APPENDIX G. ESTIMATING CARBON BUDGETS: A CARBON CALCULATOR

Contents

Fig. G.1

Create your own carbon calculator using an Excel spreadsheet

Because peatlands are an important store of carbon, in terms of climate change mitigation it is important to be able to determine the amount of carbon stored in a given peatland and whether:

1) The current carbon flow is positive, that is the peatland is absorbing more carbon than it is releasing.

2) It is carbon neutral, that is a store of carbon but with a net carbon flow neither in nor out of the peatland.

3) The current carbon flow is negative, that is the peatland is releasing more carbon than it is storing.

In practice it can be difficult to determine which of the three states applies to a given peatland. This calculator is designed to help with determining this, although it is relatively crude: hence its main use will be to estimate the order of magnitude of the various carbon stores and flows.

It will also be useful in determining the sensitivity of the results to variation of the different parameters; for example, the impact of doubling the estimated rate of peat growth, the rate of erosion, or the water content of the peat can be tested. The accuracy of the results will depend on the accuracy of the input data, but because peat bogs and their processes are complex, absolute accuracy will always be hard to attain.

It can also be used, as demonstrated here, to assess the impact of carbon flows on any peatland restoration measures; and to compare the amount of carbon stored in comparison to a commercial forest of the same area .

Structure of the spreadsheet

Create a spreadsheet using the structure below.
Alternatively, a completed version as an Excel spreadsheet is also available to download from www.fenton.scot/peat_bogs.htm

	A	B	C	D	E	F
1	**ESTIMATING THE CARBON BUDGETS OF PEATLANDS**					
2	**Input the measurements in red.** Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	**Extent of peat (ha)**	**Rate of peat growth (mm yr^{-1})**	*or* **Rate of peat growth (g dry wt/m^2/yr)**	**Erosion: area exposed surface peat (m^2)**	**Erosion: length exposed vertical peat (m)**
3	**Input value in units as in header row**	Numerical input	Numerical input	Numerical input	Numerical input	Numerical input
4	**Rate of erosion (mm depth lost yr^{-1})**	X	X	X	Numerical input	Numerical input
5	**Depth of peat (m)**	Numerical input	X	X	X	Numerical input
6	Volume of wet peat (m^3)	=B3*B5*10000	=C3/1000*((B3*10000)-E3)	X	=E3*E4/1000	=F3*F5*(F4/1000)
7	**Dry bulk density (g cm^{-3})**	Numerical input	Numerical input	X	Numerical input	Numerical input
8	Dry weight peat (t)	=B6*B7	=C6*C7	=D3/100*(B3-(E3/10000))	=E6*E7	=F6*F7
9	**Organic matter content (%)**	Numerical input	Numerical input	Numerical input	Numerical input	Numerical input
10	**Dry weight organic matter (t)**	**=B8*(B9/100)**	**=C8*(C9/100)**	**=D8*(D9/100)**	**=E8*(E9/100)**	**=F8*(F9/100)**
11	**% carbon**	Numerical input	Numerical input	Numerical input	Numerical input	Numerical input
12	**Amount of carbon gain/loss (t yr^{-1})**	X	**=C10*(C11/100)**	**=D10*(D11/100)**	**=E10*(E11/100)**	**=F10*(F11/100)**
13	**Total carbon store (tonnes)**	**=B10*(B11/100)**	*Use only one of these two columns; ignore figure below in unused column*		X	X
14	**Net carbon balance (growth minus erosion) (t yr^{-1})** *assumes all eroded peat lost to the system*	X	**=C12-E12-F12**	**=D12-E12-F12**	X	X

Note: Use figures for the catotelm only

Fig. G.2

Data to input

Input the relevant data into the fields marked in red. Use the default figures if direct measurements are not to hand.

	A	B	C	D	E	F
1	ESTIMATING THE CARBON BUDGETS OF PEATLANDS					
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	Area of bog	Annual depth increase	Annual weight gain	Area exposed surface peat	Length of exposed vertical edge
4	Rate of erosion (mm depth lost yr^{-1})	x	x	x	Annual depth loss	Annual rate of cut-back
5	Depth of peat (m)	Av. depth of peat	x	x	x	Height of vertical edge
6	Volume of wet peat (m^3)	*Calculated automatically*	*Calculated automatically*	x	*Calculated automatically*	*Calculated automatically*
7	Dry bulk density (g cm^{-3})	0.13 = Default	0.13 = Default	x	0.13 = Default	0.13 = Default
8	Dry weight peat (t)	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*
9	Organic matter content (%)	95 = Default	95 = Default	95 = Default	95 = Default	95 = Default
10	Dry weight organic matter (t)	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*
11	% carbon	55 = Default	55 = Default	55 = Default	55 = Default	55 = Default
12	Amount of carbon gain/loss (t yr^{-1})	x	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*	*Calculated automatically*
13	Total carbon store (tonnes)	*Calculated automatically*	*Use only one of these two columns; ignore figure below in unused column*		x	x
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	x	*Calculated automatically*	*Calculated automatically*	x	x
15	*Note: Use figures for the catotelm only*					

Notes

Dry bulk density. This is the dry mass of the organic matter *per* unit volume of undeformed peat, generally given in grams dry matter *per* cm^3. Chapman *et al.* (2017), give a mean value of 0.129 g cm^{-3}, range 0.100-0.180, for blanket peat at 20 Scottish sites. However within the acrotelm the bulk density varies with depth (see Appendix B) and the bulk density of the catotelm must be greater than that of the acrotelm for peat to form (see page 1.21). The default value used here is 0.13 g cm^{-3}, although in practice this may be an underestimate because the bulk density of the catotelm is likely to be higher than this. It can be determined in the field by extracting a known volume of peat (without deforming it) using a peat corer, or by extracting undisturbed catotelm peat from a vertical edge using a knife (but excluding any eroded material immediately adjacent to the edge); measure the volume of the wet peat, dry the peat in an oven (not too hot to burn the peat), then weigh the dry material. The dry bulk density can then be determined by relating the dry weight to the original volume of the wet peat.

Organic matter content. For the same sites mentioned by Chapman *et al.* (2017) above for bulk density, the average % organic matter was 94.38, range 81.66-98.60, very similar to the default figure of 95%, one commonly quoted in the literature. It could be varied depending on direct measurement: it can determined by burning a known weight of dry peat and then weighing the ash. Ombrotrophic peat, where the only input of water and minerals is from the air, will have a high organic content; however where there is water flowing into a bog, this can introduce mineral particles into the peat so that rheotrophic peat can have a lower organic matter content.

Carbon content. The default figure of 55% is one commonly quoted in the literature (for example Nayak *et al.* 2008-10).

Rate of peat growth in mm/yr. Lindsay (2010) indicates an average increase in catotelm depth of 0.5-1 mm yr^{-1}; the model can be compared using either figure, or any other figure determined by measurement. If a figure for surface erosion is entered, then this area is deducted from the area of active peat growth.

Rate of peat growth in g dry weight/m^2/yr. Many past calculations of peat growth rates have been made by subtracting the annual rate of decomposition within the peat from annual rate of plant production – see 2) on the next page.

Fig. G.3

Difficulties in determining peat growth and erosion rates

The easiest and most accurate figure the calculator will produce is the total amount of stored carbon in a given area of peatland because the main parameter, the depth of the peat, is relatively easy to measure – although it may vary considerably across a complex blanket peat landscape. However, as noted below, the resultant figure is particularly sensitive to the input value of the bulk density. Key to determining carbon fluxes is knowledge of the rate of peat accumulation and erosion. These are difficult to measure and various approaches have been used.

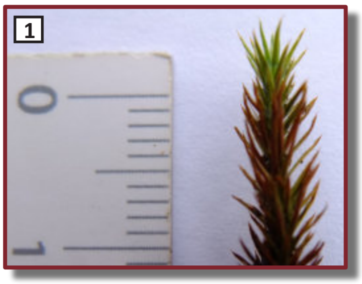
1) **Carbon-dating the peat at different depths.** This will give relatively accurate figures for the historical rate of peat accumulation, but little information on the current rate.

2) **Measuring plant growth and decomposition.** Many past calculations of peat growth rates have been made by measuring the annual rate of plant production and the annual rate of decomposition in the peat; the rate of peat growth is the difference between the two. For example, using this approach Heal *et al.* (1975) calculated the mean peat accumulation rate at Moorhouse National Nature Reserve in the Northern Pennines of England as 95 g m^{-2} yr^{-1}, with *Sphagnum*-dominated peat here having a range 100-270 g m^{-2} yr^{-1} (Clymo & Reddaway 1971); Maltby & Crabtree (1976) give a range of 6-96 g m^{-2} yr^{-1} for peat on Exmoor, England; Tallis & Switsur (1973) *ca.* 50 g m^{-2} yr^{-1} for peat in the Southern Pennines, England; and Fenton (1980) a range of 89-158 g m^{-2} yr^{-1} for Antarctic moss peat (see photographs below). However only small areas can be measured at a time – of the order of a square metre or two; if carried out over a year, there is no certainty that the year will be a representative one; and on a complex peatland, there needs to be certainty that the study area is representative.

3) **Direct measurement of gas fluxes.** Measurements of gas flows into and out of the peat have been carried out to determine the overall carbon balance: for example, in the Ecosse project (Scottish Executive 2007). These have the same limitations as 2) above, with the additional difficulty that gas fluxes are sensitive to temperature, moisture content of the peat and time of day.

4) **Direct measurement of erosion.** Considering the abundance of erosion features on peatland, there have been relatively few direct measurements of the erosion rate (Evans & Warburton 2010). One method is to put fixed pegs in eroding peat and revisit them at intervals to measure any change in the surface level. Again, such measurements may not always be representative of the eroded areas as a whole; for example, sites where water flow or animal impact are strongest will erode quicker than where this is not the case. Also, erosion may be maximal during extreme rainfall events, and such events may or not occur during the measurement period.

These, and other difficulties of measurement, explain why the calculator can only be used for estimating the carbon budgets, rather than accurately determining them: just because the calculator comes up with exact figures does not mean they are accurate. However having a simple, order-of-magnitude calculator which can be easily applied across peatlands should still be a useful tool. The other tool for quickly assessing whether a bog is in positive or negative carbon balance (although without quantification) is the visual assessment method in given in Table 4.9 on page 4.9.



Assessing the rate of peat growth: an example in an Antarctic *Polytrichum strictum* moss peat bank

1. At the end of the growing season, the annual extension growth of the moss shoots can be measured: green on the photograph, scale is mm (photograph taken in Scotland). Shoots in a known area can be cut off, dried and weighed to determine the annual production in g m^{-2} yr^{-1}

2. Buried in the peat at different depths are nylon mesh bags (marked by white pegs) containing material from that depth which has been dried, weighed and reburied. After a year or more in the ground, the bags are taken out, dried and reweighed. The measured weight loss will indicate the rate of plant decay down the profile. The rate of annual peat (dry matter) accumulation will equal the rate of production minus the amount which has decayed. The rate of annual depth accumulation can be determined by measuring the amount of compaction of the decayed shoots before they become incorporated into the permafrost. *See Fenton (1978, 1980) for full details*

3. Another way to measure the decay rate is to bury strips of cotton for a year (visible on the left of photo. 2), then remove them and measure their tensile strength down their length. The more decay there has been, the weaker the cotton will have become over the year

Using the calculator: Estimating the total carbon stored in a peatland

Fig. G.4

The examples on this page show the amount of carbon stored in 100 ha (1 km^2) of peatland, presented as screen-shots from the spreadsheet calculator.

Note that in these, and the examples that follow, the carbon store of the acrotelm is excluded; as discussed in Part 4, true 'peat' is only found in the catotelm. The carbon stored in the acrotelm is likely to be of the same order of magnitude as that of the surrounding non-peatland vegetation. **Hence the figures below give the amount of carbon stored additional to that of the surrounding vegetation, rather than the total carbon stored.** The spreadsheet could be modified to include the acrotelm where its bulk density is known.

Peat 1 m thick

Bulk density 0.13 g cm^{-3}

1		
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
3	Input value in units as in header row	100.00
4	Rate of erosion (mm depth lost yr^{-1})	X
5	Depth of peat (m)	1.00
7	Dry bulk density (g cm^{-3})	0.13
9	Organic matter content (%)	95
10	Dry weight organic matter (t)	123,500
11	% carbon	55
12	Amount of carbon gain/loss (t yr^{-1})	X
13	Total carbon store (tonnes)	67,925

Peat 2 m thick

Bulk density 0.13 g cm^{-3}

1		
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
3	Input value in units as in header row	100.00
4	Rate of erosion (mm depth lost yr^{-1})	X
5	Depth of peat (m)	2.00
7	Dry bulk density (g cm^{-3})	0.13
9	Organic matter content (%)	95
10	Dry weight organic matter (t)	247,000
11	% carbon	55
12	Amount of carbon gain/loss (t yr^{-1})	X
13	Total carbon store (tonnes)	135,850

Peat lost due to construction activities

This table can also be used to calculate the amount of carbon lost due to construction. In this case, the "input value" would be the surface area of the peat removed, and the "depth of peat" the depth removed. For example, if 100 m^2 of peat, 2 m thick is removed, the calculator shows this would amount to a carbon loss of 14 tonnes.

Sensitivity to value of the bulk density

Examples for 1 hectare of peatland with an average peat depth of 1.5 metres within the range of bulk densities quoted on the page G.2; as discussed there, the higher value of 0.18 g cm^{-3} might be a more realistic default than 0.13.

1		
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
3	Input value in units as in header row	1.00
4	Rate of erosion (mm depth lost yr^{-1})	X
5	Depth of peat (m)	1.50
7	Dry bulk density (g cm^{-3})	0.10
9	Organic matter content (%)	95
10	Dry weight organic matter (t)	1,425
11	% carbon	55
12	Amount of carbon gain/loss (t yr^{-1})	X
13	Total carbon store (tonnes)	784

1		
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
3	Input value in units as in header row	1.00
4	Rate of erosion (mm depth lost yr^{-1})	X
5	Depth of peat (m)	1.50
7	Dry bulk density (g cm^{-3})	0.13
9	Organic matter content (%)	95
10	Dry weight organic matter (t)	1,853
11	% carbon	55
12	Amount of carbon gain/loss (t yr^{-1})	X
13	Total carbon store (tonnes)	1,019

1		
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
3	Input value in units as in header row	1.00
4	Rate of erosion (mm depth lost yr^{-1})	X
5	Depth of peat (m)	1.50
7	Dry bulk density (g cm^{-3})	0.18
9	Organic matter content (%)	95
10	Dry weight organic matter (t)	2,565
11	% carbon	55
12	Amount of carbon gain/loss (t yr^{-1})	X
13	Total carbon store (tonnes)	1,411

Discussion

Estimating accurately the total amount of carbon stored depends critically on knowledge of the bulk density, which will vary down the acrotelm and be highest in the catotelm. In the examples above, peat with bulk density of 0.18 g cm^{-3} holds almost twice as much carbon as that with a bulk density of 0.10 g cm^{-3}. This is not surprising because the denser the decayed organic matter is packed, the more carbon it will contain. For the purposes of the examples which follow, 0.13 is taken as reasonable mean value.

Using the calculator: Estimating annual carbon sequestration rates

Fig. G.5

The examples on this page show the annual amount of carbon sequestered in 1 hectare of peatland, where there is active peat growth without erosion, presented as screen-shots from the spreadsheet calculator.

	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)
3	Input value in units as in header row	1.00	1.0	-
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X
5	Depth of peat (m)	1.00	X	X
7	Dry bulk density (g cm^{-3})	0.13	0.13	X
9	Organic matter content (%)	95	95	95
10	Dry weight organic matter (t)	1,235	1.24	#VALUE!
11	% carbon	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	0.68	#VALUE!
13	Total carbon store (tonnes)	679	*Use only one of these two columns; ignore figure below in unused column*	
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	0.68	#VALUE!

Peat growth input of 1 mm yr^{-1} depth increase

1 hectare sequesters 0.68 tonnes carbon *per* year

	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)
3	Input value in units as in header row	1.00	-	95
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X
5	Depth of peat (m)	1.00	X	X
7	Dry bulk density (g cm^{-3})	0.13	0.13	X
9	Organic matter content (%)	95	95	95
10	Dry weight organic matter (t)	1,235	#VALUE!	0.90
11	% carbon	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	#VALUE!	0.50
13	Total carbon store (tonnes)	679	*Use only one of these two columns; ignore figure below in unused column*	
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	#VALUE!	0.50

Peat growth input of 95 g m^{-2} yr^{-1} dry weight increase

(the average figure for blanket peat in the Northern Pennines, England, in the 1970s (Heal *et al.* 1975))

1 hectare sequesters 0.5 tonnes carbon *per* year

	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)
3	Input value in units as in header row	1.00	0.5	-
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X
5	Depth of peat (m)	1.00	X	X
7	Dry bulk density (g cm^{-3})	0.13	0.13	X
9	Organic matter content (%)	95	95	95
10	Dry weight organic matter (t)	1,235	0.62	#VALUE!
11	% carbon	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	0.34	#VALUE!
13	Total carbon store (tonnes)	679	*Use only one of these two columns; ignore figure below in unused column*	
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	0.34	#VALUE!

Peat growth input of 0.5 mm yr^{-1} depth increase

1 hectare sequesters 0.34 tonnes carbon *per* year

	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)
3	Input value in units as in header row	1.00	2.0	-
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X
5	Depth of peat (m)	1.00	X	X
7	Dry bulk density (g cm^{-3})	0.13	0.13	X
9	Organic matter content (%)	95	95	95
10	Dry weight organic matter (t)	1,235	2.47	#VALUE!
11	% carbon	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	1.36	#VALUE!
13	Total carbon store (tonnes)	679	*Use only one of these two columns; ignore figure below in unused column*	
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	1.36	#VALUE!

Peat growth input of 2 mm yr^{-1} depth increase

1 hectare sequesters 1.36 tonnes carbon *per* year

Using the calculator: Estimating the carbon balance where there is peat erosion (vertical edge cut-back)

Fig. G.6

The examples on this page show the annual carbon balance for 100 hectares (1 km^2) of peatland with a peat growth rate of 1 mm yr^{-1} and an average depth of 1.5 metres, where there is vertical edge cut-back, the rate of erosion estimated at different rates.

The calculator shows that even with 1 km of eroding vertical edges, the overall impact of this erosion on the net carbon balance of a peatland this size is low.

Gully erosion: this can be input as the length of two vertical edges *per* gully.

2	**Input the measurements in red.** Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	100.00	1.0	-	0	1,000
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X	0	1
5	Depth of peat (m)	1.50	X	X	X	1.5
7	Dry bulk density (g cm^{-3})	0.13	0.13	X	0.13	0.13
9	Organic matter content (%)	95	95	95	95	95
10	Dry weight organic matter (t)	185,250	123.50	#VALUE!	0.00	0.19
11	% carbon	55	55	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	67.93	#VALUE!	0.00	0.10
13	Total carbon store (tonnes)	101,888	*Use only one of these two columns; ignore figure below in unused column*		X	X
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	67.82	#VALUE!	X	X

1,000 m of vertical edge

Cut-back at 1mm yr^{-1}

Annual loss of carbon from erosion 0.1 tonnes

Minimal impact on overall carbon balance of this peatland of 100 ha

2	**Input the measurements in red.** Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	100.00	1.0	-	0	1,000
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X	0	10
5	Depth of peat (m)	1.50	X	X	X	1.5
7	Dry bulk density (g cm^{-3})	0.13	0.13	X	0.13	0.13
9	Organic matter content (%)	95	95	95	95	95
10	Dry weight organic matter (t)	185,250	123.50	#VALUE!	0.00	1.85
11	% carbon	55	55	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	67.93	#VALUE!	0.00	1.02
13	Total carbon store (tonnes)	101,888	*Use only one of these two columns; ignore figure below in unused column*		X	X
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	66.91	#VALUE!	X	X

1,000 m of vertical edge

Cut-back at 1 cm yr^{-1}

Annual loss of carbon from erosion 1.02 tonnes

Minimal impact on overall carbon balance of this peatland of 100 ha

2	**Input the measurements in red.** Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	100.00	1.0	-	0	1,000
4	Rate of erosion (mm depth lost yr^{-1})	X	X	X	0	20
5	Depth of peat (m)	1.50	X	X	X	1.5
7	Dry bulk density (g cm^{-3})	0.13	0.13	X	0.13	0.13
9	Organic matter content (%)	95	95	95	95	95
10	Dry weight organic matter (t)	185,250	123.50	#VALUE!	0.00	3.71
11	% carbon	55	55	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	X	67.93	#VALUE!	0.00	2.04
13	Total carbon store (tonnes)	101,888	*Use only one of these two columns; ignore figure below in unused column*		X	X
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	X	65.89	#VALUE!	X	X

1,000 m of vertical edge

Cut-back at 2 cm yr^{-1}

Annual loss of carbon from erosion 2.04 tonnes

Minimal impact on overall carbon balance of this peatland of 100 ha

Using the calculator: Estimating the carbon balance where there is peat erosion (surface erosion)

Fig. G.7

The examples on this page show the annual carbon balance of peatland with an average depth of 1.5 metres, where there is surface erosion and/or vertical edge cut-back, the rate of erosion estimated at different rates.

The calculator shows that even with 1 ha of surface erosion and 1 km of eroding vertical edges, the overall impact of this erosion on the net carbon balance of a peatland this size is low.

Expansion of pools: The surface area of pools can be input as "the area of exposed surface peat." This area will be deducted from the area of active peat growth. Pools expand both horizontally and vertically, but there is little data on the their rate of expansion. The "rate of erosion" input could be modelled at "0", *i.e.* no pool expansion, or an estimated rate of erosion, *e.g.* 1mm *per* year. The model could be run using different values to assess the overall impact on the carbon balance.

1						
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	100.00	1.0	-	10,000	1,000
4	Rate of erosion (mm depth lost yr^{-1})	x	x	x	10	10
5	Depth of peat (m)	1.50	x	x	x	1.5
7	Dry bulk density (g cm^{-3})	0.13	0.13	x	0.13	0.13
9	Organic matter content (%)	95	95	95	95	95
10	Dry weight organic matter (t)	185,250	122.27	#VALUE!	12.35	1.85
11	% carbon	55	55	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	x	67.25	#VALUE!	6.79	1.02
13	Total carbon store (tonnes)	101,888	*Use only one of these two columns; ignore figure below in unused column*		x	x
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	x	59.43	#VALUE!	x	x

100 hectares of peatland

Average depth 1.5 metres

Peat growth rate 1 mm yr^{-1}

1 hectare surface erosion

Losing 1 cm depth *per* year

1,000 m of vertical edge

Cut-back at 1 cm yr^{-1}

Annual loss of carbon from erosion = 6.79 + 1.02 = 7.81 tonnes

But overall carbon balance of this peatland is positive by 59 tonnes

1						
2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	10.00	0.1	-	1,000	100
4	Rate of erosion (mm depth lost yr^{-1})	x	x	x	20	20
5	Depth of peat (m)	1.50	x	x	x	1.5
7	Dry bulk density (g cm^{-3})	0.13	0.13	x	0.13	0.13
9	Organic matter content (%)	95	95	95	95	95
10	Dry weight organic matter (t)	18,525	1.22	#VALUE!	2.47	0.37
11	% carbon	55	55	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	x	0.67	#VALUE!	1.36	0.20
13	Total carbon store (tonnes)	10,189	*Use only one of these two columns; ignore figure below in unused column*		x	x
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	x	-0.89	#VALUE!	x	x

10 hectares of peatland

Average depth 1.5 metres

Low peat growth of rate 0.1 mm yr^{-1}

1,000 m^2 surface erosion

Losing 2 cm depth *per* year

1,000 m of vertical edge

Cut-back at 2 cm *per* year

The overall carbon balance of this peatland is negative – that is more carbon is being returned to the air than is being sequestered by the peat

2	Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})	*or* Rate of peat growth (g dry wt/m^2/yr)	Erosion: area exposed surface peat (m^2)	Erosion: length exposed vertical peat (m)
3	Input value in units as in header row	0.50	1.0	-	0	50
4	Rate of erosion (mm depth lost yr^{-1})	x	x	x	0	150
5	Depth of peat (m)	1.50	x	x	x	1
7	Dry bulk density (g cm^{-3})	0.13	0.13	x	0.13	0.13
9	Organic matter content (%)	95	95	95	95	95
10	Dry weight organic matter (t)	926	0.62	#VALUE!	0.00	0.93
11	% carbon	55	55	55	55	55
12	Amount of carbon gain/loss (t yr^{-1})	x	0.34	#VALUE!	0.00	0.51
13	Total carbon store (tonnes)	509	*Use only one of these two columns; ignore figure below in unused column*		x	x
14	Net carbon balance (growth minus erosion) (t yr^{-1}) *assumes all eroded peat lost to the system*	x	-0.17	#VALUE!	x	x

Impact of peat cutting

Removing a vertical section of peat through cutting is the equivalent of erosion through vertical edge cut-back. Here modelled with a 15 cm thick segment of peat cut from a face 1 m high and 50 m long

From a bog 0.5 ha in area, with the uncut peat deepening at 1 mm yr^{-1}

The impact of cutting is to put this bog into negative balance – a loss of 0.17 tonnes of carbon *per* year (allowing for peat regrowth below)

Using the calculator: Creating a calculator to estimate the carbon budget of a commercial forest

Fig. G.8

A carbon budget calculator using an Excel spreadsheet can be created for commercial forests as shown below. The figures below are for Sitka spruce *Picea sitchensis* which is the commonest conifer planted in commercial forests in Britain and Ireland in geographical regions where peatlands are common. Data for other species could be used.

	A	B
1	**ESTIMATING THE CARBON BUDGETS OF COMMERCIAL WOODLANDS**	
2	**Input the measurements in red.** Default figures for Sitka spruce *Picea sitchensis*: Density dry wood 0.35 g cm^{-3}; Biomass Expansion Factor 1.4; Carbon 46%	
3	**Yield class (m^3 green wood ha^{-1} yr^{-1})**	Numerical input
4	**Density dry timber (g cm^{-3})**	Numerical input
5	Tonnes dry wood ha^{-1} yr^{-1}	=B3*B4
6	**Length of rotation (yr)**	Numerical input
7	Total standing crop timber at harvesting (t ha^{-1})	=B5*B6
8	**Biomass Expansion Factor (BEF):** *the additional biomass in roots, leaves & branches* **(proportion to multiply)**	Numerical input
9	Total biomass standing crop at harvesting (t ha^{-1})	=B7*B8
10	Total average standing crop of wood – length of rotation/2 (t ha^{-1})	=B9/2
11	**% carbon**	Numerical input
12	**Average carbon standing crop (t ha^{-1})**	=B10*B11/100
13	**Average amount carbon fixed *per* year (t ha^{-1})**	=B12/B6
14		
15	**Total area of woodland (ha)**	Numerical input
16	**Average total carbon store (tonnes)**	=B12*B15
17	**Average amount carbon fixed *per* year (t)**	=B16/B11

Data to input

Input the relevant data into the fields marked in red. Use the default figures if other measurements are not to hand.

2	**Input the measurements in red.** Default figures for Sitka spruce *Picea sitchensis*: Density dry wood 0.35 g cm^{-3}; Biomass Expansion Factor 1.4; Carbon 46%	
3	**Yield class (m^3 green wood ha^{-1} yr^{-1})**	From forestry yield tables
4	**Density dry timber (g cm^{-3})**	0.35 = Default for Sitka spruce
5	Tonnes dry wood ha-1 yr^{-1}	Calculated automatically
6	**Length of rotation (yr)**	Input rotation length
7	Total standing crop timber at harvesting (t ha^{-1})	Calculated automatically
8	**Biomass Expansion Factor (BEF):** *the additional biomass in roots, leaves & branches* **(proportion to multiply)**	1.4 = Default for Sitka spruce
9	Total biomass standing crop at harvesting (t ha^{-1})	Calculated automatically
10	Total average standing crop of wood – length of rotation/2 (t ha^{-1})	Calculated automatically
11	**% carbon**	46 = Default for Sitka spruce
12	**Average carbon standing crop (t ha^{-1})**	**Calculated automatically**
13	**Average amount carbon fixed *per* year (t ha^{-1})**	**Calculated automatically**
14		
15	**Total area of woodland (ha)**	Input forest area
16	**Average total carbon store (tonnes)**	**Calculated automatically**
17	**Average amount carbon fixed *per* year (t)**	**Calculated automatically**

Structure of the spreadsheet

Create a spreadsheet using the structure on the left

Notes

Yield Class. The Yield Class of a forest is the annual volume of timber produced *per* hectare. Tables of Yield Class for different species are available from published sources; for example, for British forestry see Matthews *et al.* (2016)

Density of dry timber. The default value of 0.35 is that quoted for Sitka spruce in Moore (2011)

Length of rotation. The period between planting and harvesting

Biomass Expansion Factor. The Yield Class relates to the volume of timber produced, *i.e.* the wood in the trunk. However, to determine the carbon budget of a forest, it is necessary to determine the total biomass of the tree

A tree will store carbon in the trunk (the harvestable timber), in its leaves and branches and its roots. As a commercial forest matures, the proportion in the trunk increases before stabilising in the years before harvesting. It can be difficult to determine the exact amount of this additional biomass, so any figures quoted are likely to be approximations

To take account of this additional biomass, the biomass of the timber needs to multiplied by a factor known as the Biomass Expansion Factor (BEF). For example, a BEF of 1.3 means that the total biomass of the tree is the timber biomass x 1.3. Tobin & Nieuwenhuis (2007) calculated this biomass for Sitka spruce plantations in Ireland, with a 46 year old plantation having a BEF of 1.4: this is the default figure used here

% Carbon. Although Moore (2011) quotes a figure of 50% carbon for Sitka spruce biomass, direct measurements by Tobin & Nieuwenhuis (2007) indicate a slightly lower figure of 46%: this is the default figure used here

Average standing crop. At time of planting, the tree biomass is near zero, reaching its maximum at time of felling. The average biomass over the life of the forest before felling is therefore half the maximum

Average amount of carbon fixed *per* year. This is the average standing crop divided by the length of the rotation

Using the calculator: Comparing the carbon budgets of peatland and commercial forestry

Fig. G.9

The peatland and woodland calculators can be used together to compare the carbon budget of a peatland with that of a commercial forest in the same location. Examples are given below.

ESTIMATING THE CARBON BUDGETS OF PEATLANDS

Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)	Rate of peat growth (mm yr^{-1})
Input value in units as in header row	100.00	1.0
Rate of erosion (mm depth lost yr^{-1})	X	X
Depth of peat (m)	1.50	X
Dry bulk density (g cm^{-3})	0.13	0.13
Organic matter content (%)	95	95
Dry weight organic matter (t)	**185,250**	**123.50**
% carbon	55	55
Amount of carbon gain/loss (t yr^{-1})	X	**67.93**
Total carbon store (tonnes)	**101,888**	

100 ha of peatland with an average depth of 1.5 m will have a carbon store of *ca*. **100,000 tonnes**

If peat growth *per* year is 1 mm, it will be sequestering 68 tonnes *per* year

For a given area, a peat bog will store over 10x that of an equivalent commercial forest, although it will be seen that the forest sequesters carbon (147-196 t carbon yr^{-1}) at more than twice the rate of the peat (68 t yr^{-1})

ESTIMATING THE CARBON BUDGETS OF COMMERCIAL WOODLANDS

Input the measurements in red. Default figures for Sitka spruce *Picea sitchensis*: Density dry wood 0.35 g cm^{-3}; Biomass Expansion Factor 1.4; Carbon 46%	
Yield class (m^3 green wood ha^{-1} yr^{-1})	12
Density dry timber (g cm^{-3})	0.35
Length of rotation (yr)	50
Biomass Expansion Factor (BEF): *the additional biomass in roots, leaves & branches* (proportion to multiply)	1.4
% carbon	46
Average carbon standing crop (t ha^{-1})	**68**
Average amount carbon fixed *per* year (t ha^{-1})	**1**
Total area of woodland (ha)	100
Average total carbon store (tonnes)	**6,762**
Average amount carbon fixed *per* year (t)	**147**

100 ha of Sitka spruce of Yield Class 12 and a rotation of 50 years will have an average carbon store of *ca*. **6,800** tonnes. The amount in the timber will by 6,762/1.4 = **4,830 t**

ESTIMATING THE CARBON BUDGETS OF COMMERCIAL WOODLANDS

Input the measurements in red. Default figures for Sitka spruce *Picea sitchensis*: Density dry wood 0.35 g cm^{-3}; Biomass Expansion Factor 1.4; Carbon 46%	
Yield class (m^3 green wood ha^{-1} yr^{-1})	12
Density dry timber (g cm^{-3})	0.35
Length of rotation (yr)	60
Biomass Expansion Factor (BEF): *the additional biomass in roots, leaves & branches* (proportion to multiply)	1.4
% carbon	46
Average carbon standing crop (t ha^{-1})	**81**
Average amount carbon fixed *per* year (t ha^{-1})	**1**
Total area of woodland (ha)	100
Average total carbon store (tonnes)	**8,114**
Average amount carbon fixed *per* year (t)	**176**

100 ha of Sitka spruce of Yield Class 12 and a rotation of 60 years will have an average carbon store *ca*. **8,100** tonnes. The amount in the timber will by 8,114/1.4 = **5,796 t**

ESTIMATING THE CARBON BUDGETS OF COMMERCIAL WOODLANDS

Input the measurements in red. Default figures for Sitka spruce *Picea sitchensis*: Density dry wood 0.35 g cm^{-3}; Biomass Expansion Factor 1.4; Carbon 46%	
Yield class (m^3 green wood ha^{-1} yr^{-1})	16
Density dry timber (g cm^{-3})	0.35
Length of rotation (yr)	50
Biomass Expansion Factor (BEF): *the additional biomass in roots, leaves & branches* (proportion to multiply)	1.4
% carbon	46
Average carbon standing crop (t ha^{-1})	**90**
Average amount carbon fixed *per* year (t ha^{-1})	**2**
Total area of woodland (ha)	100
Average total carbon store (tonnes)	**9,016**
Average amount carbon fixed *per* year (t)	**196**

100 ha of Sitka spruce of Yield Class 16 and a rotation of 50 years will have an average carbon store *ca*. **9,000** tonnes. The amount in the timber will by 9,016/1.4 = **6,440 t**

Long-term fate of the harvested wood

If the harvested wood is subsequently burnt as wood-fuel, then all the carbon sequestered in the harvested timber will be released back into the air. The amount stored in the timber will be the total carbon stored reduced by the Biomass Expansion Factor (1.4), because the brash and roots are left *in situ*, rotting back over the length of the next rotation.

If however the timber harvested is used in construction, then this will act as a long-term carbon store. In the example above for 100 hectares where the peat is 1.5 m deep, it will take 10-20 forest rotations (say, 500 - 1,000 years) to have sequestered as much carbon as stored in the same area of peatland at the time of first planting. However, during this period, the peatland will have sequestered an additional 34,000 - 68,000 tonnes of carbon (67.93 x 500 or 1,000) if still accumulating peat at 1mm yr^{-1}.

Additionally, the planted trees may be oxidising any soil carbon they were planted on, reducing the total amount sequestered by the trees, as discussed on the next page.

Using the calculator: Tree planting on peat

Fig. G.10

The top two tables indicate that 12 cm of peat will store as much carbon as a Sitka spruce plantation of Yield Class 12 with a 60 year rotation. Note that in these calculations it is assumed that the biomass of the trees left behind after harvesting (brash and roots) all rots away during the subsequent rotation.

ESTIMATING THE CARBON BUDGETS OF PEATLANDS

Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
Input value in units as in header row	1.00
Rate of erosion (mm depth lost yr^{-1})	X
Depth of peat (m)	0.12
Dry bulk density (g cm^{-3})	0.13
Organic matter content (%)	95
Dry weight organic matter (t)	**148**
% carbon	55
Amount of carbon gain/loss (t yr^{-1})	X
Total carbon store (tonnes)	**82**

Note that the peat depth figures are for the catotelm only. The additional carbon in the acrotelm is not included

ESTIMATING THE CARBON BUDGETS OF COMMERCIAL WOODLANDS

Input the measurements in red. Default figures for Sitka spruce *Picea sitchensis*: Density dry wood 0.35 g cm^{-3}; Biomass Expansion Factor 1.4; Carbon 46%	
Yield class (m^3 green wood ha^{-1} yr^{-1})	12
Density dry timber (g cm^{-3})	0.35
Length of rotation (yr)	60
Biomass Expansion Factor (BEF): *the additional biomass in roots, leaves & branches* (proportion to multiply)	1.4
% carbon	46
Average carbon standing crop (t ha^{-1})	**81**
Average amount carbon fixed *per* year (t ha^{-1})	**1**
Total area of woodland (ha)	1
Average total carbon store (tonnes)	**81**

ESTIMATING THE CARBON BUDGETS OF PEATLANDS

Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
Input value in units as in header row	1.00
Rate of erosion (mm depth lost yr^{-1})	X
Depth of peat (m)	0.50
Dry bulk density (g cm^{-3})	0.13
Organic matter content (%)	95
Dry weight organic matter (t)	**618**
% carbon	55
Amount of carbon gain/loss (t yr^{-1})	X
Total carbon store (tonnes)	**340**

ESTIMATING THE CARBON BUDGETS OF PEATLANDS

Input the measurements in red. Default figures: Bulk density 0.13 g cm^{-3}; Organic matter 95%; Carbon 55%	Extent of peat (ha)
Input value in units as in header row	1.00
Rate of erosion (mm depth lost yr^{-1})	X
Depth of peat (m)	0.25
Dry bulk density (g cm^{-3})	0.13
Organic matter content (%)	95
Dry weight organic matter (t)	**309**
% carbon	55
Amount of carbon gain/loss (t yr^{-1})	X
Total carbon store (tonnes)	**170**

Discussion

As discussed in Part 3, trees planted on peat, together with the associated drainage ditches, cause loss of carbon through oxidation of the peat. This loss needs to be deducted from any carbon sequestrated by the trees as a whole.

In the United Kingdom, there is currently a policy of not planting trees on peat greater than 50 cm depth. The two examples above show the amount of carbon stored *per* hectare in 50 cm of peat: 340 tonnes in catotelm peat of 50 cm depth. However, if peat is defined as the depth of the acrotelm and catotelm combined, then, assuming an acrotelm of 25 cm depth, the amount of carbon stored as catotelm peat will be reduced to 170 tonnes. In this example, this is still 2-4x times as much as the 81 tonnes sequestered in one rotation of trees. In both cases, the carbon stored in the acrotelm is not included, although this is likely to be of the same order of magnitude as the carbon stored in any surrounding non-peat-forming vegetation.

It is noted in Part 3 that shallow peats have the best long-term potential for carbon storage, so that all peats, including shallow peats need protection from tree-planting.

Fig. G.11

Some conclusions arising from use of the calculator

The calculator is a useful tool for assessing the carbon budgets of peatlands, and for comparison with woodlands.

A landscape of blanket peat: the Flow Country of northern Scotland

A landscape of commercial plantations: the Galloway hills of southern Scotland

Calculating the exact amount of carbon stored is particularly sensitive to knowledge of the bulk density of the peat.

Estimating the carbon balance of peatlands is always likely to be an inexact science.

The amount of carbon stored in blanket peat can be ten times as much as that stored in a commercial plantation of Sitka spruce *Picea sitchensis* of the same area.

100 hectares of peatland with a 1 metre thick catotelm will store *ca.* 68,000 tonnes of carbon in the catotelm.

100 hectares of peatland with a 2 metre thick catotelm will store *ca.* 136,000 tonnes of carbon in the catotelm.

A peat growth rate of 1 mm *per* year will be sequestering *ca*. 0.7 tonnes of carbon *per* hectare *per* year.

Even if there are significant areas of peat eroding at 2 cm *per* year, this will have minimal impact on the overall carbon balance of a large peatland, although it can have a significant impact on smaller areas of peatland.

Traditional peat cutting for fuel can put a small bog into negative carbon balance.

The amount of carbon stored in a commercial forest can be ten times less than that stored in a peatland of the same area.

A bog with a catotelm 12 cm thick will store as much carbon in the catotelm as a commercial forest.

The current policy is for no tree planting on peat over 50 cm deep. If the depth of the peat is defined as the acrotelm and catotelm combined, then the catotelm peat will have a store of 17,000 tonnes of carbon *per* hectare. If defined as catotelm peat only, then the equivalent store will be 34,000 tonnes. This peat can eventually oxidise away if trees are planted on it. In comparison, the trees will only store an average of *ca.* 80 tonnes *per* hectare, which will all be released back into the air if the harvested wood is burnt as fuel; or will remain as a long-term store if used in construction.

Shallow peat, that is any vegetation with a catotelm, or the potential to form a catotelm, has a much greater potential for long-term carbon storage than any commercial forest planted on it – even though the peatland fixes less carbon *per* year than a forest of the same area.

In any calculations of the carbon mitigation impact of forests, the reduced albedo of forests (resulting in localised warming) compared to peatlands needs to be taken into account.

Peat stores an order of magnitude more carbon than the equivalent area of commercial conifers

Plantations on peat dry out the soil, releasing the stored carbon