SCOTTISH ASSOCIATION for MARINE SCIENCE

Current status & knowledge about potential sequestration capacity for 'blue carbon' sinks in Scotland

A Report for ClimateXChange

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The aim of this report is to provide a brief synthesis of the current status and scientific knowledge about the 'blue' carbon sequestration potential for Scotland. The report focuses on three of these habitats which occur in Scotland - saltmarshes, seagrass beds and kelp forests.

1. Summary

Saltmarshes, seagrass beds and kelp forests are potentially quantitatively important 'blue' carbon sinks in Scotland. Whereas Scottish (and UK) saltmarsh habitats are relatively well identified and quantified in terms of their locations and areal coverage, further investigations are needed on standing stocks and areal coverage of seagrass beds and kelp forest communities in Scottish waters before a more quantitative assessment can be made in terms of their total carbon sequestration potential. However, current literature indicates that these habitats might be relatively abundant in Scottish waters compared to other coastal areas in UK and Europe. All three habitat types are suffering from degradation due to both human and natural activities including climate change. About 80% the Scottish saltmarshes and ~50-60% of known seagrass beds in Scottish waters are currently managed within protected- or managed fisheries areas, although no information was found on the conservation status of kelp forests in Scotland. It is however worth noting the carbon sequestration potential associated with active kelp farming as demonstrated elsewhere. Undoubtedly, best practices management (e.g. through MPA's, SAC's and IMCZ's) of these habitats is needed to maintain and possibly enhance their capacity (e.g. managed realignment of saltmarshes) as 'blue' carbon sinks. Proper management actions will most likely also have positive effects on other ecosystem goods and services that these habitats provide including biodiversity, secondary production and structural stability of coastlines and shallow sediments.

2. Introduction

Coastal habitats like mangrove forests, coral reefs, saltmarshes, seagrass meadows and kelp forests have recently been highlighted for their potential as natural coastal/marine carbon sinks ('blue' carbon sinks). Despite their limited geographical extent (<2% of ocean surface) they have a disproportionally important role in the marine carbon cycle compared to both soft sediments, which makes up the majority of the ocean seabed, as well as to terrestrial carbon sinks. Recent estimates show that the standing stock of carbon in these ecosystems can be of similar magnitude to many of the considerably larger terrestrial 'green' carbon sinks, such as tropical and temperate forests and grasslands (Laffoley and Grimsditch, 2009; Duarte et al, 2004). This is due to their high productivity and high carbon sequestration capacity per unit area.

In addition to being potential hotspots for carbon sequestration these systems typically also provide many important ecosystem goods and services (nurseries and food sources for many organisms, important fishing grounds, coastal defences, storm- and flood protection). This makes them particularly important habitats to manage and protect now and in the future. Despite this, these ecosystems are rapidly degraded worldwide, and up to 50% of saltmarshes, 35% of mangroves and 29% of seagrass beds are now destroyed globally (Laffoley and

Grimsditch, 2009). Although attention has been given to managing and protecting terrestrial systems as potential 'green' carbon sinks or sources (REDD), their marine counterparts are often overlooked. If we want to maximize the potential for natural carbon sequestration, it is imperative to include, manage and protect these valuable coastal ecosystems, which then can add to our portifolio for mitigating climate change (Laffoley and Grimsditch, 2009).

Saltmarshes

Saltmarshes are intertidal ecosystems that are dominated by vascular plants. They occur on sheltered marine and estuarine coastlines from the arctic to the tropics, but are most common in temperate regions. It has recently been suggested that saltmarshes one of the most efficient habitats on earth for sequestering and storing carbon in their soils with an average sequestration rate of 210 g C m^{-2} yr^{-1} which is the equivalent of 770 g CO_2 m^{-2} yr^{-1} (Chmura et al. 2003). In addition to this, each molecule of CO_2 sequestered in saltmarsh soils are more valuable from a 'Greenhouse gas perspective' than CO_2 molecule sequestered in freshwater wetland soils which tend to produce and release methane gas (CH_4) associated with carbon accumulation. The high concentrations of sulphates and associated microbes in coastal and marine soils and sediments mitigate against CH_4 formation and escape to the atmosphere, where it otherwise would act as a considerably more potent greenhouse gas than CO_2.

In Scotland the extent of saltmarshes has been estimated to 6,747 ha which is about 15% of the total extent of saltmarshes in the UK (Burd, 1995). Scottish saltmarshes are mainly concentrated to the low lying firths of eastern and south-west of Scotland, whereas a large number of very small saltmarsh sites are located at the head of sea lochs, in embayments and on beaches in the north-west of Scotland. Approximately, 3% of the Scottish coastline is covered by saltmarsh vegetation. Given the average sequestration capacity of 210 g C m^{-2} yr^{-1} according to Chmura et al (2003), Scottish saltmarshes could potentially have an average sequestration potential of $14.1*10^{-9}$ g C yr^{-1} which equates to ~0.1-0.2% of annual Scottish atmospheric CO_2 emissions (Scottish Greenhouse Gas Emissions 2009).

Current and potential threats for saltmarsh habitats come from both human and natural activities including land claim, coastal erosion, 'coastal squeeze' and climate change. Although large scale land claim schemes for agriculture are now rare, smaller land claims of marsh area associated with development of industry, port facilities, small marinas and waste disposal sites frequently occur (www.ukbap.org.uk/PriorityHabitats.aspx). Erosion of the seaward edge of saltmarshes occurs widely in the high energy locations of the larger estuaries as a result of coastal processes and many saltmarshes are being 'squeezed' between an eroding seaward edge and fixed flood defense walls which prevent the vegetation to naturally progress landwards with the rising sea-level. Climate change, associated sea-level rise and increased storm frequency is predicted to worsen this effect (Laffoley and Grimsditch, 2009). Sediment transport and dynamics in saltmarshes may also be affected negatively by coastal protection works, changes in estuary morphology from due to land claim, dredging for shipping channels and marina construction as a few examples (www.ukbap.org.uk/PriorityHabitats.aspx). Other pressures from human activities include introduction of non-native species of certain types of cord grass (*Spartina sp.*), pollution, high nutrient loads from agricultural activities and waste disposal etc. All these activities has caused extensive loss of saltmarsh areas in the UK and best estimates show that saltmarsh habitat loss can be up to 100ha per year in the UK (www.ukbap.org.uk/PriorityHabitats.aspx).

About 80% of UK's saltmarsh areas are today designated SSSI's (inlc SAC's and SPA's) except in the North West of Scotland where about 50% notified as SSSI's (www.ukbap.org.uk/PriorityHabitats.aspx). Other management actions for the restoration of lost saltmarsh areas include soft engineering measures such as managed realignment (e.g. Nigg Bay in Cromarty Firth) and transplantation of saltmarsh plants (Maynard et al. 2011). A recent study showed that significant managed realignment of the Humber estuary could significantly enhance the carbon sequestration (150%) and nutrients (83-50%) as well as contaminant metals in the estuary (Andrews et al. 2006). Restoration of an eroding fringe saltmarsh has also been successfully carried out (Eden Estuary, St Andrews) using vegetative transplants that enhanced the sedimentation in the marsh (Maynard et al 2011).

Seagrass beds

Seagrass is a globally distributed group of marine flowering plants (~60 different species) that form extensive meadows in shallow waters of all continents except the Antarctic. In Scotland they typically occur from the lower saltmarsh limit (*Zostera noltii*) into the sublittoral zone (*Zostera marina*) at approx ~10m below the surface. It has recently been suggested that although these plants only cover a relatively small area of the global ocean floor (~1%), they are responsible for about 15% of the total carbon storage in the ocean (Laffoley and Grimsditch, 2009). The slow turn over time of seagrass biomass and its sediment trapping and binding capacity makes this habitat an important sink for carbon with an average sequestration rates of 83 g C m^{-2} yr^{-1}, which translates to global storage rates of 27-40 Tg C yr^{-1} (Laffoley and Grimsditch, 2009). As with saltmarsh sediments, carbon accumulation in seagrass beds is more efficient from a 'greenhouse gas perspective' as seagrass beds do not release other greenhouse gases (e.g. CH_4) as their terrestrial counterparts can do.

There are no complete estimates for the total coverage of seagrass beds in Scottish territorial waters and hence it is difficult to directly translate their local importance as blue carbon sinks. However, according to the Geodatabase of Marine Habitats and species in Scotland, 355 records of seagrass beds have been recorded all around the coast of Scotland. Eelgrass beds (*Zostera sp.*) are especially well developed in Scotland compared to other parts of UK, which is probably due to the presence of extensive suitable habitats and uncontaminated waters (Hiscock et al 2004). For example, Cromarty Firth alone supports probably the largest total area of dwarf eelgrass and narrow leaved eelgrass in UK (~1200ha). Distribution maps of seagrass (Green and Short, 2003), indicate that Scotland has a high number of recorded distributions of seagrass compared to much of the Western European coastlines.

A wasting disease was responsible for the die-back of large areas of seagrass in the UK in the 1930's, and has recently reappeared in seagrass beds around the Isles of Scilly (UK). Other current and potential threats to sea grass communities includes natural factors such as storms, exposure to air and fresh water pulses as well as heavy grazing by wildfowl can have a negative impact on sea grass coverage. Recent studies have shown that ~1/3 of the global sea grass distribution have now been lost through human activities associated with coastal development, which includes increased turbidity and eutrophication (nutrient enrichment) which affects seagrass photosynthesis and growth.

In order to sustain and promote the role of seagrass beds as significant carbon sinks and providers of important ecosystem goods and services, it is vital to maintain a high water quality with low mean turbidity and low levels of eutrophication, ensuring sufficient light penetration for the seagrass to thrive. Today, about 64% of the known records of seagrass beds in Scotland are in protected areas or fisheries areas according to Scottish Natural Heritage. Furthermore, synergistic effects of proper managing of coastal wetlands and saltmarshes may include enhanced water quality in many estuaries and costal embayments which often include sea grass beds.

Kelp forests

Kelp forests are assemblages of large brown algae (macroalgae) in the order of Laminariales. They dominate autotrophic biomass and production of shallow rocky substrates in temperate and arctic waters but a complete survey of the world's kelp forests is currently lacking (Laffoley and Grimsditch, 2009). Kelp forests are characterized by very high carbon turnover rates (up to 10 times yr^{-1}) but little is known about how much of the kelp is actually incorporated in the long-term storage reservoirs for carbon (Laffoley and Grimsditch, 2009). In fact, it is most likely that carbon storage in kelp-dominated ecosystems is mainly a function of the size of the standing biomass of kelp and associated fauna, rather than long-term storage of the carbon. Estimates of global kelp standing crops from modeled distributions range from 7.5 to 20 Tg C, whereas the global kelp production is estimated to 15 Tg C yr^{-1} for areas along the shallow coastline.

As for seagrass, there are few estimates of the total area cover or standing crop of kelp in Scottish waters. However, Laminarian kelp forests are found on suitable rocky areas all around the Scottish coastline, reaching their greatest extent where the sea bed slopes gently away from the land. They are less common along the east coast, where much of the sea bed is composed of sand, and are particularly extensive around Skye and the adjacent mainland, along the west coast of the Outer Hebrides, and around Orkney and Shetland (Fuller, 1999).

Current and potential threats to macroalgal communities in Scottish waters include land use practices altering the amount and constituents of runoff and coastal discharge of municipal, agricultural industrial wastes are known to have negative impacts on kelp forests (Laffoley and Grimsditch, 2009). As with seagrass beds, these threats typically affect the turbidity of the water and enhance eutrophication, which in turns affects the photosynthetic capability and growth of the kelp. Furthermore, global climate change is also likely to have a negative effect on global kelp distribution as increased surface temperatures will enhance stratification and hence decrease nutrient availability. Climate-driven increases in storm frequency are also predicted to adversely affect kelp forest coverage and ecosystem diversity (Byrnes et al. 2011).

3. Co-benefits

Saltmarshes

Apart from being very efficient traps for carbon, saltmarshes also act as natural filters for nutrients and contaminant metals in runoff water from land, preventing these constituents from reaching further out into coastal waters where they could have negative effects on other sensitive ecosystems such as seagrass beds and kelp forests, which are relatively abundant in Scottish coastal waters (www.ukbap.org.uk/PriorityHabitats.aspx). Saltmarshes also have an important function as natural defenses against floods, storms and over longer timescales also against sea-level rise. The saltmarshes acts as natural buffering zones that absorb wave energy and where the rising water levels can progress landwards naturally while continuing to deposit, sequestering carbon and associated elements into the system. Saltmarshes in Scotland are important resources particularly for wading birds and wildfowl, acting as high tide refuges for the birds feeding on adjacent mudflats, and as breeding sites for waders gulls and terns as well as a food source for wild ducks and geese during the winter season. They are particularly important for the many types of invertebrate soil fauna which also provide food for juvenile fish seeking refuge in the saltmarsh during high tide (www.ukbap.org.uk/PriorityHabitats.aspx).

Seagrass beds

Apart from acting as important carbon sinks, seagrass meadows provide other important ecosystem goods and services that have been estimated to be of high value compared with other marine and terrestrial habitats (Constanza et al. 1997). Their extensive root systems (rhizomes) bind the sediment together and prevent erosion and the seagrass itself provides substratum for a large number of different species of algae and invertebrates living on the leaves (Laffoley and Grimsditch, 2009) and fish (e.g. flatfish) is often using the sea grass meadows as nursery grounds for their young ones or as food source or for protection as adult (e.g. pollack, goby, wrasse. Eelgrass is also an important source of food for wildfowl (e.g. goose and widgeon) that feed on the intertidal beds (www.ukbap.org.uk/PriorityHabitats.aspx).

Kelp forests

Kelp forests are one of them most diverse and economically important habitats that support an extensive secondary production of both commercially and recreationally attractive species, including a wide diversity of molluscs, crustaceans and finfish (Laffoley and Grimsditch, 2009). Kelp itself is also harvested for food and food additives, pharmaceutical and cosmetic applications, animal fodder and for biofuel (Yokoyama et al 2007). In Scotland kelp harvesting occurs mainly in the Highlands and Islands, where kelp is harvested as soil fertilizer and for alginate production (Fuller, 1999). In other parts of the world kelp is grown commercially and harvested for human and animal consumption (Gutierrez et al, 2006). Recent studies have also suggested active cultivation and harvesting of macroalgal primary production could play a significant role in aquatic C sequestration and amelioration of greenhouse gas emissions (Chung et al. 2011).

4. References

Andrews et al (2006) Biogeochemical value of managed realignment, Humber Estuary, UK. Science of the total environment: 371:19-30

Boorman, L (2003) Saltmarsh Review. An overview of coastal saltmarshes, their dynamic and sensitivity characteristics for conservation and management. JNCC Report, No. 334

Byrnes et al (2011) Climate-driven increases in storm frequency simplify kelp forest food webs. Global Change Biology 17, 2513–2524

Burd, F (1995) Managed retreat: a practical guide. English Nature, Peterborough

Chmura et al (2003) Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles 17:1-12

Constanza et al. 1997 The value of the world's ecosystem services and natural capital. Nature 387:253-260

Chung et al. 2011 Using marine macroalgae for carbon sequestration: a critical appraisal. Journal of Applied Phycology 23:877–886

Duarte et al (2004) Major role of marine vegetation on the oceanic carbon cycle. Biogeosciences Discussions 1, 659-679

Fuller (1999) Kelp forests: Scotland's living landscapes. Scottish Natural Heritage Publications. 28pp.

Green and Short (2003)

Gutierrez et al (2006) Farming of the giant kelp Macrosystis pyrifera in southern Chile for development of novel food products. Journal of Applied Phycology 18:259–267

Hiscock et al. (2004). Effects of changing temperature on benthic marine life in Britain and Ireland. Aquatic Conservation: Marine and Freshwater Ecosystems, 14: 333-362.

Laffoley and Grimsditch (2009) Management of natural coastal carbon sinks. IUCN, Gland, Switzerland. 53pp

Mackey, E.C. and Mudge, G.P. (2010).Scotland's Wildlife: An assessment of biodiversity in 2010. Scottish Natural Heritage, Inverness

Maynard et al (2011) A comparison of short-term sediment deposition between natural and transplanted saltmarsh after restoration in the Eden Estuary (Scotland). Plant Ecology & Diversity 4:103-113

Yokoyama et al (2007) Energy Production from Marine Biomass: Fuel Cell Power Generation Driven by Methane Produced from Seaweed.