



A SCOPING STUDY FOR POTENTIAL COMMUNITY-BASED CARBON OFFSETTING SCHEMES IN THE FALKLAND ISLANDS



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Date: August 2020

Undertaken by  UK Centre for
Ecology & Hydrology

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Recommended citation: Evans, C. *et al* (2020). A scoping study for potential community-based carbon offsetting schemes in the Falkland Islands. Report to Falklands Conservation, Stanley.

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Registered as an Overseas Company in the Falkland Islands

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Summary

Relative to their land area, the Falkland Islands hold one of the largest stores of peatland carbon in the world. Until the mid 18th century, these peatlands developed with little or no human disturbance, and in the absence of herbivorous mammals. The subsequent settlement of the Islands and establishment of extensive livestock grazing, including historic over-grazing and burning, have led to large-scale ecological changes. These have included the decline of sensitive native species, notably coastal tussock grass, and peat erosion. Smaller areas have been affected by drainage, peat-cutting and cultivation. As in many other peatland regions of the world, this combination of pressures has likely reduced the capacity of Falkland peats to sequester carbon dioxide (CO₂) from the atmosphere through peat formation, and may have led to some areas becoming net sources of CO₂ emissions. Changes in land-management and restoration therefore offer the potential to deliver substantial climate change mitigation, both by reducing greenhouse gas (GHG) emission rates in degraded areas ('GHG reductions'), and by turning them back into actively carbon-sequestering systems ('GHG removals') through restored peat formation and the expansion of above-ground plant biomass.

In this report, we consider the potential for a future Falkland Island carbon offsetting scheme. Such a scheme would provide a mechanism by which businesses, organisations and individuals could invest in land-management and restoration schemes that would deliver GHG reductions or removals, delivering financial support to farmers and others to adopt sustainable land-management practices, undertake restoration and increase the extent of ecologically valuable habitats.

A critical requirement for any carbon offsetting scheme is a robust scientific evidence base, enabling the GHG emission savings associated with proposed intervention measures to be quantified and demonstrated. In this report we review the available evidence for the Falklands, as well as relevant data from comparable peatlands elsewhere, to estimate current rates of GHG emission from Falkland peatlands, together with the maximum rate of GHG removal that could be attained if all peatlands were restored to their natural condition. Given the scarcity of direct measurements from Falkland peatlands, and their unique characteristics, these estimates are highly uncertain, and data taken from other regions such as the UK may not be directly applicable. New data would therefore need to be collected in the Falklands to support scheme development, should it occur.

Whilst highly uncertain, our initial assessment suggests that the maximum carbon offset potential from peatland restoration in the Falklands could be high, in the region of a million tonnes of CO₂ equivalent per year. Based on the UK government's shadow price for carbon, this could generate revenue of around £47 million per year for carbon offsets. The market for carbon offsetting is expected to grow rapidly due to the International Civil Aviation Organisation's agreement to invest between £4-18 billion per year to offset growth in international aviation emissions. Whilst sales into such markets may need to be balanced against the Falkland Islands' own national targets in the future to avoid double counting, the potential market is clearly large.

We also review a range of models for a Falklands offsetting scheme, from a relatively simple, locally administered scheme based on individual and corporate donations, to incorporation in an internationally verified carbon trading scheme. The different options have different advantages and disadvantages, with international schemes offering greater investment potential but having more stringent monitoring requirements and higher operating costs. Any scheme would, however, need to adhere to international standards in terms of issues such as additionality (investments will generate carbon savings that would not otherwise have occurred), permanence (carbon savings will not be reversed at a later date) and the avoidance of leakage (i.e. emissions will not simply be displaced from

one location to another). Monitoring and verification procedures, and a strong governance structure, would also be needed to ensure that any interventions undertaken deliver the anticipated outcomes.

Overall, we consider that a Falkland Island peatland carbon offsetting scheme would have the potential to deliver significant climate change mitigation, to support habitat conservation, and to generate new sources of income for farmers, other landowners and the Islands as a whole. Any scheme would need to be sustainable and developed in partnership with the camp community and wider Falkland society to ensure that it is appropriate for the culture, economics and environment of the Islands.

Introduction

Peatlands and the carbon cycle

Peats, or histosols, are soils formed predominantly of organic matter, with a depth (according to the definition used in England and Wales) of at least 40 cm. Peats form under waterlogged conditions, where the absence of oxygen restricts aerobic decomposition, allowing undecomposed plant material to accumulate over time, potentially over thousands of years. Remarkably, peat soils occur from the polar regions to the humid tropics, and thus occupy a very wide temperature range. In most areas, peat formation is associated with a combination of high and year-round rainfall, and restricted drainage, for example in flat coastal planes, and in depressions and former shallow lakes within glaciated landscapes. 'Fen' peat forms under relatively alkaline conditions, where waterlogging is maintained by groundwater or river water, whereas 'bog' peat is acidic and nutrient-poor, and receives water directly from precipitation. In some oceanic regions, such as the British Isles, Newfoundland and Western Patagonia, 'blanket bog' peatlands can also form in areas of high rainfall and moderately undulating terrain. As the name suggests, these peatlands gradually grow and merge across the landscape to form a semi-continuous blanket of peat overlying the original topography. Many peatlands have been accumulating since the last glaciation, and in some areas may be many metres deep.

Due to their capacity to accumulate and store organic matter over millennia, peatlands now hold vast stores of carbon, despite the relatively small area of land they occupy. A widely repeated statement is that peatlands occupy 3% of the global land-area, but store one third of all soil carbon. This store, of around 500 Pg C, represents around 60% of the amount of carbon stored as CO₂ in the atmosphere. More recently estimates of peat extent and carbon storage in both the tropics (Dargie et al., 2017) and northern high latitudes (Nichols and Peteet, 2019) suggest that the global peat C store could be even higher, at over 1200 Pg; in other words, there may be more C currently stored in peat than there is in the atmosphere. Under natural conditions, peatlands typically sequester around 1-5 tonnes of CO₂ per hectare per year (t CO₂ ha⁻¹ yr⁻¹), leading to carbon accumulation rates of 0.2 to 1.5 t C ha⁻¹ yr⁻¹. However in many parts of the world – most notably Europe and Southeast Asia – the conversion of peatlands to productive land-uses has converted them into large net sources of CO₂ and greenhouse gases (GHGs) as a whole, which is estimated to be in the range of 1.2 to 1.9 Pg CO₂e yr⁻¹ (Smith et al., 2015; Leifeld and Menichetti, 2018). This represents 2.4 to 3.8% of all anthropogenic GHG emissions, and 20 -32% of emissions from land-use, making degraded peatlands second only to tropical deforestation as sources of GHG emissions from the land-use sector, and by far the most intensive sources of emissions per unit area.

The major reason that managed peatlands become CO₂ emission sources is drainage, which is a requirement for almost all current intensive agricultural activities on peat, as well as commercial forestry and horticultural peat extraction. Drainage exposes formerly waterlogged peat to oxygen, allowing the rapid decomposition of organic matter that has accumulated over thousands of years. Rates of CO₂ emission in deep-drained agricultural peatlands can therefore be very high, exceeding 25 t CO₂ ha⁻¹ yr⁻¹ in cultivated temperate peatlands, and even higher in tropical peat swamp forests converted to plantation agriculture such as palm oil production. Overall GHG emissions can be further augmented by emission of nitrous oxide (N₂O, a powerful GHG) in areas under fertilisation (Smith et al., 2015). Emissions of methane (CH₄) are highest from waterlogged and productive (e.g. fen) peatlands, and decrease with drainage, which partially offsets the detrimental impacts of drainage on CO₂ emissions but is generally insufficient to negate it, even on the 100 year time horizons typically used to compare the warming impacts of different GHGs. Over longer time horizons, the shorter

lifetime of CH₄ compared to CO₂ mean that natural peatlands have a strong cooling impact on the climate, and that peatland drainage has a correspondingly strong warming impact.

In 2014, the Intergovernmental Panel on Climate Change (IPCC) published the 'Wetland Supplement', which provided the first complete methodological basis for reporting GHG emissions from peatlands in national emissions inventories (IPCC, 2014). The Wetland Supplement includes default 'Tier 1' emission factors, which are empirically-based estimates of the emission of each GHG for each form of land-use. These Tier 1 emission factors can be multiplied by the area of peat in each country in each land-use category in order to obtain an estimate of total GHG emissions. Subsequently, the UK government commissioned an assessment of the requirements to implement the IPCC Wetland Supplement for UK peatlands (Evans et al., 2017). This assessment included the derivation of country-specific 'Tier 2' emission factors for a range of peatland types and management practices specific to the UK. In addition to drainage for agriculture and forestry, this assessment also considered a number of other management activities including grazing, managed burning and erosion, which are relevant to the Falklands.

The extent and characteristics of Falkland peatlands

The climate of the Falkland Islands is relatively dry (annual rainfall of around 350 to 650 mm yr⁻¹), which along with cool temperatures (summer mean 9 °C, winter mean 2 °C) and high wind speeds limit plant productivity, and there are no native tree species. The Falklands are very much at the dry end of the global 'climate envelope' for peat formation (Yu, 2012), but peatlands are nevertheless very extensive, which has been interpreted as evidence that the peat formed under a past wetter climate, and that the present climate may be too dry for peat formation (Otley et al., 2008). This interpretation has been challenged by Scaife et al. (2019), who suggest that peat formation occurs in the Falklands (and is continuing to occur) because the wind-adapted vegetation is resistant to decay. Payne et al. (2019) also found no evidence that peat formation was slowing down prior to human settlement; if anything, rates appear to have been increasing over the last 7,000 years.

According to some assessments, the Falklands may have the highest proportional peat area of any territory in the world. Estimates of peat extent vary widely, however; an assessment of superficial geology of the Falklands by the British Geological Survey (Aldiss and Edwards, 1999) noted the widespread presence of 'thin peat' throughout the islands, but only 3% of the land area was mapped as 'deep peat' (i.e. peat of > 1 m depth). At the other extreme, the International Mire Conservation Group Global Peatland Database (<https://greifswaldmoor.de/global-peatland-database-en.html>) provides an estimate that 94% of the land area of the Falklands was deep peat (Joosten, 2010). Although this figure has been widely repeated, it is unclear what information it is based on, and is a significant over-estimate. The estimate of 45% peat cover by Wilson et al. (1993) appears more realistic, while Evans et al. (2017) estimated that the total peat area of the Falklands at around 282,000 ha (23% of the land area). Ongoing work for the Darwin Plus soil mapping project suggests that the true extent of Falkland peat may lie closer to the higher of these two estimates, at around 38% of the land area (S. Carter, unpublished data). The total carbon stock of Falkland soils has been estimated at 934 Mt C (778 t C ha⁻¹) (Burton, 2016).

Peat occurs in the Falklands across almost the entire altitude range, from below high tide level to over 600 m. Falkland peats were placed into three categories by Aldiss and Edwards (1999): upland peat, lowland peat and tussac peat. Upland peat forms a typical blanket bog landscape, covering large areas flat or gently sloping terrain and interspersed with organo-mineral soils, rock outcrops and stone runs. It is most prevalent in the northern part of East Falkland. Vegetation largely comprises a mix of

whitegrass (*Cortaderia pilosa*), diddle-dee (*Empetrum rubrum*) and other dwarf shrubs and ferns, with shrub and fern vegetation tending to dominate in dryer areas (e.g. Figure A1). The cushion plant *Astelia pumila* (Figure A2) is locally dominant where the water table is close to the surface, while *Sphagnum* (mainly *S. magellanicum*) is mainly confined to higher-rainfall areas of East Falkland (e.g. Figure A3). Upland peat is nutrient poor with a low productivity, and grazing intensities are relatively low. It is susceptible to erosion, and eroding peat banks and pools are a feature of many areas (see following section). Peat depth is typically around 40 cm to 1 m, but can exceed 2 m in some areas, for example on peat banks.

Lowland peat forms alongside stream channels throughout East and West Falkland. It is generally on flat or near-flat terrain, typically overlying alluvial clays, and transitioning rapidly to mineral and organo-mineral soils on the steeper valley sides. Peat depth tends to increase rapidly away from the valley sides, and can be locally deep (> 1 m) in more extensive peat areas. The largest areas of lowland peat occur in the large river valleys that dissect the central mountain range of East Falkland, while many smaller areas occur alongside streams, rivers and coastal creeks throughout both major islands, notably in Lafonia. Whitegrass is the dominant vegetation (e.g. Figure A4), and with somewhat higher nutrient levels as a result of seepage from upslope mineral soils, vegetation tends to be taller and more productive compared to the uplands. As a result, lowland peat is generally subject to higher stocking densities than upland peat.

Tussac peat is a component of one of the most distinctive habitats of the Falklands, which formed in coastal areas throughout the archipelago. Tussac (*Poa flabellata*) is a large, pedestal-forming coastal grass, which can live for 200 years and grow to more than 3 m, making it the tallest native species in the Islands (Figure A5). Tussac is largely confined to areas below 200 m and within 300 m of the coast (Strange et al. 1988), although it can occur at higher altitudes or further inland, for example close to bird nests. As a result, it can cover smaller islands, but is restricted to the coastal fringes of larger ones. The likely reason for the coastal distribution of tussac appears to be its high nutrient demand, and it therefore benefits from proximity to marine birds and mammals, which bring nutrients ashore from the highly productive waters surrounding the Falklands, and which utilise the tussac stands for shelter and nesting sites (Lewis-Smith, 1985; Smith and Karlsson, 2017). By creating a habitat that attracts marine animals and increases the nutrient supply in what would otherwise be extremely nutrient-poor conditions, tussac can be considered an 'ecosystem engineer', which effectively alters the habitat in its favour. The luxuriant growth and large necromass of undecayed litter that characterise tussac stands limit competition from other species, with the result that tussac stands can become almost monospecific (Lewis-Smith and Clymo, 1984). The above-ground biomass of a mature tussac stand, around 50 t C ha⁻¹, is comparable to that of a Northern forest (Smith and Karlsson, 2017), and the accumulation of slow-decomposing litter contributes to very high rates of peat formation. Lewis-Smith and Clymo (1984) recorded one of the highest rates of peat accumulation recorded globally under tussac on Beauchêne Island, which they attributed to exceptionally high rates of primary production and litter addition to the soil. Tussac peat tends to have a high bulk density, and can accumulate to considerable depths despite forming in locations which appear hydrologically unfavourable to peat formation such as clifftops.

The history and current nature of land-use impacts on Falkland peatlands

The vegetation and soils of the Falkland Islands evolved in the absence of any herbivorous mammals, with the main grazers being shield geese (upland geese and ruddy-headed geese; Summers and Dunnet, 1984). At the time of first settlement, geese were so abundant that they could easily be

hunted by throwing stones, and numbers may even have increased following the extermination of the native Falkland wolf (warrah). The first French settlers on the Islands introduced small numbers of cattle, sheep, pigs and goats. Following the abandonment of the islands by the French in 1769, and then the departure of the Spanish in 1811, these animals roamed wild, and, cattle numbers in particular increased during the early 1800s to a reported 20,000 – 100,000 (the latter probably a significant exaggeration) all of which were on East Falkland (Wilson, 2016). Wild cattle were hunted by Argentine gauchos, and subsequently by the British settlers. Although cattle did extend to West Falkland, by the 1880s wild cattle had been largely exterminated, leaving only small domesticated herds. Conversely, sheep numbers increased dramatically, having been introduced by the British settlers from the 1830s onwards, with estimated stocks rising from 7,500 in 1850 to over 800,000 in 1898 (McAdam, 2014). Geese were generally considered to compete with sheep for good-quality grazing and repeated efforts were made to reduce numbers until at least the 1980s (Summers and Dunnet, 1984). In 2019, total sheep numbers were 476,767 (Falkland Islands Farming Statistics: Department of Agriculture 2019), down from 650,000 after the subdivision of farms in the 1980s. There are currently 4,648 cattle (Department of Agriculture 2019). Farms are managed as extensive, ranch-style systems, often exceeding 10,000 ha and over 5,000 sheep each, in order to achieve viable economic returns from the low-productivity landscape (Figure A6). Grazing management uses large fenced paddocks and includes continuous grazing (a traditional method known locally as set-stocking) and rotational grazing.

The effects of human settlement and introduced grazers on the vegetation and soils of the Falklands have been profound. The earliest impacts of livestock introductions were probably on the coastal tussac, which is exceptionally palatable due to high carbohydrate levels in the basal stems and roots (Gunn and Walton, 1985). The French explorer Bougainville wrote in 1766 that “the root is sweet and nutritious and preferred by beasts to any other food”. The first British Governor, Lieutenant Moody, recorded the presence of long wild cattle and horse tracks leading to tussac stands, and stated that cattle would eat dry tussac thatch off the roofs of houses during winter. He also recorded that it was “much injured by grazing; for all animals, especially pigs, tear it up to get at the sweet nutty-flavoured roots”. Tussac stands were also sometimes burned to clear the land, or to flush out animals for hunting, which may have led to the permanent loss of some tussac stands (Armstrong, 1994), and in some cases may have burned deep into the underlying peat. Unsurprisingly, the palatability and level of pressure on tussac led to its rapid depletion, to the extent that it was little noted by Charles Darwin when he visited in 1833-34. By the early 20th century, Jones (1924) noted that tussac, which he believed had supported the growth in sheep numbers to very high levels at this time, had been almost eradicated from all the larger islands by overgrazing. Based on Strange et al. (1988) and Strange (1992) it has been estimated that only around 4169 ha of tussac remains, around 20% of the estimated pre-settlement tussac area, most of which is on ungrazed outlying islands On East and West Falkland, less than 2% (65 ha) of the original tussac remained by 1988. Surviving tussac is also threatened by stripe rust fungus (*Puccinia striiformis*), a pathogen that is believed to have been accidentally introduced to the Falklands during the 20th century along with the invasive plant species Calafate (*Berberis microphylla*) (Upson et al., 2016).

Other human impacts on Falkland peatlands have been less dramatic, but nonetheless substantial. Extensive sheep grazing over almost the entire peatland area of the two main islands has led to large reductions in the occurrence of many native species, including larger shrubs such as fachine and boxwood and native grasses such as bluegrass; to a general reduction in plant canopy height; to compaction of the peat; and to increased bare peat exposure (Otley et al., 2008). Whitegrass, which is thought to have been the dominant species occurring on inland Falkland peat throughout the Holocene (Barrow, 1978) has withstood grazing pressures relatively successfully, and occupies a large

part of the landscape. Although the whole plant has a low palatability with large amounts of standing dead biomass, it can be an important food source across most of the peatland area. Sheep are selective grazers and will consume the green shoots as they appear, so the quality of the herbage consumed (i.e. largely green matter) will have a higher digestibility than in the overall sward. In more productive areas such as fertile coastal 'greens', damp valleys, and sheep holding pens, grazing-tolerant introduced species such as annual meadow-grass and daisies flourish, and these areas are preferentially grazed. Over time continuous grazing can reduce the diversity of the species assemblages in native pastures and large areas of land are now strongly dominated by the least nutritious native species including diddle-dee and whitegrass. Grazing can substantially reduce the amount of above ground biomass in whitegrass (e.g. Figure A7) and at high grazing levels the tussocks can be damaged or killed. In some cases, heavy grazing can lead to the displacement of whitegrass by diddle-dee and other unpalatable dwarf shrubs. The encroachment of diddle-dee is clearly detrimental for grazing, and may also be damaging to the peat if it contributes to drying, erosion or increases fire risk and severity (although diddle-dee cover is preferable to exposed bare peat). Grassland improvement through rotavation, planting of non-native grass species and fertilisation is in general targeted towards more productive mineral and organo-mineral soils, but does also occur on shallow peat soils (and did historically), and may contribute to substantial organic matter loss as a result of soil disturbance. Grazing-tolerant non-native species, which are not peat-forming, can also spread more widely at the expense of grazing-intolerant natives.

Management of grazing land through fire was previously widespread. From the mid-1980s until recently, between 5 and 20 fires were recorded in most years. Whilst the practice is now more strongly regulated and no longer encouraged (McAdam, 2014), some burning of white grass areas still occurs (Figure A8). The aim of managed burning is generally to reduce the amount of dead biomass and encourage new growth, but evidence that burning leads to a sustained increase in grazing quality is limited, with McAdam (1984) finding that burning reduced the amount of dead material substantially, but made the smaller amount of green material remaining more available to livestock, with this effect lasting for around 18 months before the burned pasture returned to its original state. Burnt areas were subject to selective grazing which, if left unchecked, could lead to significantly increased erosion risk, particularly in drier whitegrass areas. Controlled burning in wetter 'soft camp' areas carries a relatively low risk of leading to peat combustion, although this possibility cannot be excluded. Burning to remove diddle dee in dryer 'hard camp' carries a high risk of damage as the resinous woody stems and roots burn at a high temperature, and can burn down into the soil; Davies (1939) warned against all burning of hard camp for this reason. This message is even more pertinent at present given the evidence of climate change and the potential soil moisture deficits arising from climate change predictions. Uncontrolled fires can be highly damaging, leading to erosion, smouldering peat fires that can burn for months and which can at worst remove the entire peat layer, and long-term damage to vegetation (Upton et al., 2016). There is some evidence from peat cores that fires have occurred periodically since peat first started to form (Mauquoy et al., 2020), ignited by lightning strikes during dry conditions. Uncontrolled fires can still be caused by lightning strikes, but are now more often caused by human activities (either accidentally, or the result of managed burns running out of control). Their severity may also be influenced by land-use, for example drying of the peat or the presence of flammable gorse (which typically grows close to settlements). It has been argued in the UK (e.g. by Marrs et al., 2019) that rotational burning of shrubby vegetation can reduce the risk and severity of wildfires by limiting the accumulation of flammable above ground biomass ('fuel load'), although this argument has been challenged in the case of natural peatlands, which tend to accumulate fire-resistant *Sphagnum* rather than tall shrubby vegetation if wet, and are at low risk of damage from peat combustion (Baird et al., 2019). In the Falklands, where *Sphagnum* cover is naturally sparse, the

relationship between grazing, vegetation and wildfire risk requires further study. Where wildfires do occur, however, the recovery of burned areas may be slowed or halted by continued grazing (Upson et al., 2016). In general the low productivity of most Falkland vegetation will tend to limit fuel load accumulation and fire risk compared to comparable locations in the UK.

Wilson et al. (1993) provide the most detailed assessment of soil erosion in the Falkland Islands. For peat soils, they note that erosion risk is comparatively low for peat areas occupying depressions, valleys and large plateaus, which tend to be wetter, better protected from wind and less prone to gullyng. Upland blanket peats tend to be dryer, occur on slopes, and are vulnerable to wind and water erosion where the peat surface is exposed. Given the relatively low rainfall and high wind speeds, wind erosion appears to be a more important mechanism for peat erosion than it is in other parts of the world such as the upland UK, where fluvial erosion dominates. Erosional features in upland areas include widespread peat banks, which form 'islands' or 'ridges' of very dry peat (similar to, but typically larger than the 'peat hags' which characterise eroded areas of the English Pennines). Peat banks are often elevated by around a metre relative to the surrounding landscape (e.g. Figure A9). The tops of these banks are generally dry, and thinly vegetated by diddle-dee and other shrub and fern species, and they typically have steep or vertical sides of exposed or thinly vegetated peat that are subject to active wind, fluvial and block erosion. The widespread presence of these peat banks within the upland landscape strongly suggests that these areas had more extensive, and deeper, peat than they do today. The processes that led to this large-scale peat loss are however unclear; there is some evidence that similar peat banks can form under natural conditions in Sub-Antarctic islands, for example due to erosion caused by seabird colonies or changes in climate (Collins et al., 1976). However, Wilson et al. (1993) suggest that the Falkland peat banks are largely a result of human activities. Close to settlements this includes peat cutting, but in remote locations it is more likely the result of overgrazing, controlled burning, wildfire and (more recently) the use of off-road vehicles (e.g. Figure A10).

Recent and as yet unexplained die-back of diddle-dee is also of concern in case it leads to erosion in dry, exposed areas. Once the peat surface is exposed by any of these activities, dry conditions combined with high wind speeds mean that erosion may become self-sustaining. This is also true in coastal peatlands, with former tussac peat being highly susceptible after the loss of vegetation cover (Otley et al., 2008). Extreme examples of wind-driven erosion of large desiccated bare peat surfaces, and the formation of peat dunes, can be seen at Cape Pembroke (Figure A11). This area has also been affected by disturbance during the construction of the airstrip, exacerbated by uncontrolled year-round grazing which appear to have led to sustained impacts over decades (McAdam, 1980). Fluvial erosion features are less widespread, and dissolved particulate carbon concentrations in rivers are very low (C. Evans, unpublished data). Clusters of migrating peat pools with undercut wave-eroding peat faces on their downwind side do however occur on some upland peat plateaus, contributing to the loss of peat from these areas.

Historically, peat was the primary source of fuel for the population of the Falklands, and availability of peat for cutting was a factor in the relocation of the main settlement from Port Louis to Stanley; sections of the peat banks above Stanley allocated to individual households (McAdam and Burton, 2015). Cutting of peat in these areas was the likely cause of two major peat slides recorded in Stanley in 1878 and 1886, the second of which caused two fatalities (Aldiss and Edwards, 1999). Although other peat slides have been recorded more recently, such events are rare. More generally, the impacts of domestic peat cutting were limited by the small population of the islands, and have been restricted to areas close to settlements. McAdam and Burton (2015) report that peat-cutting declined by 90% between 1991 and 2012, with only 4% of households (mostly in Camp) continuing to use fuel for

heating. Nevertheless, some active peat cutting does still occur (e.g. Figure A12), and has the potential to dramatically damage a peatland, ultimately leading to near-complete peat loss, in localised areas.

In summary, there is little question that human activities have led to major changes in the ecology and function of Falkland peatlands in the 250 years since the islands were first settled. Human activities have unquestionably led to the decline in many native plant species, including some that are known to be peat forming. The amount of above-ground biomass has been reduced, soils have been exposed to wind stress, and erosion is widespread. It is therefore probable that large-scale grazing has reduced natural rates of peat formation across the bulk of the land area. In areas of more severe habitat disturbance, peatlands have almost certainly been converted from net carbon sinks into net carbon sources. In these areas of more severe damage, for example where large-scale erosion is occurring, there is clear alignment between the interests of farmers in restoring grazing land, and of conservationists in seeking to restore the land for climate change mitigation and biodiversity. In other areas, there may be co-benefits of improved stock-management if this both protects the peat and enhances productivity. However it is also probable that some peatland conservation and restoration measures would necessitate a reduction or cessation of grazing levels, and thus to a reduction in farm incomes that would need to be balanced by alternative sources of funds. Most, if not all, measures aimed at conserving and enhancing the carbon stocks of Falkland peatlands will likely require some level of investment.

Overview of international carbon markets and offsetting schemes

As global governments have agreed to try to limit global heating to 1.5 ° under the Paris Agreement there is increased attention on decarbonising economies and offsetting emissions in sectors which are hard to abate. One sector which will be particularly hard to decarbonise is international aviation, which also currently falls outside territorial emissions reporting under the UNFCCC. This sector has recently agreed to offset any growth in CO₂ emissions between 2020 and 2035 under the CORSIA scheme (Carbon Offsetting and Reduction Scheme for International Aviation). This scheme alone is likely to create investment of between £4 -18 billion per year in carbon offsetting such as afforestation and peatland restoration (ICAO 2016). There is therefore a large potential for peatland restoration which is not financially viable to be undertaken using financing from carbon markets.

To be able to sell credits into international markets, a number of key issues will have to be addressed concerning: the scientific understanding of baseline and post-restoration emissions; permanence, additionality and leakage; monitoring and verification; and accreditation through bodies which will provide a route to market. These issues will be discussed in more detail along with an outline of what a Falkland Islands offsetting scheme could look like, in sections 3 and 4 of this report.

Quantifying carbon offset potential

Current state of knowledge on greenhouse gas emissions and removals by Falkland peatlands

The only published data on rates of carbon accumulation in Falkland peats were published by Payne et al. (2019), who analysed peat cores from ten locations in East Falkland, and reanalysed data from one core from a tussac peatland on Beauchêne Island described by Lewis-Smith and Clymo (1984). One core, collected from North Arm, was only 34 cm deep and had a very young basal date (1,520 years BP, versus > 4,700 years BP for all other sites). Since this site did not meet the depth threshold to qualify as a peat (40 cm in England and Wales), it was considered that this core represented an organo-mineral soil (most likely a peaty gley) and therefore excluded it from the analysis. Of the remaining sites, three were collected under diddle-dee. One from Swan Inlet was described as 'valley fen' with close-cropped graminoid vegetation (a 'green' in local terminology). Five cores were collected under white grass, of which four were in lowland settings and one in the uplands, and the remaining two (from Cape Dolphin and Beauchêne) from tussac peat. Peat depths ranged from 47 cm to 255 cm in the East Falkland cores, with the Beauchêne core a remarkable 11 m deep. Basal dates (i.e. the date at which peat began to form) ranged from 4,740 to 13,516 years BP.

Based on the sites and calculations of Payne et al. (2019), peat carbon accumulation rates in the Falkland appear to vary by more than an order of magnitude, from under $0.03 \text{ t C ha}^{-1} \text{ yr}^{-1}$ to $1.39 \text{ t C ha}^{-1} \text{ yr}^{-1}$ (Table 1). Since these accumulation rates are based on cores spanning thousands of years, they should not be strongly influenced by recent land-use, although this possibility cannot be ruled out (for example if drying of the peat led to carbon loss throughout the peat profile, this would lead to lower apparent long-term accumulation rates). Carbon accumulation rates were generally lowest in shallow valley-type peats under white grass, intermediate under deeper, blanket bog type peatlands under diddle-dee, and highest at the Beauchêne Island tussac peatland studied by Lewis-Smith and Clymo (1984). For comparison, Loisel et al. (2014) report an average C accumulation rate of $0.23 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for a dataset of 151 peat cores collected at latitudes higher than 45° N . This led Payne et al. (2019) to describe C accumulation rates in the Falklands, with the exception of the tussac sites, as 'low to very low'. Specifically it appears the C accumulation rates in the shallower valley peats are indeed low by global standards, whereas those recorded in upland blanket bog are more broadly similar to those observed in high-latitude bogs elsewhere in the world. The C accumulation rate under tussac at Beauchêne is remarkable; Payne et al. (2019) considered it to be the highest rate of peat C accumulation reported globally, with the next-highest rate ($0.87 \text{ t C ha}^{-1} \text{ yr}^{-1}$) having been observed by Tolonen and Turunen (1996) for a Finnish mire. This high rate appears to be attributable to the exceptionally high productivity of the tussac in this remote island location, which Lewis-Smith and Clymo (1984) attributed to its proximity to large seal and seabird colonies, and resulting high rates of nitrogen and phosphorous fertilisation.

Table 1. Vegetation type, depth, long-term carbon accumulation and CO₂ sequestration rates for a set of peat cores described by Payne et al. (2019).

Location	Vegetation type	Peat depth (cm)	C accumulation (t C ha ⁻¹ yr ⁻¹)	CO ₂ sequestration (t CO ₂ ha ⁻¹ yr ⁻¹)
Swan Inlet	Short grass	145	0.052	0.19
Mount Usborne	Whitegrass	70	0.041	0.15
North Arm	Whitegrass	47	0.040	0.15
Hope Cottage	Whitegrass	50	0.027	0.10
Orqueta	Whitegrass	97	0.108	0.40
Moody Brook	Diddle dee	105	0.071	0.26
Whalebone Cove	Diddle dee	255	0.190	0.70
Sussex Mountains	Diddle dee	210	0.107	0.39
Cape Dolphin	Tussac	156	0.322	1.18
Beauchêne Island	Tussac	1100	1.390	5.10

Some caution is required in the interpretation of C accumulation rates from the Payne et al. study. Firstly, it is obviously a small dataset, and sites were mostly close to roads in East Falkland which could have resulted in some spatial bias in sampling, or could have under-estimated C accumulation rates by including sites (e.g. Whalebone Cove and Moody Brook, both close to Stanley) where land-use impacts have led to reduced recent accumulation rates or even C loss. Additionally, all of the sites except Beauchêne Island are grazed and the range of vegetation types sampled is limited to those which are common on the mainland. A larger dataset of peat depth measurements (Evans et al., 2017, reported in Payne et al., 2019) suggest that almost 50% of sampling locations that met the classification for peat (i.e. depth \geq 40 cm) were in the 40 – 75 cm range, but that there is also a long ‘tail’ of sites at which the peat is much deeper, exceeding 2 m in over 10% of sampling locations (Figure 1). While it must be emphasised that this survey was by no means a statistically representative survey, being based on a limited number of transects in different upland and lowland areas of East Falkland, the depth distribution of soils surveyed during the current Darwin Plus project appears very similar (S. Carter, pers. comm.) Together, these datasets suggest that deeper peats are extensive, with depths exceeding 1 m over perhaps 40% of the total peat area.

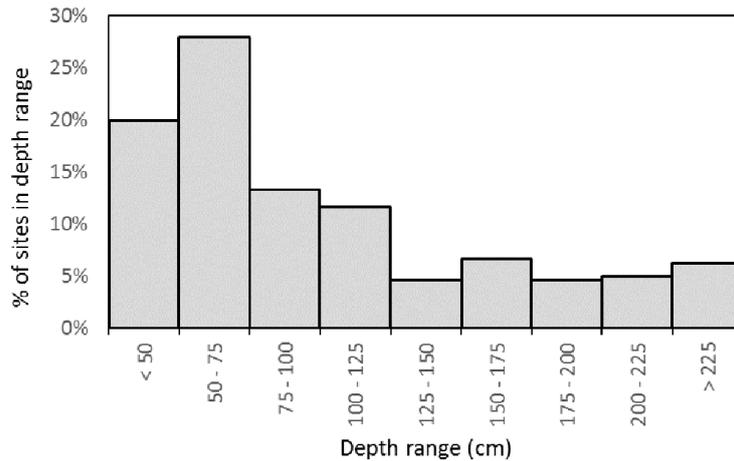


Figure 1. Percentage of 240 East Falkland peat sites with measured depths in different depth classes (data from Evans et al., 2017)

Further analysis of the Payne et al. (2019) dataset reveals a clear relationship between peat depth and long-term C accumulation rate, shown in terms of the resulting CO₂ sequestration rate (CO₂ sequestration = 3.67 x C accumulation rate) for the non-tussac peat sites in Figure 2a. A linear regression fitted through the origin gives the equation:

$$\text{Peat CO}_2 \text{ sequestration rate} = 0.0023 \times \text{Peat depth} \quad (R^2 = 0.735, p = 0.006, n = 8)$$

[Equation 1]

While it is hardly surprising that sites with deeper peat have tend also to have higher carbon accumulation rates than shallow peat sites, this is not simply an artefact of the calculation because different sites began to form at different times (basal date range 4,700 to 13,500 years BP). For tussac sites, we only have two data points so the extrapolation shown in Figure 2b (fitted through the origin) must be considered highly uncertain. Nevertheless, these very limited data do appear to suggest that C accumulation and CO₂ sequestration rates under tussac may be roughly double those from other vegetation types for an equivalent peat depth (Figure 2b).

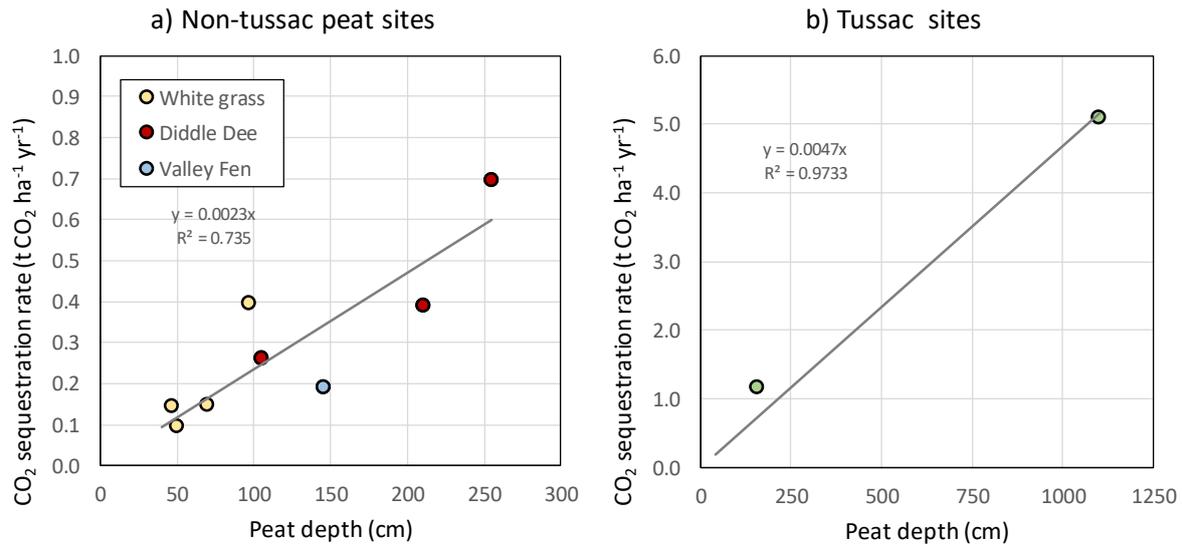


Figure 2. CO₂ sequestration rate versus peat depth for cores collected from non-tussac (a) and tussac (b) sites (data from Payne et al., 2019)

These relationships have potentially useful application. Firstly, they mean that if the depth of peat at a potential restoration site is known, some prediction can be made of long-term (effectively pre-disturbance) rate of peat C accumulation. If a substantial proportion of peat at a site has already been lost to erosion, nearby intact areas could be used as analogues. This approach could be used to set realistic CO₂ sequestration targets for offsetting schemes, and forms part of the basis for the assessment of potential management interventions below.

Secondly, we can use this relationship, together with the depth distribution shown in Figure 1, to roughly estimate the total rate of CO₂ sequestration by Falkland peats that may have been occurring prior to human settlement. Table 2 shows two ('low' and 'high') estimates of total pre-settlement peat CO₂ sequestration, with the 'low' scenario using the estimate of 23% peat cover on the islands by Evans et al. (2017), and the 'high' scenario using the 45% cover estimate of Wilson et al. (1993). Note that we have not used the latest (38%) area estimate deriving from the Darwin Plus soil mapping project, as this work is ongoing, however this value would suggest that the 'high' estimate may be more applicable. For both scenarios, we have used the estimated 4,169 ha of original tussac area from Strange et al. (1988). For each depth category shown in Figure 1 we assigned the mid-point of the depth range. For peat mapped as > 225 cm, and for all tussac peat, we assumed a mean depth of 300 cm, noting that this value is highly uncertain. For each category we then applied Equation 1 to estimate CO₂ sequestration rate (for tussac a coefficient of 0.0047 was used, based on Figure 2b), and these sequestration rates were then multiplied by the estimated area in that depth category to obtain estimates of total CO₂ sequestration as shown in Table 2. This analysis suggests that, depending on the total peat area estimate, CO₂ uptake via peat formation in the Falklands may have been in the region of 93 to 159 kt CO₂ yr⁻¹. Given the high likelihood that some of the original peat area of the Islands has been lost to fire, erosion, drainage and land conversion, these figures may, if anything, represent an under-estimate.

Table 2. Estimated spatial extent and long-term CO₂ sequestration of Falkland peats by depth class, and in total, based on the depth distributions shown in Figure 1 and regression relationships shown in Figure 2. The 'low' estimate is based on the estimate of total peat area of Evans et al., the 'high' estimate is based on the higher peat extent value reported by Wilson et al. (1993).

Peat type	Low estimate			High estimate	
	Mid-depth (cm)	Peat area (ha)	CO ₂ sequestration t CO ₂ yr ⁻¹	Peat area (ha)	CO ₂ sequestration t CO ₂ yr ⁻¹
Inland	45	52,311	5,414	106,335	11,006
Inland	62.5	73,017	10,496	148,426	21,336
Inland	87.5	34,874	7,018	70,890	14,267
Inland	112.5	30,515	7,896	62,029	16,050
Inland	137.5	11,988	3,791	24,369	7,707
Inland	162.5	17,437	6,517	35,445	13,248
Inland	187.5	11,988	5,170	24,369	10,509
Inland	212.5	13,078	6,392	26,584	12,993
Inland	300	16,347	11,280	33,230	22,929
Tussac	300	20,845	29,391	20,845	29,391
Totals		282,400	93,365	531,677	159,435

Unfortunately, there are no published direct measurements of greenhouse gas fluxes for the Falkland Islands, although a small-scale study is currently ongoing for a set of locations between the Moody Brook and Murrell River for the Darwin Plus soil project and in a Shackleton Scholarship Project in 2019 Rodrigo Olave (not yet reported) measured gaseous exchange from soils across 4 farms. The closest analogous published measurements are from two undisturbed bogs in Argentinian Tierra del Fuego, described by Holl et al. (2019). These are dominated respectively by *Sphagnum magellanicum* and the cushion plant *Astelia pumila*, both of which are present on the Falklands, and measured mean annual temperature of 6.3 °C and precipitation of 515 mm yr⁻¹ which are within the range of Falkland conditions. The measured net ecosystem exchange (NEE, i.e. the balance of CO₂ exchange between the land and atmosphere, where net uptake is recorded as negative) at these sites was -0.27 t C ha⁻¹ yr⁻¹ for the *Sphagnum* bog, and -1.22 t C ha⁻¹ yr⁻¹ for the *Astelia* bog. These values are notably high compared to the long-term sequestration rates reported by Payne et al. (2019), with the *Astelia* sequestration rate approaching that of the Beauchêne tussac peat. In part, this can be explained by differences in methodology; the core-based method records the residual carbon that remains after all loss processes are accounted for, whereas the flux-based method captures the balance of CO₂ uptake and CO₂ respiration but omits other C loss pathways including dissolved organic carbon (DOC) leaching and methane (CH₄) emissions. The loss of DOC from temperate peatlands is typically in the order of

0.2 t C ha⁻¹ yr⁻¹, while CH₄ fluxes may in the region of 0.05 t C ha⁻¹ yr⁻¹. If applied to the Tierra del Fuego study, the inclusion of these loss terms would reduce the net C balance of the *Sphagnum* bog to a low value (-0.02 t C ha⁻¹ yr⁻¹), and the *Astelia* bog to -0.98 t C ha⁻¹ yr⁻¹. The implication appears to be that intact areas of *Sphagnum* bog (which are rare in the Falklands) may have similar (and fairly low) rates of CO₂ sequestration to natural areas of inland peat under the vegetation types studied by Payne et al. (2019), but that CO₂ uptake by *Astelia* may be markedly higher. This observation seems consistent with the typical characteristics of *Astelia* bogs in the Falklands, with water tables close to the surface, and far more green biomass (suggesting higher productivity) than adjacent white grass or diddle dee. It also appears to be supported by initial results from the Darwin Plus project flux measurements (S. Carter, unpublished data) which suggest that *Astelia* has a relatively high rate of CO₂ uptake. On this basis it appears that the restoring or encouraging the expansion of *Astelia* may merit further investigation as a possible carbon offsetting measure.

For Falkland peatlands that have been modified or degraded by human activity there are currently no available measurements of CO₂ flux. There are also no available measurements of CH₄ or N₂O fluxes. The best available analogues appear to be the upland blanket bogs of the UK and Ireland, which share similarities in terms of the morphological and hydrological characteristics; history of land-use for sheep grazing; use of burning as a management tool; and the cutting or peat in some areas for fuel. Some of the main vegetation types also bear some similarities, with heather (mainly *Calluna vulgaris*) occupying a similar niche to diddle-dee and the other dwarf shrubs of the Falklands, and tussock-forming grasses such as *Molinia caerulea* and *Deschampsia flexuosa* bearing some similarity to white grass. On the other hand, *Sphagnum* mosses and sedges such as cotton grass (*Eriophorum spp.*) are far more prevalent in the blanket bogs of the UK than they are in the Falklands; annual precipitation is several times higher; erosion is largely water rather than wind driven; and practices such as ditch drainage are more widespread. On this basis, the following assessment should be considered illustrative rather than definitive.

Table 3 provides some initial emission factor estimates for each component of the peatland GHG balance for a range of Falkland-relevant peat categories. Most data are taken directly from the UK assessment (see caption and footnotes for notes on deviations from this methodology). For *Astelia* and tussac bog we attempted to derive Falkland-specific estimates of CO₂ uptake, although these estimates should be treated with considerable caution as they are based on only one or two measurement sites each. We did not incorporate the peat accumulation data from non-tussac sites reported by Payne et al. (2019), as it is unclear to what extent these rates have been influenced by land-use activities during the last 250 years, and therefore whether they are indicative of CO₂ uptake by near-natural or modified systems. The uptake rates at these sites are intermediate between the near-natural and modified values shown in the table, which could either indicate that long-term C accumulation rates have been partly affected by recent land-use, or alternatively (and perhaps more likely, given the low vegetation productivity) that near-natural CO₂ uptake in Falkland peatlands is lower than in their UK counterparts.

Table 3. Illustrative emission factors ($t\ CO_2e\ ha^{-1}\ yr^{-1}$) for Falkland-relevant peat condition categories adapted from Tier 2 emission factors developed for the UK peatland emissions inventory (Evans et al., 2017). All peat categories are assumed to be undrained, and 'indirect' N_2O emissions from watercourses were omitted due to the low density of streams (and lack of ditches) in most Falkland peatlands. Emissions of CH_4 and N_2O are expressed in CO_2 -equivalents based on IPCC AR4 100 year Global Warming Potentials (GWPs) of 25 and 298 respectively.

UK category	Falkland category	CO_2	DOC ¹	POC ¹	CH_4	N_2O	Total
Near-natural bog	Ungrazed/low-grazed bog	-3.54					-0.28
<i>Falkland only</i>	Near-natural <i>Astelia</i> bog ²	-4.47	0.40	0	2.83	0.03	-1.21
<i>Falkland only</i>	Near-natural tussac bog ³	-4.04					-0.78
Grass-dominated modified bog ⁴	Grazed whitegrass bog	-0.14	0.40	0.10	1.36	0.05	1.77
Heather-dominated modified bog ⁴	Diddle-dee dominated bog						
Domestic peat-cut bog	Domestic peat-cut bog	4.73	0.60	0.89	0.20	0.14	6.56
Actively eroding bog ⁵	Actively eroding bog ⁵	6.44	0.60	5.00	0.20	0.14	12.38
Extensive grassland	Improved grassland on peat ⁶	13.33	0.40	0.30	1.82	1.50	17.35

¹Emission factors for dissolved organic carbon (DOC) and particulate organic carbon (POC) represent the downstream emission of CO_2 estimated to result from the mineralisation of these compounds in freshwater, seawater or (in the case of POC) from material redeposited elsewhere on the land surface by wind erosion. DOC fluxes have been recalculated for the Falklands based on a small set of DOC concentration measurements obtained from pools, lakes, small streams and seeps draining peatlands in East and West Falkland (C. Evans, unpublished data).

² CO_2 emission factor for *Astelia* is based on the flux measurements for this vegetation type presented by Holl et al. (2019)

³Following the UK Tier 2 methodology the CO_2 emission factor for tussac is calculated as the average of the two peat C accumulation rates reported by Payne et al. (2019), after adjusting for C losses via DOC leaching and CH_4 emission. Given the exceptional nature of the Beachène site this could over-estimate typical CO_2 uptake rates for this vegetation type.

⁴Grass-dominated and heather-dominated modified bog are treated as separate condition categories in the UK inventory, but it has not yet been possible to assign separate emission factors due to a lack of data from grass-dominated areas.

⁵Note that UK Tier 2 emission factors for 'eroded bog' presented by Evans et al. (2017) are intended for landscape-scale reporting, and are therefore applicable to land mapped as containing erosional features, rather than to the individual eroding features themselves. The calculations assume eroded peat landscapes typically comprise 85% modified bog and 15% actively eroding areas. Here we have shown emission factors for actively eroding bare peat areas, as these are considered most relevant for restoration and offsetting projects. These emission factors are derived from measurements in areas bare peat from both eroded blanket bog and industrial peat extraction sites in the UK and Ireland (see Evans et al., 2017).

⁶UK emission factors for extensive grassland are based on lowland meadow grasslands and are therefore an imperfect analogue for areas of cultivated, fertilised and re-seeded grassland in the Falklands. However the level of soil disturbance involved in Falkland land improvement suggests that high CO_2 emissions are possible.

From Table 3 it is clear that fluxes of CH_4 and DOC have a significant impact on the overall GHG balance. For CH_4 , this partly reflects the use of IPCC 100 year GWPs, which effectively 'penalise' CH_4 emissions due to their strong short-term warming impact. The applicability of 100 year GWPs for natural wetlands has been debated, because an ecosystem that acts as a sustained sink of CO_2 and a sustained source of CH_4 will have a strong cooling impact over longer periods due to the longer atmospheric lifetime of CO_2 compared to CH_4 (Frolking et al., 2006; Cain et al., 2019). Furthermore, the transferability of UK-derived emission factors for CH_4 is questionable, because Falkland peatlands appear generally less productive, receive far less nutrients from atmospheric pollution, are often dryer

at the surface, and lack the widespread cover of sedges that can increase transfer of CH₄ from the soil to the atmosphere (Cooper et al., 2014). We would therefore expect that CH₄ emissions from many Falkland peatland types may be lower than the values shown in Table 3, which would enhance their potential role as net GHG (as well a carbon) sinks. Direct measurements of CH₄ fluxes from Falkland peatlands therefore represent a priority for both emissions estimation and support for a potential carbon offsetting scheme.

For DOC, we estimate (based on a limited dataset of field observations) that – despite very high concentrations – DOC fluxes are lower from Falkland peatlands than from their UK counterparts, due to the much lower runoff rates in the Falklands. However the UK and IPCC methodologies both assume that 90% of all DOC exported from peatlands to rivers is returned to the atmosphere as CO₂ via mineralisation in the aquatic ecosystem. In the Falklands, river lengths are short and sampling of rivers and estuaries (C. Evans and S. Felgate, unpublished data) suggest that most of the DOC exported from peatlands reaches the sea. Although its fate in the marine system is unknown, the high productivity of coastal waters could mean that a higher proportion of DOC becomes incorporated in the marine ecosystem or the (stable) ocean dissolved inorganic carbon pool. Conversely, POC losses from eroding peatlands in the Falklands may be higher than the values given in Table 3 due to factors such as the very dry condition of many peat banks (water tables often > 1 m deep) and the severe wind erosion affecting areas of exposed bare peat. Again, further research will be needed to refine estimates of indirect CO₂ emissions via DOC and POC loss for the Falklands.

Finally, N₂O fluxes are entirely based on the UK assessment, which itself carries a high uncertainty (Evans et al., 2017). Given the extremely nutrient-poor nature of all Falkland peatlands, with the possible exception of tussac peat and any areas that have been fertilised, and near-zero rates of atmospheric N deposition away from seabird colonies, it may be appropriate to assume zero N₂O emissions for most of the categories shown in Table 3.

Overall, this initial assessment of the carbon and greenhouse gas balance of Falkland peatlands is unlikely to be sufficient to form a robust basis for emissions estimation or a carbon offsetting scheme, but may provide a useful starting point for a more rigorous assessment in future by identifying relevant peat condition categories and land-use activities, highlighting important emission and removal pathways, and identifying key areas of uncertainty. Whilst these uncertainties are clearly high, we can draw the following tentative conclusions:

- 1) Near-natural areas of Falkland peat including coastal tussac, inland *Astelia* bog and other areas of undisturbed upland and lowland peat are almost certainly acting as net sinks for CO₂, and are probably also acting as net sinks for GHGs.
- 2) Grazing and other land-use activities such as burning that lead to modification of the original vegetation cover have probably reduced the magnitude of the CO₂ sink, and may have converted these areas into net GHG sources.
- 3) Areas that are affected by erosion and peat-cutting are likely to be acting as substantial CO₂ and GHG sources. Peat cutting is now limited in scale but larger areas may still be affected by the legacy of past cutting.
- 4) Cultivation, fertilisation and re-seeding of peat could have resulted in larger CO₂ emissions, although the magnitude of these emissions is essentially unknown. The areas involved are however relatively small (125 ha in 2019)

On this basis, restoration and conservation activities on Falkland peatlands should offer considerable potential both to reduce existing GHG emissions and in some cases to achieve net GHG removal.

Opportunities and mechanisms for Falkland peat restoration

In 2013, the rural population of the Falklands was just over 300 people, spread over 84 farms and 11,400 km². McAdam (2014) notes the role of farming on peat in the Falklands in underpinning a wide range of ecosystem services including provisioning services (meat, wool, water, energy), regulating services (notably climate change regulation through carbon storage and sequestration) and cultural services such as landscape, recreation and heritage. Some of these services can be directly monetised and therefore contribute to farm income; most obviously meat and wool production, but also cultural services via tourism income (McAdam notes that ecologically-oriented tourism is forming a growing proportion of some farm incomes, notably on outlying islands), and potentially renewable energy production. However, other less tangible services such as climate and water regulation do not generate direct income to farmers. In contrast to other parts of the world such as the UK and European Union, the Falkland Islands have no large-scale agricultural subsidy scheme that could support the delivery of these 'public goods'. Consequently, apart from the maintenance of grazing quality (for example minimising erosion or diddle-dee encroachment), there are few direct incentives for farmers to optimise land-use for carbon storage and sequestration.

Based on the preceding assessment, we consider that there is clear potential to conserve existing carbon stocks, reduce existing GHG emissions, and in some cases to remove GHGs from the atmosphere, through changes in land-use and management ranging from active restoration to more passive activities such as reducing grazing pressure. All of these activities have the potential to deliver climate change mitigation benefits, but in most cases they would require new funding sources to deliver, and in some cases (although not all, e.g. erosion control) they would likely involve a reduction in farm income from traditional sources such as wool and meat production. Therefore, there is a clear need for viable and robust investment mechanisms that would both support activities and ensure that farmers and other land owners are (as a minimum) not financially disadvantaged, and preferably financially rewarded for transitioning to more sustainable forms of land-management. The following sections consider the range of land-management interventions that might deliver net climate mitigation benefits; the potential magnitude of these benefits in a Falkland-specific context; and the data gaps and research needs that would need to be filled to deliver a robust basis for an emissions reduction or carbon offsetting scheme.

Tussac restoration

Given its former extent and ecological importance, and the dramatic loss of habitat that followed human settlement, tussac restoration has been a conservation and restoration priority in the Falklands. Attempts to establish tussac along with other native species on eroded bare peat have been made at the plot scale (see Section 2.2.3), and active tussac planting with tussac tillers or plug plants has taken place at larger scales in a number of areas (Figure A13), with varying success. There is some indication that tussac seed may also be spread by livestock, along with manure, which may support its establishment (Tourangeau et al., 2019). However this has not been experimentally tested - cattle do not bring in nutrients from elsewhere in the same way that marine species do, and overall it is unclear whether the benefits of limited grazing outweigh the disadvantages. Where environmental conditions are favourable, partial or total grazing exclusion by fencing of coastal areas close to residual tussac populations (for example where it grows in inaccessible locations on cliffs) can enable natural regeneration (Figure A14).

Smith and Karlsson (2017) studied the above- and below-ground carbon stocks of remnant tussac stands, eroded bare peat and tussac stands that had been restored from 2 to 23 years previously.

They found that the mature remnant stands had an average above-ground carbon stock of $50 \pm 10 \text{ t C ha}^{-1}$, which is comparable to the carbon stock of a temperate or boreal forest, mainly as a result of the dense pedestals formed by mature tussock plants. Accrual of above-ground carbon was relatively slow, however, with the oldest restored stands having a biomass carbon stock of 20 t C ha^{-1} .

Extrapolating the relationship between biomass and age obtained by Smith and Karlsson (2017) suggests that successfully restored tussock may take around 50 years to attain maximum biomass.

The analysis of Smith and Karlsson (2017) only measured the carbon stock of the upper 50 cm of peat, and found little difference between intact, eroded and restored areas. We consider that this lack of differences is likely methodological, since fixed-depth sampling of deep peat can lead to erroneous findings (for example, if erosion were to cause complete loss of the upper 50 cm of peat, exposing older and denser peat below, this method would produce an apparent increase in carbon stock). The long-term carbon accumulation rates for Cape Dolphin and Beauchêne Island reported by Payne et al. (2019) are therefore considered to provide a more realistic indication of the potential for below-ground carbon sequestration under restored tussock (range $1\text{-}5 \text{ t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$, Figure 2). It is likely that these rates of below-ground sequestration would only be attained as the stand reaches maturity. Given that Lewis-Smith and Clymo (1984) attributed the exceptionally high rate of peat formation at Beauchêne to extremely high rates of growth and litter production, it is likely that the upper rate of peat CO_2 sequestration will only be achieved after maximum above-ground biomass is attained, and perhaps only in tussock stands receiving high rates of nutrient input, for example from adjacent seabird colonies.

Grazing land management

The majority of vegetation on peat soils on the Falklands is grazed. Although stocking rates are low, the low productivity of the native vegetation away from coastal areas, exacerbated by low rainfall, high wind speeds and low nutrient levels, mean that even low intensity grazing could have a significant impact on the functioning, and therefore the carbon balance, of the peatland ecosystem. Impacts may be both direct and indirect. Direct impacts of grazing include a reduction in the proportion of net primary production (NPP) that remains in the ecosystem as living and subsequently dead biomass, and can therefore contribute to peat formation. Using North Arm Farm as a test case, Summers and Dunnet (1984) estimated that, at the stocking rates current at that time, sheep consumed $0.169 \text{ t C ha}^{-1} \text{ yr}^{-1}$ of plant growth, cattle $0.008 \text{ t C ha}^{-1} \text{ yr}^{-1}$, and geese $0.013 \text{ t C ha}^{-1} \text{ yr}^{-1}$. This compares to an annual NPP of whitegrass for the same area of $0.72 \text{ to } 1.10 \text{ t C ha}^{-1} \text{ yr}^{-1}$ (McAdam, 1986). If we take a mid-range productivity of whitegrass of $0.91 \text{ t C ha}^{-1} \text{ yr}^{-1}$, this suggests that domestic livestock typically consume around 20% of NPP. If we also assume that, in the absence of farming activity, goose numbers would be twice as high as they are today (i.e. natural grazers would remove $0.026 \text{ t C ha}^{-1} \text{ yr}^{-1}$), this suggests that litter inputs under current grazing systems are around 19% lower than they would have been before human settlement. If we assume that rates of peat formation would be reduced in proportion to this reduction in litter input, Equation 1 above can be adjusted for livestock-grazed systems to:

$$\text{CO}_2 \text{ sequestration rate of grazed peat (t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}) = 0.0019 \times \text{Peat depth (cm)} \quad [\text{Equation 2}]$$

The difference between this sequestration rate and the natural reference rate given in Equation 1 (in other words the amount of predicted additional CO₂ sequestration that would occur as a direct impact of grazing removal on peat sequestration) is then:

$$\Delta\text{CO}_2 \text{ sequestration due to grazing removal (t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}) = 0.00045 \times \text{Peat depth (cm)}$$

[Equation 3]

For a 1 m deep peat, therefore, halting livestock grazing would be expected to lead directly to around 0.05 t CO₂ ha⁻¹ yr⁻¹ of additional long-term CO₂ sequestration via peat formation.

An additional direct impact of grazing is on the stock of above-ground biomass. While this stock is small compared to the stock of carbon in peat, it is relatively dynamic. Areas of the Falklands where grazing has been effectively excluded, such as the Patricia Luxton National Nature Reserve in West Falkland, have visibly taller and denser vegetation (including an increase in fachine cover) than nearby grazed areas. This suggests that cessation of grazing could lead to a gradual increase in above ground biomass carbon stock, providing additional CO₂ sequestration until a new steady state biomass is attained. Davies et al. (1990) measured an above ground biomass of around 11.2 t C ha⁻¹ (assuming 50% C content of plant organic matter) at a low-altitude tussocky whitegrass dominated peatland site on Stanley Common, which they described as being “grazed occasionally by cattle and horses”. At a sheep-grazed ‘semi-tussocky’ whitegrass site at North Arm the peak above-ground biomass was 4.2 t C ha⁻¹, while at a higher-altitude ‘sparse non-tussocky pasture’ with low whitegrass cover and a mix of heath and other grass species, above-ground biomass was only 1.1 t C ha⁻¹. With certain caveats (for example the difference in site altitudes) these data suggest that the potential for above-ground CO₂ sequestration following grazing reductions or removal could be considerable, perhaps exceeding 10 t C ha⁻¹ (44 t CO₂ ha⁻¹) where severely degraded sites are allowed to recover to dense tussocky or shrubby vegetation. While the timescale over which this succession (and thus the annual potential rate of CO₂ sequestration) are unknown, this sequestration rate would greatly exceed the below-ground peat sequestration rate calculated above, even if succession were to take over a century. This potential for above-ground carbon sequestration does need to take into account the possible increase in wildfire risk, both to restored areas and to adjacent grazed land, although the extent to which denser vegetation over wet peat will lead to increased fire risk is currently unclear, as noted earlier.

Finally, changes in grazing levels may impact on the ecosystem carbon balance indirectly, via effects on plant competition or via changes in abiotic conditions within the peat. Competitive changes (i.e. a shift from dwarf shrub to grassland) are to some extent implicit in the calculations above, although additional benefits could occur via a reduction in exposed bare peat area (and therefore erosion risk) or reduced cover of flammable dwarf shrub species such as diddle-dee. Changes in abiotic conditions are harder to gauge at present, however observations from near-pristine or un-grazed areas where higher above-ground biomass has accumulated suggest that this may result in elevated near-surface peat moisture content (A. Stanworth, pers. comm.). This is somewhat counterintuitive, because denser vegetation is generally considered to lead to higher rates of evapotranspiration and therefore soil drying. However the distinctive conditions of the Falklands mean that such a response is plausible, firstly because transpiration rates in slow-growing Falkland species, adapted to low rainfall levels, are likely to be low, and secondly because a denser vegetation canopy may protect the peat surface from wind-driven evaporation. Consistent with this, Bond (2016) showed that during restoration experiments plots with the highest diversity of species, most canopy cover and greatest canopy height

were associated with higher soil moisture and lower soil temperatures than other plots. Bockhorst et al. (2007) also found that open plant communities in experimental sites in the Falklands and the sub-Antarctic islands were more susceptible to warming than closed communities, and that higher soil temperatures led to lower soil moisture in the Falkland sites. These observations suggest that biomass growth following grazing reduction or removal could effectively help to protect the underlying peat from temperature- and wind-driven desiccation, which would reduce rates of peat decomposition and favour higher rates of peat accumulation rates.

At this stage, the available data from which to quantify the CO₂ and overall GHG benefits of grazing reduction are limited, but do appear to suggest that the levels of avoided peat emissions and net CO₂ removal implied by a transition from modified to near-natural bog derived from UK data in Table 3 may be realistic. The benefits of increasing above-ground biomass are not captured by Table 3, but our initial analysis suggests that the amount of additional CO₂ sequestration this could deliver may be considerable.

Erosion control

Eroding areas are among the most intense sources of carbon loss and CO₂ emissions in UK upland blanket bogs, and despite large differences in the nature of erosion in the UK uplands and the Falklands (primarily waterborne versus primarily windborne) it is likely that this is also the case in the Falklands. In the UK, erosion control measures have included large-scale revegetation of bare peat areas in the Pennines (<https://www.moorsforthefuture.org.uk/our-work/our-projects/moorlife2020>). This has involved a combination of re-seeding, fertilisation and lime addition to establish an initial vegetation 'nurse crop' of grasses, after which it is hoped that bog species will re-establish. Application of heather brush, direct planting of plug plants and spreading of Sphagnum propagules have also been undertaken, along with stabilisation of bare peat surfaces using geotextiles and damming of erosion gullies. These activities are large-scale and expensive, involving the use of helicopters and many million pounds of government and European Union funding.

In the Falklands, areas of extensive wind-eroding bare peat, such as those on Cape Pembroke, would require similarly intensive (and expensive) intervention measures to re-establish a vegetation cover. Trial restoration plots at 16 sites on East Falkland established by Falklands Conservation, demonstrated the potential for restoration, but also highlight the difficulty of re-vegetating such a hostile environment. In general it was found that fencing and native species seeding alone did not result in plant re-establishment, but that the addition of sheep dung, woolly material (dags) and/or coir geotextile matting supported the establishment, in most cases, of over 50% vegetation cover and an above-ground biomass of 1.5 to 2.5 kg m⁻² after one year (Smith et al. (2018)). In some areas, including Cape Pembroke, introduced rodents (rabbits or hares) further hamper restoration efforts by selectively grazing palatable native species such as tussac.

In upland areas, the extensive peat banks present a different challenge in that, as noted earlier, they appear to be relic features of a former landscape of deeper peat. Like the peat hags of the UK, these relic features are very difficult to restore or even to stabilise because they are dry, hydrologically isolated, exposed to continued wind and water erosion, and unstable. One option may be the 'reprofiling' approach that has been used for both ditch blocking and gully restoration in the UK. This involves the removal of vegetation, reprofiling steep peat faces to create gentler slopes, and replacing the vegetation to minimise bare peat exposure (e.g. [YouTube - Peatland restoration: Hagg Reprofiling](#)). This approach has been successfully undertaken at highly exposed high-altitude sites in North Wales, and requires only a standard mini excavator and could potentially therefore be

undertaken by local contractors at relatively low cost. In some areas, there is some evidence from historic air photography that less intensive measures such as improved fencing for grazing control and pasture management may have enabled previously eroded areas to revegetate (J. McAdam, pers. comm. T. McAdam, unpublished MSc project); this may offer a lower-cost option for intervention in less degraded areas.

If undertaken successfully, measures to combat erosion should have the effect of halting ongoing carbon loss, and the probable emission of CO₂ from decomposition of eroded peat particles following their re-deposition on land or water. Reprofiling of peat banks could also increase their hydrological integrity, making them better able to retain water and thereby reducing direct emissions of CO₂ from in situ peat decomposition. On the other hand, re-establishing active peat formation in such heavily damaged areas may be difficult to achieve; the UK peatland emissions inventory and Peatland Code both consider 'modified bog' to be a realistic endpoint of most erosion restoration projects. As is illustrated by the figures in Table 3, this effectively involves converting a large emissions source into a smaller one, rather than a net GHG sink. As a means of avoiding emissions, restoration of actively eroding peat should be considered as being one of the most effective measures available on the Falklands. On the other hand, it is less clear whether restoration control could reinstate an active carbon sink, so it may have less relevance for any schemes that require active CO₂ removal.

Re-wetting

In the UK, and in many other parts of the world, drainage of peat for agriculture and forestry has been the dominant cause of carbon loss. As a result, peatland re-wetting was the major form of emissions mitigation considered in the IPCC Wetland Supplement (IPCC, 2014) and is also the main focus of the UK Peatland Code (IUCN Peatland Programme, 2017). In contrast, active drainage of peatlands has never been extensive in the peats of Falklands, which lack the networks of parallel drainage ditches ('grips') that are so characteristic of many British blanket bogs areas. However, localised drainage did occur in some areas, as is evident from aerial imagery (e.g. Figure 3). These ditches (known locally as 'buffalo ditches' after the machine used to dig them) were largely dug in the 1950s and 1960s on Fitzroy and Green Patch Farms, with the aim of draining boggy areas to improve grazing, and of making them easier to cross on horseback (Ron Binnie, pers. comm.). Historic attempts by the Falkland Island Government to use the buffalo machine to dig ditches to drain vehicle or horse tracks around Goose Green and in West Falkland were largely unsuccessful, although localised drainage occurs next to the current road network.

Since their creation, less effective ditches are thought to have naturally infilled, whereas more effective ditches (i.e. those capturing more water flow from the peat) have incised through the peat to the underlying mineral subsoil. Such ditches might be suitable for re-wetting via ditch-blocking if land-owners were keen. In these cases, it may be possible either to account for emissions reductions based on changes in vegetation cover (e.g. if the area transitions from one of the modified bog categories to a near-natural category), although re-wetted peat may still remain 'modified' if it continues to be grazed. Use of separate emission factors for drained bog may be possible, for example based on the values in the UK emissions inventory (Evans et al, 2017), but without local flux measurements any estimate will be inherently uncertain. In general, re-wetting may be a locally effective form of peat restoration, but the limited extent of drainage in the Falklands precludes its widespread implementation.

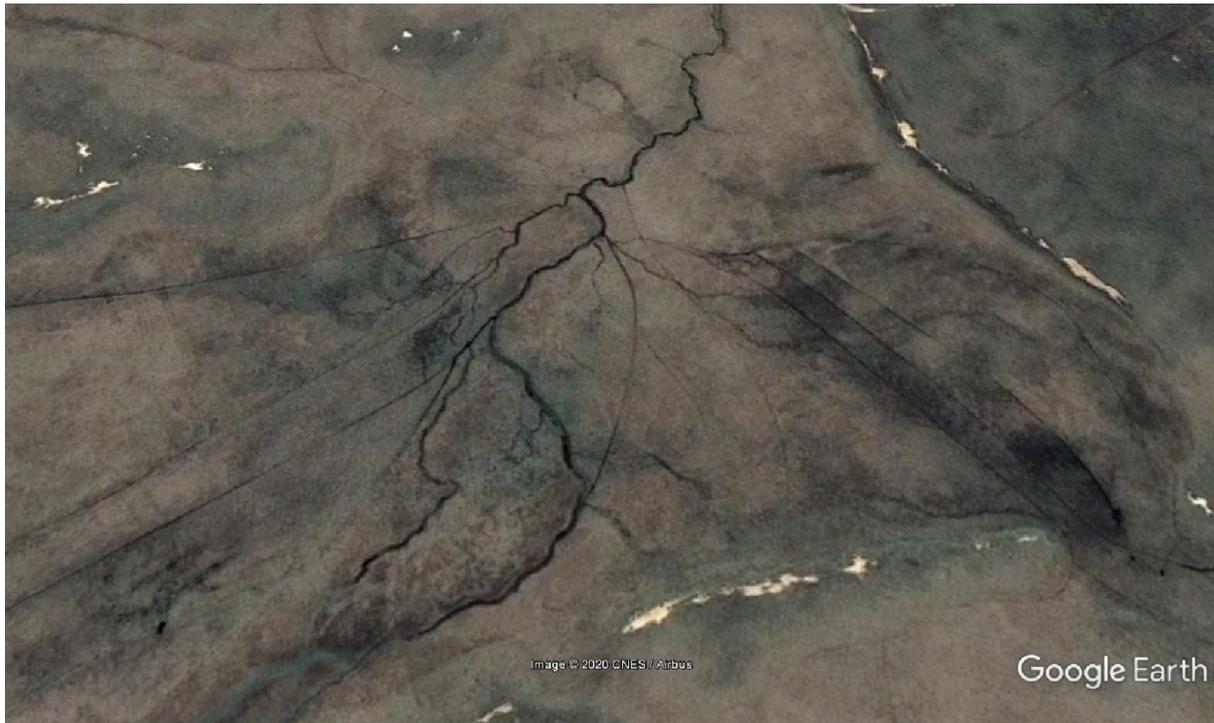


Figure 3. Aerial view of 'buffalo' ditches, Fitzroy, East Falkland. Darker shaded areas between and adjacent to some ditches may indicate increased shrub cover, suggesting that these ditches have been effective in drying the peat.

Other management options

The range of other management interventions that could be undertaken on Falkland peatlands to enhance CO₂ sequestration is fairly limited; grazing appears to be (by far) the most important human impact, and reducing or removing grazing from both coastal and inland peatlands is therefore likely to be the most effective means of reversing carbon loss, reducing erosion, and re-initiating or enhancing carbon sequestration. However, some other forms of intervention may be effective in some circumstances.

Firstly, areas of peat that have previously been cut for fuel could represent priority areas for restoration, since data from the UK and Ireland (Wilson et al., 2015; see also Table 3) indicate that such areas can remain as persistent CO₂ sources even after peat-cutting ends due to the severe hydrological modification of the peat (i.e. creation of vertical cutting faces and trenches). In some areas, for example where lateral trenches have been cut into the hillside, these effects may extend some distance beyond the area directly affected by peat cutting. The use of peat for fuel is now quite limited, however. In the past, peat was also used to build windbreaks or corrals for sheep. Historically, the most extensive peat cutting took place close to Stanley, and close to most settlements. Based on the UK figures given in Table 3, restoring these to near-natural bog could deliver a net emissions reduction of over 6.5 t CO₂e ha⁻¹ yr⁻¹, although restoration to modified bog (with a net benefit of around 4.5 t CO₂e ha⁻¹ yr⁻¹) may be more realistic. This climate change mitigation benefit mostly or entirely takes the form of avoided emissions.

One other intriguing possibility for enhancing CO₂ sequestration in Falkland peats is the very high rate of carbon uptake observed in an *Astelia* peatland in Tierra del Fuego by Holl et al. (2019). As shown in Figure 3, the implied rate of peat accumulation from this (admittedly short-term) study is comparable to rates of long-term C accumulation obtained under tussac by Payne et al. (2019). Its permanently green leaf area, dense growth form and capacity to form extensive near-monospecific ‘carpets’ in waterlogged areas all support the view that it could facilitate high rates of CO₂ uptake and peat formation where present. Hooker (1844) describes it as “most abundant... forming a large proportion of the peat”. The potential of other native species such as fachine and bluegrass to form peat is currently unknown, and may merit further investigation.

Quantifying total emissions reduction and offset potential

To calculate a theoretical emissions reduction and offset potential for Falkland peatlands, we separately calculated the change in *annual* CO₂ and overall GHG fluxes for the peat itself, and the *total* amount of carbon that could be sequestered into above-ground biomass. This distinction is necessary because, over the timescales relevant to offsetting schemes, current emissions and removals by peat can be considered as approximately fixed rates depending on land-use (although responses may be lagged in some cases, for example the reinstatement of peat formation following restoration). On the other hand, above-ground biomass can be expected to transition from one steady state condition to another, over a period of years to decades, after which no further net carbon sequestration into biomass will occur.

Offset potential from peat emissions reductions and removals

To estimate present-day and theoretical future emissions and removals from the peat (Table 4) we took the emission factors shown in Table 3, together with the total peat area estimate of Wilson et al. (1993), and assigned ‘expert judgement’ estimates of the area of peat in each category. To calculate the peat CO₂ balance we multiplied each area by the sum of emission factors for direct CO₂, DOC and POC as shown in Table 3. To obtain an overall GHG balance we additionally included the relevant emission factor for CH₄, but as discussed earlier we assumed N₂O emissions were zero, due to the very low nutrient status of the Falklands. To calculate offset potential we then ‘restored’ all peat as follows:

- 1) Tussac cover was increased to its estimated original extent of around 21,000 ha
- 2) *Astelia* cover was increased to 10% of the total peat area, as an example of active restoration of peat-forming native species.
- 3) All remaining grazed whitegrass and diddle-dee bog was returned to an ungrazed/low-grazed near-natural condition
- 4) All peat-cuttings, all improved grass and all eroding peat not restored to tussac were assumed to revert to a ‘modified bog’ category, in line with the UK emissions inventory methods (Evans et al., 2007)

It must be emphasised that this is *not* intended to represent a proposed future land-management scenario for the Falklands. Rather, it is intended to provide a rough estimate of theoretical maximum carbon and GHG offset potential that could be attained if this were the only objective of land-management. In reality, all offsetting activities will need to be balanced against other social, economic and environmental objectives for the islands, and are likely to become part of a diversified range of income sources for farmers and other landowners, rather than an outright replacement for current activities.

Table 4. Estimated maximum annual carbon and GHG offset potential associated with emissions and removals from Falkland peat. Offset potential is calculated as the difference between an illustrative ‘present day’ situation (above) and a theoretical ‘fully restored’ situation (below). ‘CO₂ balance’ incorporates both direct emissions and removals of CO₂ from the peat, and indirect emissions via loss of dissolved and particulate organic carbon (see Table 3). ‘GHG balance’ includes the additional fluxes of CH₄ shown in Table 3, but assumes that N₂O emissions are zero for all categories. Total offset potential has been disaggregated into ‘reduction’ (reduced emissions) and ‘removal’ (maximum CO₂ uptake relative to that occurring in natural areas currently)

CURRENT SITUATION

Habitat class	Area		CO ₂ balance	GHG balance
	%	ha	t CO ₂ yr ⁻¹	t CO ₂ e yr ⁻¹
Near-natural bog	9%	49,727	-156,143	-15,415
Astelia bog	5%	27,626	-112,530	-34,348
Tussac bog	1%	4,169	-15,162	-3,364
Grazed whitegrass bog	45%	248,635	89,509	427,652
Diddle-dee dominated bog	33%	182,332	65,640	313,611
Domestic peat-cut bog	1%	5,525	34,367	35,472
Actively eroding bog	5%	27,626	332,618	338,143
Improved grassland on peat	1%	5,525	77,519	87,575
<i>Total</i>		<i>551,166</i>	<i>315,817</i>	<i>1,149,326</i>

FULL RESTORATION SCENARIO

Habitat class	Area		CO ₂ balance	GHG balance
	%	ha	t CO ₂ yr ⁻¹	t CO ₂ e yr ⁻¹
Near-natural bog	80%	442,018	-1,387,935	-137,025
Astelia bog	10%	55,252	-225,061	-68,697
Tussac bog	4%	20,845	-75,812	-16,821
Restored eroded/cutover bog	6%	33,151	11,934	57,020
<i>Total</i>		<i>551,266</i>	<i>-1,676,874</i>	<i>-165,523</i>

OVERALL OFFSET POTENTIAL

	CO ₂	GHG
	t CO ₂ yr ⁻¹	t CO ₂ e yr ⁻¹
<i>GHG reduction</i>	<i>-599,652</i>	<i>-1,202,454</i>
<i>GHG removal</i>	<i>-1,393,038</i>	<i>-112,395</i>
<i>Total offset potential</i>	<i>-1,992,690</i>	<i>-1,314,849</i>

Table 4 suggests that the greatest overall climate change mitigation potential for the Falklands would be attained through the conversion of ‘modified’ (grazed whitegrass and diddle-dee bog) to ‘near-natural’ status, as a result of the very large areas involved. Restoration of tussac, eroding and peat-cut areas would generate greater mitigation on an areal basis, and therefore represent likely priority areas of intervention, but their overall mitigation potential is limited by their smaller spatial extent. Based on the analysis undertaken, and the underlying data and assumptions, most areas have the potential to become net sinks for both CO₂ and overall GHGs, with the exception of restored eroded and peat-cut bog which may remain small (albeit greatly reduced) emission sources.

As shown by Table 4, the extent of offsetting potential from peat restoration is strongly influenced by the contribution of CH₄ to total peat GHG emissions; if only CO₂ fluxes are considered, the total offset potential is almost 2 Mt CO₂ yr⁻¹, whereas if CH₄ emissions are included this reduces to 1.3 Mt CO₂e yr⁻¹. The inclusion of CH₄ has an even greater impact on the balance of reductions versus removals; if only CO₂ is considered, more than two thirds of the total offset potential is in the form of removals, whereas the inclusion of CH₄ reduces this to under 10%. The reason for this is that peatlands naturally emit CH₄, and continue to do so when modified by grazing. Once the stronger global warming potential of CH₄ is taken into account, this reduces the GHG sink strength of natural peatlands, and converts modified (but undrained) peatlands into considerably stronger emission sources than they would be on the basis for their CO₂ emissions alone. As discussed earlier, there are a number of reasons why inclusion of the warming impact of CH₄ is questionable for natural and near-natural Falkland peatlands, namely: i) that this emission is natural, and thus part of the pre-human carbon-climate

system of the planet; ii) that its short atmospheric lifetime means that the warming impact of a constant natural emission of CH₄ will decline to zero over longer time periods, such peatlands have a strong overall cooling impact on the climate; and iii) that CH₄ emission factors derived from UK blanket bogs may over-estimate true rates of CH₄ emission from the dryer, cooler, less nutrient-enriched and largely sedge-free peatlands of the Falklands. Finally, it is worth noting that the most of the calculated CH₄ emission applies to both the present-day and the full restoration scenarios, and thus appears on ‘both sides of the equation’ in climate mitigation terms. Nevertheless, the role of CH₄ emissions from Falkland peats will likely need to be taken into account in any offsetting scheme.

Notwithstanding these issues, it seems clear that there is considerable offsetting potential from restoration and altered management of Falkland peat. Over a 50 year period, even the most pessimistic approach (only recognising removals, including CH₄) could theoretically generate climate mitigation 6 Mt CO₂e, while the more optimistic approach (recognising both reductions and removals, omitting CH₄) could generate mitigation of 100 Mt CO₂e. As already noted, this analysis is a theoretical maximum based on an unrealistic level of land-use change in the Falklands, however it does suggest that even relatively modest levels of restoration and other activities such as improved grazing management could deliver worthwhile levels of climate change mitigation, with the potential to be supported through offsetting schemes.

Offset potential from increased above-ground biomass

For above-ground vegetation biomass (Table 5), we applied the same land-use change scenarios as those described above, assigning estimates of above-ground biomass for each category based on the limited available data. For near-natural bog, including *Astelia* bog, we took the above-ground biomass estimate for low-grazed tussocky vegetation site of Davies et al. (1990). For grazed whitegrass and diddle-dee we applied the average biomass from their grazed ‘semi-tussocky’ site, while for eroded, peat-cut and improved grassland sites we applied their ‘sparse non-tussocky’ value. For tussac, we assumed an average present-day biomass equal to half the biomass measured by Smith et al. (2017) for mature tussac stands. In the full restoration scenario, all formerly grazed whitegrass and diddle-dee was assigned the biomass value for near-natural bog, all tussac was assumed to attain the maximum biomass value of Smith et al. (2017), and eroded, peat-cut and improved grassland were assumed to attain the ‘semi-tussocky’ biomass value of Davies et al. (1990).

Table 5. Estimated maximum total carbon and GHG offset potential associated biomass

CURRENT SITUATION				
Habitat class	Area	C stock		
	%	ha	t C	t CO ₂ e
Near-natural bog	9%	49,727	556,942	2,042,121
Astelia bog	5%	27,626	309,412	1,134,512
Tussac bog	1%	4,169	104,225	382,158
Grazed white-grass bog	45%	248,635	1,019,403	3,737,811
Diddle-dee dominated bog	33%	182,332	747,562	2,741,062
Domestic peat-cut bog	1%	5,525	6,078	22,285
Actively eroding bog	5%	27,626	30,389	111,425
Improved grassland on peat	1%	5,525	6,078	22,285
<i>Total</i>		<i>551,166</i>	<i>2,780,089</i>	<i>10,193,660</i>

FULL RESTORATION SCENARIO				
Habitat class	Area	C stock		
	%	ha	t C	t CO ₂ e
Near-natural bog	80%	442,018	4,950,597	18,152,189
Astelia bog	10%	55,252	618,825	2,269,024
Tussac bog	4%	20,845	1,042,250	3,821,583
Restored eroded/cutover bog	6%	33,151	135,920	498,375
<i>Total</i>		<i>551,266</i>	<i>6,747,592</i>	<i>24,741,171</i>

OVERALL OFFSET POTENTIAL		
	C stock (net gain)	
	t C	t CO ₂ e
<i>Biomass C accumulation</i>	<i>3,967,503</i>	<i>14,547,511</i>

The theoretical potential for CO₂ sequestration into above-ground biomass appears large, approaching 15 Mt of CO₂. As for peat emissions and removals, the greatest total biomass sequestration potential lies in restoring grazed peatlands to near-natural status. If anything this potential may even be under-estimated, because our ‘near-natural’ biomass value was taken from a tussocky, sporadically grazed site on Stanley Common, and areas where grazing has been completely excluded appear (albeit based on visual evidence rather than measurements) to have considerably denser and taller above-ground biomass, including growth of taller shrub species such as fachine. The greatest biomass sequestration potential per unit area undoubtedly lies in tussac restoration, and this should therefore be a priority restoration measure, although again the total sequestration potential is limited by the extent of potential tussac habitat.

As already noted, and in contrast to CO₂ sequestration into accumulating peat, CO₂ sequestration into biomass is finite on timescales relevant to offsetting schemes, with tussac biomass estimated to reach a new steady state within 50 years, and other habitats within a shorter period. Nevertheless, the total mitigation potential is comparable to the ‘below ground’ mitigation achievable through peat GHG emissions reductions and removals, and could thus make a significant contribution to the overall potential of an offsetting scheme. Furthermore, above-ground biomass gains can be predicted with reasonable certainty, can be measured relatively easily, and are likely to occur within a relatively short period of time. By comparison, emissions reductions from peat are more uncertain, harder to

measure, and may be lagged. In particular, it may take a heavily degraded peatland decades to recover its peat formation function, and thus to become a net sink for CO₂ rather than simply a smaller source.

Potential scale of a Falkland offset scheme

To provide an indicative estimate of the potential scale of a Falkland offset scheme, we used the peat emissions and biomass data above to estimate the scale of emissions mitigation that might realistically be achieved via a successful scheme. For this estimate, we applied the conservative 'GHG balance' figures from Table 4 (incorporating CH₄ emissions) but included both GHG reductions and removals. For biomass we assumed that restored tussac would reach steady state biomass after 50 years, while all other vegetation would reach a steady state after 25 years. Based on their relatively high offset potential and relatively low competition with other land-use in terms of the areas involved and their current productivity, we assumed relatively high take-up of the tussac restoration and erosion control options (25% of the maximum restorable area in each case). For the much larger area of inland bog which is currently grazed we assumed a lower take-up of 5% of the total area.

Based on these figures we estimate a maximum scheme offset potential of around 150 kt CO₂e yr⁻¹. This would likely be lower during the early years of a scheme, as restored ecosystems slowly recover their peat formation function, and would reduce (to around 115 kt CO₂e yr⁻¹) once vegetation biomass reaches a new steady state. Clearly both the scientific and practical uncertainties around these figures are huge, but they do at least provide some 'ballpark' indication of the commercial potential of a scheme.

Data gaps and research needs to support an offsetting scheme

The preceding assessment represents our attempt to estimate the total mitigation potential of peatland restoration and land-management change for the Falklands, based on available data. These data are however in many cases very limited, leading to high levels of uncertainty in the potential scale of climate change mitigation that could be achieved. In order to develop a robust, credible and verifiable offsetting scheme, we recommend that the following key data gaps be addressed:

1) Improved estimate of the total extent and condition of Falkland peatlands

As noted earlier, estimates of the true extent of peat in the Falklands vary widely as a result of limited soils mapping, differing interpretations of what constitutes 'peat', and the large extent of soils with an organic horizon that lies close to the 40-50 cm depth threshold commonly used to differentiate peat from organo-mineral soils. There is also a lack of land-cover data suitable for classifying the peatland area into the condition classes used to assign emission factors. This data gap is to a substantial extent now being addressed through the SAERI-led Darwin Plus soil mapping project, which aims to produce a new map of Falkland peat extent, together with new maps of soil erosion and other aspects of habitat condition. It is likely however that further work, for example using new higher-resolution remote sensing data, may be needed to accurately classify all areas of Falkland peat into the required condition classes. From a practical restoration perspective, such comprehensive spatial data may not be needed, since an individual candidate restoration area can be assessed and classified on the ground, however comprehensive data are needed to quantify the overall potential of an offsetting scheme, and may be helpful in targeting new priority areas for restoration.

2) Falkland-specific CO₂ emission factors

The current CO₂ emission factors for the Falklands rely heavily on data from UK blanket bogs, which - despite some hydrological, climatic and land-use similarities - are typically much wetter, have higher cover of *Sphagnum* and sedges, and have been subject to differing forms of management such as widespread drainage and heather burning. Some limited measurements of peat CO₂ fluxes have been made during the Darwin Plus soils project, and during a recent Shackleton scholarship visit, but these data are not currently sufficient to derive Falkland-specific emission factors, or even to test the applicability of UK-derived emission factors. No CO₂ flux measurements have been made on Falkland restoration projects. We therefore recommend that a targeted programme of CO₂ flux measurements be made at a set of representative near-natural (low-grazed), degraded and restored sites, incorporating as many as possible of the vegetation types, forms of degradation and restoration activities discussed above, with the aim of establishing robust, Falkland-specific estimates of CO₂ emissions and removals for different peat types and condition categories. This work could be undertaken using low-cost static chamber methods, although these methods are labour-intensive, have a relatively low accuracy, and can only be undertaken in areas of relatively low vegetation (it would be extremely difficult to use this approach for established tussac, for example). We therefore recommend that, if possible, at least one CO₂ eddy covariance 'flux tower' be established in the Falklands. Although these are relatively high cost to establish, they have low running costs and can provide near-continuous, highly accurate data over extended periods (with the important caveats that equipment will need to be robust enough to survive the extreme weather of the Falklands, and that capacity to provide local technical support may be limited). Establishing multiple flux towers, for example on paired restored and unrestored sites, would provide 'state of the art' quantification of the net CO₂ offsetting achieved due to restoration. Finally, collection of additional peat cores, extending the limited dataset collected by Payne et al. (2019), would provide improved information on natural reference rates of peat formation in the islands.

3) Falkland-specific CH₄ emission factors

As shown in Table 4, the inclusion of CH₄ emissions has a huge influence on the estimated scale of overall GHG emissions offsetting, and in particular net GHG removal that could be achieved through peatland restoration and management change. As has been discussed, the appropriateness of including natural emissions of a short-lived (albeit powerful) GHG in an offsetting scheme is debatable, however it may be a requirement for internationally accredited schemes. In our judgement, the use of emission factors from naturally wet, sedge-rich UK blanket bogs may be generating an over-estimate of the true CH₄ emissions from most categories of Falkland peat, although the possibility that more nutrient-rich tussac could be a significant CH₄ source cannot be ruled out. Measurements being made during the Darwin Plus soils project may provide some initial insights into the likely scale of Falkland peat CH₄ emissions, however obtaining more comprehensive CH₄ emissions data remains a high priority. This evidence gap could be addressed as part of the static chamber flux measurement programme recommended above for CO₂, provided that suitable analytical capacity for CH₄ measurement is available. Note that an intensive programme of N₂O flux measurements is not recommended as a high priority, as most data from similarly low-nutrient bogs elsewhere suggest that fluxes are negligible. However some measurements would help to confirm this, and again the possibility of higher fluxes from tussac cannot be ruled out.

4) Improved data on above ground carbon stocks

Our assessment suggests that CO₂ sequestration by above-ground biomass could be large following restoration or management change. While relatively detailed data are available for tussac, information for other habitats is extremely limited. Collecting reference data on carbon stocks for different habitats and grazing intensities could be undertaken relatively simply and cheaply by harvesting and measuring the dry weight of above-ground biomass defined areas (e.g. 1 m quadrats) from a range of locations. If these areas included chronosequences of sites at different stages of restoration, or from which grazing has been excluded for different lengths of time, it should be possible to develop biomass accumulation curves that could be used directly to calculate annual CO₂ sequestration for offsetting

5) Enhanced understanding of restoration impacts on peat function

Finally, it would be beneficial to obtain an improved basic understanding of peatland function in the Falklands, which occupy an unusual climatic niche relative to most other peatlands globally, and may therefore not function, or respond to land-management change, in the same way as other more heavily studied peatlands. In particular, it has been suggested that peat formation occurs in the Falklands under relatively dry conditions as a result of the adaptation of native species to high wind speeds (Scaife et al., 2019). Observations also suggest that peat under taller vegetation may remain wetter at the surface (A. Stanworth, pers. comm.), possibly due to protection of the soil surface from wind-driven evaporation. Finally, it is clear that the majority of peat erosion in the Falklands is wind-driven rather than rainfall-driven, which could influence erosion rates, the fate of eroded carbon, and the factors that increase erosion risk. Basic research and measurements on Falkland peats, building on existing local capacity and knowledge, and with the support of specialist UK or international expertise where appropriate, would therefore provide improved understanding of fundamental processes, the mechanisms that lead to peat loss, the most effective measures to restore peatland function, and the future resilience of restored and unrestored peatlands in a changing climate.

Carbon markets and carbon offsetting

International carbon markets

A carbon credit is a certificate or permit equivalent to 1 tonne of CO₂. These credits are tradeable on carbon markets. Different markets for carbon credits exist with entities obliged to pay for the carbon they emit depending on policies at the company level through corporate social responsibility (CSR) targets, via sub-national policy (e.g. California state) or international level (EU emissions trading scheme). A key distinction between these types of markets is between legislated requirements for carbon reduction, which typically use a 'cap and trade' model and are sometimes known as compliance markets, and voluntary markets which have no obligation for entities to take part in them.

Cap and trade policies, such as the EU Emissions Trading Scheme (ETS), set a maximum allowable level of carbon emissions which reduces over time. Companies which emit less carbon than their allowance can then sell emissions credits to other companies in the scheme, creating a market that incentivises carbon reduction where the cost of doing so is below the carbon price. By reducing the total number of allowable emissions over time, the carbon price will steadily increase as supply is limited, thus increasing the number of carbon reduction projects which become economically viable.

Cap and trade markets do sometimes allow international offsets to be sold into the schemes, however these are usually subject to stringent requirements and are likely to be small compared to the overall market size. The EU ETS, for example, has moved to ban international offsets from its market, meaning these types of markets are less relevant to those developing projects for carbon offsetting.

Voluntary schemes allow companies or individuals to offset the carbon they produce, typically to meet CSR targets or for ethical reasons. Different certification bodies exist to ensure issues such as monitoring, verification, permanence and leakage are addressed. The certification body ensures the project has resulted in emissions reduction/removal and then allows the project developer to sell an equivalent number of credits based on the cost of the carbon reduction. The purchaser can then either 'retire' the credit to offset their carbon emissions or trade the credit themselves on the market.

As national and international carbon policies often do not align, and businesses operate at a global scale, many different legislative and voluntary schemes can apply to one company. As an example, the airline operator BA is part of the EU ETS for their flights within the EEA, part of the CORSIA commitment for their international flights, and has set a further CSR target to offset emissions from domestic aviation in the UK. The company will therefore have to buy carbon offsets and allowances that comply with each different scheme. To meet the requirements of CORSIA and to offset domestic aviation, buying credits from peatland restoration projects in the Falklands would be a viable option if the projects in question were accredited to the required standard. On the other hand, this type of project would not meet the criteria for a compliance market such as the EU ETS.

Potential markets and carbon prices

The poor record of accreditation of historical offsetting schemes such as the Clean Development Mechanism (CDM) means there are a large number of carbon credits on the international voluntary market which trade at less than \$1, barely covering transaction costs. Most schemes (including CORSIA) and CSR standards no longer allow CDM credits as it has been shown that at least 73% of them were of low likelihood to have resulted in genuine carbon reductions (Cames et al., 2016). In the future there is likely to be a growing demand for high quality carbon offsets which meet stricter accreditation standards, in part driven by the estimated £4 -18 billion per year investment from offsetting from international aviation under CORSIA (ICAO 2016).

Carbon reduction and removal projects which can sell into schemes such as CORSIA will do so on an open market and will therefore compete on price. Estimates of the cost of carbon removal projects vary, however a range of \$3-30 per tCO₂ has been suggested for afforestation projects and around \$10-100 per tCO₂ for wetland restoration. This compares favourably with engineering processes for removing carbon from the atmosphere such as BECCS (bioenergy with carbon capture and storage) and DACCS (direct air capture with carbon storage) which are both expected to be above \$100 per tCO₂ and significantly over this level in the early stages of the technologies (all in 2018 prices) (Burke et al., 2019). As requirements for offsetting are likely to outstrip the available supply from natural restoration projects (Elliot and Ritson, 2020), any project which can deliver carbon credits below the \$100 lower estimate cost of BECCS/DACCS is likely to become viable as carbon prices increase.

Future carbon prices are hard to predict, however the UK government uses a 'shadow' carbon price to evaluate public policy decisions of £14 per tCO₂ in 2020, rising to £43 per tCO₂ by 2030. It has been suggested that this will need to rise now that the UK government has committed to net zero carbon emissions by 2050, which would necessitate a shadow carbon price of £75 per tCO₂ by 2030 (Burke et

al., 2019). At these prices, carbon offsetting schemes through wetland restoration are likely to be attractive, especially given their capacity to deliver co-benefits of increased biodiversity.

Current carbon prices vary across different markets. The EU ETS market has traded between £20 and £30 per tCO₂ across 2019-20. Voluntary markets typically have lower prices with a typical range of £2.5 to 5.0 per tCO₂ in 2018, although prices for some projects were as high as £57 per tCO₂ (Hamrick and Gallant, 2018). Actors in the voluntary markets will commonly pay higher prices for projects which meet higher accreditation standards or which have quantifiable co-benefits, such as biodiversity, which fit the with buyers' CSR goals. A Falklands offsetting scheme is therefore likely to be economically viable if it can be delivered in the normal cost range for peatland restoration projects, and will be attractive to buyers through the biodiversity benefits it could also deliver.

Market versus government schemes

As well as international carbon markets, many governments have set national carbon budgets, for example under the UNFCCC framework for territorial emissions. Under this framework all emissions generated in a territory, excluding international aviation and shipping, are counted without the use of international offsets. State governments, therefore, have more pressure to reduce gross carbon emissions than companies with CSR commitments which may engage in offsetting outside the territories they operate in.

National carbon budget policies interact with carbon markets in terms of how carbon reductions are accounted for. For example, the UK has set a target of net zero emissions by 2050, excluding international aviation and shipping. If, therefore, a UK generated carbon credit was sold into CORSIA to offset the emissions of an airline, it could not also be counted towards the UK's net zero target to avoid double counting of the carbon credit. The UK government, therefore, is unlikely to allow nature-based carbon credits generated in the UK to be sold internationally as it will need all these emissions reductions to meet its own national target.

Instead, the UK government is proposing to incentivise nature-based carbon reductions by agreeing to purchase Woodland Carbon Code (WCC) credits to stimulate the market for afforestation and encouraging land use practices that sequester carbon through a new Environmental Land Management (ELM) scheme. UK farmers will essentially have to show they are sequestering carbon to receive government farming subsidies in a concept called 'public money for public goods' that will also extend to increasing biodiversity.

In the Falkland Islands, no farming subsidies are paid to farmers or land managers meaning this type of scheme is less likely to be adopted. However, if the Falkland Islands were also to adopt a climate target in accordance with its obligations under the UNFCCC, it would have to consider the balance between credits counted against Falkland emissions and those sold internationally. The scale of the potential offsets available (1 – 2 MtCO₂e yr⁻¹), however, is much larger than reported emissions from the Falklands of <0.05 MtCO₂e yr⁻¹ (EDGAR dataset, 2016), meaning it is likely that a credits could be made available to international markets once targets in the Falklands have been met.

Carbon accreditation standards and local offsetting schemes

Since the credits generated under the CDM have proven to be of low permanence and additionality, compliance markets and CSR schemes are increasing their standards to disallow these credits. Most will require some form of accreditation by a third-party organisation, the largest of which are the

Verified Carbon Standard and Gold Standard. These third parties will assess the risks of permanence and additionality involved in the project and issue their brand of credits based on their assessment of the carbon savings or removals of the project. These credits can then be sold on international carbon markets and such accreditation is a requirement to sell into the CORSIA scheme. Carbon accreditation organisations do not buy or sell credits themselves; they simply verify that a project has met their standards, analogous to a mint providing a hallmark for a bar of gold. Many accreditation organisations do, however, provide platforms to match project developers with carbon brokers to facilitate the buying and selling of credits they have approved.

An alternative to international carbon standards would be to develop a local offsetting scheme following the example of the UK peatland carbon code or woodland carbon code. This would have the benefit of being adapted to the local situation and could potentially have lower levels of monitoring, verification and the associated costs, if this was deemed justifiable. Credits from such a scheme could likely be marketed to companies operating in the Falkland Islands to meet their CSR requirements or individuals interested in nature restoration and reducing their climate change impacts, such as tourists visiting the islands. However, they are unlikely to be able to be sold into the larger international markets. This kind of funding model has been implemented in the past by the Antarctic Research Trust to fund the restoration of Hummock Island ([Antarctic Research Trust link](#)), for a relatively small area of 100 ha of tussac planting. If regulations and CSR requirements changed in the future, it would also be possible to register a local offsetting scheme with an organisation such as VCS, once the methodology and risks were better understood.

Offsets: reductions versus removals

A key difference in types of carbon offsetting is between offsets which come from a reduction in CO₂ emissions and those from a removal of CO₂ from the atmosphere. Typically, credits under schemes such as VCS and Gold Standard can be issued for either, but as economies move to net zero, removals will be required rather than just reductions. Credits derived from emissions reductions still produce net carbon emissions, meaning they can't be relied on to reach net zero. The examples below show the differences between the two types of offsets.

Reduction: Person A emits 1 tonne CO₂ but pays person B to reduce their emissions from 1 to 0 tonnes. Although the do-nothing scenario would have been 2 tonnes of CO₂ emitted, there are still emissions of 1 tonne CO₂ despite person A having paid for an offset.

Removal: Person A emits 1 tonne CO₂ but pays person B to remove 1 tonne from the atmosphere. The net result is zero emissions (assuming the removal is both permanent and additional).

As global decarbonisation progresses, therefore, there will be an increased need for offsetting via removals and a decreased possibility for offsets by reductions. The environmental think tank, Green Alliance, has suggested that by 2035 removals will need to have replaced reductions as viable credits in offsetting schemes (Elliot and Ritson, 2020). A Falklands offsetting scheme has the potential to produce both reductions in the shorter term, as peat erosion is halted, and removals in the longer term if peat forming conditions are restored.

Additionality, permanence and leakage

Additionality, permanence and leakage are three key concepts in carbon offsetting. Tests for additionality seek to make sure the activity receiving a carbon credit would not have happened under

normal conditions. This is typically done by assessing if the project could have happened without the need for carbon finance gained through the sale of credits and checking that there is no legal obligation to do the project.

As an example, credits for peatland restoration could not be sold if the government passed a law requiring that peatlands must be restored by landowners. Similarly, if restoring peatlands increased their agricultural value to the point where investing in restoration was viable, restoration projects would also not be able to sell carbon credits. As it stands in the Falkland Islands, the investment costs and likely reduction in agricultural value required by destocking means that peatland restoration is likely to be viewed as additional.

Permanence refers to whether the carbon removals attributed to the carbon credit are likely to be permanent, or whether there is a risk that carbon could be re-emitted in the future. This could be through accidental (wildfire) or purposeful (increase in grazing intensity) means. Typically, this issue will be addressed in the carbon accrediting scheme by placing legal and technical barriers to the re-emission of carbon. A further measure is the use of a 'buffer pool' of credits, typically 5 or 10%, which aren't sold but are instead used to mitigate the risk of the non-permanence of the credited carbon. The more likely a project is to re-emit carbon, the larger the buffer pool as it is essentially an estimate of the failure rate of the scheme.

Leakage addresses the possibility that the actions undertaken in a carbon project may cause an increase in carbon emissions outside the scope of the project. An example of this would be if a farmer received credits from lowering grazing intensity on one part of their land but as a result increasing grazing on other areas of land outside the project, leading to erosion and carbon losses. In this case the carbon benefit would have 'leaked' by causing erosion elsewhere. Issues around leakage are usually addressed in the verification of the scheme, for example ensuring that a farmer either has more suitable areas of land to shift grazing to at sustainable levels or reducing overall stock numbers to allow for decreased grazing capacity of their land.

Monitoring and verification

A final component of a carbon offsetting scheme is the monitoring and verification process. This is usually required in order to assess how many credits are sold, particularly if the project lasts many years. In the woodland carbon code, for example, woodlands are assessed every ten years to judge the extent of tree growth to be able to quantify the number of carbon credits which can be sold. A robust monitoring protocol would be required for a Falkland Islands offsetting scheme which would likely require a mixture of farm records on stocking density, vegetation surveys and assessments of peatland condition and perhaps measurements of carbon flux. Models can be used to help assess the potential number of credits available and can be referred to in the monitoring and verification process to understand if the restoration project is progressing as intended.

Potential role for a project developer

In many nature-based carbon offsetting projects, the project is developed and managed by a third party with expertise in carbon offsetting rather than the farmers or land managers themselves. This has a number of advantages as, a) it allows for economies of scale in monitoring and verification costs across numerous projects, b) it pools risk across projects, therefore decreasing the likelihood of failure, c) a pooled price across projects can be set which means that not only the most economic interventions will be taken forward, d) it avoids the need for farmers and land managers to have to

take credits to market and perform the monitoring and verification themselves, which they may have no training in.

A number of commercial entities exist which perform this role for afforestation projects, and these could be engaged to develop the initial methodology, manage project development, monitoring and verification, and market the credits to buyers. Alternatively, Falklands Conservation or another charitable organisation could play this role, subject to it falling within the scope of their charitable aims.

Towards a Falkland carbon offsetting scheme

Outline model for a Falkland Carbon Code

To create a Falklands Carbon Code, interventions would have to be specified which, within a reasonable degree of scientific accuracy, would lead to known reductions in carbon emissions and/or removals of carbon from the atmosphere. In Section 2 we defined the following interventions which could be adopted: replanting of bare peat, rewetting, reprofiling of erosion features and destocking/investment in fencing to allow peat formation.

To be able to quantify the number of credits available, it is necessary to be able to define a baseline condition i.e. the carbon emissions from Falkland peat in a business as usual case for the next 100 years. Then, the carbon savings from the intervention need to be quantified such that potential carbon credits can be identified and project costs estimated. Outline schemes for both peatland restoration and livestock management already exist and will be discussed further in the following sections.

Challenges and potential solutions

1. Scientific uncertainty: At present it is not clear that we have an accurate understanding of how much carbon will be emitted by Falkland peat over the next 100 years without any intervention, although we have provided some estimates in the previous sections. We also only have some preliminary data on how restoration efforts could improve this. As a first step, a demonstration project will be needed to understand how the different interventions perform and to refine models for future projects. While projections of carbon savings do not have to be completely accurate as they will be confirmed in the monitoring and verification stage, enough certainty is needed to drive investment into projects.

2. Additionality: It will be necessary to prove that peatland restoration projects meet the tests of additionality. This will require an estimate of the economic costs of restoration, any likely increase in value or income from the land as a result of restoration and then an assessment of the need for carbon finance to be able to undertake the project. Again, a demonstration project will help understand the economics of restoration projects and demonstrate the scale of carbon finance needed. This may not be required for each future project as some accreditation schemes allow activity-based assessments of additionality, meaning that once it is proved that destocking and restoration will not happen in the Falklands without carbon finance, this activity is deemed additional for each subsequent project.

Consultation with the Falkland Islands government will also be needed to confirm there is no legislation requiring landowners to restore peatlands on the islands. Any future legislation in this area might mean that new projects were not possible once the legislation had been introduced.

3. Permanence: Permanence can be difficult to assess in carbon crediting schemes involving land management changes as future landowners may change their practices in ways which reverse carbon savings. Furthermore, wildfire events or erosion can cause unexpected carbon losses from the project. To address these issues, a number of approaches can be adopted: firstly, to design the scheme such that legal commitments to management are made for the duration of the crediting period; secondly, to only sell credits for part of the project (e.g. first ten years) to limit the possibility for management reversal; thirdly, to build scientific understanding of the likelihood of potential losses through wildfire, maintenance of fencing, invasive species and erosion; fourthly, to specify a buffer pool of credits at 5 to 10% of project credits to insure against losses.

4. Leakage: to ensure that carbon savings in one project do not adversely affect other areas of the Falkland Islands issues surrounding leakage will have to be addressed. If project areas are removed from grazing it will have to be demonstrated that other areas will not be overgrazed as a result. This could be done either through land managers submitting alternative grazing plans with the project or demonstrating they have reduced herd numbers by a proportionate amount through their annual returns to the Department of Agriculture.

International leakage is not commonly addressed in carbon crediting schemes, however this should also be considered if the impact could be large as it may affect the reputation of the scheme. This can occur if the projects are likely to cause significant land use change in other countries. An example would be if a land manager stopped sheep production as part of a project and as a result, more land was brought into grazing in another country, potentially causing deforestation. This scenario is unlikely and can potentially be ruled out by quantifying any reduction in sheep numbers against the balance of imports and exports wool and lamb.

5. Monitoring and verification: a monitoring and verification scheme will have to be defined which is able to quantify the actual carbon savings against a baseline. This will have to be robust enough to provide confidence in the carbon savings whilst balancing costs to the scheme to remain economically viable. The use of proxies to assess restoration progress, such as vegetation cover, may be useful in minimising monitoring costs. Such proxies can likely be identified through a demonstration project and should include an assessment of invasive species which may impact on the potential carbon benefits.

Co-benefits and trade-offs

There are significant biodiversity co-benefits to Falkland restoration projects, and these can be quantified to increase the saleability of Falkland carbon credits. For example, the Verified Carbon Standard has an optional accreditation for projects which can demonstrate significant biodiversity gains through their Climate, Community & Biodiversity (CCB) standard. The Falkland Islands meet the requirement to achieve this standard as Key Biodiversity Areas have been identified (Langhammer et al. 2007). Therefore, if a Falklands scheme was registered with VCS they would also be able to register for the extra CCB standard which would likely attract a sale premium on carbon markets.

Trade-offs to restoration schemes include loss of farm income if livestock numbers are lower, inability to count credits against domestic climate targets, and potentially higher monitoring and verification costs than if the restoration was funded through, for example, donations. Furthermore, by introducing a market force driving restoration, rather than through government or philanthropic funding, there is

a risk that only the most economically viable restoration projects will be undertaken. The scale of this issue will need to be quantified in future work to help understand the choice of funding mechanism.

Scheme governance

A key decision in the development of a Falklands carbon offsetting scheme would be the choice of accreditation and thus which carbon markets the credits will be able to access. To be able to attract international CSR and CORSIA markets, it is recommended to undertake accreditation through a body such as the Verified Carbon Standard (VCS) or Gold Standard. These schemes have existing methodologies for peatland restoration and livestock management which could be adapted to the Falklands conditions. A Falklands scheme would be classified as a hybrid agricultural land management (ALM) and restoring wetland ecosystem (RWE) scheme, which VCS defines allowable activities as:

- a) Rewetting a wetland that includes the cultivation of biomass... to avoid long-term net soil organic carbon loss.
- b) Improved grassland management activities that reduce overgrazing, high-intensity use and gully erosion for reducing peat erosion on sloping peatlands.
- c) Improved cropland and grassland management activities that reduce wind erosion on peatlands that are devegetated or sparsely vegetated due to overgrazing, soil degradation or crop production.

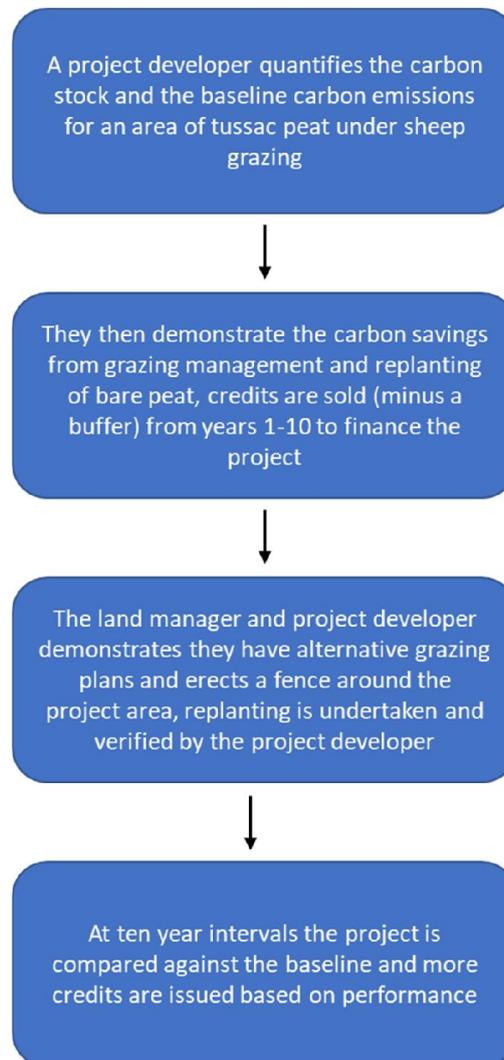
(from the VCS methodology requirements v4.0, 2019)

This would allow carbon credits to be issued for the difference in baseline emissions and restored emissions from the peat and, if destocking were undertaken, the lower emission of methane and nitrous oxide emissions from fewer sheep. Within the methodology a case would have to be made to allow the sale of the first ten years' worth of credits up front to finance the project, with future income only after monitoring and verification periods. This is acceptable within VCS methodologies, providing justification can be given, however this should be confirmed with the verification organisation as if it is not possible, different funding mechanisms may be required.

Under the VCS scheme, the organisation which develops a crediting methodology is eligible for 0.02 USD per credit issued under their method. Based on our earlier 'ballpark' estimate of the potential scale of a Falkland offsetting scheme (115-150 kt CO₂e yr⁻¹), this would mean potential revenue of around 2,300-3,100 USD yr⁻¹ to cover costs of developing the scheme and achieving accreditation (15,000 USD for method verification by VCS). Again, if credits for the first ten years can be sold up front, this would also cover the costs of method accreditation with a third party. A fee of approximately 0.1 USD is charged by the verification organisation which would increase the cost of sale of the credits.

An alternative to using VCS or Gold Standard would be to create a Falklands carbon code modelled on the UK peatland code with issuance of credits completed by Falklands Conservation or a similar body. This would potentially have lower costs of accreditation; however, many companies require an internationally recognised standard in order to purchase carbon credits so marketing the credits may become more onerous, though not impossible. For example, VCS credits are eligible to be sold into the CORSIA scheme whereas a novel Falklands scheme would not be. An advantage of using a scheme similar to the peatland code is that it would allow the sale of credits upfront, meaning finance would be available to complete the restoration without relying on loan financing or other mechanisms. An outline scheme is demonstrated in the flow chart in Figure 5.

Figure 5: An outline flow chart of steps to undertake a Falklands peatland restoration scheme



Future requirements to support scheme implementation

To be able to understand the potential scale of any carbon savings and costs to achieve them, further research will be needed in two key areas. Firstly, defining a baseline case of the carbon emissions from Falkland peat in a business as usual scenario over the next 100 years. Second, the impact of different restoration interventions on these carbon emissions and their risks of failure, such that potential credits can be quantified. To do this, further modelling work will be required to define the baseline and a demonstration project will be required to understand the costs, risks, potential co-benefits, and overall impact of the potential interventions.

Once these have been completed the funding mechanism for further restoration should be chosen. Key to this consideration will be the proportion of peat that could be restored in an economic manner, access to local or international markets, development of a long-term governance structure, the availability of carbon financing upfront and local environmental legislation.

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Appendix 1: Examples of the habitats, land-use and restoration activities described in the report

Figure A1. Diddle-dee (*Empetrum rubrum*) heath, Cape Dolphin

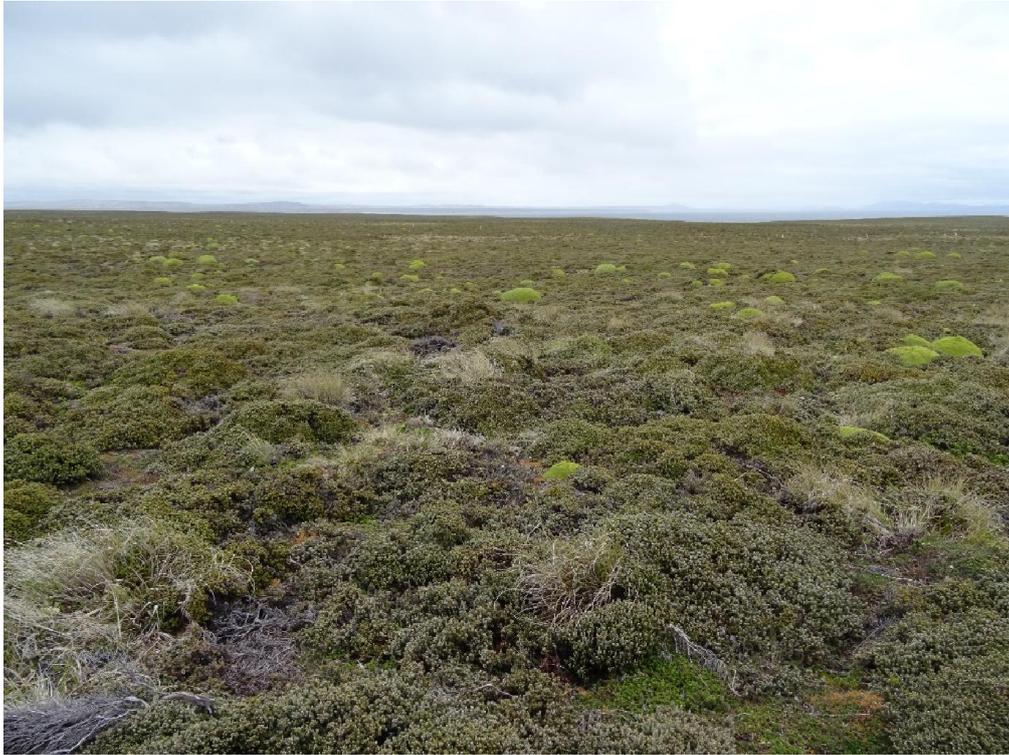


Figure A2. Soft camp bog (*Astelia pumila*) with eroding peat banks behind, Mount Longdon



Figure A3. *Sphagnum* hummocks in white grass bog, Stanley Common



Figure A4. Whitegrass (*Cortaderia pilosa*) on valley peat, Lafonia



Figure A5. Intact coastal tussac (*Poa flabellata*) with sea lions, Cape Dolphin



Figure A6. Sheep being gathered for shearing, Lafonia



Figure A7. Visible difference in whitegrass canopy height inside and outside a grazing enclosure



Figure A8. Burned whitegrass tussocks on shallow valley peat



Figure A9. Eroding upland peat banks, Goat Ridge



Figure A10. Erosion by off-road vehicles



Figure A11. Wind-eroded bare peat, Cape Pembroke



Figure A12. Peat cutting for fuel



Figure A13. Tussac planting on bare peat, Elephant Beach



Figure A14. Natural tussock regeneration following grazing control, Elephant Beach

