NatureScot
Scotland's Nature Agency

**NatureScot**

**SCIENTIFIC ADVISORY COMMITTEE**

**DISCUSSION PAPER**

# Carbon-Biodiversity Synergies

## Purpose

1. This paper explores the assumption that what is good for biodiversity is good for carbon sequestration, but the reverse (what is good for carbon sequestration and carbon stores is good for biodiversity) is not always the case. The issues raised are relevant to NatureScot advice on both the Scottish Government’s Climate Change Plan (in preparation from 2022) and the new Scottish Biodiversity Strategy (to be published in autumn 2022). We ask the Committee to endorse the value of the approach to inform policy thinking in these areas.

## Action

1. **The Committee is invited to discuss the paper and:**
2. **agree that the conceptual framing of the challenge is helpful in guiding policy choice;**
3. **support the underlying assumptions (given *in italics* in the paper);**
4. **comment on how this approach could be used to influence policy positioning and understanding of critical land use choices; and**
5. **comment on how the Committee can contribute further to the development of this approach.**

## Preparation

1. Clive Mitchell wrote the paper with contributions from Rebekka Artz, Patricia Bruneau, Duncan Stone, Cecile Smith, Alastair MacGugan, Donald Fraser, Karen Rentoul, Iain Sime, Deborah Spray, Colin Bean, Cathy Tilbrook, Nick Everett, Elana Bader and Des Thompson. Eileen Stuart sponsors it.

Background*(key assumptions in italics)*

1. The sustainable conservation and management of soils underpins NatureScot’s new Corporate Plan. The climate-nature crisis results from a short-circuiting of the carbon cycle through the burning of fossil fuels (about 70%) and land use change (about 30%). All life on Earth is carbon-based, and soils perform a pivotal role in the global carbon cycle. Soils are similarly important for ecosystems services vital to life, including nitrogen, nutrient and water cycles. *Healthy soils - diverse and effective functioning - are therefore essential to a healthy climate-nature system. The stronger our disruption to these cycles, the greater the problems for nature and people*.
2. Furthermore, the consequences of a changing climate will impact nature and the associated services that people depend on more severely the more degraded it is[[1]](#footnote-1). These consequences include increased frequency and intensity of floods, fires, drought, pests, disease and pandemics. *More diverse nature not only builds resilience to these events, it makes them less likely by correcting disruptions to biogeochemical cycles*.
3. All uses of the land and sea must be based on *simultaneously* reducing emissions for a 1.5°C goal, adapting to the 3°C world that current world action is leading us to, and enhancing the state of nature (see para 9). This is central to embedding the economy in nature[[2]](#footnote-2).
4. In addition to not burning fossil fuels, all land use must align to this triple challenge. Extending protected areas to cover 30% of Scotland by 2030 (‘30x30’) is not enough[[3]](#footnote-3). *All farming, forestry and development must play its role in creating diverse nature and healthy soils regulating a safe operating space for humanity*[[4]](#footnote-4). Anything less will be inadequate to meet Scotland’s contribution to net zero and the global 1.5°C target, condemning nature to further loss and degradation6. These multiple objectives must be achieved on the same land over the same time period, so integrated at fine scales. As a guide, 30-40% of land might be allocated for nature in the field, over the farm (or woodland or development or other ‘unit’) and across the catchment.
5. However, while it is possible to use the land and sea to meet the triple challenge of mitigation, adaptation and state of nature, there are many pathways that will present apparent trade-offs. Many of these are false choices that depend on *the boundaries of purported benefits such as the timeframes involved, the role of vegetation and of soils, short-term gains and long-term costs, likely losses from a changing climate including pests and disease*. Examples include intensively managed crop monocultures for bioenergy with carbon capture and storage and any use of the land that pursues a single objective or metric (such as carbon) over wider benefits and measures of ecosystem health.
6. In summary, uses of the land and sea (that is, nature) must simultaneously:

* Promote good soil health and associated soil functions including acting as a net sink for greenhouse gases and the soil resources including existing soil carbon stores
* Align with natural biogeochemical cycles and contribute to efforts to mitigate for a 1.5°C goal (especially through soils and marine sediments)
* Promote diverse nature to enhance resilience and provide other forms of adaptation to the consequences of a 3°C world
* Provide multiple benefits, whether the main use is for food, fibre, or, nature itself

*In most cases there will be need a need to address issues of consumption to achieve more sustainable production and embed the economy in nature.*

1. This discussion describes a much broader notion of nature than is the focus of ‘conservation’ over the last several decades, which has mainly ignored soils and restricted itself largely to protected areas and certain species and habitats of concern. The role of life in regulating a safe operating space for humanity is much more than this, and could form the basis of a new paradigm for conservation[[5]](#footnote-5).
2. During 2021, we engaged JHI in a SEFARI Fellowship to explore evaluative frameworks for nature-based solutions. It [recommended](https://sefari.scot/research/nature-based-solutions-%E2%80%93-how-should-we-plan-and-evaluate-them) that we should use the widely endorsed IUCN Global Standard, with links to some other frameworks for specific detail. This approach, which includes explicit attention to trade-offs between benefits, is consistent with the recommendations in para 9. We are using this for existing projects, including Cairngorm Connect, and recommending its use by our partners in the [Economy and Environment Leaders Group](https://www.environment.gov.scot/about-us/our-partners/).

## Carbon-Biodiversity Synergies

1. Using para 9 as a guide, we can examine carbon-biodiversity synergies and trade-offs. **Please read Annex A for detail first**. In summary:

**Peatland restoration** (Annex A, para 1)

*Good for biodiversity 🡺 good for carbon? Y*es – but need time for full benefits to be realised.

*Good for carbon 🡺 good for biodiversity? Y*es – but need time for full benefits to be realised.

**Woodland restoration** (Annex A, para 2)

*Good for biodiversity 🡺 good for carbon?* Yes: emphasis will be on native woodlands, diversity and resilience.

*Good for carbon 🡺 good for biodiversity?*

* *Yes* for native woodlands
* *It depends* for production monocultures. Monocultures enhance vulnerability to pests, pathogens and other effects of climate change including windthrow (planting density etc). Carbon benefits depend on soil disturbance and management. Market conditions will determine durability of felled timber. ‘Leakage’ (importing timber to satisfy demand; exporting the environmental footprint) is more likely without changing consumer behaviours including rates of consumption and demand for certain products.

**Restorative Farming** (Annex A, para 3)

*Good for biodiversity 🡺 good for carbon?* Yes.

*Good for carbon 🡺 good for biodiversity?*

* *Yes -* for restorative/regenerative farming techniques and multiple benefits including diversity and soil health (including carbon and reducing compaction).
* *No -* for pursuit of single benefits (including crops for CO2 removal) likely to be damaging for biodiversity and vulnerability to the risks associated with a changing climate.
* Both depend on changes in behaviour so that consumption aligns with and supports sustainable production in Scotland and overseas, and reduces the risk of ‘leakage’ (importing food and drink to satisfy demand; exporting the environmental footprint).

**Upland management** (Annex A, para 4)

*Good for biodiversity 🡺 good for carbon? Y*es

*Good for carbon 🡺 good for biodiversity?*

* *Yes* for restorative upland management for multiple benefits
* *No* for the pursuit of single benefits likely to be damaging for biodiversity and vulnerable to the risks associated with a changing climate.
* Disputes about management largely depend on visions of, or for, the uplands. Marginal ground is likely to be most contested for farming, woodland, conservation and management for quarry species if these continue to be viewed as competing, exclusive interests (but they can and are being integrated on some estates).

**Teal Carbon - freshwater systems** (Annex A, para 5)

*Good for biodiversity 🡺 good for carbon?* Yes – but knowledge gaps, and areas are subject to erosional loss during storm and flood events; and carbon accumulation in floodplain meadow grasslands depends on grazing/cutting offtake.

*Good for carbon 🡺 good for biodiversity? Depends* on detailed design and allowance for the natural dynamism of rivers.

**Blue Carbon – Scotland’s seas and coastal habitats** (Annex A, para 6)

*Good for biodiversity 🡺 good for carbon?* Generally yes. Key exception is that for a significant proportion of coastal habitats, management for biodiversity may do little to prevent erosional net loss of carbon due to sea-level rise.

*Good for carbon 🡺 good for biodiversity?* Yes.

**Carbon in towns and cities – green infrastructure** (Annex A, para 7)

*Good for biodiversity 🡺 good for carbon? Y*es – but significant changes in urban design required to design nature into the urban fabric to realise its multiple societal, environmental, and economic benefits for a wide range of people.

*Good for carbon 🡺 good for biodiversity?* Yes, if designed for multiple benefits.

* The attitudes, behaviours and consumption patterns of people, who mainly live in towns and cities, are essential to meeting the operating environment set out in para 9.
* Stronger recognition of rural-urban interdependencies required to e.g. reduce peak flow rates and surface water management in towns, and to align objectives for production (forests and farmland) with consumption.

## Next steps: key issues to resolve for the CCP and SBS

1. The principal output for this work will be embedded in the Scottish Biodiversity Strategy and Climate Change Plan (drawing on the conceptual framework here (paras 4-11)). We propose to work with others to fill knowledge gaps, especially by designing impact studies into interventions in more contentious settings such as the uplands. **We propose to publish a paper on this approach, and would welcome the Committee’s advice and input on this.**
2. We are developing some scenarios work to build capacity and understanding of how climate and nature may change under three main scenarios:

* **Low emission**: a 1.5-2°C scenario for 2040-2060, 2080-2100[[6]](#footnote-6) and 2100+ (this includes c.1.3°C increase by 2030 (a further 0.1-0.2°C from today) and 1.5-2°C by 2050)
* **High emission**: a 1.5-2°C scenario for 2040-2060 and a 3-4°C scenario for 2080-2100 and 2100+
* **Beyond 2100**: comments on longer-term effects, especially for ecosystems, for a range of emission scenarios.

**We would welcome it if one or two Committee members would provide quality assurance for the report, based on their expertise.** We expect the report to be available in March/April 2022.

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# Annex A: detailed carbon-biodiversity relationships for key habitats

## Green Carbon

## Peatland restoration

Peatland and carbon rich soils in Scotland have accumulated over thousands of years and hold more than two-thirds of our terrestrial stock of carbon. Ensuring that this resource is protected from permanent loss and incipient degradation is an essential first step in securing a net zero future; followed by restoring the functionality of degraded peatland habitat.

Around 80% of the peatland area (or 1.8 million hectares) in Scotland is degraded and no longer acts as a carbon sink, contributing to 20% of Scotland’s total emissions (approximately 9.7MtCO2e, similar to the transport sector). Historic human pressures on the land stretch back to the Bronze Age but are mostly related to increased use in the last 200 years[[7]](#footnote-7) and include drainage, excessive grazing (especially sheep and deer), afforestation, and conversion to grassland or even cropland (much of the latter now long abandoned; 7,[[8]](#footnote-8)). Consequently, peatlands are fragmented at both local and landscape scale, resulting in significant loss of habitat that once supported both generalist species and unique, wetland-specific, biota across all trophic levels7. In addition to fragmentation, these land uses typically lower the mean water table of peatlands and reduce surface soil moisture leading to carbon loss and lack of available water for peatland specialists and impacts on timing for e.g. hatching of invertebrate species7.

Restoration management aims to raise the water level, sometimes reintroducing peatland vegetation, to return peatland to being carbon-neutral or even a net sink. This will also improve peatland-specific biodiversity interests and wider habitat condition to support e.g. specialist and more generalist upland breeding birds, mammals and other vertebrate species, including those with high conservation status8,[[9]](#footnote-9). The benefits of restoration management on invertebrate and microbial populations also suggest positive impacts, however these have been largely understudied to date. Due to the relatively low capacity for dispersal of some species, success may be slower in areas where populations have been lost (requiring translocation with the associated risk of inadvertent pest or competing genotype introductions), or where the required habitat structure is difficult to reinstate. As such, reversion to a more natural state, with a full complement of peatland species, may take decades even with perfectly recreated biogeochemical and topographical condition, due to slow growth rates or limited donor pools/dispersal potential of some species8. This does not undermine the need to act early to restore degraded peatlands to reduce the adverse consequences of not doing so by limiting positive feedbacks in the climate system. There is a need to clarify the emission factors for plantation wood to restored bog transitions to allow more extensive restoration work.

There are also a large number of co-benefits in restoration, such as improved water quality, flood attenuation, and multiple social and cultural services to society, but further work is required to demonstrate these benefits from Scottish restoration projects[[10]](#footnote-10).

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*Good for carbon 🡺 good for biodiversity? Y*es – but need time for full benefits to be realised.

## Woodland restoration

In recent decades woodland development in Scotland has been polarised into ‘production’ and ‘native’ woodlands, with these respectively seeking to optimise timber production and biodiversity. Both claim carbon sequestration and storage as important outcomes.

Production woodlands are dominated by a single species, Sitka spruce. The components nominally allocated to nature (5% broadleaved woodland, 10% open space) are normally heavily grazed and of limited value for biodiversity. The sheer scale of production woodlands does benefit the species that can use them, including the rise of roe and sika deer populations, and, possibly, some woodland birds. However, these woodlands are typically poor for woodland plants and specialist species, especially those that depend upon native tree species and old-forest niches like large-dimension deadwood. A strategy to capture carbon in natural systems through production woodlands is likely to be poor for biodiversity. Purported carbon benefits depend strongly on whether soil disturbance and soil carbon is accounted for, especially on organic soils, as well as the use of the timber after felling. In addition, relying on a single, or few, species also increases the risks of loss arising from pests and pathogens, with long-standing efforts to control spruce bark beetles and aphids that could either kill trees, slow their growth or degrade timber quality.

Although native woodlands can support a range of specialised woodland species, most are in poor condition and so deliver much less than they could both for nature and for carbon capture. This is principally because they are subject to high grazing pressure in spite of the widespread use of deer fence exclosures. Invasive non-native species are also a serious problem in some areas.

Not all woodlands need to satisfy all of the aims of para 9 equally. Production woodlands should do better for biodiversity and there is a case for generating more economic activity in native woodlands, given the continuing costs of deer management. However, the most necessary change is in respect of resilience – the ability of our woodlands to absorb or bounce back from adverse impacts of changing environmental pressures, such as temperature, precipitation, drought, seasonal change, wildfire, pests, pathogens and changes in plant competitive advantage. This is especially so over the decades or centuries that typify woodland systems. Resilience needs to span both a warming climate in the medium term (before 2100, at least 0.5°C warmer than the last 100 years, possibly a further 1-2°C) and the possibility of regional cooling in the longer term (to 2300, due to weakening or shutdown of the Atlantic Meridional Overturning Current, depending on ice sheet stability).

A changing climate calls into question what is ‘native’ to Scotland, including, e.g. field maple, beech, hornbeam, lime, and how niches occupied by elm and ash are filled.

Planning woodlands for resilience is key to all objectives, including production, carbon and biodiversity. Thus far attention is mainly on tree health and biosecurity and very little has been done to increase resilience at a woodland or landscape level. Recent storms (Arwen, Corrie, Malik) have exposed the vulnerability of Sitka plantations to windthrow while native woodlands in similar areas have not been affected. We also need more diversity in the species and structure of woodlands. This includes production woodlands with a wider range of species, on a wider range of sites with different types of silvicultural management. It also means that some broadleaved and native woodlands should have more species diversity and be managed for broadleaved timber as well as for nature (we are currently exploring birchwood productive systems).

A significant area of uncertainty lies in the relative importance of peatlands and woodlands as carbon sinks in a warmer, drier climate (e.g. the east of Scotland), with the potential for fire to be a more important ecological driver. This includes succession to scrub/woodland/grassland systems with (what are now) southern tree species, similar to the Holocene Thermal Maximum, around 8,000 years ago when temperatures were about 2°C warmer than today.

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* *Yes* for native woodlands
* *It depends* for production monocultures. Monocultures enhance vulnerability to pests, pathogens and other effects of climate change including windthrow (planting density etc). Carbon benefits depend on soil disturbance and management. Market conditions will determine durability of felled timber. ‘Leakage’ (importing timber to satisfy demand; exporting the environmental footprint) is more likely without changing consumer behaviours including rates of consumption and demand for certain products.

## Restorative farming

Farmland covers about 70% of Scotland. Typical habitats include: cultivated land (grassland or crops), field margins (grassy or flower rich mixes), hedgerows, farm woodland, wetland. Farming activities result in three types of greenhouse gas emissions: methane (animals and manure), nitrous oxide (fertilisers and manure, emissions from soil), and carbon dioxide (energy use, and cultivation method). The largest share of emissions from agricultural activities originates from livestock, not cultivated soils. However, much can be done to improve carbon sequestration on farmland (both soil and above ground vegetation in uncultivated soils) and avoid loss of nitrogen and carbon.

In cultivated land, soil health and quality, erosion risk, biodiversity and net greenhouse gas emissions are controlled by interactions between crops and ecosystems services including the choice of crop and how they are managed including whether legumes are included in the rotation and the use of cover crops. There is potential to improve soil quality in these soils and build and maintain organic matter, particularly on arable soils. Agricultural habitats, especially permanent grasslands, can be important carbon stores. Carbon stored in various agricultural habitats include about 100 Mt C in arable, 170 Mt C in improved grasslands[[11]](#footnote-11), 900 MtC in moorland, 330 Mt C in rough grazing[[12]](#footnote-12).

Opportunities for carbon sequestration are variable. Hedgerows and agroforestry can be integrated on farmland, so farming is maintained, even if changed. Most hedgerows were destroyed in the 20th century and those that remain are generally in poor condition (too small; too narrow). Significantly expanding hedgerows around field boundaries, making them wider and taller would deliver both carbon sequestration and biodiversity benefits. Although some wood pasture remains, agroforestry is uncommon beyond a few pioneering farms but could sequester up to 5 tCO2e/ha/year depending on management and site conditions. Agroforestry systems are more diverse than crop monocultures and improved grassland and support a greater species diversity including arthropods, improving soil health. By integrating trees within the agricultural matrix, agroforestry and hedgerows contribute to nature networks, allowing species to move through landscapes.

Arable soils are generally net sources of greenhouse gases (< 1 tCO2e/ha/year). Cover crops may sequester up to ~ 1 t CO2e/ha/year, as well as grass leys in rotation. For permanent grasslands, sequestration will depend on whether the grassland is already at equilibrium. Research is underway to improve understanding of the link between sward diversity in grassland and carbon sequestration. Minimum till and direct drilling reduce erosion, and benefit soil microbiota and fauna, but associated carbon benefits (compared with ploughing) remain inconclusive.

Nitrous oxide emissions are associated with the application of nitrogen fertiliser while run off and leaching result in water pollution. Excessive amounts of nitrogen are currently released into the environment. These can be reduced by using nutrient budgeting plans and technology. Traditional rotations including legumes and the use of green manure can help to increase organic matter while also supplying nitrogen to the plant and providing flowers for pollinators. These agroecological measures do not eliminate the risk of nitrogen loss, but provide a multiple benefits approach to plant nutrition, unlike synthetic fertilisers.

Most of Scotland’s land is used for livestock farming. The associated greenhouse gas emissions could be reduced, overall, for example by including objectives for biodiversity through rotational grazing, more diverse swards, silvopasture (agroforestry) and hedgerows; all of which would enhance sequestration on the land, though not necessarily reduce emissions from the animals. For both beef and dairy farming animal emissions depend on diet, health and breeding.

Farm management is tied to the food system as a whole. Whilst considering production in Scotland, it is important to take into account patterns of consumption.

The controversy surrounding the consumption of red meat and its impact on climate takes three forms: 1) reduced/no meat consumption; 2) consume white meat instead; 3) red meat from pasture-fed ruminants is sustainable because of the carbon sequestration in the soil. Additional benefits of pasture-fed livestock systems include maintaining habitats such as species-rich grasslands. Sourcing meat from Scottish farms that satisfy the objectives in para 9 reduces the environmental footprint of consuming meat imported from other parts of the world with less sustainable systems.

Considerations above for more regenerative farm systems apply to emerging pressures for crops that remove CO2 from the atmosphere, such as bioenergy with carbon capture and storage. If mainly driven by the amounts of CO2 stored, then production systems are likely to be geared for bulk productivity. Production of these and other new crops should satisfy the objectives in para 9.

*Good for biodiversity 🡺 good for carbon?* Yes.

*Good for carbon 🡺 good for biodiversity?*

* *Yes -* for restorative/regenerative farming techniques and multiple benefits including diversity and soil health (including carbon and reducing compaction).
* *No -* for pursuit of single benefits (including crops for CO2 removal) likely to be damaging for biodiversity and vulnerable to the risks associated with a changing climate.
* Both depend on changes in behaviour so that consumption aligns with and supports sustainable production in Scotland and overseas, and reduces the risk of ‘leakage’ (importing food and drink to satisfy demand; exporting the environmental footprint).

## Upland management

Upland habitats can be diverse, comprising peatlands, heaths, fens, flushes, grassland, tall herb communities, scrub, riparian woodlands, and summit communities. These habitats have different abilities to store carbon and ways in which carbon is stored between soils and vegetation. Approximate grouped values for carbon storage are usually calculated from the above ground vegetation and the top layers of soil e.g. (for vegetation plus soil to 100cm depth[[13]](#footnote-13)): upland dry heath – 205 t C ha-1; wet heath 313 t C ha-1; *Molinia* grassland 237 t C ha-1; and, other grassland with *Molinia* 337 t C ha-1. If considering management solely for carbon storage, ‘other grassland with *Molinia’* has the greatest value, but these systems tend to be species poor, with degraded wet heath or wet woodland supporting greater biodiversity. Uplands are managed in a variety of ways for a range of objectives some of which lead to carbon/biodiversity losses and gains.

The biodiversity of open habitats, including species rich grasslands, flushes and tall herb communities and associated wader populations, is an important part of our uplands. These habitats often readily succeed to trees/woodlands. A functioning woodland which contains ground flora and scrub layers results in a high potential for carbon storage[[14]](#footnote-14), but with woodland rather than open habitat biodiversity.

A balance is needed between habitats that store the greatest amount of carbon and those that support a greater diversity of species. Such diversity across landscapes will provide resilience to a changing climate. Similarly, re-establishing riparian woodlands, scrub and enhancement of montane scrub should consider net gains and losses for multiple benefits, not only carbon.

The role of muirburn as a management tool is contested with potential benefits depending on how and when it is carried out. Burning can change vegetation composition by reducing/removing fire intolerant species. Grazing, browsing and trampling pressures from herbivores can also have positive or negative impacts depending on habitat susceptibility, e.g. open habitats will benefit from some grazing, whereas woodlands are less tolerant. Regenerating trees can be a pressure on open moorland habitats in the uplands and on species like waders (by providing cover for predators and reducing potential nesting and feeding habitats).

Competing objectives including those for woodland and open habitat can be managed through integrated land management plans and deer management plans, with cull targets, developed to achieve a range of management objectives, focusing on appropriate grazing levels to allow open habitats for biodiversity and/or woodland habitats. Models can be used to evaluate trade-offs between biodiversity and carbon sequestration for a range of land management decisions. Open, moorland habitats sequester carbon and support ground nesting birds; deer and other quarry management supports local economies and employment in the uplands.

The impacts of controlled burning (muirburn) on reducing fire risk, biodiversity, soil condition and net emissions in the short and long term[[15]](#footnote-15) is contested. Preferred locations for woodland expansion in the uplands are also disputed due to impacts on net emissions and loss of carbon from carbon rich soils. There are mixed results on the effects of tree planting on shallow peaty/carbon rich soils. Disputes often reflect markedly differing visions of, or for, the uplands.

*Good for biodiversity 🡺 good for carbon? Y*es

*Good for carbon 🡺 good for biodiversity?*

* *Yes* for restorative upland management for multiple benefits
* *No* for the pursuit of single benefits likely to be damaging for biodiversity and vulnerability to the risks associated with a changing climate.
* Disputes about management largely depend on visions of, or for, the uplands. Marginal ground is likely to be most contested for farming, woodland, conservation and management for quarry species if these continue to be viewed as competing, exclusive interests (but they can and are being integrated on some estates).

## Teal Carbon

## Carbon in freshwater systems

Often overlooked in terms of transitioning to net zero, freshwaters play a major role in the carbon cycle, transferring carbon from terrestrial to marine reservoirs. Although limited, studies suggest large mitigation potential in Scottish freshwater systems. Most of the carbon is stored or sequestered in ponds, plant biomass and wetland soils and loch sediments. The main flows include increasing dissolved organic carbon (DOC – a significant component arising from re-naturalising of soil following reduction in sulphur deposition), but also from erosion as particulate inorganic carbon (PIC) and organic carbon (POC), dissolved inorganic carbon (DIC) plus NOx and NH4.

The freshwater cycle is disrupted especially through habitat change and fragmentation including: the disconnection between floodplains and rivers/lochs; drainage of floodplain wetlands; fragmentation and loss of wetlands, ponds; loss of riparian woodland (and lack of regeneration due to e.g. grazing pressure); eutrophication; loss of wetlands to afforestation; and, lack of active management of wetlands.

Restoring natural freshwater systems and processes, including enhancing carbon sequestration and restoring biodiversity involves: reinstating floodplains as floodplains; drain blocking; habitat creation (ponds and riparian woodlands); floodplain/wet meadow management; river restoration; species reintroductions (beavers); reducing grazing pressure; restoring and creating wetland habitat (beyond current wetland boundaries); and, reinstating active management of wetlands.

Co-benefits of restoring freshwater systems include: flood management (catchments); nutrient cycling; shading and climate refugia (freshwater fish and pearl mussel); and, improved resilience of wetland habitats to climate change.

The scale of carbon sequestration in some habitats remains unclear (e.g. some loch sediments). Evidence base of some nature-based solution is limited to small catchments – there is a need for large scale empirical research to inform upscaling. Improved knowledge of the location, extent and type of wetlands in the wider countryside required to inform priorities for site selection and development of large scale wetland creation /restoration projects.

*Good for biodiversity 🡺 good for carbon?* Yes – but knowledge gaps, and areas are subject to erosional loss during storm and flood events; and carbon accumulation in floodplain meadow grasslands depends on grazing/cutting offtake.

*Good for carbon 🡺 good for biodiversity?* Can be but depends on detailed design and allowance for the natural dynamism of rivers.

## Blue Carbon

## Carbon in Scotland seas and coastal habitats

In Scotland, coastal and marine habitats (saltmarshes, sand dunes, machair, seagrasses, kelp beds and biogenic reefs) and marine sediments can all contribute to carbon storage. Marine sediments store the vast majority of this carbon, with over 9,600 megatonnes of CO2 equivalent[[16]](#footnote-16) (Mt CO2-eq) – equivalent to 230 times Scotland’s annual emissions figures - stored in Scottish marine sediments down to a depth of 0.1 m. Annually, Scotland's blue carbon habitats sequester an estimated 28.4 Mt CO2-eq[[17]](#footnote-17). Marine sediments again sequester a high proportion of this carbon, due to their great extent, but saltmarsh is believed to have the highest sequestration rate per area.

Although it is likely that various pressures will impact on the effectiveness of blue carbon sequestration and storage, little is yet understood. For example, although it is likely that grazing intensity on saltmarshes will affect carbon storage, research findings are currently limited and inconclusive on the interactions and optimum management (for carbon and for biodiversity). There is also significant current interest in the impact of seabed disturbance on sedimentary blue carbon stores, but the evidence base is still being developed. Early work suggests that both the marine sediment characteristics (e.g. carbon content, susceptibility of carbon to change) and the intensity and type of disturbance (e.g. nature of fishing gear used) will affect sedimentary carbon release. Impacts will therefore be very spatially varied. There is also uncertainty on the ultimate fate of any CO2 released into the water column (e.g. whether it will contribute to atmospheric CO2 levels or remain within the sea, perhaps affecting ocean pH levels).

For most areas of coastal habitats, both sequestration and biodiversity fundamentally depend on natural functioning, with dunes, marshes and other landforms evolving dynamically. The installation of artificial defences to reduce coastal erosion is typically counterproductive, severing the process linkages that otherwise support sequestration and biodiversity. However, management for biodiversity doesn’t necessarily secure net carbon *storage*. This is because in many Scottish locations, accelerating sea-level rise will cause increasing net erosional loss of coastal habitats[[18]](#footnote-18) - though there is uncertainty over re-sequestration of eroded carbon in intertidal or seabed sediments. In certain limited situations where habitats could potentially expand inland, this is very often constrained by existing land uses, from agriculture to built development.

Better understanding these interactions is key to informing management and conservation approaches. These aspects are being explored by the Scottish Blue Carbon Forum and will inform policy development in relation to marine protection (e.g. Highly Protected Marine Area work); broader marine planning and fisheries management; and guidance on coastal and marine habitat recovery and enhancement. In most cases, the priority will be to manage or remove existing pressures in order to allow degraded marine and coastal habitats to naturally recover their biodiversity and sequestration potential. However, in some limited cases, intervention to restore or create habitats, such as managed coastal realignment to expand saltmarsh and/or tidal flats, can be a useful approach. Here the potential gains for biodiversity have been contested, and together with sequestration potential, have yet to be fully demonstrated.

As well as trapping and storing carbon, blue carbon habitats can help in climate adaptation and provide a range of other benefits for nature and society. Investing in their health can provide valuable nature-based solutions and bolster Scotland’s natural capital assets. For example, as well as carbon storage and sequestration, a healthy saltmarsh can also provide resilience to sea level rise / coastal flooding and erosion; a nursery habitat to benefit fisheries productivity; and wildlife habitat and recreational opportunities.

*Good for biodiversity 🡺 good for carbon?* Generally yes. Key exception is that for a significant proportion of coastal habitats, management for biodiversity may do little to prevent erosional net loss of carbon due to sea-level rise.

*Good for carbon 🡺 good for biodiversity?* Yes.

## Urban Carbon

## Carbon in towns and cities – green infrastructure

Over 80% of Scotland’s people live in towns and cities. This paper focuses on carbon/biodiversity synergies and not the wider benefits of green infrastructure which we are marshalling, for example, through the Green Infrastructure Strategic Intervention and Green Health Partnerships.

Carbon-benefits are generally overlooked as small or marginal, but UK urban forests can store as much carbon as tropical rainforests[[19]](#footnote-19). The numbers of trees in urban settings add up to a small woodland for most settlements, but are not currently counted in this way (e.g. the city of Leicester covers approximately 0.03% of Britain’s land area but accounts for approximately 0.2% of Britain’s above ground carbon store with over 230,000 tonnes of carbon stored, 97.3% of this is attributable to trees[[20]](#footnote-20)). In Scotland, there are plans to plant 18 million trees in the Clyde Climate Forest alone, with another set of millions of trees being planned for the Forth Climate Forest, both looking at canopy, connectivity, and carbon. Many of these will be in urban areas, but reaching into catchments further helps to reduce peak flow and flood risk in urban settings. In addition to the UK practice of removing soils for construction, urban drainage has significantly altered local hydrology and soil characteristics, including soil health, soil carbon, compaction and sealing[[21]](#footnote-21), which contribute to surface water run-off rates and flood risk.

Integration of grey/blue-green infrastructure can reduce or even waive the need for some grey infrastructure interventions, such as the North Glasgow Integrated Water Management System in Glasgow. By diverting surface water into the Smart Canal system, the project will realise an initial 5,000t CO2eq capital saving combined with a 500t CO2eq/annum saving over the 60 year operational agreement, compared to a standard traditional drainage solution, at 35% (£15m) of the cost of the alternative, grey solution (ca. £45m). More generally, Scottish Water are increasingly focused on blue-green infrastructure to reduce the costs (including carbon intensity) of managing surface water run-off through engineered solutions, for example in Edinburgh and Dundee.

Flood risk in urban settings involves significant rural/urban interdependencies including land management throughout the catchment from peatland restoration, through woodlands, soil health and compaction, to wetlands and rivers, depending on the intensity and patterns of rainfall. Within settlements, blue-green infrastructure – biodiversity – is required to supplement traditional piped sewer systems and channelized urban waterways to manage the increased frequency and intensity of rainfall in a changing climate. Sustainable drainage systems (SuDS) mimic natural drainage using, e.g. raingardens, permeable pavements, swales and wetlands[[22]](#footnote-22).

Highly modified urban environments create highly modified perceptions of nature through reduced opportunities to directly experience nature, leading to an “extinction of experience” that drives shifting baseline syndrome (SBS) and its consequences[[23]](#footnote-23),[[24]](#footnote-24). In turn, the indirect drivers of biodiversity loss and over-exploitation of natural resources that fuel climate change, are created and intensified[[25]](#footnote-25).

The extent to which production of timber, food, drink and fibre in rural settings aligns with enhancing the state of nature depends on consumer preferences for those, or other, less sustainable products, including those sourced overseas. Addressing ‘leakage’, wherein production standards in Scotland lead to increased demand for less sustainably sourced products from overseas is vital to a just transition.

*Good for biodiversity 🡺 good for carbon? Y*es – but significant changes in urban design required to design nature into the urban fabric to realise its multiple societal, environmental, and economic benefits for a wide range of people.

*Good for carbon 🡺 good for biodiversity?* Yes, if designed for multiple benefits.

* The attitudes, behaviours and consumption patterns of people, who mainly live in towns and cities, are essential to meeting the operating environment set out in para 9.
* Stronger recognition of rural-urban interdependencies required to e.g. reduce peak flow rates and surface water management in towns, and to align objectives for production (forests and farmland) with consumption.

1. E.g. successive IPCC reports and IPBES (2019) [↑](#footnote-ref-1)
2. Dasgupta (2021) The Economics of Biodiversity [↑](#footnote-ref-2)
3. E.g. CCC recommendations [↑](#footnote-ref-3)
4. Rockström et al (2021) – [We need biosphere stewardship that protects carbon sinks and builds resilience. *PNAS* **118** (38)](https://www.pnas.org/content/118/38/e2115218118) [↑](#footnote-ref-4)
5. IPCC/IPBES (2021) [Biodiversity and Climate Change workshop report](https://ipbes.net/sites/default/files/2021-06/20210609_workshop_report_embargo_3pm_CEST_10_june_0.pdf), p.16 (para 8) [↑](#footnote-ref-5)
6. This also covers 2030 in that 2030 is a mix of today and mid-Century [↑](#footnote-ref-6)
7. IUCN (2010) [Peatlands and the Historic Environment](https://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/Review%20Peatland%20Historic%20Environment,%20June%202011%20Final.pdf) [↑](#footnote-ref-7)
8. IUCN (2010) [Peatland Biodiversity](https://www.iucn-uk-peatlandprogramme.org/sites/default/files/Review%20Peatland%20Biodiversity%2C%20June%202011%20Final_1.pdf) [↑](#footnote-ref-8)
9. Minayeva, T et al (2016) [Peatland biodiversity and its restoration](https://discovery.dundee.ac.uk/ws/files/18392264/CHAPTER_THREE.pdf). In [A. Bonn et al (eds) *Peatland Restoration and Ecosystem Services: Science, Policy and Practice* (pp. 44-62). (Ecological Reviews). Cambridge University Press.](https://www.cambridge.org/core/books/abs/peatland-restoration-and-ecosystem-services/peatland-biodiversity-and-its-restoration/7D9E5F919AC0A2D1D37BED56EE2FB4EE) [↑](#footnote-ref-9)
10. Artz R et al (2018) [Peatland restoration – a comparative analysis of the](https://www.climatexchange.org.uk/media/3141/peatland-restoration-methods-a-comparative-analysis.pdf)

    [costs and merits of different restoration methods](https://www.climatexchange.org.uk/media/3141/peatland-restoration-methods-a-comparative-analysis.pdf). ClimateXchange [↑](#footnote-ref-10)
11. [ClimateXChange - payment for carbon sequestration in soils - a scoping study](https://www.climatexchange.org.uk/media/3629/payment-for-carbon-sequestration-in-soils-a-scoping-study.pdf) [↑](#footnote-ref-11)
12. Pers comm from James Hutton Institute: Carbon stocks were calculated for each soil unit found on the National Soil Map of Scotland and then aggregated by LCM2007 land cover map habitat types by intersecting the soil data with the land cover map. Thus, we calculate to a depth of 1 m and rounded to 100 MT C02e [↑](#footnote-ref-12)
13. Baggaley NJ, et al (2021) [*Understanding carbon sequestration in upland habitats*. ClimateXChange.](https://era.ed.ac.uk/handle/1842/37744) [↑](#footnote-ref-13)
14. Gregg R et al (2021) *Carbon storage and sequestration by habitat: a review of the evidence (second edition)*. Natural England Research report NERR094, Natural England, York. [↑](#footnote-ref-14)
15. *Burning impacts on soil carbon and carbon storage* – NatureScot commissioned work to be delivered by Autumn 2022 (linked with Muirburn Licensing evidence) [↑](#footnote-ref-15)
16. Smeaton, et al., 2021 [↑](#footnote-ref-16)
17. Shafiee, 2021 [↑](#footnote-ref-17)
18. www.dynamiccoast.com [↑](#footnote-ref-18)
19. [UK urban forest can store as much carbon as tropical rainforests](https://www.ucl.ac.uk/news/2018/jun/uk-urban-forest-can-store-much-carbon-tropical-rainforests), UCL News (2018); [City trees and soil are sucking more carbon out of the atmosphere than previously thought](https://phys.org/news/2022-02-city-trees-soil-carbon-atmosphere.html), Phys Org, Feb 2022 [↑](#footnote-ref-19)
20. Davies, Z.G., et al. (2011). [Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale](https://besjournals.onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2011.02021.x). *Journal of Applied Ecology*, 48, 1125-1134. [↑](#footnote-ref-20)
21. E.g. Rodríguez-Espinosa, T et al. (2021) Urban areas, human health and technosols for the green deal. *Environmental geochemistry and health* **43** (12): 5065-5086. [doi:10.1007/s10653-021-00953-8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8093134/) [↑](#footnote-ref-21)
22. E.g. Cadotte MW et al (2021) Nature-Based Solutions and the Built Environment, Ch 11 *In* Stafford, R et al (Eds.) [Nature-based Solutions for Climate Change in the UK: A Report by the British Ecological Society](https://www.britishecologicalsociety.org/policy/nature-based-solutions/read-the-report/). London, UK. [↑](#footnote-ref-22)
23. Miller, J.R. (2005). Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution* **20** (8) 430-434. [doi.org/10.1016/j.tree.2005.05.013](https://doi.org/10.1016/j.tree.2005.05.013) [↑](#footnote-ref-23)
24. Soga, M and Gaston, K.J. (2018). Shifting baseline syndrome: causes, consequences, and implications. *Frontiers in Ecology and the Environment* **16** (4): 222-230. [doi.org/10.1002/fee.1794](https://doi.org/10.1002/fee.1794) [↑](#footnote-ref-24)
25. E.g. Bulkeley H et al (2021) [Realising the Urban Opportunity: Cities and the Post-2020 Biodiversity Governance](https://www.pbl.nl/sites/default/files/downloads/pbl-2021-realising-the-urban-opportunity-4247.pdf), PBL Netherlands Environmental Assessment Agency. [↑](#footnote-ref-25)