ECOSYSTEM SERVICE MODELLING

RULE-BASE DEVELOPMENT – SUGGESTIONS FOR USER

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Soil Carbon Storage			
CICES Ecosystem Service Typology:			
Section Regulation and Maintenance	**Division** Maintenance of physical, chemical, biological conditions	**Group** Atmospheric composition and climate change	**Class 1** Global climate regulation by reduction of greenhouse gas concentrations

Soil carbon storage description	
	Soil carbon storage is an important ecosystem service which results from interactions of different ecological processes. An important component which contributes to the service is the amount of organic matter present within the soil profile. Soil organic matter (SOM) is a heterogeneous mixture of materials that range in stage of decomposition from fresh plant residues (leaf litter) to highly decomposed material known as humus. SOM is made up of organic compounds that are highly enriched in carbon. Soil organic carbon (SOC) levels of different soil types are directly related to the amount of organic matter contained in soil from growth and death of plant roots and foliage, as well as indirectly from the transfer of carbon-enriched compounds from roots to soil microbes. The soils within the UK contain more carbon than the vegetation and it has been estimated that the soils of Scotland contain 19 000 Mt and those in England and Wales 2773 Mt carbon (Milne and Brown, 1995; Howard et al, 1994).

Factor 1a - Soil	
Soil Types	To be able to define or identify carbon richness within organic, organo-mineral and mineral soils the soil types need to be identified and their properties understood within the chosen area of study.
Mineral	Mineral soils contain few organic horizons within the soil profile.
Organo-Mineral	Organo-mineral soils are classified as having organic surface horizons less than 50cm thick in Scotland and less than 40cm thick in Wales, which overly mineral horizons or rock (ECOSSE, 2007). Major soil groups include humus-iron podzols, peaty podzols, subalpine podzols, alpine podzols, peaty gleys, humic gleys, peaty rankers, podzolic rankers, peaty lithosols and peat alluvium (ECOSSE, 2007). Organo-mineral soil groups within Wales include humic gley soils, humic rankers, podzols, stagnohumic gley soils and stagno-podzols.
Organic	Organic soils are mainly classified as peat. In Scotland peat soils are defined as containing more than 60% organic matter and exceeding 50cm in thickness, while in Wales they must contain at least 50% organic matter and the surface horizon must extends to a depth of 30-50cm. The unified Avery classification of soils in England and Wales (Avery, 1980) states that a peat soil is one which contains between 20-50% organic matter, depending on the clay content.
Soil Systems	**Wetland systems which lack oxygen** In these systems organic carbon accrues rapidly. There are few organisms that are able to tolerate anaerobic environments and respiration rates are low, therefore release of CO_2 is also low. In addition, the low temperatures and acid conditions present in wetlands slows the decomposition rate, causing dead plant material to build up in layers of organic matter. These systems are atmospheric CO_2 sinks, however they do release methane (Whiting and Chanton, 2001). If these systems are drained the increased oxygen availability allows soil micro-organisms to utilize the carbon and leads to the release of CO_2 (Armentano and Menges, 1986). Other management such as ploughing in arable systems on deep peat is a large carbon source, as layers of peat are oxidised each year as the ground is disturbed. In these waterlogged systems the most important vegetation contributors to soil carbon build up are species such as *Sphagnum* mosses, in particular *S. capillifolium* and *S. papillosum*. These mosses are resistant to decay and therefore accumulate relatively quickly in the litter layers and eventually form peat. The significance of vegetation for soil carbon on these wetland systems is therefore scored based on the amount of Sphagnum present (or inferred from the habitat type) and on the likely perturbation of the system.
	Dry, well oxidised soil systems; mineral soils Within dry soil systems vegetation has a different interaction with soil types. Here carbon is respired by plant roots, soil microbial communities and the communities that feed on plant litter. Therefore the depth and quantity of root and depth of plant litter will be key features in scoring the carbon potential of these vegetation types. Within these dry systems, the depth of organic matter in the profile is related to its likelihood of being used in respiration; carbon deep in the profile is less likely to be utilised. Where vegetation types are very long lived this carbon at depth can be an important part of the carbon sink, and so habitats with these deep rooting features are scored as having a moderate soil carbon resource. Where the habitats are disturbed (e.g. re-sown grasslands) this carbon is likely to be used, as exposure to oxygen in the perturbation allows micro-organisms to respire and in the presence of sufficient nitrogen. Habitats such as ancient broad leaved woodland, with deep rooted species, which produce a large amount of leaf litter are scored as moderately high in terms of

	carbon storage on mineral soils.
Factor 1b - Geology	
	Underlying geology does not greatly influence carbon storage in soils. However, studies have shown that soils may have a varying degree of inorganic fluxes through the weathering of carbonates contained in soil and underlying geology (Kutsch et al., 2012).

Factor 2 - Habitat		
Biophysical properties of habitats		Habitats contain living plant materials and can be defined as the above ground biomass carbon pool. The habitats are described in terms of their biophysical properties and contribution towards soil carbon storage in soils. The user should bear in mind that there will be differences within habitat types and locations due to their heterogeneity and are context dependent. This makestop-soil carbon stocks within habitats difficult to generalise.
Below ground physical features	*Root depths*	**Deep rooted species** such as trees and subsequently woodlands (including their soils) currently store 790Mt of Carbon. Carbon sequestration rates in trees, woody vegetation and soils vary with species, site condition and management (Alonso et al, 2012). 75% of carbon stored in woodlands is found in their soil. **Habitats which are perennial in nature and have moderate rooting systems.** For example, grasslands and dry dwarf shrub heath store most of their carbon within the soil. Soil beneath grassland is usually perceived as storing less carbon than other habitats but due to its extensive coverage means that it holds a third of the UK's below ground carbon stock (Alonso et al., 2012; Hagon et al., 2013). The 2007 Countryside Survey has reported that within a depth of 0-15cm of the soil profile the belowground soil carbon concentration for Neutral grassland is estimated at 61.9g/kg and 208.2g/kg for acid grassland, which is normally associated with being present on organo-mineral soils and can indicate the presence of high-carbon soils (Bullock et al., 2011; Countryside Survey, 2009; Hagon et al., 2013). Improved grassland, due to higher productivity and disturbance, stores the least carbon in comparison to neutral and acid grasslands. Wet heaths, with a more peaty soil are more significant stores than drier heath on sandy or other mineral soils or dune heaths (Alonso et al, 2012). Mire habitats store large amounts of organic matter in their soils. **Shallow rooted species**, for example bracken, stores carbon in the soil relatively well. However, due to their location and preference for thin soils in rocky environments, lichen-bryophyte heaths provide limited opportunities for soil carbon storage.
Below ground biological features	*Species richness*	A diverse soil ecosystem helps break down and incorporate carbon into the soil and maintain a well aerated structure. Within mineral soils a species rich soil fauna will be a positive attribute for soil carbon; such ecosystems build up over time and are generally highest on unworked land. Peat forming ecosystems are generally species poor;

<table>
<tr><td></td><td></td><td>here species richness does not play a significant factor in soil carbon resource. Undisturbed peat soil systems are likely to sequester the most carbon.</td></tr>
<tr><td>Above ground physical features</td><td>Biomass / canopy height</td><td>The amount of leaf litter falling from the vegetation will be an important contributor to soil carbon storage.</td></tr>
<tr><td>Above ground biological features</td><td>Species richness</td><td>Species richness affects soil carbon as a combination of the features above, meaning that for some habitats the more diverse the vegetation the more variation there is in soil structure and more oxidation can occur.</td></tr>
<tr><td colspan="2">Other effects (How other data can be used as a proxy indicator of functionality)</td><td>Vegetation type affects the amount of soil carbon in the soil in two main ways:
• The first is the accruement of carbon within the soil itself from dead root material. The rooting depth also has a bearing on the number of soil micro-organisms and on the microrrhizae activity. Vegetation with deep rooting depths tends to have good soil aeration and a higher soil system activity.
• The second is the incorporation of leaf litter into the soil surface. Activity of macrofauna e.g. earthworms (drag litter below ground & assist decomposition and lead to a more even distribution of organic matter).
Factors to consider when scoring vegetation types for their contribution to soil carbon systems can therefore be summarised as:
• Likely to be on a wet / peat based system (high for soil carbon) vs dry / mineral based soil system (lower for soil carbon),
• On wetland systems – presence of bog forming sphagnum species (higher) vs presence of species likely to indicate degradation and oxidation of the surface, e.g. grasses (lower),
• On mineral soil, the longevity of the habitat, rooting depth and amount of leaf litter produced are key to enhancing soil carbon, therefore semi-natural ancient broadleaved woodlands (higher) vs temporary grass lays (lower),
• Drainage characteristics. Poorly drained soils with a peaty top (higher) vs sandy well drained soils (lower)
• Carbon storage associated with coniferous plantations varies with stage of management, it can increase organic matter in well grown plantations but this organic matter content will decrease after felling,
• Climate change data would be useful to incorporate as a means of predicting long term trends in organic matter balance.</td></tr>
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Factor 3 - Landform	
	• **Topography effects**, shallower slopes are more likely to accumulate carbon in the soil than steeper slopes which are overlaid by thinner alpine soils. • **Depressions**, organic matter can accumulate in depressions due to wetter conditions. The presence of artificial drainage in these locations needs to be considered and whether is it part of the active management.

Factor 4 - How it is managed	
Negative Management	Negative management, leading to the release of carbon: • Drainage • Ploughing • Overgrazing • Management which allows soil erosion • Management which allows soil compaction • Applying lime or fertiliser • Clear felling large areas • Tilling on organic soils • Planting root crops which disturb the soil
Positive management	Positive management, leading to increased storing of carbon: • Improvement of species diversity of grassland through species management • Reduction of grazing to avoid overstocking • Improvement of soil structure • Retention of permanent pasture over cropping where feasible • Drainage and grip blocking

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