive and, under wet conditions Important peat-forming species. Water purification potential (Phosphates and nitrates removal). Avoided C losses. Biodiversity support.	Köbbing et al 2013/14 Steffenhagen et al. 2008 Schulz et al. 2011 Timmermann 2009 Wendelin Wichtmann, 1999 Kask, 2007
Cattail / Common Reedmace (*Typha spp.*)	Material: Raw material for insulating materials, light weight construction boards	4.8 – 22.1	Currently being developed as highly durable insulation board material	Data surrounding the commercial aspect of Typha boards is pending – patents have been filed.	Highly productive on nutrient-rich sites. Leaves have very low thermal conductivity. Resistant to fungal and insect infestation. Water purification potential (Phosphates and nitrates removal). Avoided C losses. Biodiversity support	Timmermann 2003; Wichtmann & Joosten, 2007 Steffenhagen et al. 2008 Schulz et al. 2011 Pratt et al.1984
Reed canary grass (*Phalaris arundinacea*)	Fodder Energy: biogas, direct combustion, pellets	3.5 – 22.5			Can grow where insufficient water is available for complete re-wetting. Winter and summer harvested biomass can be utilized. Biodiversity support, Nutrient load reduction, Avoided C losses.	Wichtmann & Joosten 2007 Schulz et al. 2011 Wichtmann et al. 2013
European black alder (*Alnus glutinosa*):	Material: Timber for furniture, construction materials Energy: biogas, biomass for direct combustion (e.g. as woodchips)	On long rotation (60 yrs) average yields est. 424 m^3 per ha. On a 20 - 40 yr cycle est. 10m^3 per ha	(Tillhill, 2017) UK mixed age forest – suggests avg values of £7,000 per ha (from an Investor point of view not crop)	Can be sold by lumbermills for £530 per m^3 (Sawmills, 2018) Avg saw log price of £43.35 per m3. (Forestry Commission, 2017)	Suited to nutrient rich fen peat soils. With correct water levels (just below the surface (c.10cm)) alder woodland can sequester 1186kg CO^2 equivalent /ha/yr Biodiversity support. Nutrient load reduction.	Wichtmann, Joosten and Schröder, 2016; Wichtmann & Joosten 2007 Schulz et al. 2011; Wichtmann et al. 2013

Note on yields: Yields will vary significantly depending on nutrient status of water, weather, time of harvest etc. and the vegetation on each site will be site specific. As such the following figures should only be used as a guide and indication of what a habitat type may produce (figures taken from Mills, 2016).

Peat moss (*Sphagnum spp.*) farming on lowland raised mire

Long term harvest:

Rotation harvesting on longer time scales (2 - 3 years?) – method to be established. Yields of 5 - 6.5 Tonnes (dry matter) per hectare (*S.palustre* and *S.papillosum*)

Ecosystem services:

Avoided C losses, biodiversity, spin off products.

Sustainability:

Can reduce nutrient flows

Key product:

Sphagnum moss can be processed for growing media, for medical applications or used as raw material for reptile and snake trade, orchid growing etc.

Move from wild harvest

To efficient cultivation

Sphagnum farming has successfully been tested on rewetted bogs that had been drained and used as grassland and on bogs after peat extraction. Species tested include: *Sphagnum palustre*, *S. papillosum* and *S. fallax. S. palustre* seems to be the most promising as it establishes quickly, and has high productivity.

Agricultural conditioner

S. palustre in particular is suitable for providing a renewable alternative to fossil peat in horticultural growing media. Fresh peat moss biomass has similar properties as slightly humified Sphagnum peat ('moss peat') and allows for plant cultivation without a loss of quality.

Raw material

Orchid trade is worth a staggering 505 million USD annually in global exports and imports. The Netherlands is the worlds largest exporter at nearly 40%. New Zealand moss 'harvest' is worth $5.1 million NZD annually (2.5 million GBP) the majority of this goes to Japan for Orchids.

Medicine

Sphagnum has antibacterial properties due to an active compound called sphagnan. Historically in WW1 dried sphagnum moss was used as the 'first field dressing' by soldiers which both absorbed blood and stopped infection.

Recent research shows it to be effective in inhibiting growth of several bacterial species of biomedical interest such as *Campylobacter jejuni* , *Escherichia coli O157:H7*, *Listeria monocytogenes* , and *Salmonella enterica*, *S. epidermidis*, *S. aereus*, *K. pneumoniae* as well as respiratory pathogens. There is a large untapped potential here.

Table 5: Peat moss (Sphagnum spp.) farming on lowland raised mire

Case studies

Greifswald University (Germany) is the leading centre for the development of scientific methods of paludiculture. These methods have been successfully applied in several countries. Experiences from long-term paludiculture are mostly lacking, but there is a growing body of good practice examples ranging from the use of wetland biomass for energy heat production (Belarus, Germany, Ukraine/Romania) for water purification (Sweden, Spain, Italy, Canada) , to using wetland biomass for construction materials (Denmark, Poland).

Case study: Pioneering Fen biomass heating plant in Malchin, Germany

A pioneering heating plant powered by biomass from wet meadows, is providing heat to more than 500 households, and several public buildings in the German city of Malchin.

Figure 12: From fen biomass cultivation to household heating in Malchin. Images © Greifswald Mire Centre (2017)

Set up in 2014, the plant produces ~4000 MWH heat every year from hay produced from Common Reed, Reed canary grass, and Sedges, harvested in summer with adapted grassland machinery from re-wetted fen peatlands at lake Kummerow, in the federal state of Mecklenburg-Vorpommer. By substituting natural gas, the use of the biomass mitigates about 1000 t of CO_2 annually. Additionally, the utilisation of biomass from landscape management sustains the agricultural use of 300 ha of re-wetted peatland.

The city of Malchin is situated at the western end of the Peene valley in NE Germany. With 17,810 ha of peatlands, the Peene valley is one of largest fen areas in Germany. The fens had been drained for agriculture, but large areas were re-wetted during the 1990s. The re-wetting created an outstanding nature conservation area; however local farmers had to find alternative ways to use the changing vegetation, which was no longer as suitable for cattle fodder.

The project, to integrate an adapted biomass boiler powered by wet fen vegetation into the existing heating grid (and replace a natural gas fired boiler) was made possible through a network of local stakeholders – biomass producers, plant operators, local energy suppliers, consumers (households of Malchin, a kindergarten, schools, and office buildings) and research scientists – spearheaded by local farmer Hans Voigt together with the University of Greifswald.

The biomass heating plant Malchin combines peatland protection, sustainable energy provision, landscape protection and new perspectives for local added value:

- Bioenergy substitution of natural gas saves greenhouse gas emissions, approximately 850 t CO_2 -eq. per year.
- Climate protection avoiding greenhouse gas emissions compared to drained peatlands (approx. 10 t CO_2-eq. per hectare).
- Water protection avoiding nutrient discharge and eutrophication compared to drained peatlands.
- Biodiversity maintaining and creating habitats of rare species.
- Tourism maintaining a diverse, open landscape.

Biomass harvest **Vegetation: Reed canary grass and sedges** **Area: ca. 300 ha fen meadows** Harvest time: June – September Biomass yield: about 800 – 1,200 t fuel (4,200 – 6,500 bales) Energy yield: 14.9 GJ per t FM (w 15 %), equalling 350,000 l heating oil	**Boiler:** Type: Lin-Ka HE 800, modified Rated power: 800 kW Heat production: >4,000 MWh per year Fuel demand: 1,200 t Investment costs: 640,000 € State subsidy: 182,000 € (EU-EFRE) Construction time: 6 months
Greenhouse gas emission savings **Bioenergy: 850 t CO2-eq./a** **Rewetting: appr. 10 t CO2-eq. /ha*a**	

Case study: Reaping multiple benefits: Cattail for bioenergy and nutrient recovery in Manitoba, Canada

The Netley–Libau Nutrient-Bioenergy project in Manitoba, Canada demonstrates that linking lake nutrient management with bioenergy production is an opportunity that can create economic benefits, produce environmentally-friendly products while also restoring wetlands (Grosshans et al.2011)

The problems: Lake Winnipeg in Canada is the 10th largest freshwater lake in the world and an integral part of Manitoba's economy, recreation and culture. However, Lake Winnipeg has also become one the most eutrophic large lakes in the world due to the inflow of nutrients, mainly phosphorus, from its surrounding watershed (Grosshans et al.2011b).

Cattail solution: The IISD, the University of Manitoba and Ducks Unlimited Canada have collaborated on a major research study since 2006 at Netley–Libau Marsh to decrease the nutrient loading to Lake Winnipeg utilising the different potential functions of Cattail (*Typha spp*.), which also opens up opportunities for innovations regarding bioenergy. The study demonstrated the impressive ability of *Typha spp*. (hereafter *Typha)* to intercept and store nutrients as well as produce large amounts of biomass for bioenergy each growing season.

The benefits: The *Typha* harvesting approach used at Netley–Libau Marsh has multiple benefits, both for the ecosystems and economies within the Lake Winnipeg Basin. Cattail effectively removes nutrients (nitrogen and phosphorus) that cause eutrophication in aquatic systems by absorbing these nutrients as they grow (Joosten et al, 2016). The nutrient-laden *Typha* are then harvested which removes the nutrients permanently from the marsh ecosystem - decreasing nutrient loading and the effects of eutrophication.

The harvested biomass (calculated yield = 13 t ha^{-1}) is used for bioenergy production - compressed fuel products (i.e. pellets and cubes) - which supplies a new bioenergy source for the Manitoban bioeconomy. Combustion trials show *Typha* provides comparable energy to commercial wood pellets: *Typha* showed a gross calorific value of 17-20 MJ kg^{-1} DM, compared to 17 MJ kg^{-1} for commercial wood pellets. The burning of *Typha* also produces nutrient-rich ash that can later be used for fertilizer. Phosphorus is a scarce and important natural resource that is crucial to global food security.

Figure 13: Typha power: From biomass harvest to bioenergy production with Typha harvested from the shores of Lake Winnepeg. Photos © Michelle Paetkau and Richard Grosshans

Carbon credits: The burning of *Typha* biomass results in fewer green house gas emissions than coal and other fossil fuels. *Typha* bioenergy can also generate profitable carbon credits to be sold as offsets on the carbon market. One tonne of *Typha* biomass used to displace coal for heat production would generate 1.05 t of CO_2 offsets (Grosshans et al. 2011b)

Habitat improvement: The *Typha* harvesting has other knock on biodiversity benefits, through the removal of the dense accumulation of dead plants, which opens the marsh to sunlight, spurring new plant growth and renewing wildlife habitat. Although the current research in Manitoba focusses on naturally occurring stands of *Typha*, cost effective means for establishing plants on larger scales are available (Grosshans R. in Wichtmann et al. 2016). The Netley–Libau Nutrient-Bioenergy project demonstrates that plants like *Typha*, with multiple environmental and economic benefits can be a key driver for a regional bioeconomy – and create incentives for wetland restoration.

Case study: Paludiculture and the UK.

Experiences from long-term paludiculture are missing in Europe, and paludiculture is still in its infancy in the UK. The following outlines some agriculture-orientated trials in the UK in the Somerset Levels and Moors and East Anglia.

Energy for Nature – turning conservation biomass to bioenergy in the Somerset Levels and Moors (*taken from Mills et al (2015) Defra PES Pilot: Round 3 Energy for Nature, Final Report)*

Figure 14: Wet grassland on the Somerset Levels

The RSPB manages over 150,000 ha of land for the benefit of wildlife, including habitats of national and international importance, which require continuous management interventions to maintain or restore these habitats. Managing areas for nature conservation is challenging in many ways, but particularly so from a biomass disposal and resourcing perspective; finding new ways to managing large areas efficiently and effectively is high on the agenda.

The RSPB recently looked at the Payment for Ecosystems Services approach for managing areas for nature conservation. This resulted in their 'Energy for Nature' project which looked at opportunities for a 'PES-like' approach to wetland management on the area of the Somerset Levels and Moors by converting conservation biomass from the wetlands, to bioenergy.

Although the 'Energy For Nature' project was not set up strictly as a 'paludiculture pilot', the project vision encompasses all the elements crucial for paludiculture - developing an adaptable model for managing wetland that links biomass producers, through intermediaries and markets, to the buyers of their bioenergy products. In doing so, the aim is to create a sustainable funding stream that provides a reliable, and ecologically sustainable, source of bioenergy to local communities using biomass from wetlands, whilst supporting the continuation of essential conservation work.

Figure 15: Wetland biomass harvesters being tested

The production of bioenergy from conservation biomass and the sale of bioenergy products locally could contribute to the resilience of rural communities to climate change, reducing their dependence on traditional fossil fuels for heat and power, and also deliver wider environmental benefits in relation to carbon, as well as enhancing habitats for biodiversity.

Energy for Nature potentially provides a dual solution to the challenges of biomass removal and funding faced by land managers. Within just the study area for the RSPB, it was estimated the conversion of vegetation, which costs c. £70,000 per year to harvest and remove, into bioenergy products could produce wholesale loose biomass worth £150,000, or over £5 million if converted into biochar and sold retail.

Figure 16: Converting rush into briquettes for bioenergy

Two models (Land Manager and Community) were developed which make Energy for Nature schemes accessible to a wider range of stakeholders within a landscape. A Conservation Biomass Calculator has also been developed - an electronic tool designed to help land managers explore the potential of converting their biomass into bioenergy.

A range of challenges were identified in developing such a scheme, from variability in the quantity and quality in the supply of feedstock, initial infrastructure investments costs, to the length of contracts between sellers and processors, and transaction costs. One important potential barrier to scheme success for a combustion set-up is that the burning of wetland biomass products is not yet approved for the Renewable Heat Incentive (RHI) scheme. Further research is also needed to quantify the additional ecosystem services delivered and how these change through habitat creation, restoration and management.

The Great Fen project, East Anglia

(*Taken from Carver (2017) The Great Fen A lowland peatland restoration)*

The Fens were once England's greatest wetlands, a huge natural fenland landscape in East Anglia made up of a mosaic of bogs, fens and wet woodland. Drained and farmed intensively, over 99% East Anglian wetland habitat has been lost, with just remnants of natural and semi natural fen surviving within intensively cultivated arable land. The Great Fen project was the first of the Wildlife Trust movements' Living Landscapes, working to create a new wetland landscape of 3,700 ha to surround and connect two National Nature Reserves, Woodwalton Fen and Holme Fen.

The project has multiple aims with the focus on achieving a sustainable landscape for wildlife and people. The masterplan aims to restore natural wetland and low-intensity farming, while protecting and enhancing natural environments; creating accessible environments for education and recreation; developing the local economy; and contributing to climate change adaptation and mitigation.

Figure 17: Reed beds in the Great Fen

Peats up to 4 m deep are being removed from intensive agricultural production, sown with grass and where possible the ground water table raised. Land forming has taken place to create new pools and conditions for reedbed colonization. The Great Fen is seeking solutions to water quality issues, and also recognizes the need to continue farming on deep peats on which pump drainage is increasingly unsustainable.

Figure 18: Testing the economic viability of paludi-crops in the Great Fen

The masterplan's economic aim, to contribute to the diversification and development of the local economy, includes the testing of new methods of wetland agriculture.
Working with the University of East London the project is trailing paludiculture, exploring biomass crops, such as *Glyceria fluitans,* and novel uses, to see whether it is possible to create a paludicultural system which is economically viable, offers ecosystem service benefits (such as clean water & nutrient removal) and can be applied across the region and on other wetland creation projects.
www.greatfen.org.uk; www.greatfen.org.uk/great-fen-masterplan

Economics

Paludiculture has to be economically feasible if it is to become an alternative land management methodology to agriculture on drained lowland peatlands. Revenue from paludiculture is generated through use and sale of biomass, but could also potentially come from the provision of other services (e.g. agri-climate and agri-environmental funding programmes, water abstraction charges and carbon credits) and premiums, such as direct payments, or support for organic farming (Wichtmann et al, 2016).

Paludiculture is a comparatively new phenomenon, so there is relatively little information available about the economic aspects of paludiculture – the majority of data is based on experience in Germany.

Economic feasibility

Experience in Germany indicates that cultivating wetland plants, particularly as a bioenergy source and building or insulation material, is both feasible and practical (Wichtmann and Schäfer, 2007; Wichtmann and Tanneberger, 2011).

Research by peatland expert Sabine Wichmann (Wichmann, 2017) from the Greifswald Mire Centre shows that reed biomass cultivation is the most economically feasible for paludiculture currently. Harvesting reed biomass for roof thatching is the most profitable, and also the most established option (Table 5) – and the current international market for thatching reed has stimulated development of specialised machinery (Wichmann, 2017).

Winter mowing of reeds to make bales for direct combustion is a promising option for wider application, since harvesting sites that would not meet the quality demand of thatching reed could be used, and profitability is also likely to grow, given the continuing rise in the price of fossil fuels (Wichtmann & Schäfer, 2007).

Reed harvest type	**Revenue**	
Harvesting chaff for biogas production	€ −195 ha^{-1}	Not profitable
Harvesting bales for combustion	€ 53 ha^{-1}	Covers costs
Harvesting bundles for thatching	€ 572 ha^{-1}	Profitable

Table 6: Revenues of different types of reed (Phragmites) harvest. From (Wichmann, 2017)

Other experience outside of the UK show that high quality end products, such as water buffaloes grazed on wet/re-wetted fens, have also shown to be economically successful (Grootjans, Ab P, 2017).

There have been few studies assessing the economic feasibility of paludiculture land use in the UK. The RSPB's 'Energy for Nature' project, which looked at opportunities for a 'PES-like' approach to wetland management on the area of the Somerset Levels and Moors by converting conservation biomass from the wetlands to bioenergy, found that it could be profitable – but also that profit margins will be greatly influenced by the volumes and types of biomass, and bioenergy production processes used (Energy for Nature, Mills et al, 2015).

Compared to the current agricultural uses of peatland soils, paludiculture has a lower land use intensity, lower crop management, lower harvest frequency, less crop rotation and less crop establishment. So the costs of running a paludiculture business may be lower in these aspects. However harvesting costs are likely to be higher than conventional harvesting – harvesting machinery for paludiculture has to be adapted to work on peat soils with a low bearing capacity, whilst limiting damage to the ground. The acquisition and operation costs of this harvesting machinery is difficult to calculate as the majority of machinery used so far has largely been designed as a bespoke solution.

A range of other challenges have been identified which will influence the economic feasibility and competitiveness of paludiculture enterprises. These include processing technology and logistics, market demand and acceptance, legal restrictions, access to agricultural subsidies, or payments for external benefits they could provide, as well as the opportunity costs of current farming activities. As such, legal and policy regulations will have a major influence on profitability and feasibility (Wichmann, 2017; Wichtmann and Schäfer, 2007). Paludicultures are likely to become more competitive with increasing energy prices, higher future carbon prices (as predicted by DECC) and technical progress in processing biomass (Kuhlman et al, 2013; Morris et al, 2010).

Research does show that re-wetting of peatlands is a very cost-effective way of climate change mitigation; the costs to reduce CO2 emission by re-wetting peatlands (without further agricultural use) are 2-3 times lower than for hydro- and wind-power generation, and 20-25 times lower than, for instance, maize-based biogas production (Grootjans, Ab P (2017; Schäfer, 2011)

There is not one single answer to whether paludiculture is profitable or not: it will often be crop, site and market-specific. The establishment costs of paludiculture, aside from site conditions, also depend on scale, lifetime, available (water) infrastructure, and the purpose of paludiculture in each specific case (Geurtz and Fritz (eds), 2018)

Overall – with the information available in the literature at present, paludicultures may not be economically viable in strict farming terms if viability is based on sales revenues alone. It is currently difficult to assess the economic viability of paludiculture against drainage-based agricultural use, as these are supported by subsidies, which distort the market prices of agricultural products (Grootjans, Ab P, 2017).

Instruments to pay for the public goods that are generated through the implementation of paludiculture are needed to increase the financial viability at present.

Economic incentives

Incentives which combine re-wetting or restoration with continued production could, in comparison to re-wetting without subsequent paludiculture, result in considerably higher value creation and acceptance as well (Tannenberger and Wichtmann, 2011).

UK Agricultural Policy & agri-environment measures

The regulatory framework of the UK's current agriculture policy, based on the EU Common Agricultural Policy (CAP), could potentially be suited to provide top-down financial incentives to shift to wetter ways of farming (subsidies and direct payments greatly influence farmer's business decisions). The subsidies and agri- environment schemes, would need to be refined to support paludiculture activities, and are not without shortcomings at present (Wichmann, 2018).

Other potential economic incentives include Carbon Offset funds, the government's Shadow Price for Carbon (as matched funding for a paludiculture project) and public or privately financed payment for ecosystem service schemes. Current examples, primarily for upland peatlands, include voluntary carbon markets (UK Peatland Code) for climate protection or water companies financing peatland restoration in their catchment areas (United Utilities 'ScaMP', South West Water 'Upstream thinking', Pumlumon Project in Wales) for flood control and water quality.

Brexit – challenge or opportunity?

The EU framework for UK land management funding and policy has had a major impact on our peatlands since the 1970s, but the UK will have to leave the EU Common Agricultural Policy (CAP) under any Brexit scenario, and the body of EU regulation which forms the CAP will become 'retained EU law' on Exit Day.

Brexit is both an opportunity and a challenge for paludiculture. It is a challenge for future peatland projects, which may be cut off from EU Environment LIFE funds that have supported peatland conservation activity, and also for peatland farmers dependent on income through CAP based direct payments (subsidies) and rural development payments; these funds currently make up to around 50 - 60% of UK farm income and are a mainstay support for peatlands management. There may also not be the political will to support novel/uncertain schemes, such as paludiculture, in the short term.

However, Brexit also brings opportunity: freedom to radically reshape domestic agricultural policy, to push for policies that support sustainable production on lowland peatlands and change incentives under payment and policy regimes which currently maintain income for farmers who are active in drainage-based agriculture, that cause harm to peatlands. Post-Brexit, instead of predominantly area-based payments (e.g. under Pillar 1) funding could be more related to payments of public benefits and include incentives to encourage a transition from conventional drainage-based agriculture to wetter farming (Wichmann, 2018). The scale of potential change in UK agricultural policy has been compared to the *Agriculture Act 1947* which sought to increase food production after the Second World War (Emma Downing, 2018).

Challenges of paludiculture - addressing barriers and risks

Paludiculture presents a promising, inclusive solution to the question of sustainable production on lowland peatlands (Wichtmann, Schroeder and Joosten, eds., 2016). Numerous management options for this 'wetter farming' on fen peatlands have been trialled outside of the UK to produce pulp and paper, building materials and energy with plant species such as common reed (*Phragmites australis*), sedges (*Carex spp.*) and reed canary grass (*Phalaris arundinacea*). The trials have demonstrated these as marketable and sustainable, wetland biomass resources (Abel et al, 2013; Wichtmann and Couwenberg, 2013). Moreover, wetland biomass harvesting would not only bring climate change mitigation benefits but also align well with the provision of other ecosystem services provided by fen peatlands such as water and nutrient regulation, and nature conservation (Wichtmann, Schroeder and Joosten (eds., 2016). Why then, in spite of these advantages compared to conventional land use, has paludiculture has not yet been implemented in the lowland peatlands of the UK? The following key challenges to the implementation of paludiculture and proposed solutions capture the results of multi-stakeholder discussions at the Paludiculture UK 2017 conference (Natural England, 2018) .

(a) Lack of policy, legal framework and funding support

A change to paludiculture at the scale needed implies a paradigm shift in land management, however the agricultural policy and legal framework to support such a transition is lacking in the UK.

1. There is uncertainty about the status of wetland adapted plants as agricultural crops, paludiculture is not recognised as a form of agricultural production and paludiculture land is not classified as as agricultural land in policy; therefore, biomass cultivation on wet or re-wetted peatlands is not included in agricultural subsidy schemes.
2. Current agricultural legislation maintain income, through subsidies, for farmers who use drainage-based agriculture, artificially increasing the profitability of this and offering little incentive to change.
3. There is an apparent lack of policy coherence and consistency across different departments. For paludiculture to become the norm not the exception, it requires existing land use and other policies to be joined up and work together for the common good.
4. Paludiculture implies a major change in operational management, and substantial investment in adapted machinery so that a change to paludiculture is virtually irreversible on the individual farm level. There is lack of confidence in long term support of paludiculture.
5. The legal and policy framework currently does not adequately assess or account for the provision of multiple peatland ecosystem services - or have penalties for disservices.
6. Current water management systems are not favourable for paludiculture and primarily still reflect the need of farming that depends on drained landscapes. Also, it is extremely difficult to sufficiently re-wet single plots surrounded by fields that continue to be drained, so paludiculture would potentially require water levels altered for an entire catchment area.
7. Uncertain financial flows. Paludiculture is currently a relatively unknown, niche market in the UK; funding is needed to establish paludiculture and markets for paludiculture products, but it will be hard to drawn down funding or investment until paludiculture activities exist which show that it is economically viable.

Paludiculture is explicitly mentioned as a sustainable land use option in several global initiatives as well as in the IUCN UK Peatland Programme's UK Peatland Strategy 2018-2040. However, the UK is yet to adopt the initiative into national policy, and there is no explicit mention of wetter farming or reference to Paludiculture in the UK Government 25-year Environment Plan.

Solutions:

The legal, policy and funding framework in the UK successor to the Common Agricultural Policy must be adapted to create effective incentives for a change to enable sustainable and profitable use of wetland biomass.

1. Change agriculture legislation so that paludiculture is recognised as being production of agricultural products on agricultural land - to ensure general eligibility of wetland adapted crops. This needs to be

accompanied by clear policy signals from government in support of paludiculture in policy statements, associated parliamentary bills and documents.

2. Phase out support of counter-productive subsidies for agriculture on drained peatlands, so it is no longer profitable; if that is not possible at least remove market distortions.

3. Establish longer term (15 - 20 year) AES schemes, to convince farmers of continuity of support and provide planning security.

4. Support for paludiculture needs to provide real incentives, increasing income and reducing financial risks for all steps of paludiculture implementation. Build rewards for ecosystem services into the post-Brexit Common Agricultural Policy. Develop results-orientated payment structures that adequately account for external costs and benefits. Make use of scoring systems, targeting approaches (e.g. carbon priority maps) and develop evidence-based, outcome orientated schemes. Paludicultures should ultimately be self-supporting but because of the important ecosystem services generated for wider benefices, it is reasonable that paludiculture projects are supported by public financing at least in the intermediate term.

5. Re-assess UK carbon-related policy; link paludiculture to other existing plans and policy targets, to secure support and funding – for example, flood management schemes.

6. Exploration and promotion of the scope for markets in ecosystem services provided by paludiculture to encourage private investment, including through Payment for Ecosystem Services (PES) and recognised market standards, e.g. the Peatland Code.

7. Set up a national multi-stakeholder 'paludiculture task force' to define plans and strategies at national and local levels, to coordinate action, encourage partnerships, establish a robust evidence base, monitor and report on progress. The development of a scoring system or spatial mapping would help regional policy makers/land managers/planners to make evidence-based decisions on the best locations for paludiculture production in the UK.

Socio-economic barriers

1. There is a lack of (large scale) UK pilot studies to trial and demonstrate paludiculture systems and crops. Paludiculture is currently a novel form of land management, largely unknown in the UK. Novelty alone means land managers may be unwilling to move away from profitable arable and horticultural crops, unless they have seen it done successfully.

2. Lack of uptake among farmers and land owners. Taking land out of conventional farming is a very sensitive issue, and farmers also face a lack of knowledge on alternatives. There are also cultural perceptions that wetlands are a flood risk. As such there could be a lot of resistance towards halting and then reversing land drainage.

Solutions:

1. Set paludiculture pilot projects and demonstration farms in the UK to:

   a) provide more robust estimates for different paludiculture models and crops and

   b) demonstrate best practise to farmers and land managers - farmers and land owners are more likely to deliver change if it's seen to be viable.

   There will be no 'one size fits all' solution, so pilot projects need to demonstrate a mixture of paludiculture models at various scales, crops, processing methods, machinery and infrastructure needs, potential markets, and sources of funding.

2. Improve knowledge transfer and advice through agricultural consultation for site adapted peatland use.

3. Initiate dialogue with land managing groups to discuss reservations against paludiculture and workable solutions; recognising that sustainable management will equate to different things in different landscapes. Communicate that Paludiculture is about diversifying agriculture activities, rather than a complete change of land management.
4. Establish a paludiculture advisory service and/or regional paludiculture facilitators – e.g. to support cooperation among farmers and with other stakeholders; for example to encourage joint action (sharing machinery for harvest and processing, joint marketing), connect sellers, processors, harvesters and buyers of biomass; also have a knowledge base of conversion processes, different forms of biomass, and availability within the landscape, promote scheme successes.
5. Investment in Research and Development programmes to establish the potential of different paludiculture systems and crops (based on the DPPP); support development of products, processing lines, and markets for wetland biomass (build economies of scale or create niche markets for high end products)
6. Public engagement. In addition to farmers and representative groups, raise awareness paludiculture to potential investors or influencers - water companies, utility and renewable energy companies, NGOs, policy makers, peat companies, horticultural suppliers, end users of public benefits derived (i.e. general public), academic community, and the media.

Machinery and logistics

Manufacturing products from wetland biomass requires specially adapted procedures ranging from plant cultivation, harvest, biomass transport and storage to biomass processing and use.

1. Specialised harvesting machinery and logistics are still immature, especially in the UK (Komulainen et al., 2008)
2. It remains unclear whether current machinery is suitable for use in the large-scale implementation of paludiculture.
3. Specialised machinery that can work on wet and easily-damaged soils will require considerable investment.
4. Biomass processing is also mainly restricted to local markets due to the high costs of transporting fresh biomass with a high-water content, and not readily accepted.
5. Lack of biomass or raw material for companies wanting to use it.

Solutions:

1. Support research and development of harvesting technology, exploring best practise examples elsewhere. Develop and adapt existing farming equipment to cope with harvesting on wet soil
2. Support the establishment of contractor hubs and machinery rings to pool labour, expertise and machinery. This will be of particular help s farm/land owners transition to working with 'wet agriculture'
3. Provide incentives for the processing stage to overcome the low acceptance of practitioners and help widely established wet fermentation biogas plants adapt to use biomass of low digestibility

Christian Schröder and colleagues have put together an excellent review of available machinery and approaches to biomass harvesting as well as of the logistics and infrastructure requirements required to facilitate the implementation of paludiculture, as does the DECC funded report on Wetland Conservation Biomass to Bioenergy (Mills, 2016).

Recommendations -setting a new course

Actions required for achieving large scale paludiculture:

Identify suitable (perennial) crops and develop markets for the new type of biomass.

Overcome technical challenges for harvesting and processing of wet biomass.

Establish pilot projects and demonstration farms to demonstrate viability and best practise.

Adapt laws, rules and regulations to accommodate wet peatland agriculture.

Remove market distortions, such as situations where subsidies are provided for drainage-based peatland agriculture but not for paludiculture.

Run long term schemes (e.g. 15 - 20 years) to convince farmers, provide planning security and ensure continuity of climate and environmental benefits.

Develop incentives, such as payments for ecosystem services, that adequately account for the social and environmental costs and benefits of paludiculture, in addition to any biomass revenues.

Facilitate paludiculture implementation, at national to local through a paludiculture task force and facilitation hubs.

Conclusion - Starting a paradigm shift

Our management of lowland peatlands of the UK should represent a better balance of land uses which reflects their true value to society and seeks to integrate the range of other benefits we gain from living, healthy peatland landscapes (NE report 257). Wherever possible, a mire, be it a fen or a bog, should be allowed to exist in its natural form and function. However, where we have highly modified mire soils such a drained grassland on peat, we should aim to utilise these soils in the most sustainable way, ensuring that there is no further loss of carbon and where possible, future sequestration.

There is no one solution to fit all scenarios but rather a spectrum of options that can be applied to the many different degrees of mire degradation. The trajectory of travel should always be to shift a degraded mire soil into a management system that will cause less degradation than previous. This approach allows for a step change in management where wholesale restoration of a wetland system may not be possible or desirable.

Ultimately, the ability for land managers to adapt to the application of paludiculture will dictate the potential success of this paradigm shift, and therefore, the practicalities along with the necessary policy changes must provide support. The challenges associated with the implementation of the paludiculture agenda are numerous, but the potential for transformation of UK lowland peatlands through wetter ways of farming is enormous - for the climate, the economy, the environment and people.

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