Ricardo
Energy & Environment

Assessment of Shetland Islands Council Land Carbon Sequestration

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Final Report for Shetland Islands Council

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Executive summary

Shetland Islands Council (SIC) are looking for strategic and technical support to assist them in determining how they might most effectively transition towards net zero. SIC have a number of commitments which require a review of the current carbon balance of its land cover, as well as assessing opportunities to reduce/offset emissions. Therefore, SIC require an assessment of the offsetting potential of the land cover within the council's landholdings and operating area, covering the Shetland Islands.

Ricardo Energy and Environment (REE) have developed the TerraC6 model to help local authorities better understand carbon stocks and annual fluxes for land, to meet policy and climate change commitments. The TerraC6 model uses a combination of geoprocessing (derivation of land cover and condition from geospatial datasets) and modelling (using a REE developed Excel-based model) in order to calculate the carbon balance of land cover. The outputs from the geoprocessing stage feed into the model as land cover areas categorised by condition. As part of a wider Net Zero project, SIC have commissioned REE to undertake an assessment of the offsetting potential of SIC, using the TerraC6 model.

The baseline carbon assessment model results identified that the overall carbon stock of Shetland (area-wide) and SIC Landholdings is 196,258 ± 22,278 kt CO_2e and 28,413 ± 3,156 kt CO_2e respectively. The model outputs identify that the *Peat bog* land cover stores the largest proportion of the carbon within Shetland (area-wide) and SIC Landholdings, ~91% and 92% of total carbon stock respectively.

The baseline carbon assessment model results identified an overall cumulative CO_2e flux (emission) from Shetland land cover of 36,618 ± 2,308 kt CO_2e over the 50-year model run period 2022-2072. The largest net sequester of CO_2e for SIC over the period is semi-natural condition *Natural grassland* (-3,073 kt CO_2e cumulative total from 2022-2072), while the largest net emitter of CO_2e is *Peat bog* (specifically actively eroding) (29,120 kt CO_2e cumulative emissions total from 2022-2072).

For SIC Landholdings, the baseline carbon assessment model results identified an overall cumulative CO_2e flux (emission) of 5,441 ± 318 kt CO_2e over the 50-year period 2022-2072. The largest net sequester of CO_2e for SIC over the period is semi-natural condition *Natural grassland* (-261 kt CO_2e cumulative total from 2022-2072), while the largest net emitter of CO_2e is *Peat bog* (specifically actively eroding) (4,264 kt CO_2e cumulative emissions total from 2022-2072).

Subsequent to reviewing the outcomes of the baseline carbon assessment, the model was run for five individual carbon reduction scenarios based on restoration of degraded condition land cover within Shetland (area-wide) and SIC Landholdings. The potential carbon flux for each carbon reduction scenario was modelled to give a projected carbon flux under scenario conditions and compare this to the baseline scenario. The baseline scenario assumes no change in land cover or condition takes place over the 50-year period from 2022-2072.

It was identified that restoration of degraded peatland is likely the most effective strategy to reduce emissions from land cover. However, it is acknowledged that there are significant potential considerations to account for when designing suitable management actions, specifically agriculture, costs, technical expertise, maximising co-benefits and integrating with existing or proposed peatland restoration. These factors all need to be considered to ensure that any selected actions can be implemented effectively and without detriment to stakeholders and provide the necessary beneficial outcomes across the island.

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Abbreviations

GHG	Greenhouse Gas
GIS	Geographic Information System
LULUCF	Land Use, Land Use Change and Forestry
REE	Ricardo Energy and Environment
RMS	Root Mean Square
SIC	Shetland Islands Council

Units

C	carbon
CO_2e	carbon dioxide equivalent
ha	hectares
kt	kilotonnes (thousands of tonnes)
kt C	kilotonnes of carbon
kt CO_2e	kilotonnes of carbon dioxide equivalent

Glossary

Carbon balance: The process of identifying and quantifying carbon added to, or removed from, the atmosphere by natural and human activity.

Carbon dioxide equivalent: A common unit for describing different greenhouse gasses signifying the amount of CO_2 which would have the equivalent global warming impact.

Carbon flux: The volume of carbon exchanged between different **carbon sources** or **carbon sinks**.

Carbon neutrality: A state of balance between carbon emitted and removed from the atmosphere. This can also be achieved by buying 'carbon credits' and carbon offsetting. A commitment to carbon neutrality does not require a commitment to reduce overall GHG emissions, as businesses are required only to offset the GHG emissions it produces.

Carbon sequestration: Refers to the measures, deliberately undertaken, that increase **carbon stocks** above those already present[1].

Carbon sink: A process, activity or mechanism that removes carbon from the atmosphere[2].

Carbon source: A process, activity or mechanism that delivers carbon to the atmosphere[3].

Carbon stock: The absolute carbon held at any specified time or component of a wider climate system[4].

Land cover: The observed (bio) physical cover on the earth's surface[5]. Aspects describing land itself rather than land cover are included (e.g. bare areas, water bodies, etc.) because in practice the scientific community is used to describing those aspects under the term land[6]. Changes in land cover may be due to natural phenomena or be human-induced.

Land use: The predominant purpose for which an area of land is employed[7]. Land use can be further defined as the arrangements, activities and inputs people undertake in a certain **land cover** type to produce, change or maintain it[8]. By definition, land use changes are always human-induced[9].

Net zero: A balance between greenhouse gases emitted and removed from the atmosphere, achieving through reducing emissions where possible, and offsetting the remaining emissions.

Root Mean Square: The square root of the arithmetic mean of the squares of a set of values[10].

Woodland: A grouping consisting of forest, other wooded land and individual trees, wooded hedgerows and scrub.

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[1] Metz, B., Davidson, O., Swart, R. and Pan, J., (2001). Climate Change 2001: Mitigation. Cambridge, UK: Cambridge University Press.
[2] IPCC, (2013). Glossary of terms. Annex I: Atlas of Global and Regional Climate Projections [van Oldenborgh, G.J., M. Collins, Arblaster. J, Christensen. J.H, Marotzke. J, Power .S.B, Rummukainen. M, Zhou. T (eds.)]. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[3] IPCC, (2013). Glossary of terms. Annex I: Atlas of Global and Regional Climate Projections [van Oldenborgh, G.J., M. Collins, Arblaster. J, Christensen. J.H, Marotzke. J, Power .S.B, Rummukainen. M, Zhou. T (eds.)]. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[4] IPCC, (2013). Glossary of terms. Annex I: Atlas of Global and Regional Climate Projections [van Oldenborgh, G.J., M. Collins, Arblaster. J, Christensen. J.H, Marotzke. J, Power .S.B, Rummukainen. M, Zhou. T (eds.)]. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[5] Di Gregorio, A., and Jansen, L.J.M., (2000). Environment and Natural Resources Service, GCP/RAF/287/ITA Africover - East Africa Project and Soil Resources, Management and Conservation Service. 179pp, Rome.
[6] Di Gregorio, A., and Jansen, L.J.M., (2000). Environment and Natural Resources Service, GCP/RAF/287/ITA Africover - East Africa Project and Soil Resources, Management and Conservation Service. 179pp, Rome.
[7] USDA Forest Service, (1989). Interim Resource Inventory Glossary. File 1900. US Department of Agriculture, Forest Service, Washington, DC, 96pp.
[8] Di Gregorio, A., and Jansen, L.J.M., (2000). Environment and Natural Resources Service, GCP/RAF/287/ITA Africover - East Africa Project and Soil Resources, Management and Conservation Service. 179pp, Rome.
[9] Lund, H.G., (1999). A 'forest' by any other name…Environmental Science & Policy, Vol. 2 (2): p125-133.
[10] Oxford University Press. (2009). A Dictionary of Physics (6 ed.). Oxford University Press.

1 Background

Shetland Island Council (SIC) are looking for strategic and technical support to assist them in determining how they might most effectively transition towards net zero. The council are specifically looking for routemaps and tools to be developed that detail the technical, behavioural and strategic projects and programmes that need to be developed to identify pathways towards net zero for both the Council's own operations and the entire Islands.

SIC have a number of commitments which require a review of the current carbon balance of its landholdings and wider operating boundary area, as well as assessing opportunities to reduce/offset emissions. These include:

- In January 2020 SIC officially recognised the **global climate emergency**;
- The **ORION project** has set local emissions reductions targets for Shetland for net zero / carbon neutrality by 2030; and
- The **Climate Change Act 2019** has legally committed the Scottish Government to achieve net zero greenhouse gas emissions target by 2045.

As set out in a separate report produced by Ricardo Energy & Environment, the annual area-wide greenhouse gas emissions for the Shetland Islands are estimated to be roughly 670 ktCO_2e/yr.[11] Of this total, approximately 50% is associated not with fuel consumption, but with emission from land use, land use change and forestry (LULUCF). The reason that LULUCF emissions are so high is because most of Shetland lies on former peat bogs, which continue to emit GHGs long after they are drained or converted for other land uses. Scottish Natural Heritage has estimated that 80% of Scotland's peat bogs are damaged due to years of draining and grazing and therefore release carbon into the atmosphere[12]. In light of this, improving the carbon sequestration potential of the land will be crucial in order to achieve a significant proportional (%) reduction in Shetland's emissions.

REE have developed the TerraC6 model to help local authorities better understand carbon stocks and annual fluxes for land, to meet policy and climate change commitments. SIC have commissioned REE to undertake an assessment of the offsetting potential of land within SIC Landholdings and Shetland (area-wide), using the TerraC6 model.

This report outlines the current carbon balance of land cover within SIC's landholdings and Shetland (area-wide) (**Section 3**) and provides an assessment of the potential carbon reduction opportunities (**Section 4**). Conclusions and recommendations are summarised in **Section 5**.

It should be noted that the approach adopted herein does not attempt to supplant current national emissions statistics nor is it expected that the results from the approach will directly align with national statistics due to differences in methodology. However, the results do confirm that the general order of magnitude of LULUCF emissions is very high and the results of the model can be used to define potential strategies for reducing them.

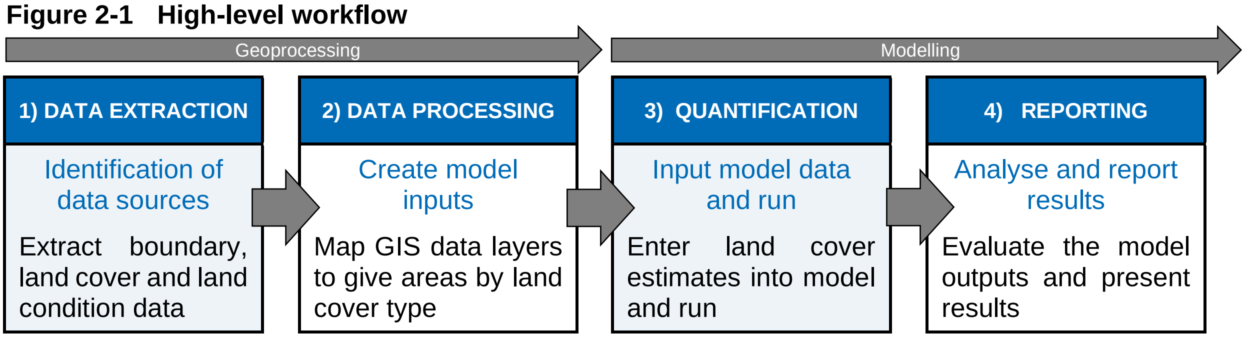
[11] Includes Scope 1 and 2 emissions from land-based activities only. See the Net Zero Shetland Routemap (NZSR) report for further details.

[12] NatureScot, (2020). Restoring Scotland's Peatlands. Available at: https://www.nature.scot/professional-advice/land-and-sea-management/carbon-management/restoring-scotlands-peatlands

2 Methodology

An overview of the approach to quantify the carbon balance within SIC Landholdings and Shetland (area-wide) is provided in the high-level workflow presented in **Figure 2.1**.

Figure 2-1 High-level workflow



Full details of the geoprocessing methodology used (including derivation of geospatial datasets) and modelling methodology (including assumptions and errors) are summarised in **Appendix A**.

2.1 Model inputs

2.1.1 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. The data used to determine land cover and condition in Shetland is summarised in **Appendix A**.

2.1.2 Land Cover

The areas in hectares for each of the land cover types was determined from the geoprocessing stage and is used as a key input to the model. **Table 2.1** presents a summary of the total area of each land cover type across Shetland (area wide) (**Figure 2-2**) and SIC Landholdings (**Figure 2-3**).

Table 2-1 Land cover areas in hectares for SIC

		SIC Landholdings		Shetland	
Group	Land Cover	Area (ha)	%	Area (ha)	%
Peatlands and wetlands	Peat bog - actively eroding	3,577	19	24,430	17
	Peat bog - drained	2,093	11	14,293	10
	Peat bog - modified	1,212	7	8,275	6
	Peat bog – semi-natural	3,683	20	25,151	17
	Wetlands, fen, marsh, swamp	80	0	767	1
Marine	Salt marsh	0	0	0	0
Grassland	Natural grassland	4,095	22	48,167	33
Heathland	Upland heath/moorland	0	0	0	0
	Lowland heath	2,944	16	12,212	8
Water	Inland water	179	1	4,611	3
Other	Artificial	136	1	2,768	2
	Bare rock, sand and ground	533	3	5,562	4
Agricultural land	Agricultural land - pastoral land/intensive/improved grassland	0	0	194	0
	Agricultural land - arable land	1	0	25	0
	Orchards	0	0	0	0
Woodland	Woodland - broadleaved	8	0	62	0

		SIC Landholdings		Shetland	
	Woodland - coniferous	0	0	24	0
	Woodland - mixed	0	0	0	0
Total area		**18,540**		**146,543**	

The data indicated that there was 18,540ha of land (including inland water) within SIC landholdings, with the majority of land cover compromised of *Natural grassland* (22%), *Peat bog – semi-natural* (20%) and *Peat bog – actively eroding* (19%).

The data indicated that there was a 146,543ha of land (including inland water) within Shetland as a whole, with *Natural grassland* land cover compromising the largest area (33%), followed by *Peat bog – semi-natural* (17%) and *Peat bog – actively eroding* (17%).

Peatland land cover is categorised in the model in line with IUCN peatland categories. The geoprocessing stage identified 10,564ha peatland within SIC Landholdings and 72,149ha peatland within Shetland. Following spatial analysis of the peatland land cover the total area was split into the IUCN sub-categories ‘actively eroding’, ‘drained’ or ‘modified’ as part of the condition assessment (presented in **Table 2.2, Section 2.1.3**). Further details of how IUCN peatland categories have been applied to the peatland land cover within Shetland are outlined in **Appendix A**.

The final land cover map of the Shetland Islands determined in the geoprocessing stage is shown in **Figure 2-2**, while the land area covered by the SIC landholdings only is provided in **Figure 2-3**.

Figure 2-2 Land cover map of Shetland Islands

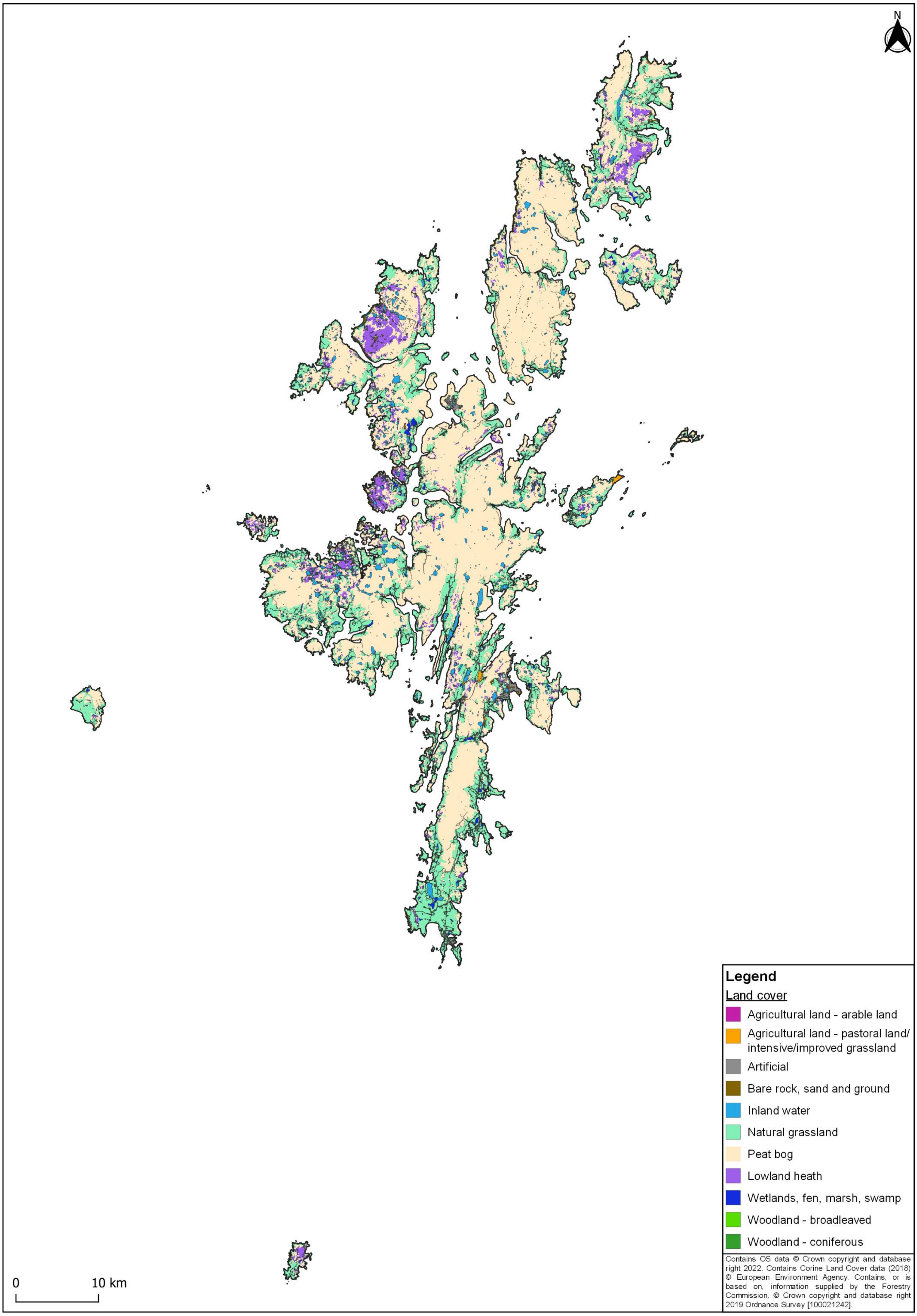
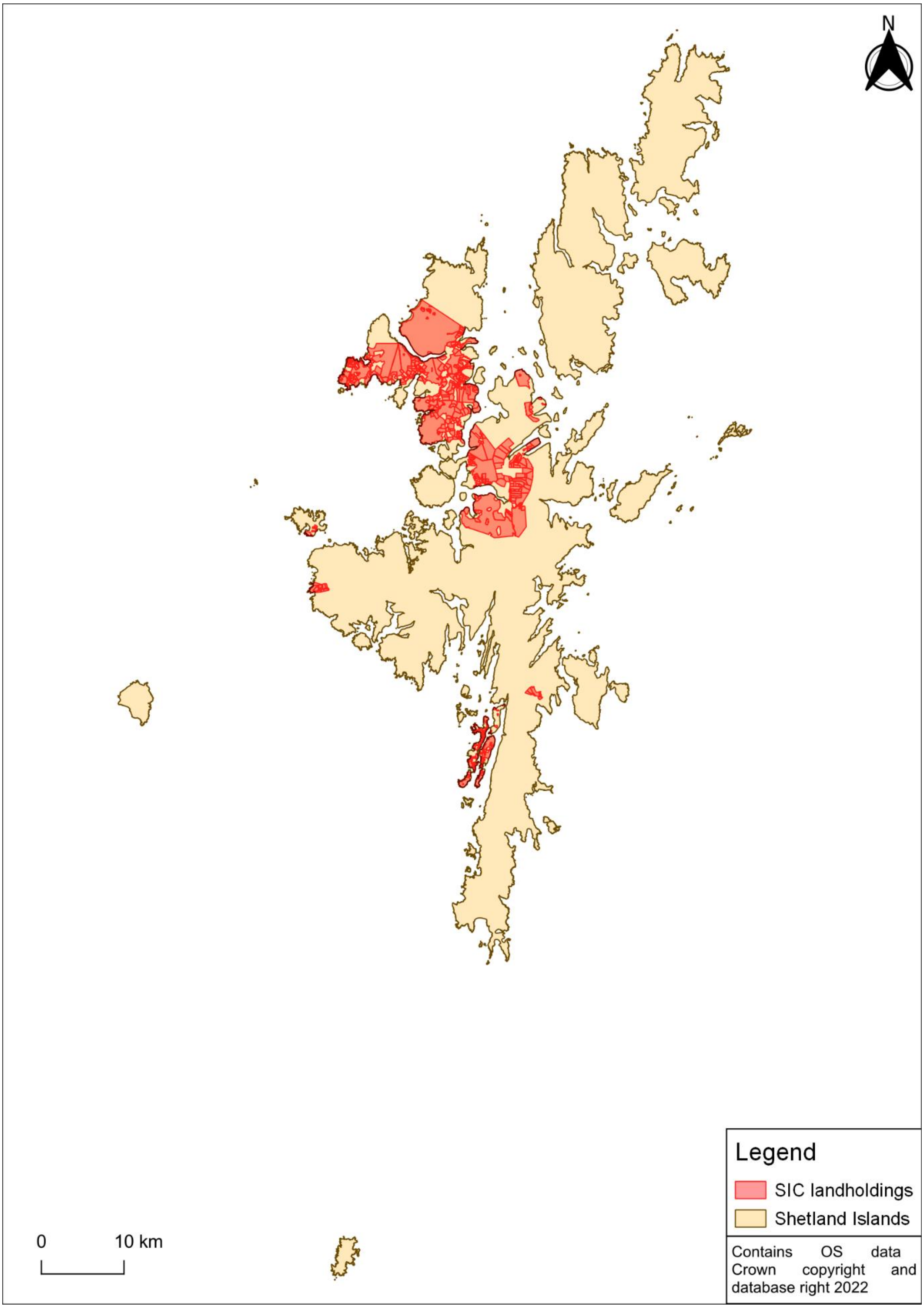


Figure 2-3 Map of SIC landholding areas on Shetland Island



Land cover validation

In order to quantify the thematic accuracy of the generated land cover dataset, a simple validation exercise was undertaken. This involved comparing land cover data extracted from 200 points on the land cover dataset within Shetland to the same points on the most recent Google Earth[13] satellite imagery available. Land cover data was found to be 85.5% accurate, detailed results of the land cover validation are presented in **Appendix A**.

2.1.3 Land Condition

Within the model, land cover data is categorised into three condition statuses: semi-natural, degraded and managed. Currently, there is no widespread land cover condition status available for the UK, Scotland or Shetland aside from condition statuses specific to designated sites, such as Special Areas of Conservation of Sites of Specific Scientific Interest. Due to this condition status of land cover has been assigned using assumed condition based on the land cover type, values published in scientific literature and spatial analysis (peatland only). It is acknowledged that there are limitations to this approach, and without field based study of each land cover parcel it is difficult to assess the true land condition of each land cover type. Further details of how condition has been assigned to land cover is outlined in **Appendix A**.

The areal split of each land cover based on condition status, as a result of the geoprocessing of land cover and condition data, is shown in **Table 2-2** and in **Figure 2-4** and **Figure 2-5** for SIC landholdings and the whole of Shetland respectively. Definitions of condition status, e.g. *semi-natural*, *degraded* and *managed* are provided in **Appendix A**.

[13] Google Earth (2020-2021). Landsat (Copernicus), CNES (Airbus), 2021.

Table 2-2 Areal split of each land cover based on condition status within SIC Landholdings and Shetland (area-wide)

Land cover	Area (ha)							
	SIC Landholdings				Shetland (area-wide)			
	Semi-natural	Degraded	Managed	Total	Semi-natural	Degraded	Managed	Total
Peat bog - actively eroding		3577		3577		24,430		24,430
Peat bog – drained		2093		2093		14,293		14,293
Peat bog – modified	3683	1212		4894	25,151	8,275		33,427
Wetlands, fen, marsh, swamp	51	30		80	483	284		767
Salt marsh	0	0		0	0	0		0
Natural grassland	2375	1720		4095	27,937	20,230		48,167
Upland heath/moorland	0	0		0	0	0		0
Lowland heath	618	2325		2944	2,565	9,648		12,212
Inland water	179	0		179	4,611	0		4,611
Artificial	136	0		136	2,768	0		2,768
Bare rock, sand and ground	533	0		533	5,562	0		5,562
Agricultural land - pastoral land/intensive/improved grassland			0	0			194	194
Agricultural land - arable land			1	1			25	25
Orchards			0	0			0	0
Woodland - broadleaved	0		8	8	0		62	62
Woodland - coniferous	0		0	0	0		24	24
Woodland - mixed	0		0	0	0		0	0
Total area	**7,574**	**10,957**	**9**	**18,540**	**69,078**	**77,160**	**305**	**146,543**

Figure 2-4 Areal split of each land cover based on condition status within SIC Landholdings

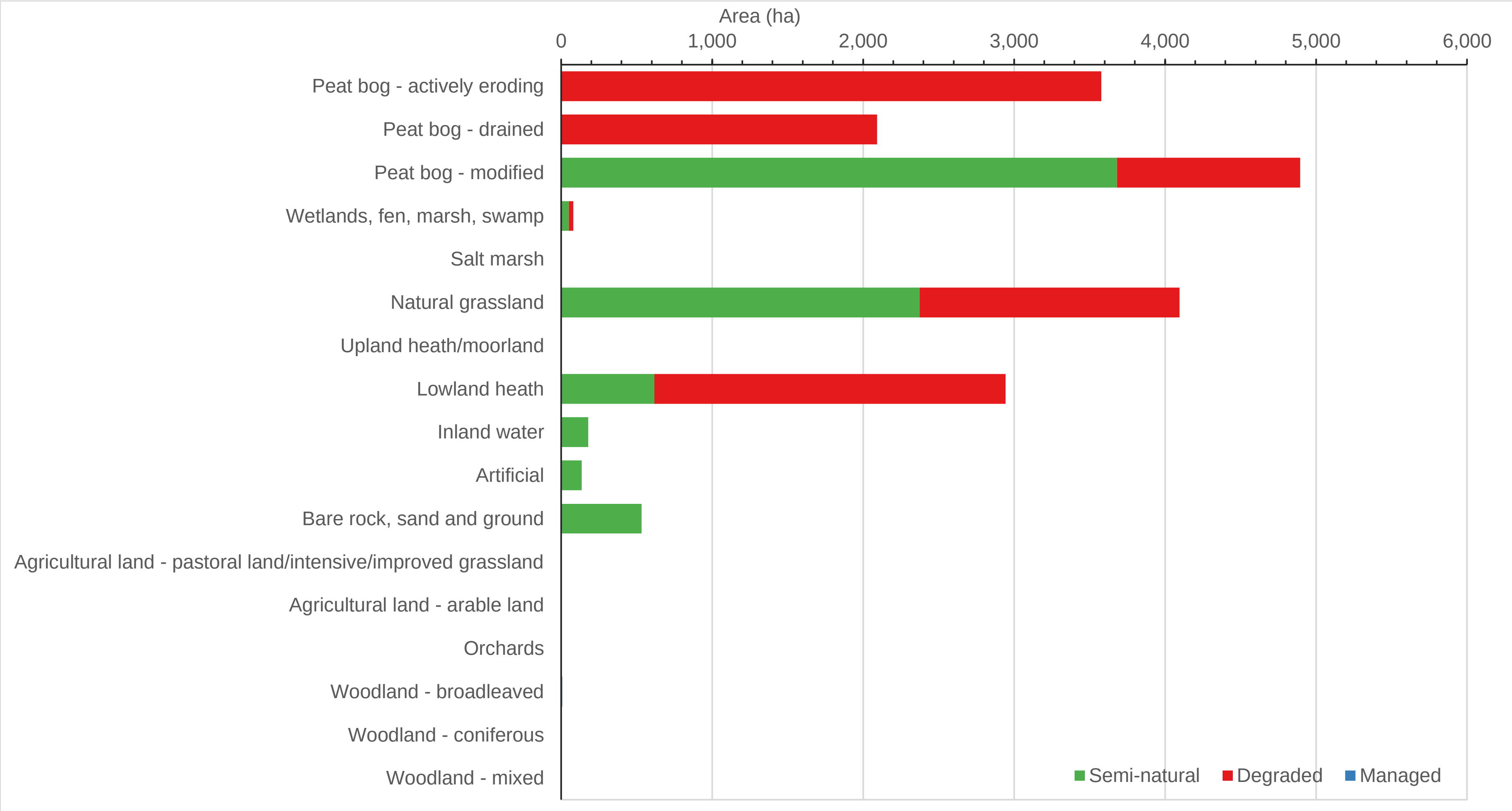
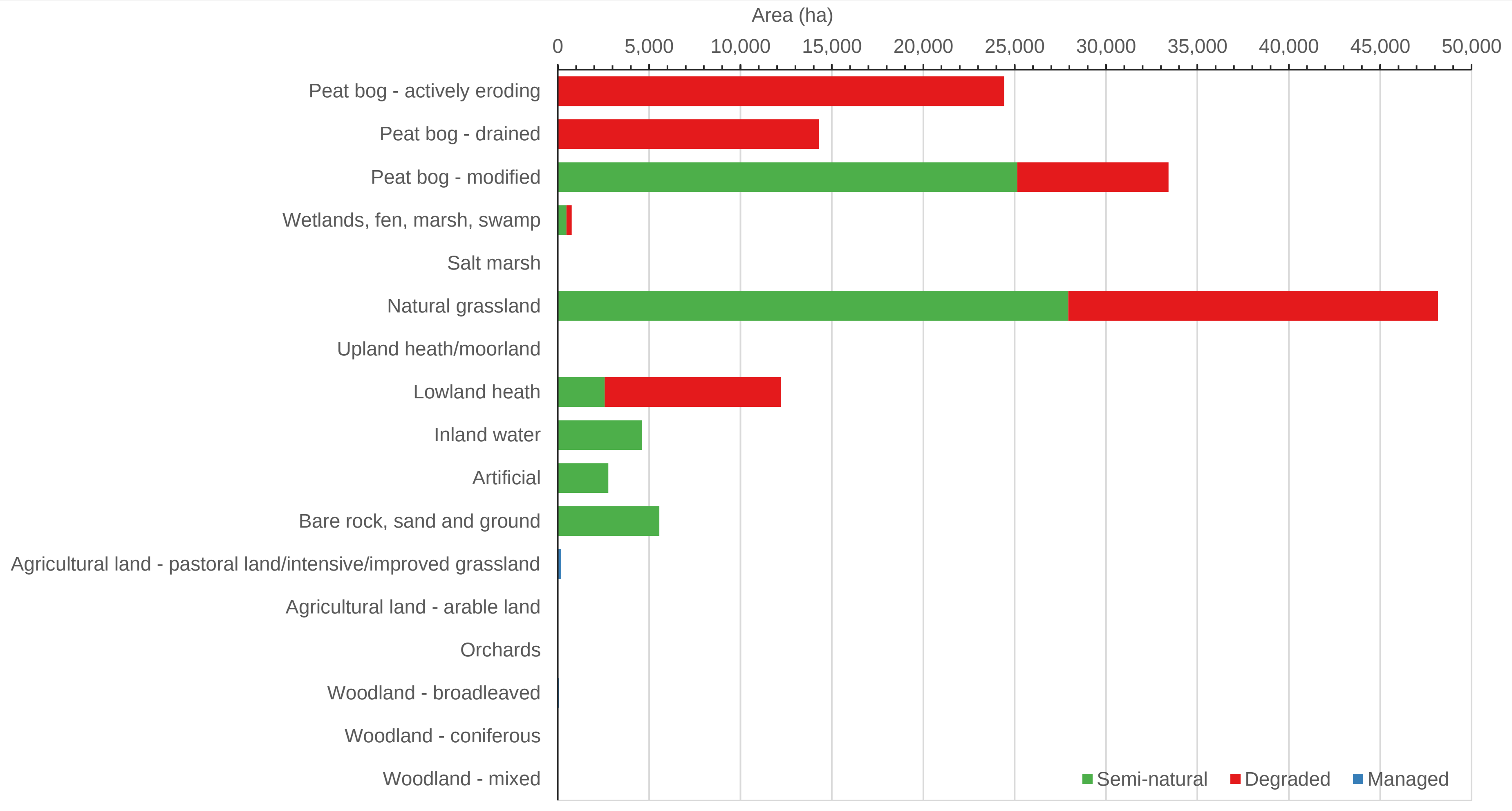


Figure 2-5 Areal split of each land cover based on condition status within Shetland (area-wide)



3 Baseline carbon assessment

The model presents an assessment on carbon stocks (the amount of carbon stored in the soil) and carbon flux (the movement of CO_2e whether sequestering or emitting) of each land cover type mapped on Shetland. The model does not currently link changes in CO_2e flux with carbon stock calculated during the baseline (e.g. CO_2e emissions causing a loss in carbon stocks). 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.

All simulations were run from the baseline assessment year of 2022. The baseline carbon stock is of consequence in determining the year 0 land cover, site condition and land management inputs to the model. For the baseline model runs, providing results based on current land cover and condition status of Shetland, it is assumed that land cover and land condition remain constant over the 50 year period (to 2072) to the present baseline.

The model calculates CO_2e fluxes out to a 50-year timescale. This is limited to 50 years 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.

Full details on the methodology for calculating carbon stock and carbon flux are provided in **Appendix A**.

Although the model is based on values published in scientific literature and uses the most relevant and reliable data available, it is noted that the model outputs provided should be taken as a guide. Any actions implemented as a result of model outputs should be done so with appropriate technical guidance, seeking expert advice wherever necessary. Further assumptions made during the geoprocessing and modelling stages are outlined in **Appendix A, Section A2.4** – these should be considered when interpreting the baseline carbon assessment results.

3.1 Baseline carbon stock

The calculation of baseline carbon stock is based on the input areas determined in the geoprocessing stage (see **Table 2-2** and **Section 2.1.3)** and the default carbon stock coefficients listed in **Appendix B**.

The model outputs identify that the overall carbon stock of SIC Landholdings is 28,413 ± 3,156 kt CO_2e with semi-natural condition *Peat bog – modified* and degraded condition *Peat bog – actively eroding* land cover storing the largest proportion of carbon (43% and 31% respectively).

The model outputs identify that the overall carbon stock of Shetland is 196,258 ± 22,278 kt CO_2e with semi-natural condition *Peat bog – modified* and degraded condition *Peat bog – actively eroding* land cover storing the largest proportion of carbon (42% and 31% respectively). For context, this indicates that SIC landholdings account for c. 10-20% of the total carbon stock.

Baseline (2022) carbon stock for each land cover type within SIC Landholdings and Shetland (area-wide) are presented in **Table 3-1**.

Table 3-1 Total carbon stock for each landcover type within SIC Landholdings and Shetland for the baseline year 2022

Land cover	SIC Landholdings			Shetland		
	Total carbon stock per land cover (kt CO_2e)	Error RMS (kt CO_2e)	% total stock	Total carbon stock per land cover (kt CO_2e)	Error RMS (kt CO_2e)	% total stock
Peat bog - actively eroding	8,879	1,953	31%	60,643	13,341	31%
Peat bog - drained	5,195	1,143	18%	35,480	7,806	18%
Peat bog - modified	12,150	2,117	43%	82,977	14,460	42%
Wetlands, fen, marsh, swamp	180	0	1%	1,722	0	1%
Salt marsh	0	0	0%	0	0	0%
Natural grassland	916	590	3%	10,774	6,943	6%
Upland heath/moorland	0	0	0%	0	0	0%
Lowland heath	1,079	63	4%	4,478	293	2%
Inland water	0	0	0%	0	0	0%
Artificial	0	0	0%	0	0	0%
Bare rock, sand and ground	0	0	0%	0	0	0%
Agricultural land - pastoral land/intensive/improved grassland	0	0	0%	52	48	0%
Agricultural land - arable land	0	0	0%	5	3	0%
Orchards	0	0	0%	0	0	0%
Woodland - broadleaved	14	8	0%	111	67	0%
Woodland - coniferous	0	0	0%	17	16	0%
Woodland - mixed	0	0	0%	0	0	0%
Total carbon stock	**28,413**	**5,875**		**196,258**	**42,976**	

3.2 Baseline carbon flux

The calculation of baseline carbon flux is based on the input areas determined in the geoprocessing stage (see **Table 2-2, Section 2.2.3**) and the default CO_2e flux coefficients listed in **Appendix B**.

The results below contain the aggregated CO_2e flux for carbon dioxide, methane and nitrous oxide for each land cover class and its associated condition status. For all results, negative values represent sequestration and positive values represent emission, following the common convention for reporting CO_2e flux.

Results are presented as annual/average annual CO_2e flux and cumulative CO_2e flux. Cumulative CO_2e flux refers to the successive addition of annual CO_2e flux. An average of annual carbon flux over the 50-year period 2022-2072 is shown in **Table 3-2**, this presents an averaging of the cumulative flux observed over the 50-year period.

The results indicate a minor change in rate of sequestration with an overall decrease in sequestration over time, with the biggest rate of change in flux occurring at the start of the 50-year period. The change in rate over time is as a result of tree growth, which have a non-linear rate of sequestration over their lifetime, and the initial assumed age of trees.

Specific project carbon flux values have been stated below for the years 2030 and 2045 (to give indications of potential carbon flux in line with Shetland and Scotland carbon neutrality targets respectively) and 2072 (representing the end of the 50-year model period). The model outputs identify that the cumulative carbon flux of SIC Landholdings and Shetland is as follows:

Table 3-2 Baseline carbon flux results

Land cover area	Baseline cumulative carbon flux (kt CO_2e)			Average annual carbon flux over 50-year period 2022-2072 (kt CO_2e)
	2030	2045	2072	
SIC Landholdings	870 ± 51	2,503 ± 146	5,441 ± 318	109
Shetland (area-wide)	5,857 ± 369	16,841 ± 1,062	36,618 ± 2,308	732

The cumulative CO_2e flux over the 50-year model period 2022-2072 is presented in **Figure 3-1** and **Figure 3-2**. Full model results for CO_2e flux over the 50-year period 2022-2072 are included in **Appendix C**.

Figure 3-1 SIC Landholdings: Cumulative baseline CO_2e fluxes over 50-year period (2022-2072)

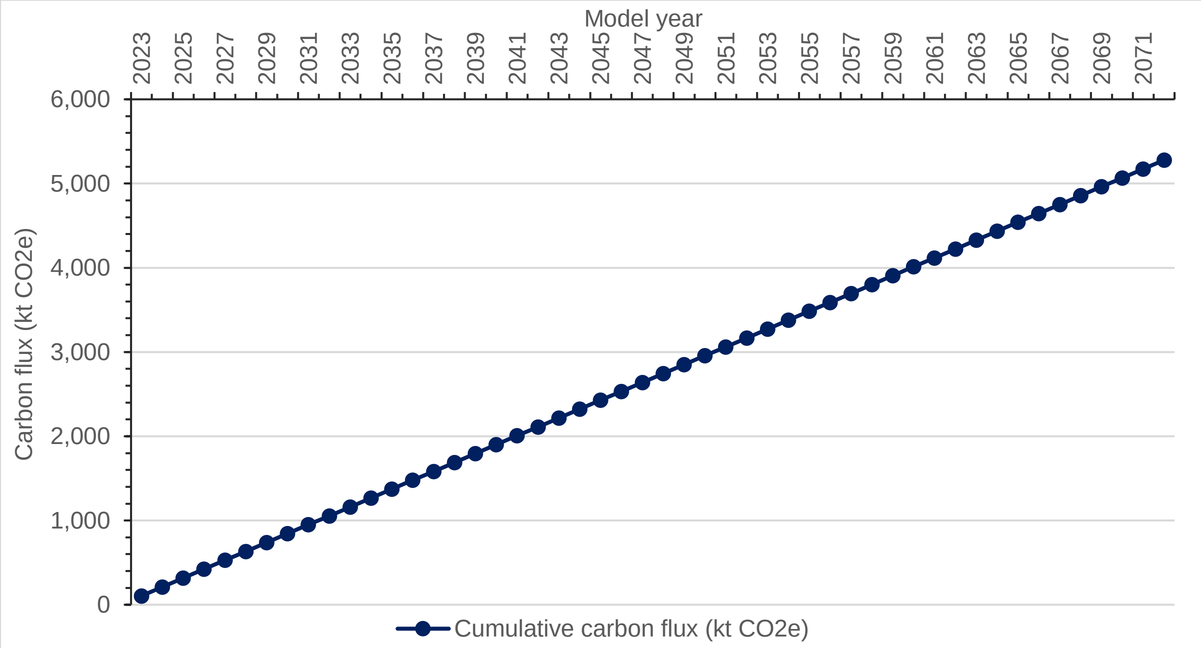
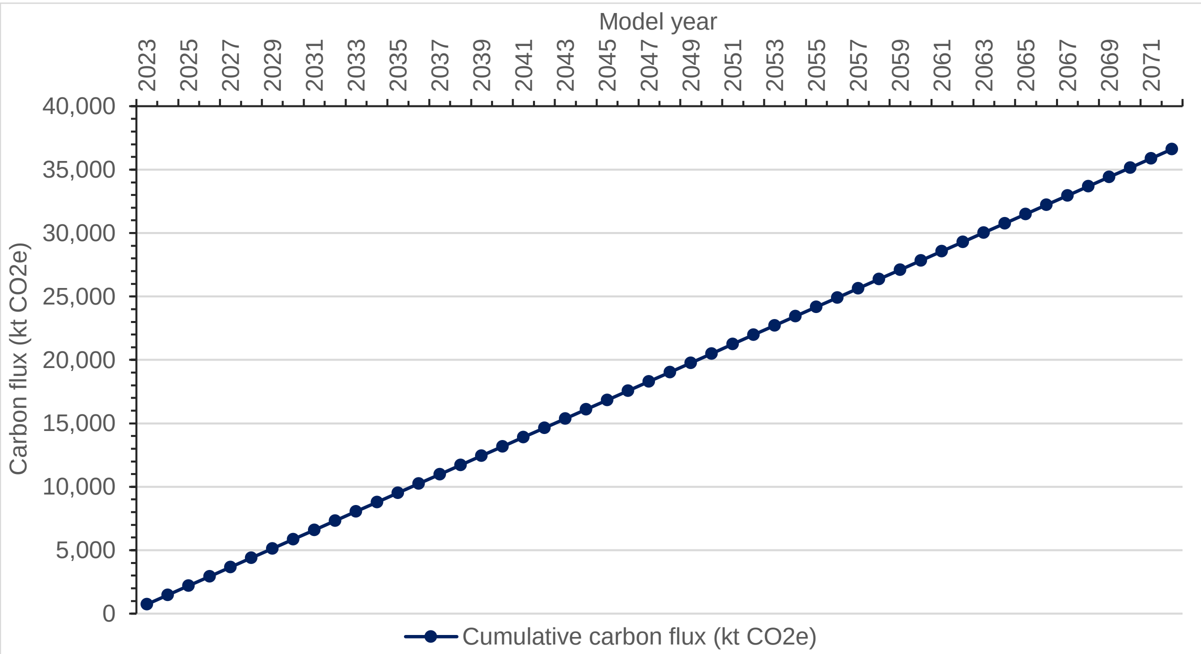
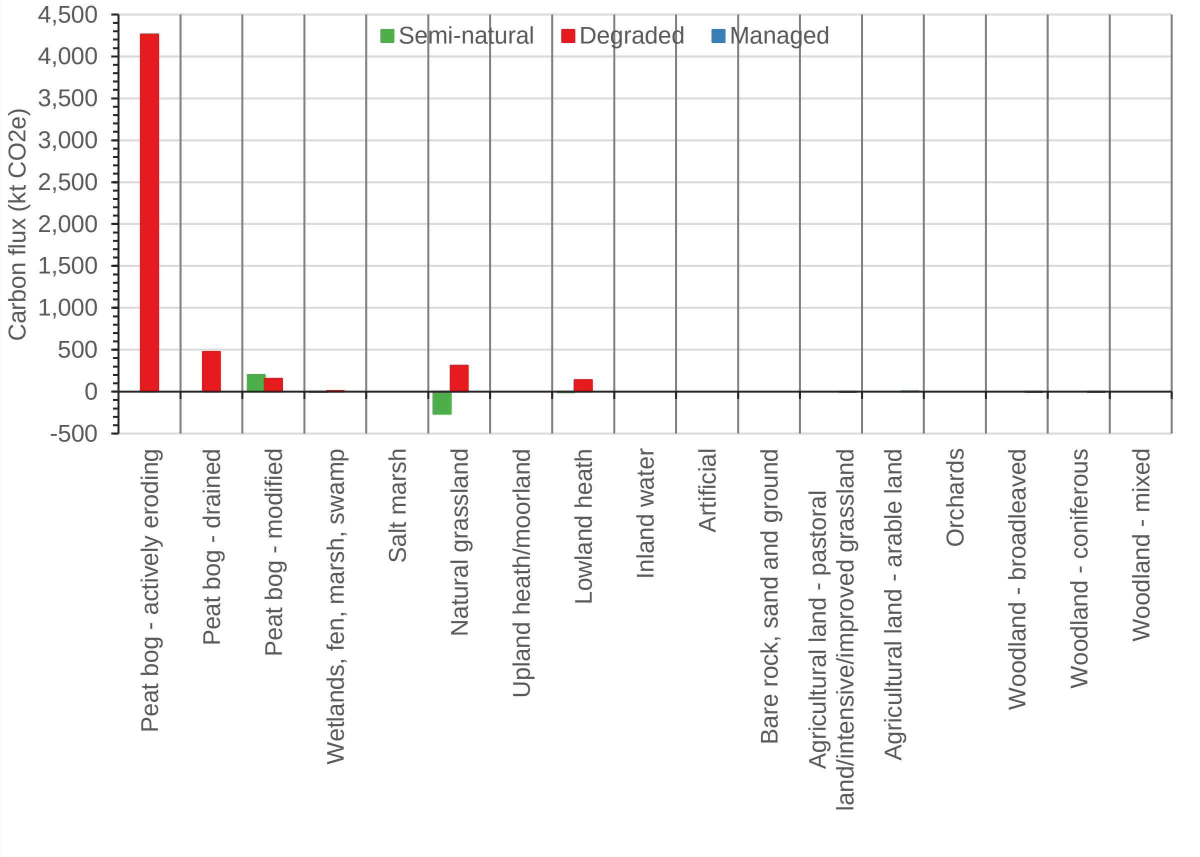


Figure 3-2 Shetland (area-wide): Cumulative baseline CO_2e fluxes over 50-year period (2022-2072)



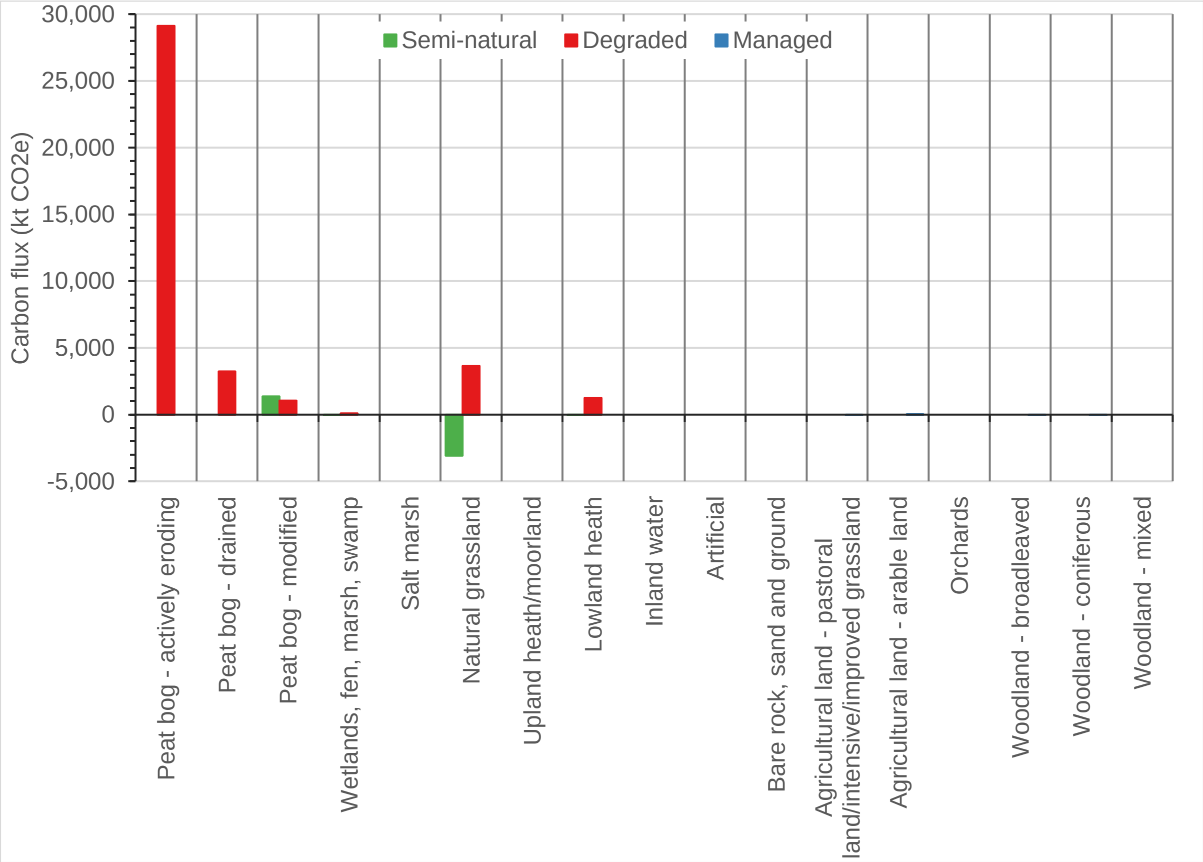
The largest net sequester of CO_2e for SIC Landholdings over the period is semi-natural condition *Natural grassland* (-261 kt CO_2e cumulative total from 2022-2072) and the largest net emitter of CO_2e is *Peat bog - actively eroding* (4,264 kt CO_2e cumulative total from 2022-2072) (**Figure 3-3**).

Figure 3-3 SIC Landholdings: Break down of cumulative carbon flux for 2072 per land cover and status



The largest net sequester of CO_2e for Shetland land cover over the period is semi-natural condition *Natural grassland* (-3,073 kt CO_2e cumulative total from 2022-2072) and the largest net emitter of CO_2e is *Peat bog - actively eroding* (29,120 kt CO_2e cumulative total from 2022-2072) (**Figure 3-4**).

Figure 3-4 Shetland (area-wide): Break down of cumulative carbon flux for 2072 per land cover and status



4 Assessment of carbon reduction scenarios

Subsequent to reviewing the outcomes of the baseline carbon assessment the model was run for four carbon reduction scenarios:

- **Scenario 1:** Restoration of all degraded condition *Peat bog* land cover to semi-natural condition at a rate of 350ha per year for five years, then 2,500ha per year until total area is restored.
    a) Within SIC Landholdings.
    b) Within Shetland.
- **Scenario 2:** Restoration of all IUCN condition *Peat bog – actively eroding* land cover to semi-natural condition over the 20-year period 2022-2042.
    a) Within SIC Landholdings.
    b) Within Shetland.
- **Scenario 3:** Restoration of all degraded condition *Peat bog* (except modified) to semi-natural condition over the 20-year period 2022-2042.
    a) Within SIC Landholdings.
    b) Within Shetland.
- **Scenario 4:** Improve all degraded condition *Natural grassland* within SIC Landholdings to semi-natural condition over the five-year period 2022-2027.
- **Scenario 5:** Improve 10,000ha of degraded condition *Natural grassland* within Shetland to semi-natural condition over the 10-year period 2022-2027.

The results of each scenario are presented below, with figures presenting the annual and cumulative flux over the 50-year period 2022 to 2072. Once degraded land is restored in a scenario it is maintained as semi-natural throughout the lifetime of the model run and not converted to an alternative land cover. The conversion from degraded to semi-natural land, and its response in CO_2e flux is assumed to occur over the course of a year in each scenario. This rate of improvement may not occur in reality and therefore this could lead to an overestimate in modelled CO_2e within each scenario.

It should be noted that any outputs should be used as a guide and are based on the most relevant science/literature available. Any actions implemented as a result of model outputs should be done so with technical guidance, seeking expert advice where necessary. A range of assumptions made during the geoprocessing and modelling stages are outlined in **Appendix A, Section A2.4** – these should be considered when interpreting the carbon reduction scenario results.

Scenario 1a: Restoration of all degraded condition *Peat bog* land cover within SIC Landholdings to semi-natural condition

Scenario details

The land cover data indicates that there is 6,881ha degraded condition *Peat bog* land cover (actively eroding, drained and modified) within SIC Landholdings. This scenario assumes that 350ha of degraded condition peatland is improved to semi-natural condition each year for the first five years, increasing to 2,500ha per year until the total area is restored to semi-natural condition (2030).

Scenario results

The implementation of Scenario 1a results in a decrease in carbon flux from SIC Landholdings land cover from 5,442 kt CO_2e (baseline scenario) to 1,376 kt CO_2e, a difference of -4,066 kt CO_2e (-75%) by the end of the 50-year period (**Figure 4-1** and **Figure 4-2**).

Figure 4-1 Scenario 1a cumulative CO_2e flux over 50-year period

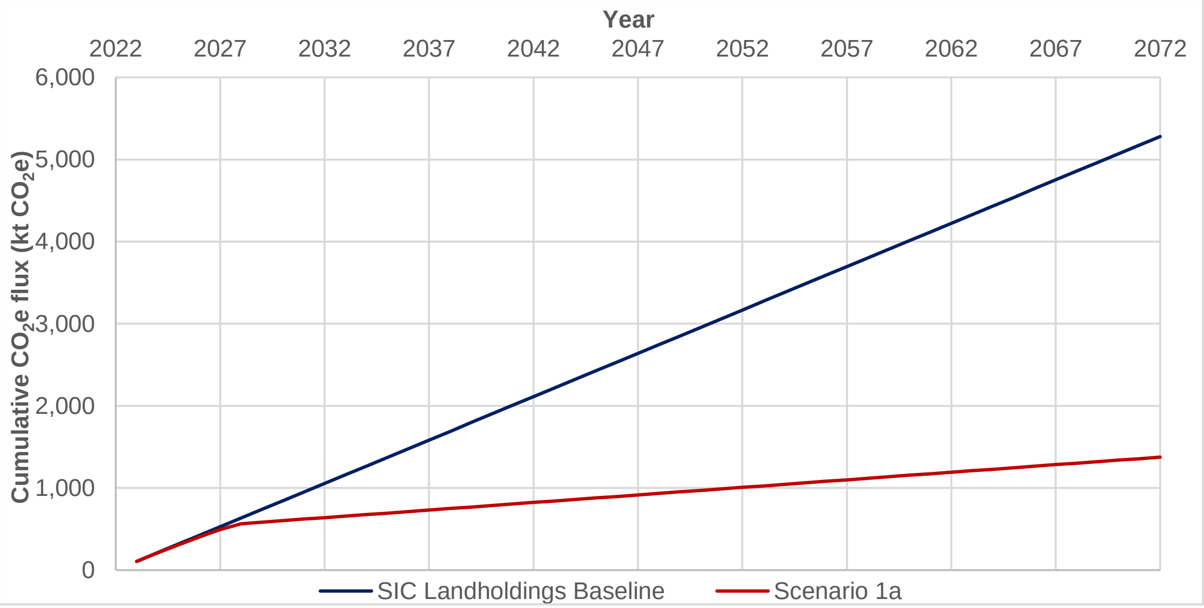
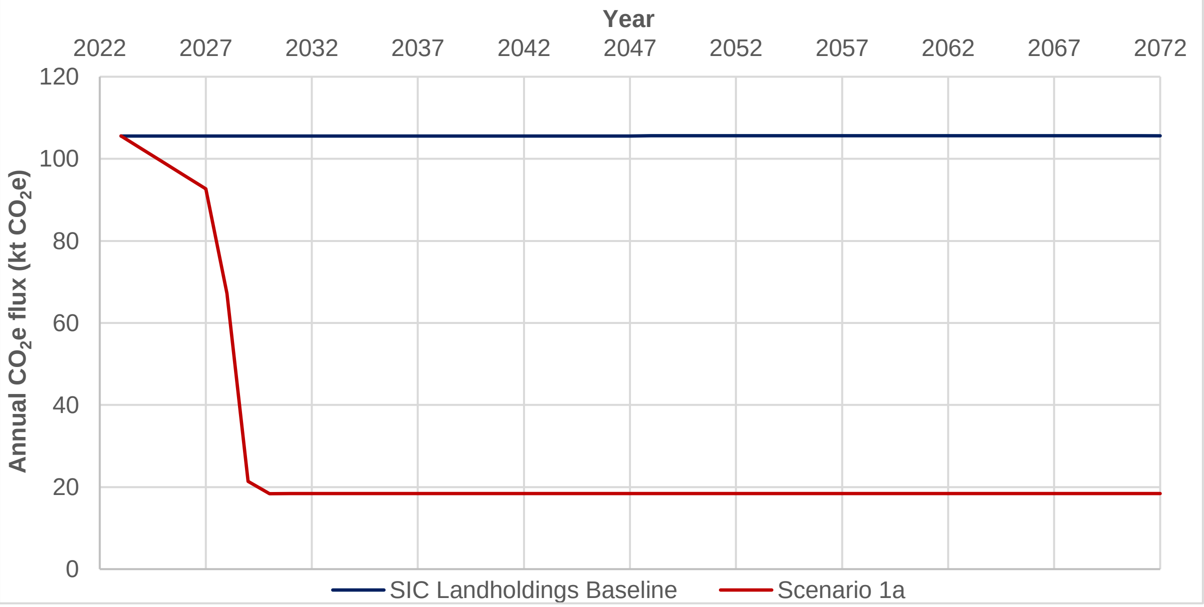


Figure 4-2 Scenario 1a annual CO_2e flux over 50-year period



Scenario 1b: Restoration of all degraded condition *Peat bog* land cover within Shetland to semi-natural condition

Scenario details

The land cover data indicates that there is 46,998ha degraded condition *Peat bog* land cover (actively eroding, drained and modified) within Shetland. This scenario assumes that 350ha degraded condition peatland is improved to semi-natural condition each year for the first five years, increasing to 2,500ha per year until the total area is restored to semi-natural condition (2046).

Scenario results

The implementation of Scenario 1b results in a decrease in carbon flux from Shetland (area-wide) land cover from 36,618 kt CO_2e (baseline scenario) to 15,006 kt CO_2e, a difference of -21,611 kt CO_2e (-59%) by the end of the 50-year period (**Figure 4-3** and **Figure 4-4**).

Figure 4-3 Scenario 1b cumulative CO_2e flux over 50-year period

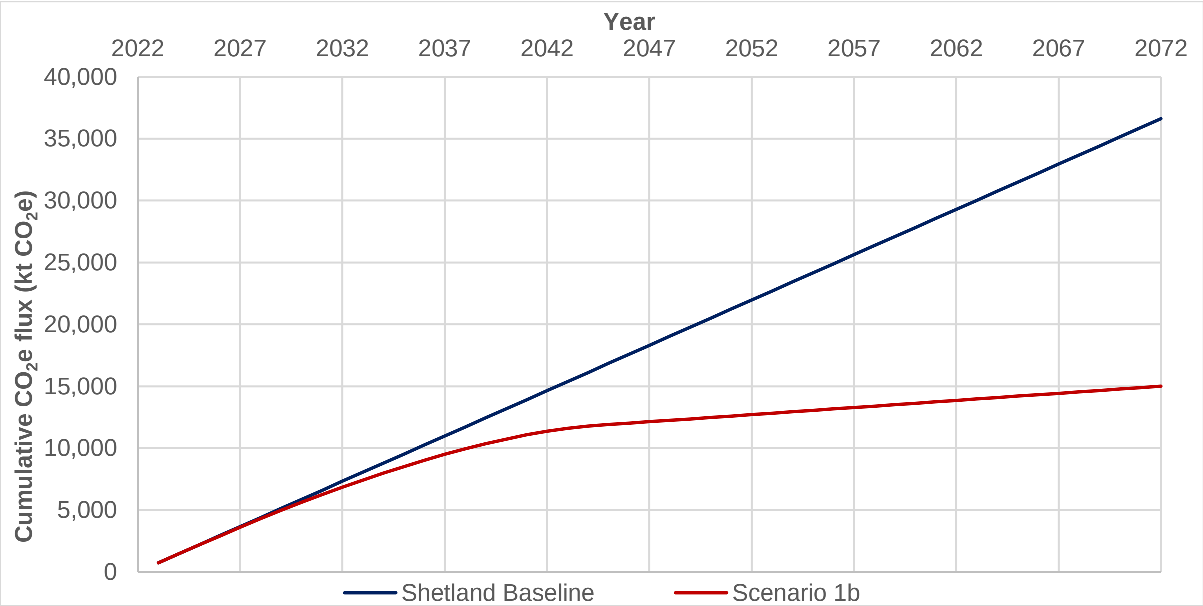
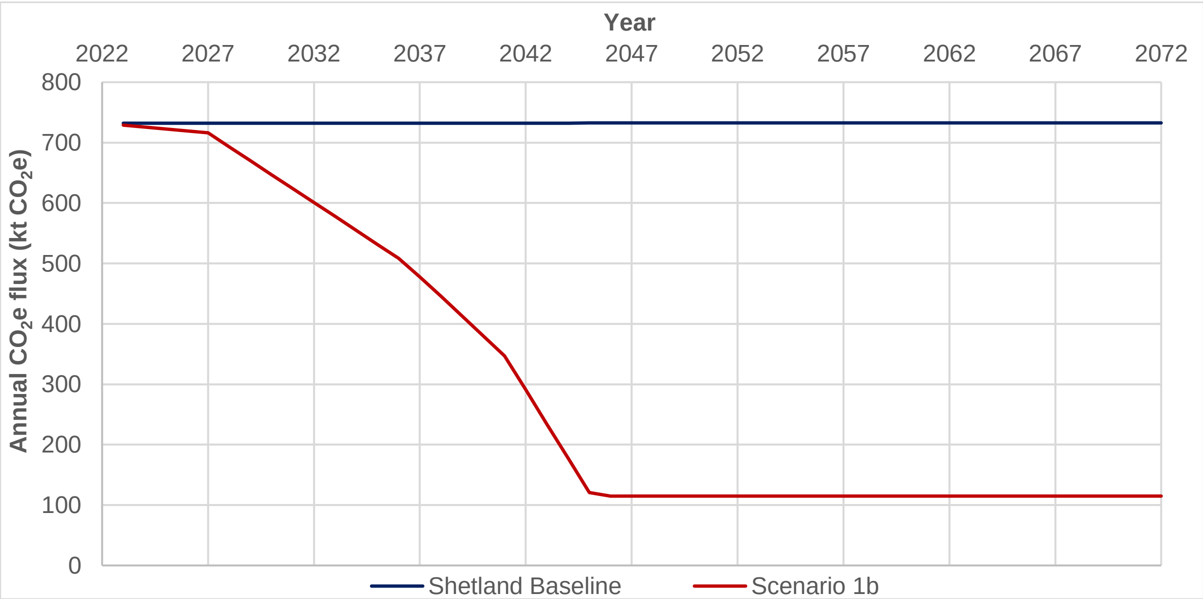


Figure 4-4 Scenario 1b annual CO_2e flux over 50-year period



Scenario 2a: Restoration of all IUCN condition *Peat bog - actively eroding* land cover within SIC Landholdings to semi-natural condition over the 20-year period 2022-2042

Scenario details

The land cover data indicates that there is 3,577ha of *Peat bog – actively eroding* land cover within the SIC Landholdings. This scenario assumes that all of this area is restored to semi-natural condition over the 20-year period 2022-2042 at a rate of 179ha per year.

Scenario results

The implementation of Scenario 2a results in a decrease in carbon flux from SIC Landholdings land cover from 5,442 kt CO_2e (baseline scenario) to 2,144 kt CO_2e, a difference of -3,297 kt CO_2e (-61%) by the end of the 50-year period (**Figure 4-5** and **Figure 4-6**).

Figure 4-5 Scenario 2a cumulative CO_2e flux over 50-year period

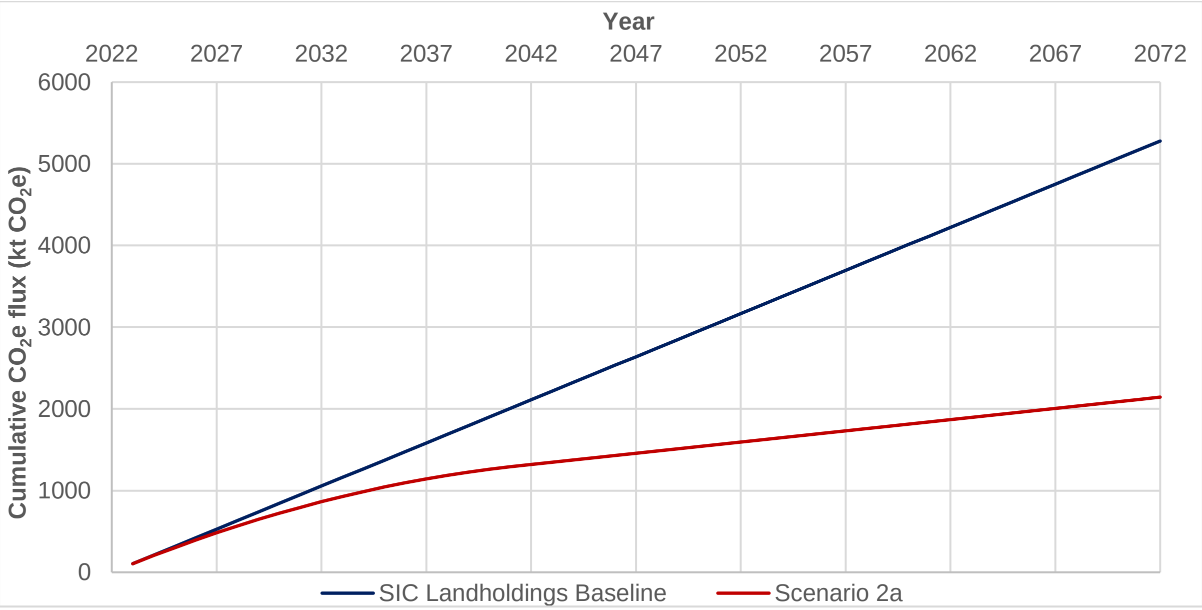
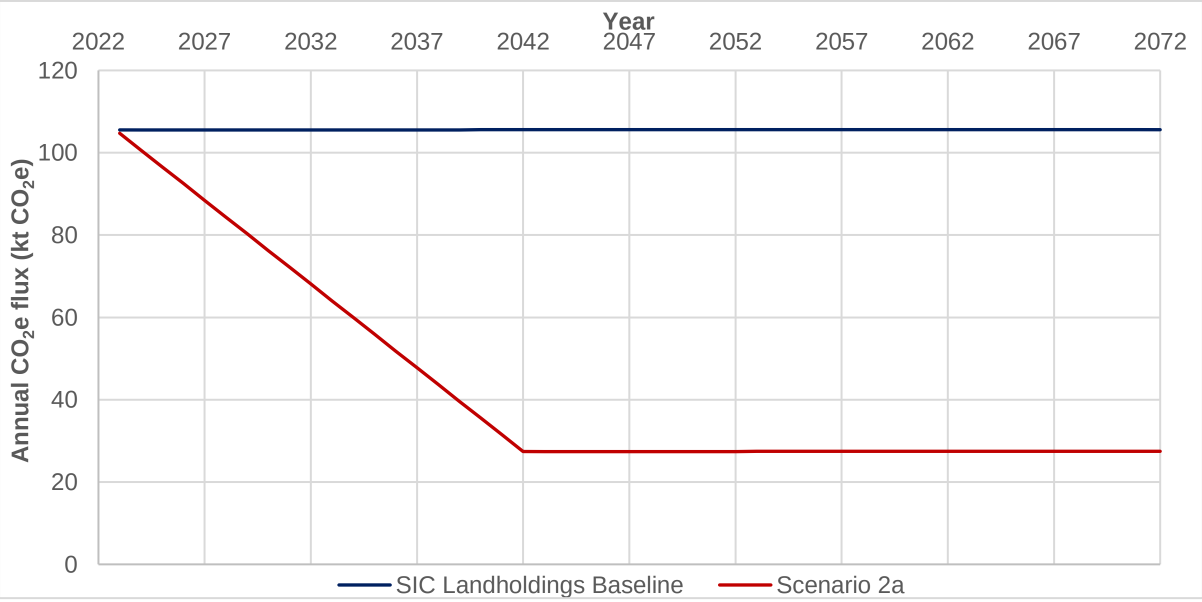


Figure 4-6 Scenario 2a annual CO_2e flux over 50-year period



Scenario 2b: Restoration of all IUCN condition *Peat bog - actively eroding* land cover within Shetland to semi-natural condition over the 20-year period 2022-2042

Scenario details

The land cover data indicates that there is 24,430ha of *Peat bog – actively eroding* land cover within the Shetland. This scenario assumes that all of this area is restored to semi-natural condition over the 20-year period 2022-2042 at a rate of 1,222ha per year.

Scenario results

The implementation of Scenario 2b results in a decrease in carbon flux from Shetland (area-wide) land cover from 36,618 kt CO_2e (baseline scenario) to 14,099 kt CO_2e, a difference of -22,519 kt CO_2e (-61%) by the end of the 50-year period (**Figure 4-7** and **Figure 4-8**).

Figure 4-7 Scenario 2b cumulative CO_2e flux over 50-year period

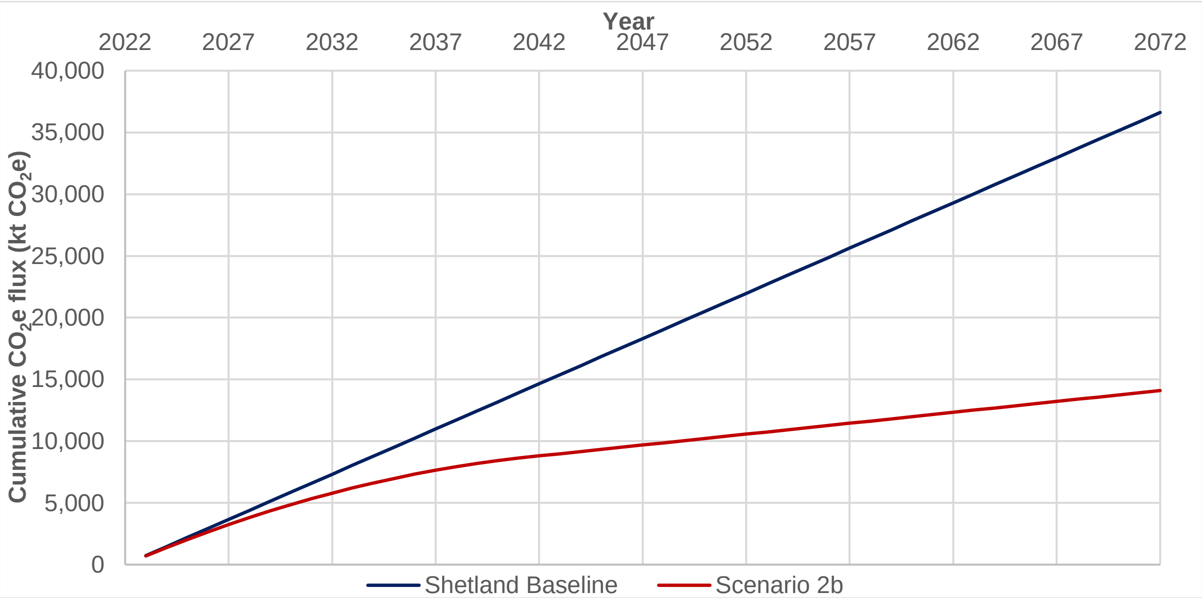
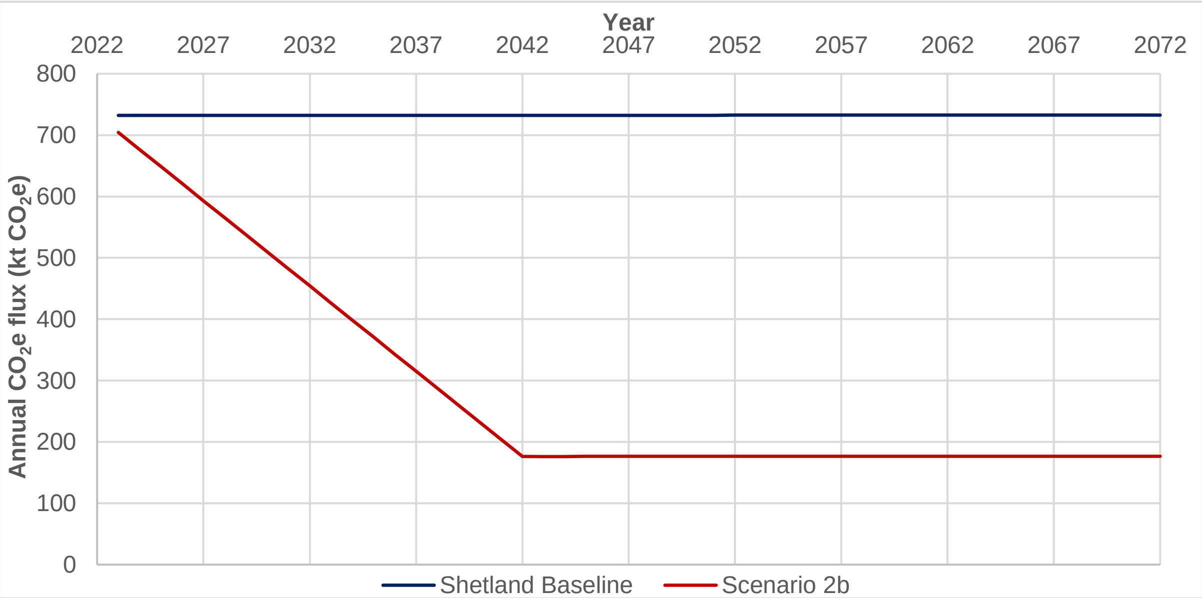


Figure 4-8 Scenario 2b annual CO_2e flux over 50-year period



Scenario 3a: Restoration of all degraded condition Peat bog (except modified) within SIC Landholdings to semi-natural condition over the 20-year period 2022-2042

Scenario details

The land cover data indicates that there is 3,577ha of *Peat bog – actively eroding* and 2,093ha of *Peat bog – drained* land cover within SIC Landholdings. This scenario assumes that all of this area (a total of 5,670ha) is restored to semi-natural condition over the 20-year period 2022-2042 at a rate of 283ha per year.

Scenario results

The implementation of Scenario 3a results in a decrease in carbon flux from SIC Landholdings land cover from 5,442 kt CO_2e (baseline scenario) to 1,851 kt CO_2e, a difference of -3,590 kt CO_2e (-66%) by the end of the 50-year period (**Figure 4-9** and **Figure 4-10**).

Figure 4-9 Scenario 3a cumulative CO_2e flux over 50-year period

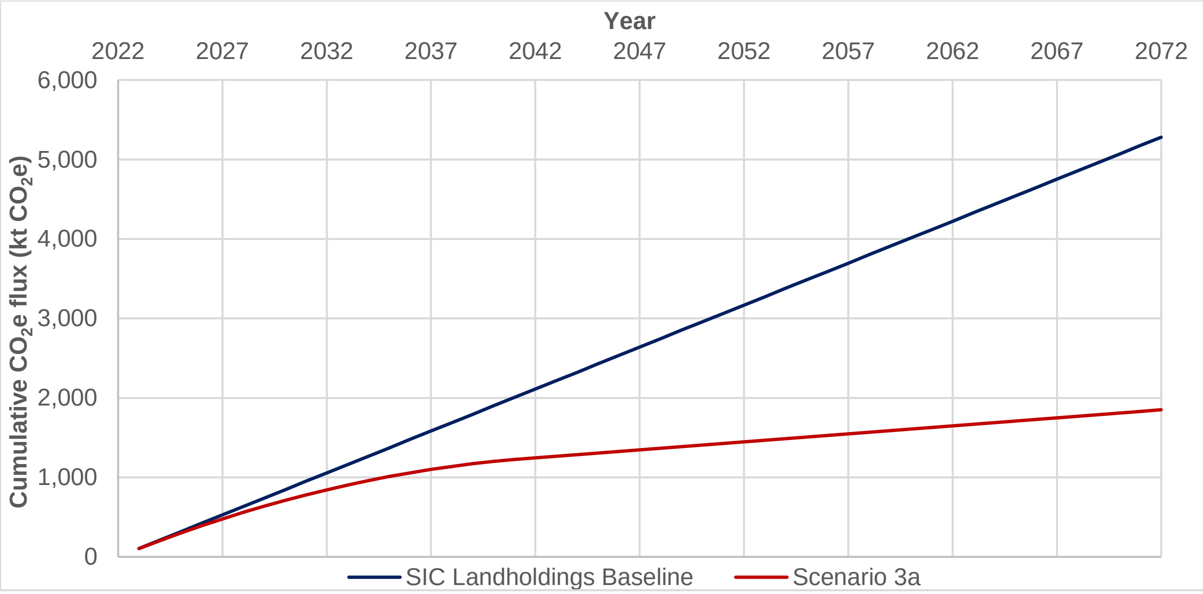
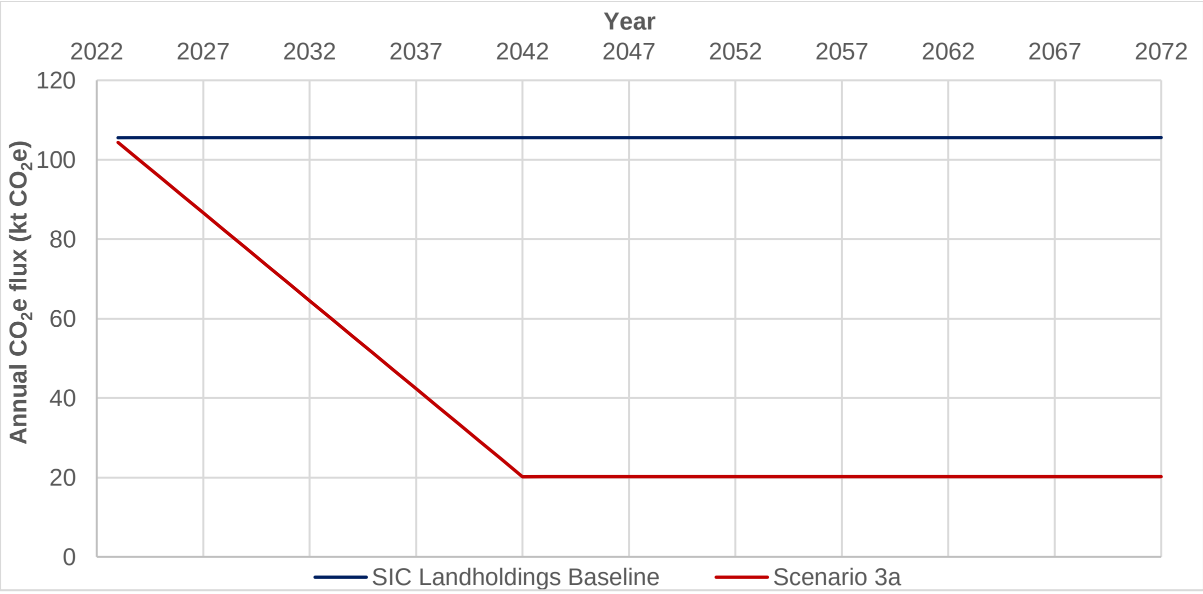


Figure 4-10 Scenario 3a annual CO_2e flux over 50-year period



Scenario 3b: Restoration of all degraded condition Peat bog (except modified) within Shetland to semi-natural condition over the 20-year period 2022-2042

Scenario details

The land cover data indicates that there is 24,430ha of *Peat bog – actively eroding* and 14,2930ha of *Peat bog – drained* land cover within Shetland. This scenario assumes that all of this area (38,722ha) is restored to semi-natural condition over the 20-year period 2022-2042 at a rate of 1,936ha per year.

Scenario results

The implementation of Scenario 3b results in a decrease in carbon flux from Shetland (area-wide) land cover from 36,618 kt CO_2e (baseline scenario) to 12,096 kt CO_2e, a difference of -24,522 kt CO_2e (-67%) by the end of the 50-year period (**Figure 4-11** and **Figure 4-12**).

Figure 4-11 Scenario 3b cumulative CO_2e flux over 50-year period

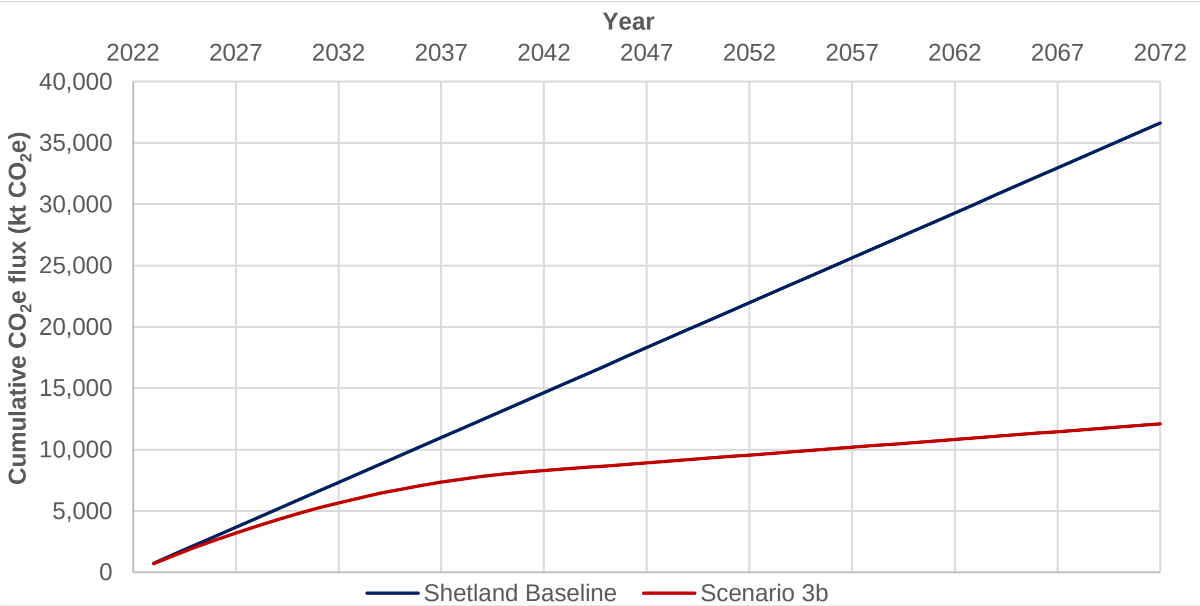
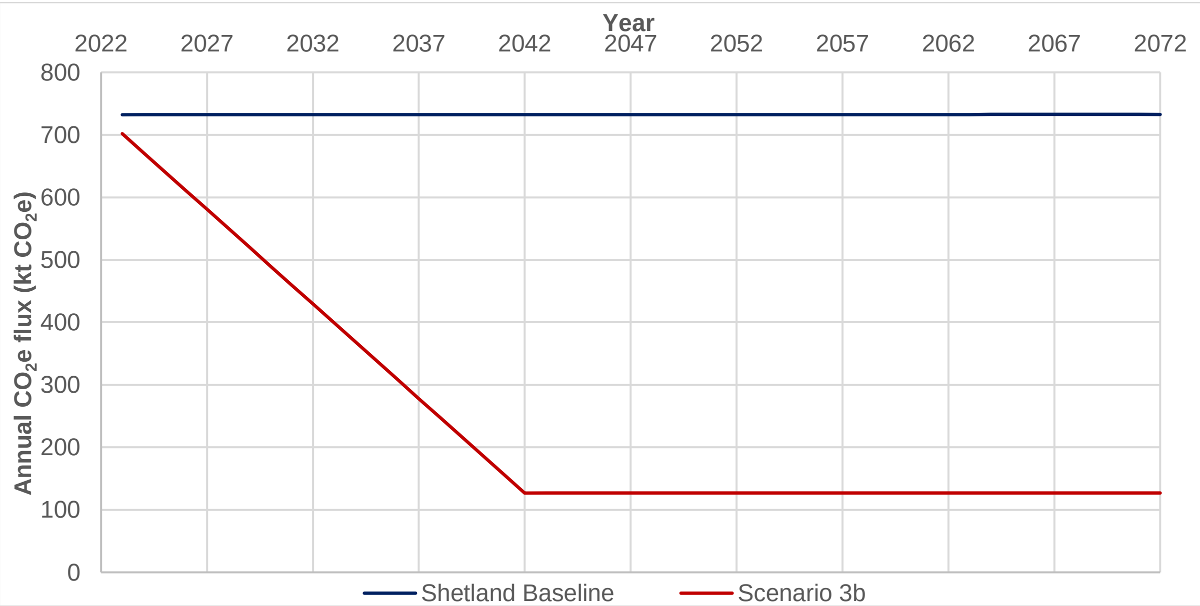


Figure 4-12 Scenario 3b annual CO_2e flux over 50-year period



Scenario 4: Improve all degraded condition *Natural grassland* within SIC Landholdings to semi-natural condition over the five-year period 2022-2027.

Scenario details

The land cover data indicates that there is 1,720ha of degraded condition *Natural grassland* within the SIC Landholdings. This scenario assumes that all of this area is improved to semi-natural condition over the five year period 2022-2027 at a rate of 344ha per year.

Scenario results

The implementation of Scenario 4 results in a decrease in carbon flux from SIC Landholdings land cover from 5,442 kt CO_2e (baseline scenario) to 4,963 kt CO_2e, a difference of -479 kt CO_2e (-9%) by the end of the 50-year period (**Figure 4-13** and **Figure 4-14**).

Figure 4-13 Scenario 4 cumulative CO_2e flux over 50-year period

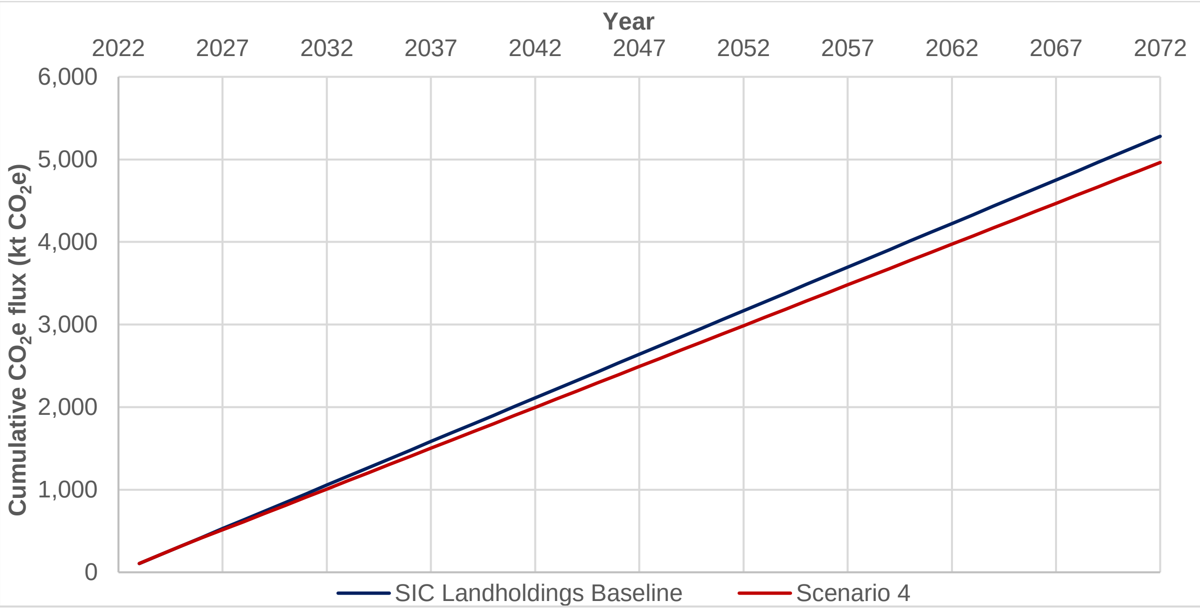
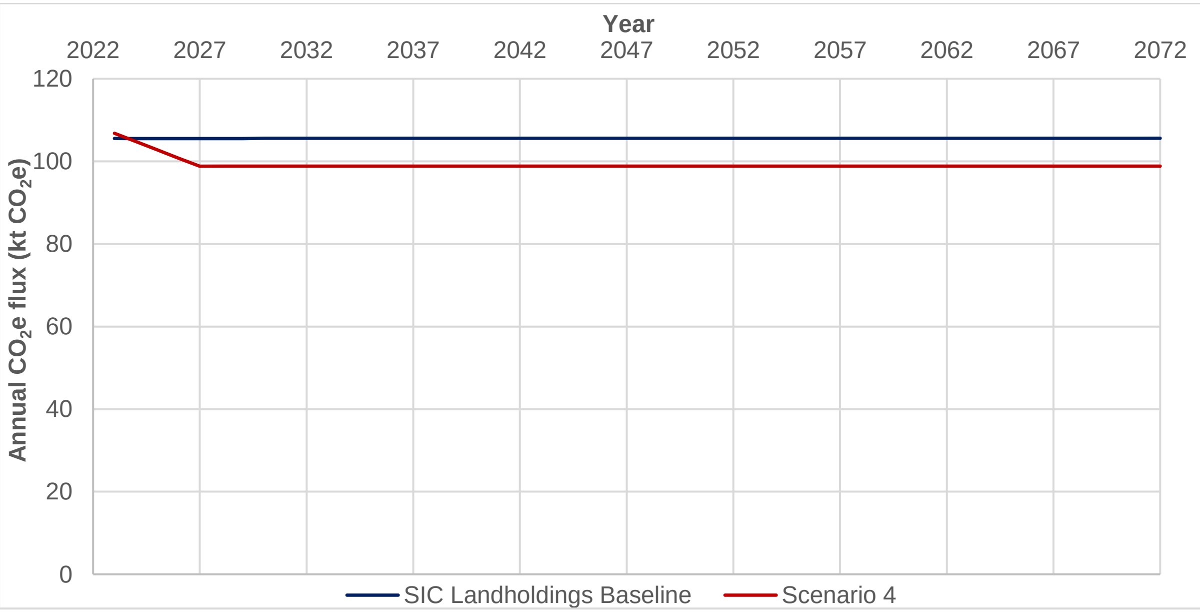


Figure 4-14 Scenario 4 annual CO_2e flux over 50-year period



Scenario 5: Improve 10,000ha of degraded condition *Natural grassland* within Shetland to semi-natural condition over the 10-year period 2022-2032

Scenario details

The land cover data indicates that there is 20,230ha of degraded condition *Natural grassland* within Shetland. This scenario assumes that 10,000ha of this area is improved to semi-natural condition over the 10-year period 2022-2032 at a rate of 1,000ha per year.

Scenario results

The implementation of Scenario 5 results in a decrease in carbon flux from Shetland (area-wide) land cover from 36,618 kt CO_2e (baseline scenario) to 33,979 kt CO_2e, a difference of -2,639 kt CO_2e (-7%) by the end of the 50-year period ((**Figure 4-15** and **Figure 4-16**).

Figure 4-15 Scenario 5 cumulative CO_2e flux over 50-year period

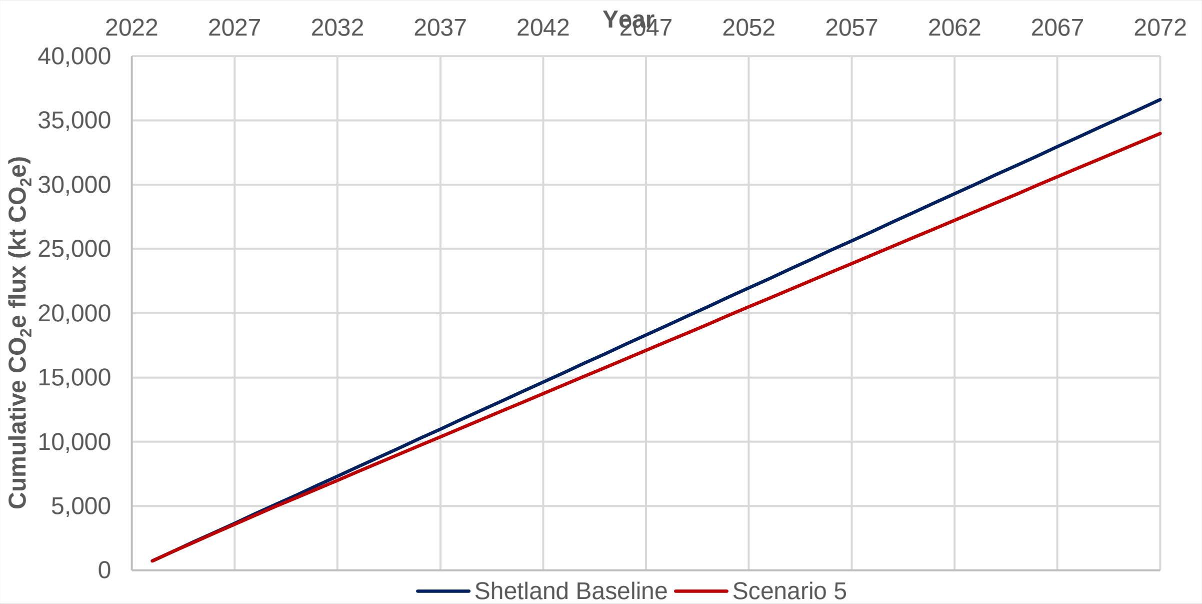
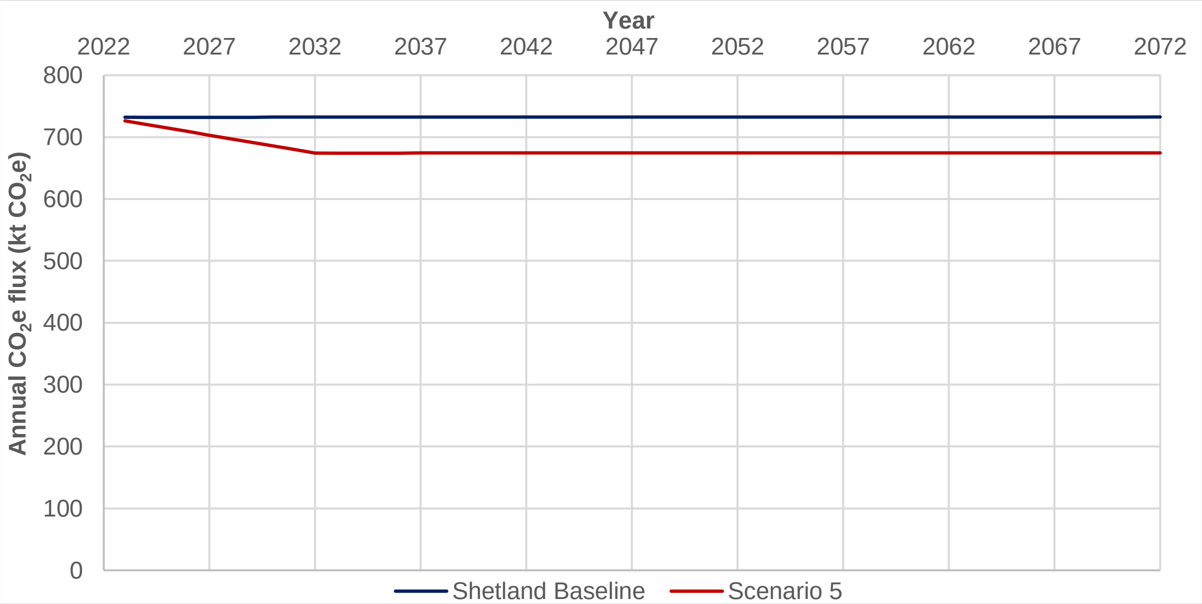


Figure 4-16 Scenario 5 annual CO_2e flux over 50-year period



4.1 Summary of carbon reduction assessment

The results of each of the carbon reduction scenarios are summarised below. Projected cumulative carbon flux values and annual flux are stated for 2030 and 2045 (to give indications of potential carbon flux against Shetland and Scotland carbon neutrality targets respectively) and 2072 (representing the end of the 50-year model period).

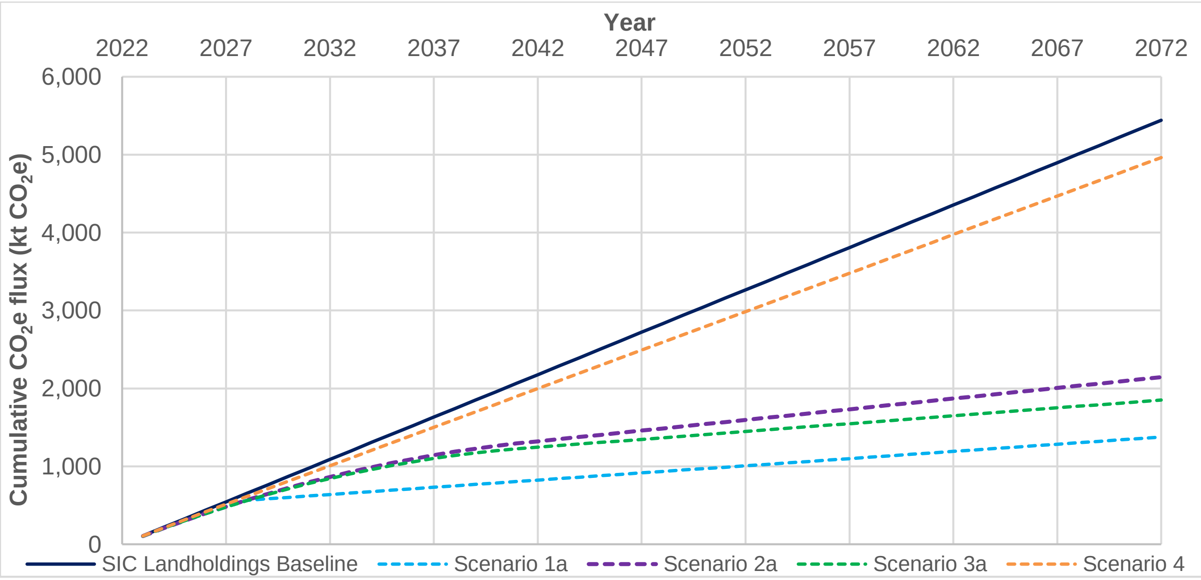
4.1.1 SIC Landholdings

The results of the SIC landholdings carbon reduction scenarios (SIC Landholdings Baseline, Scenario 1a, Scenario 2a, Scenario 3a and Scenario 4) are summarised in **Table 4-1** and **Figure 4-17** below.

Table 4-1 Annual and cumulative carbon flux for each SIC Landholding carbon reduction scenario for 2030, 2045 and 2072.

Scenario	Year	Annual carbon flux	Cumulative carbon flux	Difference in cumulative carbon flux from baseline	Difference in cumulative carbon flux from baseline
		kt CO_2e	kt CO_2e	kt CO_2e	%
SIC Landholdings Baseline	2030	109	870		
	2045	109	2,503		
	2072	109	5,442		
Scenario 1a	2030	18	603	-268	-31
	2045	18	878	-1,624	-65
	2072	18	1,376	-4,066	-75
Scenario 2a	2030	76	724	-147	-17
	2045	27	1,404	-1,099	-44
	2072	27	2,144	-3,297	-61
Scenario 3a	2030	73	711	-160	-18
	2045	20	1,306	-1,197	-48
	2072	20	1,851	-3,590	-66
Scenario 4	2030	99	811	-60	-7
	2045	99	2,293	-209	-8
	2072	99	4,963	-479	-9

Figure 4-17 Cumulative carbon flux for each SIC Landholding carbon reduction scenario for the 50-year period 2022-2072.



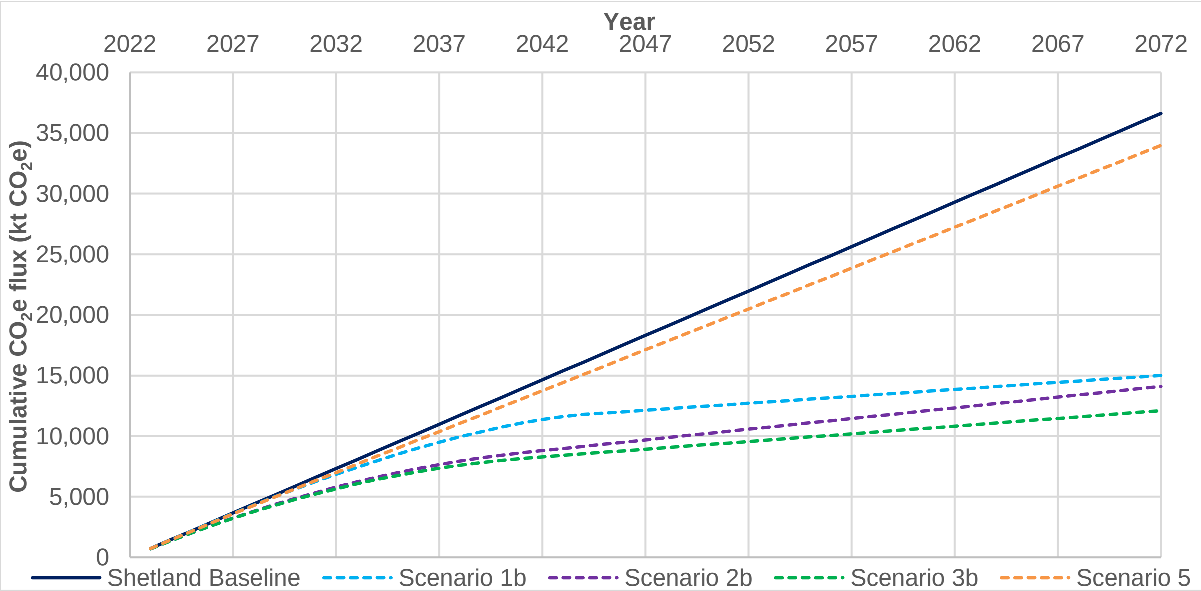
4.1.2 Shetland (area-wide)

The results of the Shetland (area-wide) carbon reduction scenarios (Shetland Baseline, Scenario 1b, Scenario 2b, Scenario 3b and Scenario 5) are summarised in **Table 4-2** and **Figure 4-18** below.

Table 4-2 **Annual and cumulative carbon flux for each Shetland (area-wide) carbon reduction scenario for 2030, 2045 and 2072.**

Scenario	Year	Annual carbon flux	Cumulative carbon flux	Difference in cumulative carbon flux from baseline	Difference in cumulative carbon flux from baseline
		kt CO_2e	kt CO_2e	kt CO_2e	%
Shetland (area-wide) Baseline	2030	732	5,857		
	2045	732	16,841		
	2072	733	36,618		
Scenario 1b	2030	647	5,622	-235	-4
	2045	120	11,903	-4,937	-29
	2072	115	15,006	-21,611	-59
Scenario 2b	2030	510	4,856	-1,001	-17
	2045	176	9,334	-7,506	-45
	2072	177	14,099	-22,519	-61
Scenario 3b	2030	490	4,767	-1,090	-19
	2045	127	8,667	-8,174	-49
	2072	127	12,096	-24,522	-67
Scenario 5	2030	686	5,648	-209	-4
	2045	674	15,768	-1,073	-6
	2072	675	33,979	-2,639	-7

Figure 4-18 Cumulative carbon flux for each Shetland (area-wide) carbon reduction scenario for the 50-year period 2022-2072.



5 Conclusions and recommendations

The conclusions and recommendations outlined below are based on the baseline carbon assessment (**Section 3**) and the assessment of carbon reduction scenarios (**Section 4**).

5.1 Conclusions

Based on the results of the modelling, the key conclusions show that:

- Baseline carbon stock of the Shetland Islands is 196,258 ± 22,278 kt CO_2e. Of this, 91% is stored in peat bogs (which are taken to be on average 169cm deep) the majority of the remaining carbon is stored in *Natural grassland* (6%), *Lowland heath* (2%) and *Wetlands, fen, marsh, swamp* (1%). Baseline carbon stock of SIC Landholdings is 28,413 ± 3,156 kt CO_2e. Of this, 92% is stored in peat bogs (which are taken to be on average 169cm deep) the majority of the remaining carbon is stored in *Lowland heath* (4%), *Natural grassland* (3%) and *Wetlands, fen, marsh, swamp* (1%).
- Out to 50 years (2072), cumulative carbon flux for Shetland (area-wide) is estimated to be 36,618 ± 2,308 kt CO_2e, with a cumulative carbon flux of 16,841 ± 1,062 kt CO_2e by 2045 (Scottish Government Net Zero target deadline).
- Out to 50 years (2072), cumulative carbon flux for SIC Landholdings is estimated to be 5,442 ± 318 kt CO_2e, with a cumulative carbon flux of 2,503 ± 146 kt CO_2e by 2045 (Scottish Government Net Zero target deadline). For context, this is c. 10-20% of the total for the Shetland Islands as a whole.
- In the baseline year, annual carbon flux for SIC landholdings has been calculated to be approximately 105 kt CO_2e. Carbon flux from landholdings is not typically estimated or included as part of organisational emissions baselines, but for comparison, SIC's Scope 1, 2 and 3 emissions as calculated within the Net Zero Council Routemap (NZCR) were 93 kt CO_2e in the financial year 2019/20. Again, it is important to emphasise that there is much greater uncertainty associated with the carbon flux estimates as compared with metered energy and fuel use data. Nonetheless, these results indicate that these sources of emissions are comparable in terms of their order of magnitude.
- The largest net sequester of CO_2e over Shetland is semi-natural *Natural grassland*, sequestering -3,073 kt CO_2e cumulative total between 2022-2072. The largest net sequester of CO_2e over SIC Landholdings is semi-natural *Natural grassland*, sequestering -261 kt CO_2e cumulative total between 2022-2072.
- The largest net emitter of CO_2e over Shetland is degraded peat bog (*Peat bog – actively eroding*), emitting 29,120 kt CO_2e cumulative total between 2022-2072. The largest net emitter of CO_2e over SIC Landholdings is degraded peat bog (*Peat bog – actively eroding*), emitting 4,264 kt CO_2e cumulative total between 2022-2072.
- Degraded *Lowland heath* and *Natural grassland* were also identified as a source of net emissions of CO_2e, however this was much smaller than degraded peat bogs.
- Five carbon reduction scenarios were modelled. Three were based around restoration of varying areal extents of degraded peat bogs while the remainder considered restoration of degraded natural grassland. In principle, these activities (restoration of peatland and grassland) could take place in parallel, although they have been modelled separately for the purpose of this study.
- For Shetland (area-wide), Scenario 3b (restoration of the most severely degraded peat bogs) offered the greatest potential benefits to reducing CO_2e by -24,522 kt CO_2e (-67% compared to baseline scenario) over the 50-year model period.
- For SIC Landholdings, Scenario 1a (restoration of all degraded peat bog) offered the greatest potential benefits to reducing cumulative CO_2e by -4,066 kt CO_2e (-75% compared to baseline scenario) over the 50-year model period. This suggests that – at least in theory – carrying out

carbon sequestration projects on SIC-owned land could provide up to c. 15% of the total improvement that can be achieved across Shetland as a whole. Again, it is important to emphasise that there is significant uncertainty involved, not just from a scientific/technical standpoint but also from a practical standpoint, so these figures should be interpreted with caution.

5.2 Recommendations

The results of the baseline carbon assessment and carbon reduction scenarios have identified that peatland comprises the most significant carbon stock on the Shetland Islands and within SIC Landholdings, and that degraded peatland is the most significant contributor to the emission of CO_2e from land cover on the islands. It is therefore recommended that restoration of degraded peatlands should be a focus for reducing the contribution of land cover emissions within Shetland and SIC Landholdings.

It is acknowledged that there are a range of challenges with all forms of land cover restoration, particularly with peatland restoration. Such restoration requires the implementation of significant actions, commonly over large areas, for long durations. Economic costs can also be high, although there are relevant grants available (e.g. NatureScot's Peatland ACTION Fund) and such streams should be investigated as necessary. As with all environmental schemes, detailed expert technical input is required throughout, from planning and inception to the physical implementation and post-restoration management of any mitigation measures. These factors need to be borne in mind.

Of key concern on the Shetland Islands is the current use and ownership of the land for agriculture (including peatland), and the impact to agriculture, associated livelihoods and food security on the island which restoration actions could have. As such, any restoration actions which are planned, the locations being targeted and the scale of the planned restoration work are all likely to be directly constrained by agriculture. This is not to say that actions cannot occur, more that it is of vital importance that any restoration actions and their long term management are developed to work in sympathy with agricultural practices and stakeholders, taking their views into account, so that benefits to improving the land can be directly felt by all. However, it is noted that for major improvements to the current carbon emissions, large scale restoration of the degraded peatland (including areas under current use by agriculture) would have to occur.

The restoration of degraded land for carbon sequestration and emissions reductions should also be considered holistically alongside the other range of potential opportunities and significant benefits linked to restoration, such as biodiversity and habitats gains, enhancing habitat connectivity, improvements in water quality, enhanced recreation etc. Stakeholder meetings carried out as part of the NZSR study have made it clear that land use and agricultural practices are a highly complex topic area, so and a key recommendation from the NZSR will be to carry out additional work to identify the opportunities and practices that are suitable for adoption within Shetland.

It is understood that restoration of some peatland has already occurred and that wider initiatives are currently planned to actively begin to restore large areas of peatland in the Shetland Islands. It will be beneficial to explore the integration of any proposed peatland restoration measures with those already existing and planned in order to maximise the magnitude of potential benefits, and also to allow sharing of relevant knowledge and experience, and potentially costs.

It is important to note that even if all of Shetland's peat bogs were restored to a natural condition, the mechanism by which peat bog habitats function will mean that they *will always remain* slight net emitters of CO_2e. However, the difference in CO_2e flux between degraded and semi-natural peat bogs (23.48t CO_2e/ha/yr and 1.08t CO_2e/ha/yr respectively) means that there will always be significant and direct benefits to emissions by restoring peat land. Evans et al., 2017[14] state that area of near natural bog and fen within the UK is believed to be continuing to act as a significant net sink for CO_2, however, this CO_2 sink is *"counterbalanced by similar emissions of methane (CH_4) when its greater 100-year Global Warming Potential is taken into account making near-natural peatlands close to carbon neutral. Over longer time-horizons, natural peatlands have a strong net cooling impact on climate, due to the longer atmospheric lifetime of CO_2 compared to CH_4"*.

All five land cover carbon reduction scenarios modelled in this report provide varying degrees of increasing carbon sequestration potential by reducing the carbon flux associated with land cover in the SIC operating area. Any opportunities taken forward need to be considered as part of the council's plan for carbon neutrality and also should actively consider all of the wider implications discussed above, particularly those around farming and other current land use practices. These should then be fully integrated into any plan alongside extensive stakeholder engagement. This is critical to ensure that outcomes are positive and effective on an island-wide scale.

As noted previously, the outputs from the model should be considered within the foundation of the model assumptions and the associated errors. The management scenarios assessed by this investigation are broad scenarios. Should these measures be considered for implementation suitable expert advice and technical guidance should be sought to correctly develop and implement these scenarios.

[14] Evans, C., Artz, R., Moxley, J., Smyth, M.A., Taylor, E., Archer, E., Burden, A., Williamson, J., Donnelly, D., Thomson, A. and Buys, G., 2017. *Implementation of an emissions inventory for UK peatlands* (pp. 1-88). Centre for Ecology and Hydrology.

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