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Blue carbon

Marine ecosystems around the UK can both increase and decrease atmospheric carbon dioxide levels. Carbon loss and gain globally by these ecosystems has the potential to influence climate change. This POSTnote summarises the marine ecosystems in the UK that contribute to these processes, their current and potential future extent, and pressures on them.

Overview

- 'Blue carbon' refers to carbon that is stored in marine ecosystems, where management of those ecosystems impacts that carbon.
- These ecosystems sequester and store around 2% of UK emissions per year.
- Marine ecosystems also provide other benefits such as biodiversity, flood protection, and support for valuable fish and shellfish populations.
- Disturbance of marine ecosystems may result in release of stored carbon and thereby contribute to climate change, but the exact volume released is unknown. The UK Government will pilot new approaches to protecting blue carbon.
- Investment in blue carbon projects in the UK is limited by a lack of verifiable standards and scientific evidence, although development of codes is ongoing.
- Blue carbon projects are not a substitute for substantial emissions reductions.

Background

The UK is legally committed to reaching net zero emissions of greenhouse gasses (GHGs) by 2050, with an interim commitment to a 78% reduction from 1990 levels by 2035.[1–3] The UK's independent Climate Change Committee (CCC) has determined that meeting this target will require not just reducing emissions, but also the active removal of GHGs from the atmosphere, particularly carbon dioxide (CO_2).[4–6] While technological solutions are being developed (PN-618), natural systems already remove CO_2 from the atmosphere (PN-636).

The process of removing CO_2 from the atmosphere and into a store is known as carbon sequestration.[7,8] In natural habitats, this involves CO_2 being converted into organic carbon, such as plant matter, which can then be stored in the long-term as a 'stock'.[9,10] Subsequent damage to these habitats can cause stored carbon to be released back to the atmosphere.[11] Blue carbon is almost entirely stored in sediments, which gives it the potential to be stored over long timescales.[8,10,12] However, blue carbon is not included in the UK's national GHG inventory and the carbon sequestration and release is not accounted for.[13] Blue carbon habitats are generally less well understood than equivalent terrestrial habitats,[14] but there is evidence of their importance to the global carbon budget, particularly for countries with extensive coastlines.[14–16] This includes the UK, which has a marine Exclusive Economic Zone of 756,639km² locally, and a further 6,031,910km² associated with the UK Overseas Territories.[17,18] UK Overseas Territories (UKOTs) make up around 1% of emissions in the UK's national GHG inventory, but contribute a much greater percentage of the UK's marine carbon sequestration.[18,19] Various blue carbon habitats exist in the UK, some of which are better understood than others.[20]

Well understood systems

The earliest studies on blue carbon focussed on three coastal habitat types: saltmarsh, seagrass, and mangroves.[15,21] These are still the best understood stores of blue carbon, and are the only three blue carbon habitats where the Intergovernmental Panel on Climate Change (IPCC) has published guidelines for inclusion in national GHG inventories.[22,23] However, most are not currently included in the UK's national GHG inventory.[13,24] These habitats are all either found in UK waters or in UK Overseas Territories' waters.[25,26]

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Saltmarsh

Saltmarshes are coastal ecosystems that are flooded at high tide and exposed at low tide, which support a characteristic plant community.[20] There are approximately 441km² of saltmarsh in the UK, 325km² of which are in England: around 30% of all saltmarsh in Europe.[27,28] Natural saltmarshes sequester carbon very efficiently in terms of area: estimates from the UK range between 235 and 804tCO_2e/km²/year (tonnes of carbon dioxide equivalent per square kilometre per year), with most estimates falling between 440 and 550tCO_2e/km²/year.[25,29] The rate of sequestration is partially offset by methane emissions from saltmarshes at the low salinity end of estuaries.[30] Mature saltmarshes also store a stock of previously sequestered carbon.[31] Saltmarshes in Eastern England contain a mean carbon stock of 25,500tCO_2e/km² in the top 30cm of sediment.[32]

It is estimated that UK saltmarsh extent has declined by more than 15% since 1945, and possibly by as much as 85% since 1870, primarily due to coastal development.[20,33,34] Climate change also threatens saltmarsh through a process known as "coastal squeeze", where artificial coastal defences prevent saltmarsh from adapting to sea level rise (PN-647).[35] Coastal squeeze is projected to reduce saltmarsh extent by as much as 4.5% in the next 20 years.[29] The potential for creating or restoring saltmarsh is uncertain: estimates range from 100 km² in the UK as a whole to 220 km² in England alone, but examples of successful restoration projects exist (Box 1).[20,36–38] Saltmarsh creation can occur through a variety of mechanisms, depending on the initial state of the land being used.[37] Estimated costs vary from £1,000,000-£5,000,000/km², although outliers exist.[20,39] This equates to between £37 and £183 per tCO_2e after 100 years.[32] Because the majority of the cost comes from land purchasing, costs will vary by location.[20]

Restored saltmarshes rapidly begin to sequester carbon. A study of restored saltmarshes in eastern England estimated an initial sequestration rate of 385tCO_2e/km²/year, falling to 241tCO_2e/km²/year after 20 years.[32] Overall, sequestration in restored saltmarshes is slower than in natural saltmarshes, but total stored carbon in sediments is similar after 100 years.[32] Saltmarsh provides a variety of non-carbon benefits, such as flood prevention, improved water quality, and biodiversity.[40,41] However, biodiversity in restored saltmarshes is lower than in historic saltmarshes, and can take time to establish.[42]

Seagrass

Seagrasses are a group of aquatic plants that form submerged meadows on shallow sandy or muddy sediments. There are several species in UK waters.[43] Their total extent is uncertain, but is estimated to be 70-90km², more than half of which is in England.[44–46] Most blue carbon studies have focussed on Mediterranean systems, but studies of restored seagrass meadows in temperate waters suggest carbon sequestration rates of between 42 and 136tCO_2e/km²/year.[20,45,47,48] Seagrass meadows also contain a carbon stock, stored in sediments.[43,49] The size of this stock varies between sites due to differences in species, water quality and sediment, but average stocks to 1m depth range from 36,264 to 51,889tCO_2e/km², and the UK stock may be one of the largest in Europe.[43,49,50] Many UKOTs, such as Bermuda and those in the Caribbean, also contain seagrass.[53] Their sequestration rates and stocks may differ from those in the UK. Seagrass has declined by up to 92% in the UK due to disease, physical damage, and pollution of coastal waters.[44,45] Marine heatwaves, driven by climate change, may cause widespread loss of seagrass meadows, and increased storm frequency may increase sediment erosion.[54,55] However, seagrasses may sequester and store more carbon with climate change due to factors such as sea level rise and increased CO_2 levels.[20,56,57]

Natural regeneration of seagrass is slow, and the potential extent of UK seagrass restoration is uncertain, with estimates ranging from less than 200km² to 820km².[20,45] 820km² of new seagrass meadow may increase UK blue carbon sequestration by around 1%.[47,48,58] Temperate seagrass restoration projects are rare, but large scale restoration has been undertaken in Virginia, USA, where 2km² of seagrass was seeded, which has now expanded into more than 36km².[59,60] Smaller scale projects exist in the UK, such as a 0.02km²-planting project in Pembrokeshire and a 0.08km² planting project in Devon.[60,61] In the case of the Virginia project, only 10% of restoration costs could be recuperated from monetised carbon offsets.[48,62] Costs in the US vary greatly between US$120,000/km² and US$400,000,000/km², but figures for the UK cannot yet be established due to lack of large projects.[20,48] As with saltmarsh, seagrass restoration can provide co-benefits other than carbon sequestration including improved water quality and increased abundance of economically valuable fish and shellfish.[45,59,63] Seagrass also provides biodiversity benefits although, in Bermuda, grazing by turtles has reduced seagrass extent.[64,65]

Mangroves

Mangroves are coastal forests that are found in the tropics and that support unique ecosystems of plants and animals.[26] There are an estimated 316km² of mangrove in the UKOTs.[26] The

Box 1: Steart Marshes case study

Steart Marshes is a 4.8km² area of created wetland in Somerset, including 3km² of saltmarsh, managed by the Wildfowl and Wetlands Trust. The project was devised as a method of compensating for habitat loss in the Severn Estuary due to rising sea levels.[51] Flooding of land to create saltmarsh (a process called managed realignment) has doubled the organic carbon content of the soils. At present, carbon sequestration provides no funding. It has been valued at £15,375-£46,125 annually, but this is probably an underestimate.[40] Funding for ongoing management of Steart Marshes comes primarily from the UK Government's Higher Level Stewardship agri-environment scheme, which provides approximately £120,000 annually. However, Steart Marshes provides numerous co-benefits other than carbon sequestration such as tourism, flood protection, biodiversity, and grazing land for cattle, which have an estimated total annual value of £491,155-£913,752.[40]

Steart Marshes has taken several steps to engage with the local community and ensure their support for the project.

- It made use of land that was at elevated risk of flooding, which reduced the effective cost to landowners.
- The local community has been involved in consultations about project plans since April 2009.[52]
- Publicity has been restricted in order to limit visitor numbers, at the request of the local community.
- Tennant farmers graze cattle on parts of the saltmarsh.[52]

majority of this area is found in Turks and Caicos, where CO_2 sequestration by mangroves may exceed emissions.[26,66,67] Mangroves have a high CO_2 sequestration rate, estimated at 603tCO_2e/km²/year, and a substantial carbon stock, estimated at 104,710tCO_2e/km².[68,69] The UK Government provides funding to support mangroves in Asia through the Official Development Assistance Strategy.[70]

Less well understood systems

There is evidence that less well understood marine habitats may offer contributions to marine carbon sequestration. This includes kelp, shelly reefs, maerl reefs, and marine sediments. Some of these habitats are also important stores of carbon.[71] No internationally agreed guidelines currently exist for incorporation of these habitats into national GHG inventories.

Kelp

Kelp are marine algae (seaweeds) that forms underwater forests around the coast. UK extent estimates range from less than 4,000km² to 8,151km², most of which is probably in Scottish waters.[25,46,72,73] Unlike saltmarsh and seagrass, kelp grows on solid rock rather than sediments.[74] However, the carbon sequestered by kelp can be buried in sediments away from the site of kelp growth, but this is hard to measure and estimates of carbon sequestration rates are uncertain.[75,76] Studies of Scottish kelp productivity, coupled with international estimates of burial rate, suggest a potential carbon burial by UK kelp forests of 147tCO_2e/km²/year, but there may be substantial regional variation.[25,77] Kelp forests also hold short term carbon stores while alive. These stores have an estimated carbon content of 2,372tCO_2e/km², but this varies between sites due to differences in temperature and species.[46,74] Climate change poses a threat to kelp carbon sequestration because kelp grows less rapidly in warm waters.[74] In addition, warm water kelp species, which may displace cold water species due to climate change, decompose more rapidly, releasing carbon before it can be stored in sediments.[78] Increasing frequency of storm events and heatwaves may also damage kelp forests.[79,80]

Kelp forest regeneration is in its infancy in the UK. In 2020, the Sussex Inshore Fisheries and Conservation Authority introduced a trawling exclusion zone to allow regeneration of kelp forests in 200km² of inshore coastal waters, and the carbon benefits are under investigation.[60,81] Costs of kelp restoration in the UK are currently unknown.[20] The maximum possible extent of kelp forest in the UK is also unclear, but a figure of 19,000km², with a further 11,000km² of another seaweed, is realistic.[82] Kelp has extensive co-benefits beyond carbon sequestration: it acts as a nursery for economically valuable fish and shellfish, improves water quality, and may also reduce coastal erosion.[83–85] Seaweed aquaculture can be used to produce a variety of products, including food, medicines, bioplastics and biofuels, with businesses in Cornwall and Yorkshire.[86–88] These biofuels have the potential to reduce fossil fuel emissions.

Shelly reefs

Shelly reefs include bivalve reefs (such as oyster beds and mussel beds) and cold water corals.[71] The extent of these habitats in UK waters is uncertain.[73] An extent of 20.5km² has been estimated for Scotland.[71] The capacity of shelly reefs to net sequester carbon is also uncertain.[89] The primary store of carbon in shelly reefs is the shell material.[73] However, this shell is formed in a process called calcification, the net effect of which is to release CO_2.[90–93] Other processes on shelly reefs can contribute to carbon storage by burying organic carbon.[94]

As such, the net effect of shelly reefs on atmospheric CO_2 levels is highly context dependent.[91] Even if the formation of reefs has resulted in net CO_2 emissions, damage to those reefs could result in further emissions through release of organic carbon.[91] Although their credentials as blue carbon habitats remain uncertain, shelly reefs have numerous co-benefits for biodiversity, water quality, coastal defence and fish stocks.[95,96] Restoration projects for shelly reefs are ongoing.[97]

Maerl reefs

Maerl are areas of calcifying seaweed that form extensive reef-like habitats and produce CO_2 in the same way as shelly reefs.[89,98] However, maerl reefs can also sequester CO_2, both by producing organic carbon and by trapping organic carbon from other sources.[12,99] The physical structure of maerl means that even beds that have died may still sequester and store organic carbon from other sources provided they are not physically damaged.[12,100] Despite their low growth rates, maerl beds can contain stocks of stored organic carbon.[12,99] Samples from a maerl reef on the West coast of Scotland recorded organic carbon stocks of 2,675tCO_2e/km² within the top 25cm of sediment.[12]

The extent of maerl in the UK is uncertain, but modelling suggests that the extent could exceed 7,000km².[73,101] Sites are also known from the West coast of England and Wales, and from Northern Ireland, although the majority of the habitat is probably in Scottish waters.[102,103] Globally, maerl is predicted to decline rapidly as a result of climate change in the next 30 years, and dredging and trawling could release carbon through disturbance of sediments.[12,101,104–106] Maerl can take many years to recover from damage, even after pressures are removed.[107] In addition to carbon sequestration and storage, maerl provides benefits in terms of increased biodiversity and abundance of economically valuable fish and shellfish species.[100,101,105]

Seafloor muds and sands

Seafloor sediments are increasingly being recognised as important stores of organic carbon.[108–110] Although the rate of carbon sequestration by sediments is low, this is compensated for by their vast area: sediments cover the seafloor throughout the UK's 756,639km² EEZ.[9,17,25,111] Organic carbon is sequestered locally by plankton and transported to these habitats by rivers and ocean currents, which produces carbon accounting challenges.[71] The carbon content of seafloor sediments has been mapped throughout the UK EEZ.[9] An average organic carbon stock of 2,606tCO_2e/km² has been measured for the top 10cm of the UK EEZ as a whole, but this varies substantially from site to site.[9] The sequestration rate of organic carbon in marine sediments is also variable: measurements range from 0.74-217tCO_2e/km²/year depending on location and sediment type.[46,73,112,113] An average of 6tCO_2e/km²/year has been suggested for the shallower UK sediments.[25] These sediments also contain a large carbonate stock, but as this is produced by calcification, it does not reduce atmospheric CO_2 levels.[9,91,92]

The primary threats to organic carbon in sediments are practises that disturb the sediment surface, such as bottom trawling, construction, and dredging, where heavy equipment is dragged across the seafloor.[109,110,114,115] Emissions from seafloor disturbance have been estimated at several million tCO_2e/year, but lack of measurements from control areas makes the impact difficult to determine.[44,109] The slow accumulation rate of sediment carbon means that damage from seabed disturbance is very long-lasting, even if damaging activities cease.[109] Bottom trawling is often focussed in areas with higher sediment carbon stocks.[9,38,111] Warming in the surface ocean, and overfishing, may alter the rate at which phytoplankton contributes to sediment carbon stocks.[108,111,116,117]

The future of blue carbon

Marine ecosystems in the UK have an estimated total carbon sequestration rate of 11 million tCO_2e/year, although this value is very uncertain, and higher estimates exist.[46,58] This compares with estimates of sequestration by UK terrestrial ecosystems of 28 million tCO_2e/year, but is still just over 2% of UK emissions.[13,60] Conservation of existing areas of habitat protects stocks of carbon that have already been sequestered, whereas compensating for habitat loss in one area with habitat creation in another is liable to lead to creation of carbon emissions from the disturbed sediment.[56,118,119] Research is ongoing regarding the interactions between habitats that may support carbon storage processes. These may produce carbon sequestration benefits that are greater than the sum of the two habitats working independently, such as oyster reefs reducing erosion of saltmarsh or shellfish improving water quality for seagrass.[120,121]

Carbon value

Marine carbon sequestration and storage in the UK has an estimated value of £57.5bn annually.[58] Understanding of saltmarshes is now close to the stage where its incorporation into the national GHG inventory would be possible, but there are data gaps to resolve.[20,32,38] Other UK blue carbon habitats are not yet as well understood.[20] As much as 50% of the carbon stored in blue carbon habitats is not produced in those habitats.[12,122–124] This provides a challenge for measurement of carbon sequestration within individual habitats.[14,125] Shelf sediments and kelp are difficult to incorporate into national GHG inventories because they may also export carbon across jurisdictional boundaries.[44,123,126] Establishing verification standards could reduce these problems, but there are no mandatory monitoring requirements for blue carbon projects to collect and supply data to inform these.

Private investment

Many private sector investments in carbon sequestration projects occur through voluntary carbon markets, where businesses fund carbon sequestration projects to offset their own emissions.[127,128] These projects must be verified by a third party as conforming to certain standards that ensure the carbon sequestration value of the project.[127] Standards for blue carbon restoration projects have existed since 2015, but the Verra organisation has recently introduced a method for also crediting avoided emissions (i.e. conservation) in these systems.[129,130] UK-specific verification bodies exist for woodland and peatland.[131,132] The UK Government has provided the UK Centre for Ecology & Hydrology, and a team of partners, with funding to explore the development of a saltmarsh carbon code, which may encourage private investment.[81]

Carbon sequestration projects often employ blended finance, where projects are funded by a combination of public and private finance.[133,134] In general, voluntary carbon markets are weakly regulated.[135] This, alongside scientific uncertainty, can cause problems for investors because they cannot trust the quality of carbon credits that they purchase. In blue carbon projects, the value of non-carbon benefits is often much greater than value of carbon sequestration.[40,136,137] Monetisation of non-carbon benefits can improve viability of projects.[40,138]

Current frameworks

Current legislation designates more than 1/3 of UK waters as Marine Protected Areas (MPAs).[139] The UK Government's National Adaptation Programme states that the UK Government will protect natural carbon stores within MPAs.[140] However, 95% of UK MPAs permit bottom trawling, which disturbs carbon stocks in sediments.[101,139] Consequently, few UK MPAs meet the IUCN standards for effective protection.[141,142] A new category of MPA - Highly Protected Marine Areas (HPMAs) – has been proposed to address this issue.[143] This proposal, made by the Benyon review, recommended that at least one of the five pilot sites designated as an HPMA should be designated on the basis of its blue carbon value.[143] This may provide data on effective management approaches.[144] The UK Government is now in the process of identifying sites where HPMAs can be piloted.[145,146] Internationally, the UK leads the Global Ocean Alliance, and is calling for a '30by30' target to protect at least 30% of the land and of the ocean globally by 2030.[147,148] The UK has also committed to reversing loss of nature by 2030, and to investing £3bn in natural solutions to fight climate change over the next five years.[149] Current government investment into blue carbon has come from the Natural Environment Investment Readiness Fund and the UK Research Institute.[81,150,151]

Given the widespread distribution of sediment carbon stocks, area-based protections alone are not likely to be sufficient to prevent carbon emissions from disturbance.[141,152] The UK Government and the devolved administrations have published a series of regional marine plans that are designed to govern the use of UK waters.[153] These plans include a consideration of the blue carbon value of the waters, and require that projects take appropriate steps to, in order of preference, avoid, minimise, mitigate, or compensate for damages.[154]

Many organisations including the Inshore Fisheries and Conservation Authorities, Marine Management Organisation, Environment Agency, and Crown Estate all share some responsibility for the management of blue carbon projects in UK waters.[34] Guidelines for licencing and regulating blue carbon projects have yet to be established by these authorities. Coordination among devolved administrations is necessary to ensure consistent administration of blue carbon projects. The Scottish Government has established the Scottish Blue Carbon Forum, which carries out research on blue carbon issues to provide advice to policymakers.[155] No equivalent body yet exists for the UK Government. The Scottish, Welsh, and UK Governments have all commissioned reports on the potential of blue carbon habitats within their waters.[46,71,156]

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