Appendix A - Methodology

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A1 Introduction

A1.1 Background to the tool

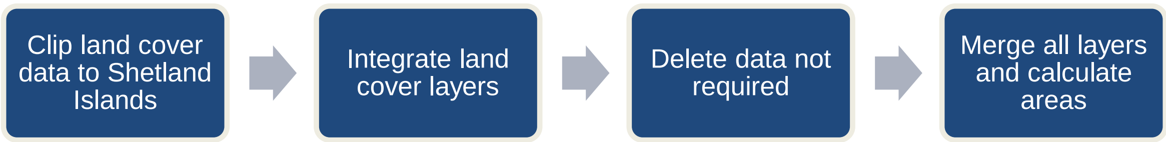
The aim of the tool is to determine a baseline carbon stock of a land area and an estimation of the change in carbon over time. The developed methodology comprises of two key stages:

- **Geoprocessing** using geographic information system (GIS) mapping of data layers to characterise land cover and derive their areas to input into the spreadsheet model.
- **Modelling** using a Microsoft Excel model developed by Ricardo Energy and Environment (REE), which performs multiple calculations using the area outputs from the geoprocessing stage to provide outputs of carbon storage and annual change (flux).

A1.1.1 Geoprocessing

Geospatial data were used for initial spatial analysis within GIS to establish a baseline representation of land cover and land cover condition. For the purposes of modelling, land cover is categorised into 18 different types and an aggregated area for each of these is produced as an output from the geoprocessing stage, although this has been modified for the purposes of this project (**Section A2**). The process undertaken in the geoprocessing stage is presented in **Figure A1.1**.

Figure A1.1 Geoprocessing Methodology



A1.1.2 Modelling

The land cover areas are fed into a model previously developed by REE, which presents a method for the calculation of carbon storage and flux (calculations are outlined in **Section A5**). Carbon storage and flux for each land cover are calculated using appropriate coefficients published in scientific literature[1] (see **Appendix B**). Carbon storage is presented for the baseline year 2022[2] and carbon flux is presented from the baseline year through to 2072. A 50-year scenario interval was selected for this model due to uncertainties to the potential impact of changes to climate after this date.

The annual flux associated with CO_2, CH_4 and N_2O exchange is calculated in units of CO_2e for all land cover types. CO_2 is an important quantifier for carbon storage and flux for all land cover types, methane is primarily significant for peatland and wetlands and nitrous oxide for agricultural land, including arable, grassland and orchards as well as peatland and wetlands. The derivation of annual flux is also based on an assumed starting (baseline) condition of each land cover. The model uses three types of condition status for land cover types: *degraded*, *semi-natural* and *managed* (see **Section A3.2**).

[1] Coefficients are mainly used from the NERR043 report for calculations of carbon storage and carbon flux. Woodland growth coefficients are derived from the Woodland Carbon Code calculator. The source of the coefficient used for each land cover and condition status are fully referenced in the model.

[2] This is under the assumption that the baseline land cover data used in the geoprocessing stage has not changed since being published and is representative of 2022.

A2 Rationale

A2.1 Land cover classification

For the purposes of this project, the model has been altered to use only 15 broad land cover types (**Table A2.1**) in order to provide granularity of the carbon balance associated with each of these land covers. These selected land cover types are based off land cover categories as presented in literature.

Table A2.1 Land cover classifications used in the model

Group	Land cover type
Peatland and wetlands	Peat bog - actively eroding
	Peat bog - drained
	Peat bog - modified
	Wetlands, fen, marsh, swamp
Heathland	Upland heath/moorland
	Lowland heath
Grassland	Natural grassland
Woodland	Broadleaved
	Coniferous
	Mixed
Agricultural Land	Pastoral land/intensive/improved grassland
	Arable land
	Orchards
Water	Inland water
Marine	Salt marsh
Other	Bare rock, sand and ground
	Artificial surfaces

The reduction in land cover types for this model reflects the land cover in Shetland and the aims of the modelling. The water category has been aggregated to include both lakes, ponds, reservoirs and watercourses. The model has two heathland land cover categories, *Upland heath/moorland* and *Lowland heath*. All heathland land cover identified in the geoprocessing stage has been assigned *Lowland heath* due to the elevation of Shetland[3]. Finally, peatland land cover categories have been modified to allow more discretisation of peatland condition (and their associated carbon flux) than the model previously allowed.

A2.2 Coefficients

Following a review of relevant scientific literature, carbon stock and flux coefficients were selected for each land cover type. Carbon flux coefficients are presented according to land cover condition: semi-natural, managed and degraded (see **Section A3.2** for details). Where multiple values were provided in the literature for one land cover, the most suitable option was selected, for example where coefficients are presented for one land cover type with multiple management options. Final coefficients (including references) are presented in **Appendix B**.

A2.3 Model errors

In order to provide an estimate of the uncertainty in the outputs a basic facility has been implemented in the model to automatically calculate errors on outputs. This uses a series of percentage errors for each land cover carbon coefficient which are manually input, allowing the user to vary these as they

[3] For the purposes of the modelling, upland heath is defined as heathland lying ≥350m elevation.

require, for example as carbon coefficients in the literature change. Currently the errors represent the range for carbon coefficient values related to each land cover class as presented within literature (particularly the NERR094 report[4]). They are high in many cases and this directly reflects the actual uncertainty in the values.

Where there is a cumulative carbon stock or carbon flux measurement calculated, a single error is given. This is calculated using the root mean squared (RMS) error of all calculated carbon stock or flux errors for each land cover type. RMS error[5] is the square root of the arithmetic mean of the squares of the carbon stock or flux error for each land cover type and represents a measurement of the spread of the data around the average (standard deviation).

RMS error is calculated as:

$$\text{RMS}=\sqrt{\frac{a^2+b^2+c^2\ldots}{n}}$$

Where:

a, b, c… = carbon stock and flux errors.

n = number of stock/flux values.

A2.4 Model assumptions

The carbon sequestration tool makes the following assumptions:

- It is a research model and the outputs should be used as a guide only. As with all models the outputs should be independently appraised and considered with the foundation of the model assumptions and the associated errors before any firm conclusions or decisions are made using the model outputs.
- The model has been designed to be compatible with the carbon stock and CO_2e flux coefficients readily available in the literature and therefore is a pragmatic representation of the current knowledge base.
- The selection of three land cover statuses represents a robust and pragmatic simplification based on the available carbon stock and CO_2e flux coefficients within the literature. Further subdividing the statuses would result in an increase in complexity without any increase in model accuracy or fidelity.
- Although complex, the representation of trees within the model, particularly with respect to tree species and tree growth, remains a simplification, albeit based on robust data sources (the Woodland Carbon Code (WCC)[6] and guidance based therein). This is predominantly due to limitations with the availability of input data.
- Mixed woodland is assumed to be a 50:50 split between the key broadleaf and coniferous tree species selected in the model (Sycamore, Ash and Birch and Scots Pine). It is accepted that mixed woodland is rarely an equal split but without a significant increase in data input the use of this assumption is required.
- Carbon soil and vegetation stock values are not split by land cover status as no available data could be identified to allow this to be performed.
- For peatland carbon stocks the soil is assumed to be organic peat, while for other land covers the soil is assumed to be mineral soils. For peatland, carbon stocks are based on stock values scaled up to the average measured depth of blanket bog of 169cm (taken from the James Hutton Institute Peatland ACTION peat depth map). Non-peatland soil carbon stocks used within the model are derived from soil samples taken down to 15cm in depth.

[4] Gregg, R., Elias, J., Alonso, I., Crosher, I., Muto, P. and Morecroft, M. (2021). Carbon storage and sequestration by habitat: a review of the evidence (second edition). Natural England Research Report NERR094. Natural England, York. 240pp.
[5] Oxford University Press. (2009). A Dictionary of Physics (6 ed.). Oxford University Press.
[6] https://www.woodlandcarboncode.org.uk/. Accessed 28 March 2022.

- As soil carbon stocks can vary greatly with depth we have largely used soil carbon stocks from a single uniform dataset.
- The model uses aggregated CO_2e flux coefficients for CO_2, CH_4 and N_2O. However, due to the data available in the literature and the gaseous response of specific land cover types, CO_2 fluxes are calculated for all land cover types, while aggregated CO_2, CH_4 and N_2O fluxes are calculated for *Wetlands, fen, marsh, swamp* only.
- The CO_2e flux coefficients for management actions are limited by data available in literature.
- No attempt has been made to link changes in CO_2e flux with carbon stock calculated during the baseline. No literature could be found which discusses the implementation of this, and while it is possible on a chemistry basis there are a range of potential pitfalls, e.g. exhaustion of carbon stock, underestimation of carbon stock, spatial and temporal variability in carbon stock and CO_2e flux etc.
- The model incorporates error calculations within its framework. These are based around the ranges of carbon stock and CO_2e flux coefficients identified in the literature. Where a single error value is provided it is calculated using the RMS of the error to provide a representative value. The model errors should be considered against all outputs to place these into context. As science evolves and more data is collected these errors are likely to reduce.
- The model calculates CO_2e fluxes out to a 50-year timescale only. This is limited since the robustness of the flux coefficients to extrapolation over long periods is not known. Furthermore, the effect of future climate change is likely to control these fluxes and could have an as yet uncertain control on carbon dynamics.
- The baseline land cover conditions are presented for the year 2022. This is under the assumption that the baseline land cover data used to assign condition status to land cover has not changed since being published (noting the oldest dataset used is 2016).
- Baseline scenario calculations assume that all land condition remains constant over the 50-year period, that degraded condition land cover that is recovering is not restored to semi-natural condition during this time and that no woodland is created through natural succession over the 50 year scenario period.
- It is assumed that the *Inland water*, *Artificial* and *Bare rock, sand and ground* land cover types have no sequestration or emission value.

A3 Model inputs

A3.1 Derivation of geospatial datasets

The selection of data to determine land cover areas and conditions was based on availability, cost, accuracy and spatial/temporal resolution. There are two main groups of data selected: boundaries and land cover, summarised in **Table A3.1**.

The geoprocessing stage integrates GIS data into a single, unified land cover dataset. Land cover is prioritised in the order set out in **Table A3.1**. The resulting multiple land cover classes in the single, unified dataset are then further classified into the 15 broad land cover classes used in the current modelling (**Table A2.1**).

Table A3.1 Summary of geospatial datasets used to determine land boundaries and land cover

Group	Data	Source	Year	Purpose
Boundary	Shetland Islands boundary	Ordnance Survey - Open Zoomstack	2021	Spatial data to set the boundary conditions of the assessment.
Land Cover	Roads, railways and airports	Ordnance Survey - OS Zoomstack roads and railways	2021	Data to characterise land cover within the boundary.
	Buildings	Ordnance Survey – OS Zoomstack local buildings	2021	
	Surface water	Ordnance Survey – OS Zoomstack	2021	
	Woodland	National Forest Inventory	2019	
	Greenspace	OS Open Zoomstack greenspaces	2021	
	Peatland	Carbon and Peatland Map – Hutton Institute	2016	
	EUNIS habitats	Habitat Map of Scotland	2017	
	CORINE High resolution grasslands	CORINE	2018	
	CORINE High resolution urban	CORINE	2018	
	Habitat and Land Cover	Habitat and Land Cover Map 2020	2020	

The following licence attributions cover the spatial data used in the modelling:

- **National Forest Inventory** - Contains, or is based on, information supplied by the Forestry Commission. © Crown copyright and database right 2022.
- **Ordnance Survey - Open Zoomstack** – Contains OS data © Crown copyright and database right 2022.
- **Carbon and Peatland 2016** – The Carbon and Peatland 2016 map is based on soil and land cover map data produced by the James Hutton Institute. Used with the permission of The James Hutton Institute. All rights reserved.
- **Habitat Map of Scotland EUNIS** – Contains public sector information licensed under the Open Government Licence v3.0.
- **Habitat and Land Cover Map 2020** – Maps and data created by Space Intelligence with input and support from NatureScot, © SNH. Contains public sector information licensed under the Open Government Licence v3.0.
- **CORINE data** - © European Union, Copernicus Land Monitoring Service 2018, European Environment Agency (EEA).

A3.2 Land Condition

Within the model, land cover data is categorised into three condition statuses: *semi-natural*, *degraded* and *managed*. The condition status of each land cover has been assigned using assumed condition based on the land cover type, values published in scientific literature and spatial analysis (peatland only). An outline of the assignment of land condition status is provided below.

- *Wetlands, fen, marsh, swamp* land cover condition has been assigned based on values provided in the literature for lowland grassland habitats listed in Annex I of the Habitats Directive and lowland grassland Biodiversity Action Plan (BAP) Priority habitats in Scotland[7]: 63% semi-natural condition and 37% degraded condition.
- *Salt marsh* land cover is not identified in the land cover datasets as being present on the Shetland Islands, therefore assignment of condition status is not required.
- *Natural grassland* land cover condition has been assigned based on values provided in the literature for lowland grassland habitats listed in Annex I of the Habitats Directive and lowland grassland Biodiversity Action Plan (BAP) Priority habitats in Scotland[8]: 58% semi-natural condition and 42% degraded condition.
- *Upland heath/moorland* land cover is not identified in the land cover datasets as being present on the Shetland Islands due to elevation of the land, therefore assignment of condition status is not required.
- *Lowland heath* land cover condition has been assigned based on values provided in the literature for UK SAC heathland condition status[9]: 21% semi-natural condition and 79% degraded condition.
- *Inland water*, *Artificial* and *Bare rock, sand and ground* land cover are assumed to have no sequestration potential, therefore condition status does not impact modelled sequestration potential and is not required for these land cover categories.
- Managed condition status is assigned based on the land cover type. Land cover categories automatically assigned as *Managed* land include *Agricultural land – pastoral land/intensive/improved grassland*, *Agricultural land – arable land*, *Orchards* and all *Woodland*[10].

A3.2.1 Peatland condition status

Within the model, peatland land cover condition has been assigned based on a spatial analysis using a simplification of the International Union for the Conservation of Nature (IUCN) Peatland Code condition categories[11]. Within the IUCN Field Protocol the following condition categories and their emission factors are defined as:

- **Actively Eroding: Hagg/gully** – 23.84tCO2e/ha/yr.
- **Actively Eroding: Flat bare** – 23.84tCO2e/ha/yr.
- **Drained: Artificial** – 4.54tCO2e/ha/yr.
- **Drained: Hagg/Gully** – 4.54tCO2e/ha/yr.

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[7] Werritty, A., Pakeman, R.J., Shedden, C., Smith, A. and Wilson, J.D. (2015). A review of sustainable moorland management. Report to the Scientific Advisory Committee of Scottish Natural Heritage.

[8] Dadds, N.J. and Averis, A.B.G. (2014). The extent and condition of non-designated species rich lowland grasslands in Scotland. Scottish Natural Heritage Commissioned Report

[9] Joint Nature Conservation Committee, (2015). UK Terrestrial & Freshwater Habitat Types: Lowland Heathland Habitat descriptions. Table 5.2.

[10] There are no carbon coefficients available in the literature to characterise degraded woodland, therefore the woodland land covers can be assigned as either semi-natural or managed. Most woodland on Shetland Islands within the land cover dataset appear to be planted or managed to some degree. As such the small extent of woodland identified is classified in the model as being *managed*.

[11] IUCN, (2017). Peatland Code. Field Protocol: Assessing Eligibility, Determining Baseline Condition Category and Monitoring Change. Version 1.1, March 2017. 10pp.

- **Modified** – 2.54tCO_2e/ha/yr.
- **Near natural** – 1.08tCO_2e/ha/yr.

As a simplification for the purposes of identifying degraded peatland, and since actively eroding and drained condition categories share the same emission factor, these categories were subdivided for the modelling into actively eroding, drained, modified and semi-natural.

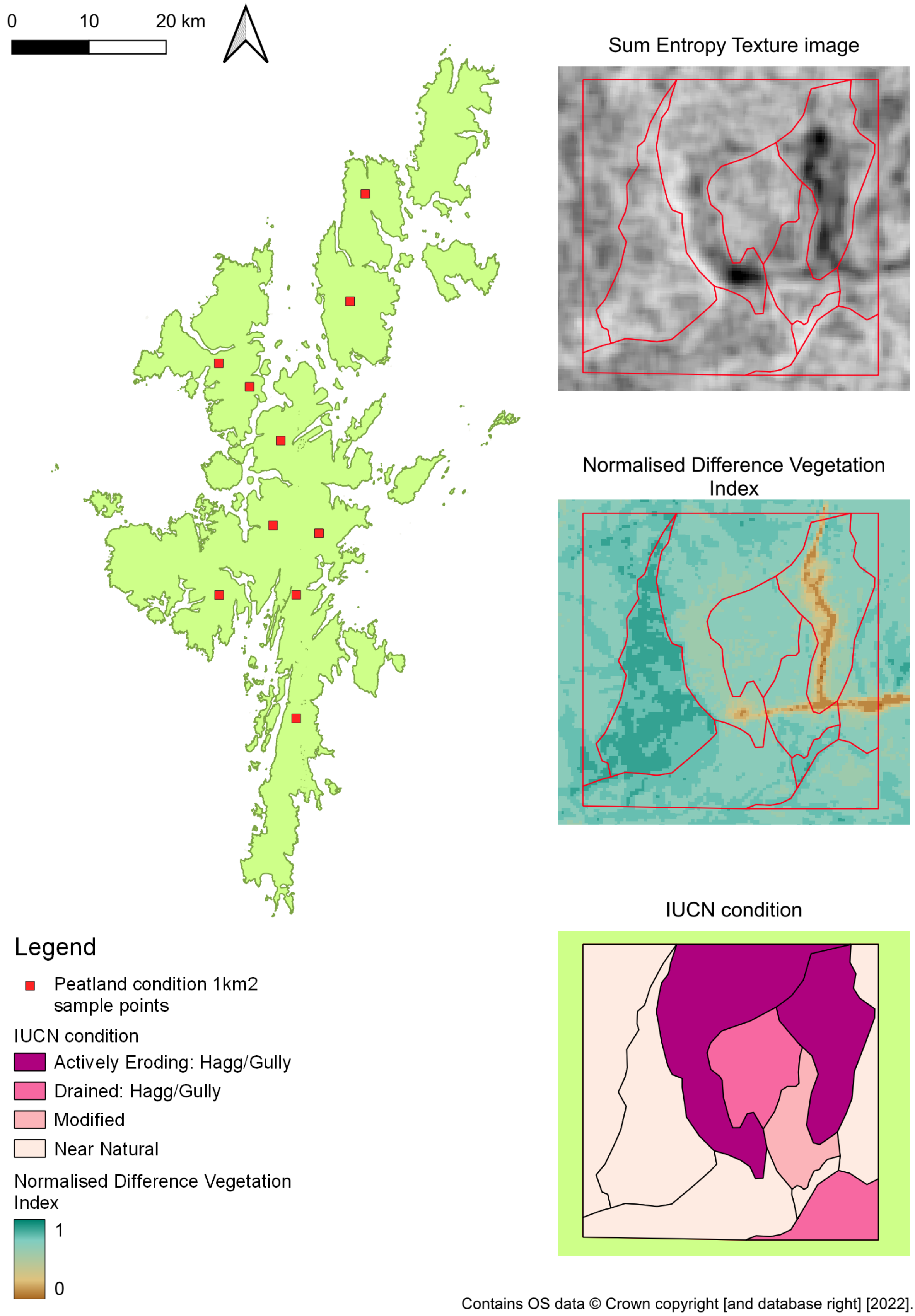
In order to rapidly develop an understanding of the current peatland condition in the absence of any condition data covering peatland across the Shetland Islands, a simple methodology was applied. This involved randomly selecting ten 1km^2 areas within the identified peatland boundaries (**Figure A3.1**) and dividing the peatland within these 1km^2 areas into either of the four selected peatland condition categories using visual, spectral and topographic differences based on a range of remotely sensed data (Google Earth, a mosaic of Sentinel 2 imagery of Shetland captured between 1 June and 1 July 2021 and processed into a Normalised Difference Vegetation Index (NDVI) and textural classification images and the OS Terrain 50 digital elevation model) (**Figure A3.1**[12]). The categorisation of the peatland into four different conditions were also supported with reference to the condition examples within the IUCN Peatland Code Field Protocol.

The results of this exercise determined the percentage cover of each of the four peatland categories within the ten 1km^2 sample areas. The resulting percentages were then applied to the total peatland cover identified on the Shetland Islands to scale this data into each of the relevant four peatland condition categories. The percentage cover of each peatland land cover sub-category determined by the spatial analysis is as follows:

- **Peat bog – actively eroding** = 33.9%.
- **Peat bog – drained** = 19.8%.
- **Peat bog – modified** = 11.4%.
- **Peat bog – semi-natural** = 34.9%.

[12] Due to licencing, an image of Google Earth imagery cannot be provided in a commercial document, hence an example is not provided here.

Figure A3.1 Location of ten randomly selected peatland condition assessment sites with example condition assessment



The results show that 65.1% of the peatland covered by the ten 1km^2 areas is degraded, while 34.9% of the remaining peatland was semi-natural. This compares relatively well with estimates of degraded peatland throughout Scotland being between 70%[13] to over 80%[14]. However, the approach adopted was developed to give a very rapid overview of peatland condition and there are inherent simplifications in the approach, most notably:

1. The condition assessments only cover a limited area of Shetland.
2. The potential for errors in visual interpretation of peatland condition.
3. No ground-truth data exist to calibrate the data used for the visual estimates of peatland condition.
4. Only features at the resolution of the datasets can be clearly identified (e.g. small drains may not be visible).

Therefore, the limitations of this approach should always be borne in mind when interpreting the carbon flux outputs from the model. However, it is clear that numerous improvements can be made to such a methodology in the future (which were well beyond the scope of this investigation), for example by adopting automated processing of remotely sensed imagery (e.g. multispectral and synthetic aperture radar data) and high resolution LiDAR, assessments by unmanned aerial vehicles and field-based condition assessments. It is recommended that work in this area is undertaken in the future to better understand peatland condition throughout Shetland.

A3.3 Woodland age and carbon stock and flux

A literature review of the coefficients available for woodland carbon stock and flux showed that the woodland type and woodland tree age have an influence on the associated coefficient values.

The land cover datasets outlined in **Table A3.1** were used to determine woodland classification. Woodland age distribution, as percentage age class split, was determined from Forestry Commission datasets for the standing volume of trees in Scotland classified by age class, for broadleaved[15] and coniferous[16] species (**Table A3.2**). This was used to calculate the areal split of each woodland type by age range (**Table A3.3**). Mixed woodland age class and carbon stock were based on an average of broadleaved and coniferous woodland values.

Table A3.2 Age class percentage split of woodland in Scotland

Age class (years)	Age class % split		
	Broadleaved	Coniferous	Mixed
0-10	0.0%	1.4%	0.7%
11-20	1.7%	1.4%	1.5%
21-40	21.0%	49.9%	35.5%
41-60	35.3%	35.9%	35.6%
61-80	20.7%	6.9%	13.8%
81-100	11.9%	2.1%	7.0%
100+	9.3%	2.5%	5.9%

Table A3.3 Summary of areal split for land cover areas

Age class (years)	Split of age class by area (ha)		
	Broadleaved	Coniferous	Mixed
0-10	0.01	0.33	0.00
11-20	1.03	0.33	0.00
21-40	13.04	11.87	0.00
41-60	21.88	8.54	0.00
61-80	12.85	1.64	0.00
81-100	7.39	0.50	0.00
100+	5.79	0.59	0.00

[13] https://www.iucn-uk-peatlandprogramme.org/news/peatland-restoration-shetlands. Accessed 29 March 2022.
[14] Peatlands (2016). Eds: Artz, R. and Chapman, S., The James Hutton Institute, Craigiebucker, Aberdeen, 24 pp.
[15] National Forest Inventory. (2013). Standing volume of broadleaves in woodland in Great Britain. Forestry Commission.
[16] National Forest Inventory. (2011). Standing coniferous timber volume. Forestry Commission.

Woodland carbon stock and flux values were derived with direct reference to these tree ages using data from the WCC carbon calculation spreadsheet[17]. In order to select realistic carbon stock and flux values for woodland, an understanding of the most common tree species composing woodland, their yield classes, spacing and thinning was required.

Site assessment using the Forestry Commission's Ecological Site Classification (ESC) tool[18] identified that Downy Birch and Grey Alder (Sycamore/Ash/Birch species, WCC tree code SAB) had the highest suitability for growth in Shetland, while Scots Pine (WCC tree code SP) had the highest suitability for coniferous species.

Estimate of yield class was derived by randomly selecting 100 locations within both broadleaved and coniferous woodland land cover within Shetland Island and feeding these locations into the Forestry Commission's ESC tool. The Ecological Site Classification tool calculated yield classes for all trees at each location and the average yield class for Sycamore/Ash/Birch and Scots Pine were derived from the dataset. Values for tree spacing and thinning were derived from the WCC manual[19]. From the analysis the following woodland parameters were selected:

- **Broadleaved woodland –** Sycamore/Ash/Birch species, yield class of 4, 2.5m spacing and no thinning.
- **Coniferous woodland –** Scots Pine, yield class of 4, 1.5m spacing and no thinning.

There is no specific mixed woodland class in the WCC Calculator. Due to the lack of any data to characterise the species mix and numerical composition of these species in mixed woodland, mixed woodland is assumed to be a 50:50 split of broadleaved and coniferous trees (Sycamore/Ash/Birch and Scots Pine) for the purposes of specifying carbon stocks and fluxes. Full details of the carbon stock and flux coefficients selected for the model based on the broadleaved and coniferous woodland data can be found in **Appendix B**.

While it is acknowledged that the approach to woodland is a generalisation, the currently available woodland data sourced through geospatial data sources (**Table A3.1**), is insufficient to identify individual tree species in woodland, and attempting to simulate this in the model would not be realistic due to inaccurate parameterisation.

A4 Spatial data validation

To check the accuracy of generated land cover map and the validity of the derived model outputs, a check of land cover at 200 random locations[20] within the Shetland Islands was performed (**Figure A4.1**). Of these 200 points, 150 points were randomly selected within non-peatland land cover, and 50 points within peatland land cover. The generated final land cover map was compared to the most recent Google Earth satellite imagery available.

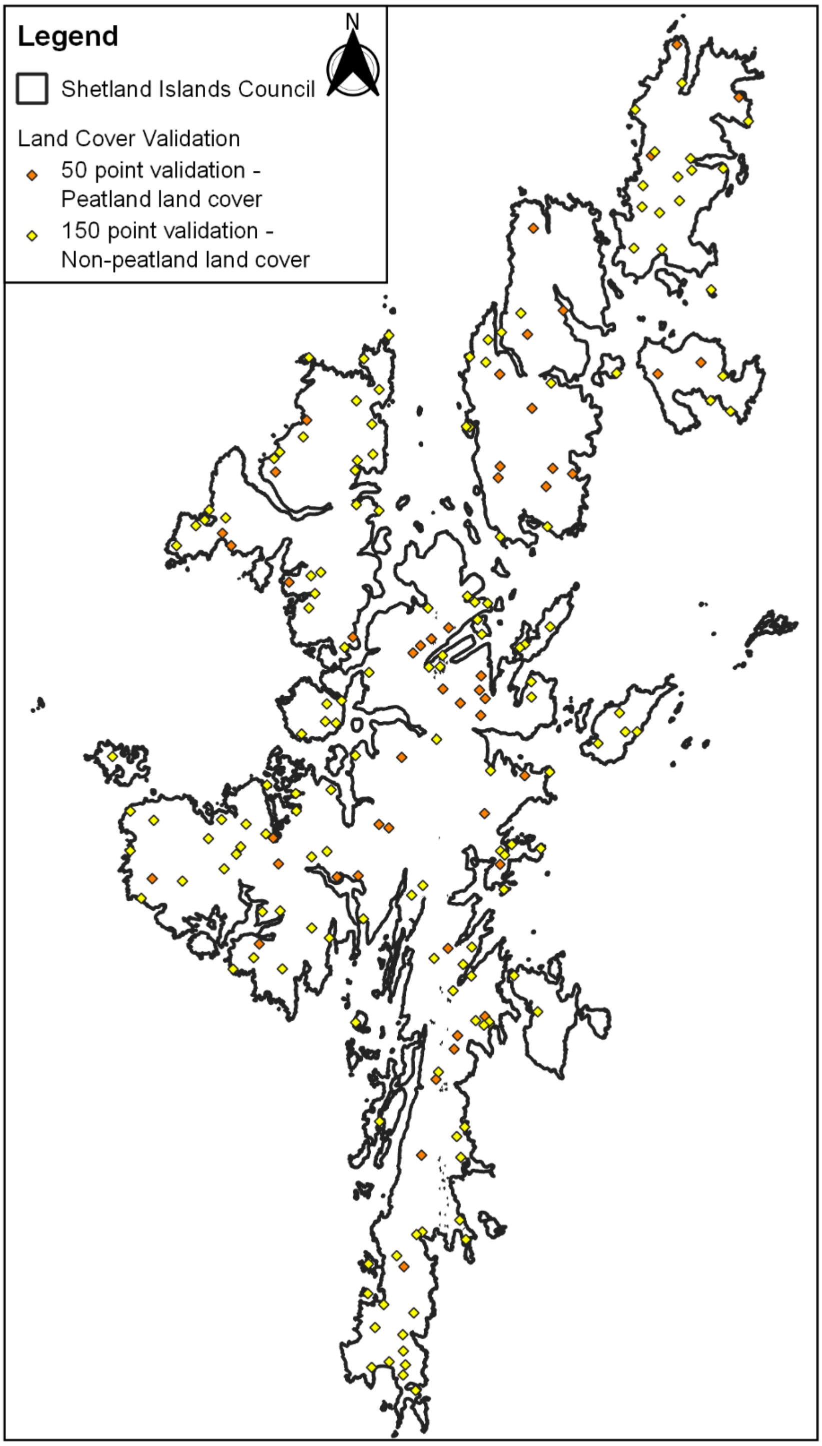
[17] Woodland Carbon Code carbon calculation spreadsheet v2.1, 21 November 2019 (https://www.woodlandcarboncode.org.uk). Accessed 12 February 2021.

[18] http://www.forestdss.org.uk/geoforestdss/

[19] Woodland Carbon Code carbon calculation spreadsheet v2.4, March 2021 (https://www.woodlandcarboncode.org.uk). Accessed 02 February 2022.

[20] Random locations generated using geoprocessing spatial analysis tool.

Figure A4.1 Location of random point land cover validation within Shetland Islands



Comparison of the land cover extracted from spatial datasets and satellite imagery at 150 random points with non-peatland land cover and 50 points within peatland land cover in the Shetland Islands confirmed 85.5% of the land cover allocations were correct, and an additional 1.0% were correct out to a distance of 5m from the random sample point location Therefore 13.5% of the land cover types did not appear to be correct at the exact location or within a 5m buffer when compared to satellite imagery.

A summary of reasons for the 13.5% of inaccuracies are outlined below.

- **Natural grassland**: Incorrect allocation of *Natural grassland* land cover occurred at 18 locations (9.5%). In all cases this was due to classification of the CORINE high resolution grassland data as *Natural grassland*. Satellite imagery identified the correct land cover at the majority of these locations as agricultural land, with 11 cases being identified as *Agricultural land - pastoral land/intensive/improved grassland* and three locations identified as *Agricultural land - arable*'. At the remaining five incorrect allocations, the correct land cover was identified as *Peatland*.

- **Bare rock, sand and ground**: 2.5% of the spatial data land cover was incorrect due allocation of *Bare rock, sand and ground* at five locations which satellite imagery identified as *Natural grassland* and *Peatland* land cover.
- **Artificial**: 1.5% of the spatial data land cover was incorrect due allocation of *Artificial* land cover at three locations which satellite imagery identified as *Natural grassland* and *Peatland* land cover.
- **Peatland**: Incorrect allocation of *Peatland* land cover occurred at one location (0.5%). Satellite imagery identified the correct land cover at this location as *Agricultural land - pastoral land/intensive/improved grassland*.

The validation check of the land cover at the 200 locations within the Shetland Islands suggests a confidence of 85.5% within 5m. The geoprocessing is therefore taken to be of high accuracy and is considered suitable for predicting land cover changes over such a large area. Any errors in carbon predictions due to misclassification of these land covers will be very small in comparison to the realistic errors applied to the carbon predictions.

A5 Model calculations

A5.1 Carbon stock calculation

Total carbon stock is calculated as:

$$C_{tot} = (C_s \times L) + (C_v \times L)$$

Where:

C_{tot} = Total carbon stock (t C).

C_s = Soil carbon stock (t C/ha).

L = Land cover area (ha).

C_v = vegetation carbon stock (t C/ha).

Soil/water stock – Soil/water stock coefficients are used to parameterise the amount of carbon stored in the soil (or water for lakes and rivers) for each specific land cover (in t C/ha). With exception of peatland and *Wetlands, fen, marsh, swamp* which are assumed to be peat soils with carbon stored in the top 169cm or 40cm of the soils respectively, the other land cover classes assume mineral soils with carbon stored in the top 15cm of the soil profile.

Vegetation stock – Vegetation stock coefficients are used to parameterise the amount of carbon stored in the vegetation which grows on each specific land cover (in t C/ha).

Percentage vegetation stock sequestered – This is a factor which can govern the amount of carbon stock in the vegetation which is sequestered year on year into the stock and can be added to the five yearly CO_2e model flux outputs. This percentage could be set / varied based on estimates of vegetation growth, die-back or removal. Currently there is no literature to support this calculation therefore we have implemented a default setting of zero.

It is acknowledged that there are a range of stock coefficients in the literature for different land cover types, particularly peatland, e.g. 74t C/ha (Alonso *et al.,* 2012)[21], 261t C/ha (Hagon *et al*., 2013)[22], 675t C/ha (Heinemeyer and Pateman, 2020)[23] and 928t C/ha (Worrall and Holden, 2010)[24]. The range of values represents differing analysis methods, differing environmental conditions, differing soil depths of sampling (which carbon stock is very sensitive to) etc. For this reason, we adopted a single uniform dataset of peat bog carbon soil stock values sourced from (Heinemeyer and Pateman, 2020).

For *Inland water*, *Artificial* and *Bare rock, sand and ground* land covers the coefficients are currently set to zero. These are included in the model as the land cover types do have carbon stock and flux potential, however no carbon flux values could be found to appropriately represent these land cover types at present.

It should be noted that the depth of soil and the depth to which the carbon stock coefficient is referenced can have a significant impact on the modelled carbon stocks. As soil depths vary throughout the landscape then carbon stocks will also vary, although this is not straightforward as it is dependent on characteristics such as the soil type, the carbon concentration in the soil and how it is distributed through the soil profile. The current approach uses carbon stocks in mineral soils based on 15cm deep soil profile and increases in soil depth could lead to large increases in estimated carbon stocks. This would be even more significant for peat bogs whose depths can be up to several meters, and this reflects the approach adopted in the modelling to scale carbon stocks for peat bogs by an average of measured blanket bog depths on Shetland of 169cm. While the current model uses a consistent coefficient dataset at a set number of depths, a fuller understanding of carbon stock in an area would need to actively

[21] Alonso, I., Weston, K., Gregg, R. and Morecroft, M. (2012). Carbon storage by habitat - Review of the evidence of the impacts of management decisions and condition on carbon stores and sources. Natural England Research Reports, Number NERR043. 58pp.
[22] Hagon, S., Ottisch, A., Convery, I., Herbert, A., Leafe, R., Robson, D. and Weatherall, A. (2013). Managing land for carbon: a guide for farmers, land managers and advisors. Lake District National Park Authority / University of Cumbria. 25pp. http://insight.cumbria.ac.uk/id/eprint/2256/.
[23] Heinemeyer, A. and Pateman, R., 2020. Restoration of heather-dominated blanket bog vegetation on grouse moors for biodiversity, carbon storage, greenhouse gas emissions and water regulation: comparing burning to alternative mowing and uncut management.
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consider soil depth and carbon content changes with depth and such data is not readily available. Therefore, carbon stock values and any conclusions drawn from them need to always be contextualised against these considerations. Carbon stock coefficients are detailed in **Appendix B**.

A5.2 Woodland carbon stock

The woodland vegetation stock coefficients are calculated on an annual basis per tree species per tree age class using a non-linear regression model which is calculated using the data held in the WCC for each tree species (Sycamore, Ash and Birch and Scots Pine). Trees are aged annually. CO_2e stock coefficients for mixed woodland assume a 50:50 mixture of broadleaved and coniferous trees are the average of the broadleaved and coniferous stock values.

A5.3 Carbon flux calculation

Baseline CO_2e flux is calculated automatically over a 50-year period within the model and is based on the input land cover areas and the default CO_2e flux coefficients. The flux coefficients for CO_2, CH_4 and N_2O are summed together in the model to provide the aggregated CO_2e flux coefficient[25].

The output calculations provide a cumulative and annual CO_2e flux until the end of the 50-year modelling period. These fluxes are provided for each land cover type and their status.

The annual CO_2e flux is calculated as:

$$CO_2e\ flux = ((-(L \times (C_v \times 3.6667))) \times (C_{vp}/100)) + (L{*}F_c)$$

Where:

CO_2e flux = Carbon dioxide equivalent flux (t CO_2e)

L = Land cover area (ha)

C_v = vegetation carbon stock (t C/ha)

C_{vp} = The percentage of vegetation carbon sequestered per year as part of the flux (0-100%)

F_c = aggregated CO_2e flux coefficient per land cover (t CO_2e/ha/yr) (i.e. CO_2 flux+CH_4 flux+N_2O flux for each land cover as relevant in CO_2e/ha/yr)

Note: 3.6667 is used for the conversion between carbon and CO_2e (derived from molecular weight).

It should be noted that there are CO_2 fluxes for all land cover types (except *Inland Water*, *Artificial* and *Bare rock, sand and ground*) but there are only methane and nitrous oxide flux values for *Wetlands, fen, marsh, swamp*). Therefore, CO_2 fluxes are calculated for all land cover types, while aggregated carbon dioxide, methane and nitrous oxide fluxes are calculated for *Wetlands, fen, marsh, swamp* only.

Carbon flux coefficients are detailed in **Appendix B**.

A5.4 Woodland carbon vegetation flux

The woodland vegetation flux coefficients are calculated on an annual basis per tree species per tree age class using a non-linear regression model which is calculated by the model using the data held in the WCC for each tree species (Sycamore, Ash and Birch and Scots Pine). Trees are aged annually. CO_2e flux coefficients for mixed woodland assume a 50:50 mixture of broadleaved and coniferous trees are the average of the broadleaved and coniferous flux values.

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