Soil carbon: Indicator document - Ecosystem Service Modelling & Rule-base development

Indicator	CICES classification
SOIL CARBON (REGULATION OF GREENHOUSE GASES (CARBON))	**Section**: Regulation & Maintenance **Classes:** Global climate regulation by reduction of greenhouse gas concentrations **CICES IE Sub-class:** Areas important for emissions reduction
Scale	**CICES Cascade Level**[1]
Strategic/National. ~~Regional/Local~~	~~Structure/Function/~~Service/~~Benefit/Value~~

[1] Potschin, M. and R. Haines-Young (2016): Frameworks for ecosystem assessments. In: Potschin, M., Haines-Young, R., Fish, R. and Turner, R.K. (eds) Routledge Handbook of Ecosystem Services. Routledge, London and New York, pp 125-143.

What the service is

Soil carbon storage is an important ecosystem service as it can help mitigate climate change by storing CO_2 and preventing its release into the atmosphere. It occurs as the result of the interactions between different ecological processes. The amount of organic matter present within the soil profile is an important component of the service. Soil organic matter is a heterogeneous mixture of organic compounds that are highly enriched in carbon, ranging in decomposition state from fresh plant residues (leaf litter), to highly decomposed material known as humus.

The soil organic carbon levels of different soil types are directly related to the amount of organic matter contained in the 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. Inorganic carbon from the mineral component of the soil is not readily released to the atmosphere or water from the soil so it has not been considered in this analysis.

The scientific framework outlined below helps to determine the type of data that could be used for modelling of this service, and provides general guidance which indicators are likely to have a positive or negative impact on service provision.

Scientific framework for modelling Soil Carbon

Overview:	There is good evidence on the role of soil type, landform and habitats in soil carbon storage mainly from literature concerning the terrestrial environment. The most relevant material is summarised here. An important component of soil carbon storage is the amount of organic matter present within the soil profile (Six et al., 2002). Soil organic carbon (SOC) levels of different soil types are directly related to the amount of organic matter contained within the soil from growth and death of plant roots and foliage (Melillo et al., 1989; Rasse et al., 2005), as well as indirectly from the transfer of carbon-enriched compounds from roots to soil microbes (Helal and Sauerbeck, 1986; Wardle, 1992).
Soil systems	In temperate climates, it has been estimated that soils are more important for carbon storage than vegetation (Milne and Brown, 1997; Alonso et al., 2012). In Wetland systems which lack oxygen, organic carbon accrues faster than in most other systems. Due to few organisms being able to tolerate anaerobic environments, respiration rates are low, which causes low rates of CO_2 release (Brady and Weil, 2002; Bain et al., 2011). In addition, the low temperatures and acidic conditions present in wetlands further slow the decomposition rate, causing dead plant material to build up in layers of organic matter (Lindsay, 2010; Bain et al., 2011). In these waterlogged systems the most important vegetation contributors to soil carbon build up are species such as Sphagnum mosses (Lindsay, 2010; Bain et al., 2011). That Sphagnum sp. do not facilitate methane release in the way vascular plants do is an additional factor contributing to climate change mitigation by Sphagnum dominated peatlands (Frenzel and Karofeld, 2000; Lindsay, 2010). The significance of vegetation for soil carbon in 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. The presence of vascular plants, or of particularly wet

	microclimates with no oxic zone above the water table, are indicators of peatlands with high methane emissions (MacDonald et al., 1998; Kayranli et al., 2010). Within dry soil systems, vegetation has a different interaction with soil types. Here, carbon is respired by plant roots, soil microbial communities and other communities that feed on plant litter (Singh and Gupta, 1977; Brady and Weil, 2002). Therefore, the depth and quantity of roots and depth of plant litter will be key features in scoring the carbon potential of these vegetation types. Within dry soil systems the likelihood of organic matter in the soil profile being used in respiration is related to its depth, with carbon deep in the profile less likely to be utilised (Singh and Gupta, 1977; Fontaine et al., 2007). This carbon at depth can be an important part of the carbon sink (Milne and Brown, 1997; Alonso et al., 2012). Where the habitats are disturbed (e.g. re-sown grassland) (Hagon et al., 2013), carbon is likely to be utilised, as exposure to oxygen in the perturbation allows micro-organisms to respire (Brady and Weil, 2002), input of new carbon promotes the usage of ancient, buried carbon (Fontaine et al., 2007) and micro aggregates stabilising soil organic matter are broken down (Six et al., 2002). Good information regarding soil composition, particle size, pore spaces, and peat content in Ireland have been recorded by Teagasc (Teagasc Soils Guide[5]; Teagasc, 2007).

[5] http://gis.teagasc.ie/soils/soilguide.php

Management	Negative management practices leading to the release of carbon include: • Drainage (Armentano and Menges, 1986, Bellamy et al. 2005, Holman 2009, Natural England 2010) • Ploughing (Holden et al. 2004, Bain et al. 2011) • Overgrazing (Britton et al. 2005) • Management causing soil erosion (Eswaran et al. 1993, Davari et al. 2010) • Management which causes soil compaction (Dominati et al. 2010) • Applying lime or fertiliser (West and McBride 2005, Biasi et al. 2008) • Clear felling large areas (Eswaran et al. 1993, Foley et al. 2005, Davari et al. 2010) • Tilling on organic soils (Dawson and Smith 2007) • Planting root crops which disturb the soil • Peat harvesting Positive management practices leading to increased storing of carbon include: • Improvement of species diversity of grassland through species management (Fornara and Tilman 2008, Mommer et al 2010) • Reduction of grazing to avoid overstocking (Britton et al. 2005) • Improvement of soil structure • Retention of permanent pasture over cropping where feasible • Drain blocking (Armentano and Menges, 1986, Bellamy et al. 2005, Holman 2009)

Supporting evidence: References

Alonso, I., Weston, K., Gregg, R., & Morecroft, M. (2012). Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon stores and sources. (N. England, Ed.) Natural England. Retrieved from http://publications.naturalengland.org.uk/publication/1412347

Armentano, T., & Menges, E. (1986). Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. The Journal of Ecology, 755-774. Retrieved from http://www.jstor.org/stable/2260396?seq=1&uid=3738032&uid=2&uid=4&sid=21104577687553

Bain, C., Bonn, A., Stoneman, R., Chapman, S., Coupar, A., Evans, M., Worrall, F. (2011). IUCN UK Commission of Inquiry on Peatlands. Retrieved from http://roar.uel.ac.uk/3591/1/IUCN%20UK%20Commission%20of%20Inquiry%20on%20Peatlands%20Full%20Report%20spv%20web.pdf

Bellamy, P., Loveland, P., Bradley, R., Lark, R., & Kirk, G. (2005). Carbon losses from all soils across England and Wales 1978--2003. Nature, 437(7056), 245-248. Retrieved from http://www.nature.com/nature/journal/v437/n7056/abs/nature04038.html

Biasi, C., Lind, S., Pekkarinen, N., Huggunen, J., Shurpali, N., Hyvönen, N., Repo, M. and Martikainen, P., 2008. Direct experimental evidence for the contribution of lime to CO2 release from managed peat soil. Soil Biology and Biochemsitry, 40, pp. 2660-2669.

Brady, N. C., and R. R. Weil. (2002) In The Nature and Properties of Soils (13th Edition). Upper Saddle River, NJ: Prentice-Hall, Inc.

Britton A. J., (2005) Impacts of grazing on montane heath vegetation in Wales and implications for the restoration of montane areas. Biological Conservation 125(4), 515:524.

Davari, M., Ram, M., Tewari, J., Kaushish, S., & others. (2010). Impact of agricultural practice on ecosystem services. International journal of Agronomy and Plant Production, 1(1), 11-23. Retrieved from http://www.ksngo.org/en/images/2010%20Ram.pdf

Dawson, J. and Smith, P., 2007. Carbon losses from soil and its consequences for land-use management. Science of the total environment, 382, pp.165-190.

Dominati, E., Patterson, M., & Mackay, A. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecological Economics, 69(9), 1858-1868. Retrieved from http://www.sciencedirect.com/science/article/pii/S0921800910001928#

Eswaran, H., Van Den Berg, E., & Reich, P. (1993). Organic carbon in soils of the world. Soil science society of America journal, 57(1), 192-194. Retrieved from http://nature.berkeley.edu/classes/espm-120/Website/Eswaran1993.pdf

Foley, J., DeFries, R., Asner, G., Barford, C., Bonan, G., Carpenter, S., others. (2005). Global consequences of land use. science, 309(5734), 570-574. Retrieved from http://www.sciencemag.org/content/309/5734/570.short

Fontaine, S., Barot, S., Barr{\'e}, P., Bdioui, N., Mary, B., & Rumpel, C. (2007). Stability of organic carbon in deep soil layers controlled by fresh carbon supply. Nature, 450(7167), 277-280. Retrieved from http://www.nature.com/nature/journal/v450/n7167/abs/nature06275.html

Fornara, D., & Tilman, D. (2008). Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology, 96(2), 314-322. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2745.2007.01345.x/full

Frenzel, P., & Karofeld, E. (2000). CH4 emission from a hollow-ridge complex in a raised bog: the role of CH4 production and oxidation. Biogeochemistry, 51(1), 91-112. Retrieved from http://link.springer.com/article/10.1023/A:1006351118347#page-1

Hagon, S., Ottitsch, A., Convery, I., Herbert, A., Leafe, R., Robson, D., & Weatherall, A. (2013). Managing Land for Carbon - A guide for farmers, land managers and advisers. Retrieved from http://www.lakedistrict.gov.uk/caringfor/projects/carbon

Helal, H., & Sauerbeck, D. (1986). Effect of plant roots on carbon metabolism of soil microbial biomass. Zeitschrift f{\"u}r Pflanzenern{\"a}hrung und Bodenkunde, 149(2), 181-188. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/jpln.19861490205/abstract

Holden, J., Chapman, P., & Labadz, J. (2004). Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration. Progress in Physical Geography, 28(1), 95-123. Retrieved from http://ppg.sagepub.com/content/28/1/95.short

Holman, I. (2009). An estimate of peat reserves and loss in the East Anglian Fens. Department of Natural Resources, Cranfield University / RSPB. Retrieved from http://www.rspb.org.uk/Images/Fenlandpeatassessment_tcm9-236041.pdf

Kayranli, B., Scholz, M., Mustafa, A., & Hedmark, A. (2010). Carbon storage and fluxes within freshwater wetlands: a critical review. Wetlands, 30(1), 111-124. Retrieved from http://www.jlakes.org/web/CARBONSTORAGE-FLUXES-FRESHWATERWETLANDS-W2010.pdf

Lindsay, R. (2010). Peatbogs and carbon: a critical synthesis to inform policy development in oceanic peat bog conservation and restoration in the context of climate change. RSPB Scotland. Retrieved from http://www.rackspace-web3.rspb.org.uk/Images/Peatbogs_and_carbon_tcm9-255200.pdf

MacDonald, J., Fowler, D., Hargreaves, K., Skiba, U., Leith, I., & Murray, M. (1998). Methane emission rates from a northern wetland; response to temperature, water table and transport. Atmospheric Environment, 32(19), 3219-3227. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231097004640

Melillo, J., Aber, J., Linkins, A., Ricca, A., Fry, B., & Nadelhoffer, K. (1989). Carbon and nitrogen dynamics along the decay continuum: plant litter to soil organic matter. In Ecology of Arable Land — Perspectives and Challenges (pp. 53-62). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-94-009-1021-8_6

Milne, R., & Brown, T. (1997). Carbon in the Vegetation and Soils of Great Britain . Journal of Environmental Management, 49(4), 413-433. Retrieved from http://www.sciencedirect.com/science/article/pii/S0301479785701181

Mommer, L., Van Ruijven, J., De Caluwe, H., Smit-Tiekstra, A., Wagemaker, C., Joop Ouborg, N., De Kroon, H. (2010). Unveiling below-ground species abundance in a biodiversity experiment: a test of vertical niche differentiation among grassland species. Journal of Ecology, 98(5), 1117-1127. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2745.2010.01702.x/full

Natural England, 2010. England's Peatlands – Carbon storage and greenhouse gases. Natural England.

Rasse, D., Rumpel, C., & Dignac, M. (2005). Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. Plant and soil, 269(1-2), 341-356. Retrieved from http://link.springer.com/article/10.1007/s11104-004-0907-y

Singh, J., & Gupta, S. (1977). Plant decomposition and soil respiration in terrestrial ecosystems. The Botanical Review, 43(4), 449-528. Retrieved from http://link.springer.com/article/10.1007/BF02860844#page-1

Six, J., Conant, R., Paul, E., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant and soil, 241(2), 155-176. Retrieved from http://link.springer.com/article/10.1023/A:1016125726789#page-1

Teagasc (2007). Creamer, R., Simo, I., Reidy, B., Carvalho, J., Fealy, R., Hallett, S., Jones, R., Holden, A., Holden, N., Hannam, J., Massey, P., Mayr, T., McDonald, E., O'Rourke, S., Sills, P., Truckell, I., Zawadzka, J. and Schulte, R. Irish Soil Information System – Synthesis Report (2007-S-CD-1-S1). Environmental Protection Agency, Wexford.

Wardle, D. (1992). A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biological reviews, 67(3), 321-358. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1469-185X.1992.tb00728.x/full

West, T. and McBride, A., 2005. The contribution of agricultural lime to carbon dioxide emissions in the United States: dissolution, transport, and net emissions. Agriculture, Ecosystems & Environment, 108, pp. 145-154.