The Impact of Conservation Grazing on GHG emissions

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Foreword

The climate and nature crisis are interlinked problems. Climate change accelerates biodiversity loss and erodes the ability of species to respond to future extreme weather events brought about by climate change. Greenhouse Gas (GHG) emissions reduction across all sectors is therefore essential. Natural England are driven to exploring long-term, nature-based solutions, which work to address both the restoration of habitats and the challenges of climate change. However, the solutions do not always solve both problems, with the solution to one problem potentially causing challenges for another.

Conservation grazing is an important tool for delivering high biodiversity outcomes through increasing the diversity and structure of vegetation swards. As an extensive system, conservation grazing only removes a proportion of the annual vegetation growth, leaving opportunities for other species to exploit for feeding and breeding requirements. Furthermore, livestock species preferentially eat different vegetation species, meaning that conservation goals can be designed with specific grazers in mind. This helps create variation in habitat structure which can help species adapt to changing climate conditions.

Livestock produce GHG emissions during grazing. These emissions are produced by enteric fermentation of the vegetation during digestion or following manure deposition. The magnitude of GHG emissions vary depending on the different species or the size of the animal. Different habitat vegetation will also influence the extent of GHG emissions due to how easy the vegetation is to digest.

Natural England commissioned this work as there is a need to understand the significance of GHG emissions within conservation grazing systems. To better support land managers' decision making on how to limit GHG emissions whilst also achieving conservation outcomes for biodiversity. Conservation grazing is widely used in many sites to benefit wildlife outcomes. We presently use it on many of our National Nature Reserves and within Agri-environment schemes we set up with land managers.

This project constructs a carbon calculator for conservation grazing which aims to give an indication of how changing breed size/ species choice as well as stocking rate for different habitats quantifiably affects GHG emissions while maintaining conservation outcomes. **However, the lack of robust data to populate key parts of the model used in the calculator means that any outputs are limited and cannot be used to justify one mode of land management over another.**

We hope it can be read and used for the purposes of stimulating thinking among land managers of extensive grazing systems and act as a guide in attempting to balance limiting GHG emissions in conservation grazing systems while achieving good conservation outcomes for biodiversity. This is seen as the start of building better understanding of this subject by highlighting the areas of uncertainty to inform future work.

Executive summary

The purpose of this work, within the remit of Natural England to conserve and enhance the natural environment, was to demonstrate the impact of conservation grazing on greenhouse gas emissions (GHG). Conservation grazing is an important tool in the management of semi-natural habitats to ensure a diverse range of flora and fauna can thrive. The grazing of cattle, sheep and ponies, plus occasionally novel species such as bison and water buffalo, is used to help maintain areas of open habitat by helping to prevent the ingress of scrub and woodland, which might shade out other species. As a result, biodiversity is increased by reducing the abundance of dominant species and enabling others to grow.

However, it is important to understand the extent to which different livestock species and stocking densities impact the outcomes of conservation grazing on GHG emissions. Therefore, the aim of this project was to develop an Excel-based model that allows users to understand the potential climate change impact of using different grazing livestock species and breeds to manage a variety of different habitats, enabling them to potentially adapt grazing patterns to lower emissions.

Natural England have detailed knowledge of conservation grazing approaches and their biodiversity benefits. They have also developed one of the most comprehensive reviews of the data available for GHG fluxes (emissions and removals) from semi natural habitats (Gregg et al. 2021). However, Natural England have a more limited understanding of the emissions from the livestock themselves. This project, therefore, aimed to bring together the evidence for emissions from different livestock species and breeds to create a simple model that would allow conservation grazing practitioners to understand the greenhouse gas emissions of their grazing management approaches.

The model was built using The Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodologies to calculate the methane emissions from enteric and manure pathways, and the N_2O emissions from deposition for cattle, sheep, water buffalo and bison. Tier 1 methodologies were used to calculate the enteric methane emissions, manure methane emissions and N_2O emissions from the deposition of dung and urine for ponies. This study focused on the livestock emissions themselves – therefore it did not include emissions from energy consumption to manage the livestock or habitats.

The model has a simple user interface that allows selection from a list of eight habitats for grazing and the area of those habitats to be entered. The user can then select the species (sheep, cattle, ponies, bison, or buffalo), in some cases the size of the animal as a proxy for breed (broadly categorised as large, medium or small breeds), and the number of individuals (adult or juvenile) to be grazed across a particular area of habitat(s). The outputs of the model indicate the total annual emissions of methane and nitrous oxide, for a whole site or per hectare from the livestock. In addition, the model provides indicative stocking rates to guide the user when entering data, indicating whether the stocking density entered is considered to be high, medium or low to allow comparison with other habitats.

Alongside the assessment of the emissions from the different conservation grazing systems, the project also considered available information on the potential degree to which the different habitats could sequester or emit carbon dioxide. The data available for many of these habitats is sparce, uncertain and highly variable, particularly for typically grazed habits such as grasslands. There is also the challenge that when assessing emissions from grazed habitats it is unclear whether researchers have included or excluded the grazers from the habitat when completing GHG flux assessments. Therefore, the decision was taken not to include single GHG fluxes from the habitats within the model outputs, but rather to discuss the range of emissions or removals from the different habitats and how they compare in scale to the levels of emissions seen from different conservation grazing management scenarios.

It is also important to recognise that the emissions from grazing livestock include significant assumptions, for example most modelling is based on commercial production systems, with higher nutritional density than is typically found in semi-natural habitats. The sparce grazing and reduced digestibility of forage in some habitats could impact on enteric methane emissions, however, insufficient data on digestibility of forage in different habitats was available to make robust distinctions in the modelling, therefore digestibility was maintained as a constant across all habitats. This is a clear evidence gap that could be addressed to increase accuracy of future modelling.

To understand the implications of a range of different grazing management systems for site level emissions, a number of scenarios were run through the model to address the following questions:

1. Which species of livestock have the lowest emissions per livestock unit?
2. Does size (as a proxy for breed) have an impact on emissions per livestock unit?
3. When grazed at low stocking rates, as is typical in conservation grazing systems, how do the emissions compare to the potential removals that the habitat can deliver when well managed?
4. How do carbon emissions vary between different stocking densities of the same livestock type, breed and habitat?

These scenarios were written up as brief case studies. The key findings of which are summarised below.

- The species of the animal selected has the biggest impact on emissions per stocking unit. On a per livestock unit (LU) basis the lowest emissions came from monogastric ponies, whereas ruminant livestock, such as cattle or sheep, produced higher emissions.

- The size (i.e. weight) of animals within a species has an impact on emissions, with larger animals producing fewer emissions per livestock unit than smaller animals due to slightly higher digestive efficiency.

- It is known that digestibility of forage has an impact on methane emissions from cattle and sheep, with less digestible forage resulting in higher emissions. Horses, as monogastrics, digest fibre differently, they don't have a rumen containing high concentrations of methanogenic bacteria, therefore have lower emissions overall, but little research has been done on the impact of digestibility on those emissions. There was a lack of data available on the digestibility of forage in the different habitats to enable robust assumptions to be made in the calculations.

- Data on methane emissions and nitrous oxide emissions specifically relevant to conservation systems were lacking, and therefore data had to be extrapolated from regional assumptions, for example Western Europe.
- Incorporating the impact of conservation grazing verses GHG fluxes from habitats is challenging. There is significant variability in the GHG flux data available, with much of the data based on small sample sizes, increasing uncertainty over its validity for wider application. Furthermore, there is uncertainty as to whether the systems assessed for carbon fluxes included or excluded livestock emissions in their measurements. Therefore, it is not practical at present to determine a carbon balance where both emissions from livestock and carbon fluxes from habitats are considered. **However, indications for the data are that in certain habitats with the ability to sequester carbon, some conservation grazing is possible without causing net emissions to arise.** For habitats where the carbon flux is in equilibrium or that are net emitters, any addition of livestock will lead to further increases in emissions. The habitats that are more likely to be found to sequester carbon are those that have high water tables leading to low decomposition rates of organic matter (salt marsh, fen, raised or blanket bog in good condition).
- A major finding of this work was that the data available on livestock emissions in conservation grazing systems is limited and much more work is needed in this area to build up a reliable and robust evidence base. Equations and parameters derived from conventional systems were used in this report to give an indication of emissions based on the best available data. This report and the model are able to give an indication of the potential climate impact of grazing different species and sizes of animals, but it was concluded that it is not possible based on the current evidence base to accurately reflect the impact of forage quality or specific breed characteristics (other than size) on methane or nitrous oxide emissions. In addition, the data on fluxes from different habitats is insufficiently robust at scale to enable accurate balancing of landscape emissions against livestock emissions. The model can therefore give an indication of how different species combinations could impact emissions but should not be used as the sole approach to selecting land management approaches.

Contents

Introduction

Conservation grazing is an important tool in the management of semi-natural habitats to ensure a diverse range of flora and fauna are able to thrive. The grazing of cattle, sheep and ponies, plus occasionally novel species such as bison and water buffalo, is used to help maintain these habitats by maintaining areas of open habitat by helping to prevent the ingress of scrub and woodland, which might shade out other species. As a result, biodiversity is increased by reducing the abundance of dominant species and enabling others to grow.

However, it is important to understand the extent to which different livestock species and stocking densities impact the outcomes of conservation grazing on greenhouse gas (GHG) emissions. Therefore, the aim of this project was to develop a model that enables conservation grazers to understand the potential climate change mitigation impact of different grazing management practices, and potentially adapt grazing patterns to lower emissions.

Background

Natural England has a remit to conserve and enhance the natural environment for the environmental and socioeconomic benefits that it offers, alongside delivering the 25-year Environment Plan. Natural England are committed to finding long-term, nature-based solutions to tackle both the restoration of habitats and the challenges of climate change. However, the use of these solutions is not always straightforward, with the solution to one problem potentially causing challenges for another. This has been highlighted within the use of conservation grazing, where the practice is known to deliver biodiversity benefits, but typically requires the use of cattle or sheep which are associated with methane and nitrous oxide production.

Further understanding of the interactions of grazing animals, conservation outcomes and GHG emissions is needed, to develop systems that can effectively deliver biodiversity benefit whilst minimising negative climate impact. Natural England have detailed knowledge of conservation grazing approaches and their biodiversity benefits. They have also developed one of the most comprehensive reviews of the data available for GHG fluxes (emissions and removals) from semi-natural habitats (Gregg et al. 2021). However, Natural England have a more limited understanding of the emissions from the livestock themselves. This project, therefore, aimed to bring together the evidence on emissions from different livestock species and breeds to create a simple model that would allow conservation grazing practitioners to understand the greenhouse gas emissions of their grazing management approaches.

Conservation grazing

Conservation grazing refers to the use of livestock to manage different semi-natural habitats to improve biodiversity. Different grazing species have different conservation outcomes when used for grazing. Sheep are light on the land and can be grazed in places where heavier animals would sink and potentially cause damage (Chapman 2017). However, larger animals are used in some situations for that very reason as they can clear open spaces in coarser vegetation via trampling, e.g. through scrub. The species also graze in different ways, with sheep grazing close to the ground, creating a short uniform sward (The Wildlife Trusts 2016). Sheep have small dexterous mouths and tend to be very selective in what they graze – often favouring broadleaved species; they will graze out species such as ragwort, dock, and nettle (Payne 2020). Cattle graze very differently, using their tongues to wrap around longer vegetation and tear it up, which can help to open up the sward (Payne 2020). Cattle with their larger mouths are generally less selective feeders and rely on quantity of forage rather than quality (Chapman 2017). They eat grass or broadleaved species as they come to them, but tend to leave patches of longer coarser grasses, which can help to create diverse structure (Payne 2020). Ponies are highly selective and graze close to the ground creating smooth swards, but also create latrine areas where they will not graze, also creating habitat diversity (The Wildlife Trusts 2016; Payne 2020). Ponies will also browse trees and shrubs.

There is less certainty on the nature and scale of differences in grazing behaviour between different breeds of cattle and sheep. However, smaller native breeds tend to be hardier and better adapted to living in harsh conditions on poorer quality forage (Chapman 2007). The native breeds also tend to have better mothering behaviours than larger commercial breeds, so are easier to manage with less input if breeding is the intention (Payne 2020). Many conservation grazing programmes will use different species at different times of year to deliver different habitat goals, e.g. to clear land of coarse vegetation to reduce competition for small flowering plants, clearing grass growth to open up space for flowering species to set seed. The choice of species and breed used may also be influenced by whether the grazier is aiming to get a financial return off the land as well as the conservation benefits.

Five different species were chosen for the model: sheep, cattle, ponies, bison, and water buffalo. This selection was influenced by their use in conservation grazing management approaches within the UK. As each species is suited to different habitats and provide different conservation outcomes, the model allows for comparisons to be made according to species selection. Additionally, a variety of size categories have also been included for sheep, cattle, and ponies, to enable users to compare the emissions associated with different size animals. This is used as a proxy for breed as breed specific data is not available. The species and sizes captured within the model are set out in Table 1 (with indicative breeds given for each size).

Table 1 – Livestock species and sizes included in the model (Adapted from Martin et al. 2013: Table D & F) with indicatives breeds also given (*Note: breed specific data is not available therefore it is size rather than breed that drives the analysis*).

Livestock species	Breed size categories	Livestock breed examples
Cattle	Small (<500 kg)	Galloway, Highland, Dexter
	Medium (500 kg - 700 kg)	Longhorn, North (Ruby) Devon, Welsh Black
	Large (>700 kg)	Continental Cross Breed, South Devon, Sussex
Sheep	Small (<50 kg)	Black Soay, Hebridean, Herdwick
	Medium (50 kg - 70 kg)	Southdown, Scottish Blackface, Cheviot
	Large (>70 kg)	Blue-faced Leicester, Dorset Horn, Texel
Equine	Small (<300 kg)	Exmoor, Dartmoor, Shetland
	Medium (300 - 600 kg)	Konik, Fell, Highland
Bison	Standard (360 - 990 kg)	European
Water buffalo	Standard (300 - 600 kg)	N/A

There are alternatives to conservation grazing for managing semi-natural habitats, with other practices including slashing, mowing, and strimming. However, as indicated in the Wildlife Trust report (Thom & Doar 2021) these alternatives have other socioeconomic and environmental implications. For example, while there would be reduced methane emissions as a result of not having livestock, there would be carbon dioxide emissions from the fuel consumed to power the machinery; at least until a 100% renewable energy alternative could be achieved.

The key sources of emissions from grazing livestock are methane from digestive processes and nitrous oxide emissions from urine and faeces deposition whilst grazing. Methane emissions are highest in ruminant (cattle, sheep, bison, and buffalo) livestock where there is an anaerobic digestion phase (rumination or enteric fermentation) that utilises methanogenic bacteria to support the breakdown of fibrous elements of the diet. These methanogenic bacteria produce methane as a result of their activities, which is released via the mouth when the cow regurgitates the semi digested food to chew again before it passes through the subsequent phases of digestion. A small amount of methane is also lost via the back passage. Non-ruminant livestock, such as ponies, do not have this anaerobic digestion phase, instead the fibre passes through the stomach, and intestines and the majority of the breakdown of fibre occurs in the hind gut – again using bacteria to support fermentation. However, this process results in far less methane production than rumination. In ruminant livestock the enteric fermentation process produces more methane in the presence of poor-quality forage (such as might be seen in semi-natural habitats) than good quality forage. The more fibrous the forage source the more active the bacteria in the rumen are to extract the nutrients that the animal requires.

Nitrous oxide emissions relate to the nitrogen content of the faeces and urine that are deposited by the animal. Typically, a diet that is lower in nitrogen (as is expected from semi-natural grazing, verses supplementary feeding), will result in lower nitrogen excretion.

In these conservation grazing systems, it has been assumed that there is no supplementary feeding of either forage (brought in from offsite) or compound feed, as these systems aim to maintain a nutrient balance and minimise the import of nitrogen (or other nutrients) into the system.

Project aims

The aim of this project was to develop a simple Excel-based model that could be used by conservation grazing practitioners to guide understanding of the potential climate impact of different conservation grazing management systems.

The modelling framework needed to enable the assessment of emissions from different species and breeds of livestock, at different stocking densities, and place them into the context of potential removals or emissions delivered by different habitats.

A further aim was to develop a basic assessment of greenhouse gas emissions in a conservation grazing system to compare with the scale of carbon sequestration and emissions from different habitats to inform future approaches to delivering Net Zero commitments.

Approach

Assessment boundary (and limitations)

The assessment boundary is for one year of management of the site. On some sites the livestock might graze for the whole of that year, while on others the livestock might only be present for part of the year. The model presents the results on an annual basis, although only calculates the emissions from the livestock for the period of time they are present on site.

The boundary for the livestock emissions assessment was determined as the time they spent within the conservation grazing system. The assessment of livestock emissions focuses on enteric methane emissions from digestive processes, and nitrous oxide emissions from manure (dung and urine) deposition. Methane emissions from manure deposited at grazing were calculated but are generally considered to be minimal due to the aerobic conditions the manures are exposed to. This is reflected in the scale of the emissions factor that is applied to methane from deposition.

The model is NOT able to respond to the interaction between livestock species and habitat although in practice such interactions could be expected to impact enteric methane emissions. For example, the energy requirement of the animal is determined by the habitat type. More rugged or steep habitats with low forage availability are likely to require the animal to burn more calories to find their food than flatter, more even habitats with plentiful forage. In addition, the quality of the forage could also impact the methane emissions from ruminants, with higher emissions expected where the forage diet is more fibrous.

There is also new evidence emerging that methane is taken in by methanotrophic bacteria in a natural grassland much more readily than in more intensive systems (Pan et al. 2021) There is currently limited information on the scale and extent of fluxes driven by methanotrophic bacteria. It is assumed for the purpose of this analysis that these fluxes are incorporated in the methane emissions reported in the papers used, which have been determined through in-field assessment.

Eight different habitat types, which are common throughout England were considered within this model (Table 2). As there is limited data available on the specific crude protein and digestibility of the main forage species in the habitats a general assumption of ‘poor quality forage’ was made for all habitats; a value of 15% crude protein and 55% digestibility was used for the analysis. However, it is recognised that there is a lot of variability surrounding digestibility and crude protein content of the different species present in semi-natural habitats and these variations would have a substantial impact on total emissions from the conservation grazing system. There is the potential to develop this functionality in the future as further data becomes available.

Table 2 – The definitions of each of the eight habitat types considered within the conservation grazing model.

Habitat type	Description	Reference
Calcareous grassland	Situated on chalk or limestone substrates, these habitats are rich in flora with scrub present depending on grazing patterns.	The Wildlife Trusts (n.d.a)
Salt marshes	Coastal wetland which gets flooded with salt water that is brought in by the tides.	The Wildlife Trusts (n.d.b)
Sand dunes	Formed by sand blown inland by onshore winds, initially dominated by tough beach grasses that allow more sand to accumulate. Over time, as the salinity of the sand dune reduces, a diverse range of finer grasses, herbs and lichens are able to grow.	The Wildlife Trusts (n.d.c)
Heathland	Often occurs on nutrient poor land, dominated by heathers, gorse, and heathland grasses.	The Wildlife Trusts (n.d.d); The Wildlife Trusts (n.d.e)
Wood pasture	Land containing trees, either of ancient or recent origin, which has been managed through grazing.	Woodland Trust (n.d.)
Rush pasture	A mixture of grassland and wetland habitats, with different grass and flower species growing on peaty mineral soils.	The Wildlife Trusts (n.d.f)
Blanket bog	An upland habitat that is dominated by bog-mosses, heathers, and cotton grasses.	Wildlife Trust (n.d.g)
Fen	A wetland habitat dominated by species such as reeds, rushes, and sedges.	Wildlife Trust (n.d.h)

The emissions are calculated on a per hectare and per site basis. The user is able to select the number of animals and species that they want to include on the site – the model uses ‘typical’ stocking densities for that habitat to enable the user to compare high, medium or low stocking densities in different habitats. These values are indicative and should not be used to inform stocking densities for a desired conservation outcome as every conservation grazing system will have different goals and needs and habitat variability cannot be fully captured in the broad habitat categories of the model. The categories aim to help the user understand how the values they have entered compared to typical stocking densities on that habitat type.

Carbon sequestration and storage varies by habitat. There can also be significant variability within habitats, and it is recognised that there are evidence gaps (Gregg et al., 2021) with sample sizes often being small and insufficient clarity as to whether emissions include those from grazing livestock or not[1]. Given the range of variation and evidence gaps, this report presents GHG flux values in ranges, from the lowest GHG fluxes (greatest removal or lowest emissions in range presented by Gregg et al. (2021)) to the highest GHG fluxes (lowest removal or greatest emissions in range presented by Gregg et al. (2021)). These habitat GHG flux values aim to provide further context to understand the scale of livestock emissions compared to those derived from the modelled habitat but should not be used to create a carbon balance.

The boundary for calculating livestock emissions specifically excludes:

- Any embedded emissions from livestock production off site
- Any emissions from the livestock for any parts of their lifecycle that are spent off the site (e.g. in housing, winter grazing, finishing)
- Embedded emissions from supplementary feed – it is assumed that no feed is brought onto the site any hay fed would be produced on site
- Fossil fuel emissions associated with the management of the site – e.g. mowing, cutting etc.
- Any transport of livestock to and from the site
- It does not account for the productivity of the animals (e.g. how much meat, wool or milk is produced).

The model therefore aims to allow the user to understand the livestock emissions from the different species and sizes used within the conservation grazing system. Comparison of these outputs with habitat GHG flux values give an indication of whether livestock emissions are high or low in relation to the overall emissions and removals that the type of habitat(s) can produce.

Model format

ADAS have created an Excel-based model to achieve the goals of this project. The model user interface is a single screen that acts as a dashboard. Here, the user can input data

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[1] Natural England have an ongoing project to fill some of these gaps in the evidence.

and see the results instantly. Behind the scenes, the model has calculation worksheets and emissions factors worksheets. The model focuses on emissions from livestock only. There is additional functionality available to Natural England that allows the comparison of emissions to GHG fluxes from these habitats – this module is separate due to the significant uncertainties around the GHG fluxes in different habitats. This aspect of the tool can be primarily used for research purposes, allowing users to model various scenarios and investigate different outcomes.

The user can input a range of data. The model asks for habitat information first. Here, the user can select up to three different habitat types from a dropdown menu. These habitat types are: calcareous grassland; salt marsh; sand dunes; heathlands; wood pastures; rush pastures; blanket bog; and fen. The user then enters the area of each habitat type that is being considered. The combined habitats entered are here on referred to as the 'site'. Next the user can enter livestock data. The model asks for species, providing the following options: sheep; cattle; equine; bison; and water buffalo. The model allows the user to select from a subset of size categories (typical of certain breeds) within each livestock type. The model then asks for the number of adults and juveniles in each category and the percentage of time in one year spent grazing.

The model gives the overall estimated emissions for the site based on the livestock present and period of time spent grazing, using a number of specified assumptions. These emissions are provided in both tonnes $CO_2e\ yr^{-1}$ for the site and tonnes $CO_2e\ ha^{-1}\ yr^{-1}$, allowing the user to report their emissions for the entire site or on a per hectare basis (useful when comparing between different projects or sites to allow comparison on a like for like basis). The model also indicates the number of livestock units based on the livestock present and suggests whether the stocking density is low, medium or high for that habitat compared to published recommended values.

Emissions calculations

The emissions calculations in the model have been aligned to the 2019 refinements to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use (IPCC 2019). The IPCC methodology has a three-tiered approach for their calculations. The difference between these tiers are:

Tier 1: This uses spatially coarse activity data that is country-specific if possible, but otherwise global. The IPCC has created equations for these data that determine the GHG emissions from the system. Tier 1 emissions factors have an uncertainty of ± 30-50% (Gavrilova et al. 2019).

Tier 2: Emissions factors and stock change factors are based on country- or region-specific data. There is some overlap in the calculations for Tier 1 and Tier 2 emissions factors. Tier 2 emissions factors have an uncertainty of ± 20% (Gavrilova et al. 2019). However, this is dependent on the accuracy of the input data – uncertainties will be higher where the data quality is lower. For example, much of the available input data relates to industrial-scale farming systems rather than being specifically tailored to conservation grazing systems.

Tier 3: This tier does not use IPCC defined emissions factors or equations. Instead, it is for purpose-built process-based models and inventory measurement systems that have been built to fit specific circumstances and are repeated over time with high-resolution activity data that is regional rather than national.

This model uses Tier 2 calculations where possible and Tier 1 calculations when Tier 2 factors are not available.

The model uses IPCC equations to calculate enteric methane emissions, manure methane emissions and manure N_2O emissions. The enteric methane emission calculations use the Tier 1 methodology for equine (as no Tier 2 approach is available). Tier 2 methodology is used for sheep, cattle, bison and water buffalo. The variation in these tiers align with the animals that have monogastric (ponies) or ruminant (sheep, cattle, bison and water buffalo) digestion, with the latter producing much more enteric methane. The manure methane calculations also used Tier 1 methodology for equine and Tier 2 methodology for sheep, cattle, bison and water buffalo. N_2O emissions from manure have been calculated using the Tier 1 methodology for all livestock. The nitrogen calculations estimate direct N_2O emissions from deposition during grazing, as well as indirect N_2O emissions that come from ammonia volatilisation or nitrate leaching.

Key assumptions

A variety of assumptions have been made about the data and the calculations. Different assumptions have been made for calculating the livestock emissions, estimating the stocking density, and considering the carbon storage and sequestration rates at the different habitats. These assumptions are set out below.

Converting GHG emissions to carbon equivalents

Greenhouse gas (GHG) emissions are reported in carbon dioxide equivalents (CO_2e) using the global warming potentials (GWP) for each gas over a 100-year period, as set out in the IPCC guidelines (IPCC 2021). The GWP_{100} for methane is 27 (non-fossil methane) and nitrous oxide is 273, meaning for each 1kg of those gasses they are multiplied by that number to give the CO_2e value. Previous reports discussing livestock GHG emissions may have used a GWP_{100} of 28 for methane and 265 for N_2O (IPCC 2013) or 25 for methane and 298 for N2O (IPCC 2007).

Assumptions made for calculating the GHG emissions from livestock

The livestock emissions were calculated using equations in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories for Agriculture, Forestry and Other Land Use (Gavrilova et al. 2019; Hergoualc'h et al. 2019). The model used calculations for enteric methane emissions, manure methane emissions and manure nitrous oxide emissions. The IPCC equations were designed for livestock systems that are productive and predominantly for food, not conservation, although they do include production on extensive rangelands such as used in the USA. However, it is unclear how appropriate these assumptions are to the UK system given the highly variable nature of production systems globally. Therefore, the equations may not be as accurate for the breeds, diets, lifestyles and habitats used for UK conservation purposes. In order to compensate for this as much as possible, emissions factors were chosen for the least productive system where available. However, a high degree of uncertainty remains around the use of IPCC methodology and standard input values for conservation grazing systems. Future work should aim to address these knowledge gaps and adjust the model appropriately.

The IPCC Tier 1 calculations for enteric methane, manure methane and N_2O emissions do not use livestock weights. Therefore, there is just a single value for equines which encompasses both horses and ponies. It is likely that ponies would have slightly lower emissions than horses due to their smaller size, however, given the relatively low emissions compared to ruminants this is not considered to be a significant source of error.

The IPCC Tier 2 calculations for enteric methane use livestock weights as part of their calculations. Manure methane and N_2O emissions are determined by weight in Tier 2 calculations indirectly. This is because the calculations are based on dietary requirements, which is linked to weight. Weights were taken from the Martin et al. (2013) report, which reflected the livestock units presented per weight category (see assumption note below). It was assumed that the average weight of the juveniles across the year was 40% of the adult body weight, based on the weights presented in AHDB (2023).

The IPCC did not always have data for all of the livestock included in the model at each tier. Where data were missing for buffalo and bison, but present for cattle, cattle data were used. Specifically, the IPCC provided Tier 1 data for buffalo but not bison. The IPCC also provided factors that could be used for cattle or buffalo for Tier 2 data. The model uses the Tier 2 data and assumes that bison have the same factors.

The IPCC Tier 2 calculations for enteric methane emissions require digestible energy. For the purpose of this model, the calculations were adapted and simplified based on assumed requirements for the livestock systems. The model focused on net energy for maintenance and activity, and for juveniles, net energy for growth – but did not include calculations for pregnancy, or lactation, as these add unnecessary levels of complexity to the model.

To calculate net energy, the energy requirement of the animal is determined by the habitat type. More rugged or steep habitats with low forage availability are assumed to require the animal to burn more calories to find their food than flatter, more even habitats with plentiful forage. IPCC gives two factors one for confined grazing and one for range land or hilly terrain. For this model we assumed that all habitats needed the same grazing energy requirement as hilly terrain.

In addition, the quality of the forage also impacts the methane emissions from ruminants with higher emissions expected where the forage diet is more fibrous. As mentioned above, limited data were available on the specific crude protein and digestibility of the main plant species grazed in the habitats, therefore a general assumption of ‘poor quality forage’ from the IPCC report was made for all the habitats. However, it is recognised that there is a lot of variability surrounding digestibility and crude protein content and these variations would have an impact on total emissions from the conservation grazing system. There is the potential to develop this functionality in the future.

Assumptions made about the livestock data

Assumptions were made about the livestock weight and the number of livestock units present. For the different species and breeds of livestock simplified assumptions were made for the weight of the animals based upon ranges presented in Martin et al. (2013). For ruminant species, the individual livestock units were estimated using the following equation that was presented in Martin et al. (2013):

$$livestock\ unit = \frac{livestock\ weight}{650}$$

Livestock weights and livestock units are presented in Table 4. They are presented based on the assumption that one livestock unit corresponds to a 650kg animal.

Following Martin et al. (2013), a simplified approach was used for equines. As equines are not ruminants their digestive system is less efficient in converting food to energy. In this case, one livestock unit corresponds to a medium sized horse (300-600 kg), with a small pony (<300 kg) representing 0.8 livestock units.

Table 3 – Liveweight values applied for adult animals in the model, and number of livestock units per adult.

Livestock species	Breed size categories	Livestock breed examples	Modelled liveweight (kg liveweight / animal)	Livestock units per animal
Cattle	Small <500 kg	Galloway, Highland, Dexter	400	0.62
	Medium 500 - 700 kg	Longhorn, North (Ruby) Devon, Welsh Black	500	0.77
	Large >700 kg	Continental Cross Breed, South Devon, Sussex	700	1.08
Sheep	Small <50 kg	Black Soay, Hebridean, Herdwick	50	0.08
	Medium 50 - 70 kg	Southdown, Scottish Blackface, Cheviot	65	0.10
	Large >70 kg	Blue-faced Leicester, Dorset Horn, Texel	100	0.15
Equine	Small <300 kg	Exmoor, Dartmoor, Shetland	N/A*	0.8
	Medium 300 - 600 kg	Konik, Fell, Highland	N/A*	1.00
Bison	Standard	European	675	1.04
Water buffalo	Standard	N/A	450	0.69

*Weights for ponies are not used in the modelling process as this is completed using Tier 1 methodologies which are insensitive to size. However, because the larger ponies have a higher livestock unit, if you stock to a certain density of one versus the other you will have fewer ponies with larger breeds and therefore differences in emissions.

Stocking density

Stocking density is determined by the user as they enter the number of animals that they have within their grazing system. However, to give an indication of how the number of stock entered compares with typical recommendations for stocking densities given by Natural England and the Scottish Agricultural College, the model also gives an indication of whether the stocking density is:

- **High |** This is aligned to rates required for Environmental Cross-Compliance. Here, there is a reduction in stocking density when compared to commercial rates, but little measurable improvement in the condition of the vegetation (Martin et al. 2013).
- **Medium |** This is aligned with guidance for maintenance of habitats for Higher Level Stewardship. It allows for the maintenance of some species but may not improve the condition and deterioration from grazing can still happen (Martin et al. 2013).
- **Low |** This is aligned with guidance for habitat restoration for Higher Level Stewardship using low density grazing. This allows for some recovery of vegetation, which may lead to potential increase in vegetation cover (Martin et al. 2013).

Table 4 – Guide stocking density ranges used for each habitat numbers given in livestock units per hectare.

Habitat	High	Medium	Low	Reference
Calcareous Grassland	0.50	0.25	0.125	Crofts and Jefferson (1999)
Salt Marsh	0.50	0.25	0.125	Chapman (2007)
Sand Dunes	0.30	0.10	0.05	Chapman (2007)
Heathlands*	0.15	0.07	0.04	Martin et al. (2013)
Wood Pastures	0.07	0.04	0.02	Chapman (2007)
Rush Pastures	0.40	0.20	0.10	Chapman (2007)
Blanket bog	0.07	0.035	0.018	Martin et al. (2013)
Fen	0.20	0.10	0.05	Chapman (2017)

* Here an average of dry and wet upland heath.

These categories applied to stocking rates entered into the model are not intended to support stocking rate calculations for conservation aims. The precise stocking rate for maintenance / restoration of any given site will be highly variable, and will depend on a range of factors not captured by the model including, precise habitat type (rather than the broad categories used in this project), current condition, and conservation aims. If needed separate advice should be sought on setting a stocking rate to deliver defined, site-specific conservation aims.

In order to maintain the simplicity of data entry it is assumed that all species graze equally across all habitats selected.

Values for habitat GHG fluxes

Two reports were used to determine the GHG flux values for the different habitats. These reports were the Gregg et al. (2021) report "Assessing carbon storage and sequestration by habitat" and the Thom & Doar (2021) report "Quantifying the potential impact of nature-based solutions on greenhouse gas emissions from UK habitats". These two papers reviewed a range of different studies to collate reference values, but both found limitations in the available data for different habitats and complexities around how GHG fluxes were measured (e.g. whether grazing livestock were present or not). Due to the budgetary constraints on this project, it was not possible to review the original papers used to collate the data and therefore there are potentially some nuances in the data that were not explicit in the reports that might impact results. For this reason, we have presented the highest and lowest reported values as a range to give an indication of whether habitats are tending to emit or tending to sequester. The low GHG flux value represents the smallest emissions or highest sequestration in the range presented for the habitat whilst the high GHG flux value represents the lowest sequestration value or highest emission value for that habitat. The values used for the GHG fluxes are set out in Table 5, with the specific assumptions made for each habitat when selecting sequestration and emissions data laid out in Table 6.

Table 5 – Range of GHG fluxes on different habitats in t CO_2e ha^{-1} yr^{-1}. With low GHG flux representing the lowest value in the published data and high GHG flux the highest value in the published data. Negative numbers indicate sequestration, whilst positive numbers indicate emissions.

Habitat	Low GHG flux	High GHG flux*
Calcareous Grassland	0.00	0.04
Salt Marsh	-6.00	-2.35
Sand Dunes	-2.68	0.00
Heathlands	-5.60	0.20
Wood Pastures	No data	No data
Rush Pastures	No data	No data
Blanket bog	-0.02	13.14
Fen	-0.93	32.89

*Some of the higher values presented in this data set are expected to include grazing emissions as it is difficult to assess habitat emissions in grazing systems without capturing emissions from the livestock as well.

Table 6 – Assumptions behind the emission and sequestration data. With low impact representing the lowest value in the published data and high the highest value in the published data.

Habitat	Assumption	Reference
Calcareous grassland	Assuming lowland calcareous grassland *Low GHG flux* – assumed 0 based on expert judgement *High GHG flux* – used highest value in the “undisturbed by management” classification	Thom & Doar (2021)
Salt marsh	*Low GHG flux* – used the lowest value in the range presented for the salt marsh classification *High GHG flux* – used the highest value in the range presented for the salt marsh classification	Gregg et al. (2021)
Sand dunes	*Low GHG flux* – assumed 0 based on expert judgement *High GHG flux* – used the highest value in the range presented for the salt marsh classification	Gregg et al. (2021)
Heathlands	Assuming upland heath *Low GHG flux* – used the lowest value for the “undisturbed” classification *High GHG flux* – used highest value for the “undisturbed” classification	Thom & Doar (2021)
Wood pastures	No data	Gregg et al. (2021); Thom & Doar (2021)
Rush pastures	Insufficient data	Gregg et al. (2021)
Blanket bog	*Low GHG flux* – used the value for near natural bog *High GHG flux* – used the value for eroded modified bog	Gregg et al. (2021)
Fen	*Low GHG flux* – used the value for near natural fen *High GHG flux* – used the value for cropland	Gregg et al. (2021)

Soil carbon stocks were selected from reviews from Natural England (Gregg et al. 2021) and the Wildlife Trusts (Thom & Doar 2021). The depth of the soil carbon reported varies between the different habitats. The soil carbon depth was reported in the model alongside the soil carbon stock. Vegetation carbon stocks were selected from the Natural England report (Gregg et al. 2021).

Data gaps

Livestock data

The livestock emissions calculations use digestibility of feed and crude protein content as factors. Ideally the model would have habitat specific values for these factors. However, at the time of creation these values were not available for the selected habitats. Therefore, it was necessary to use IPCC default values, although functionality is available in the model to allow variations in this data to be added at a future date. It would be expected that the digestibility and crude protein content would vary between the habitats due to the different species compositions present in the vegetation. In addition, differences in feeding behaviour and food selection between livestock types will also affect the nutritional value they receive. The model uses values for the ‘least productive systems’ from IPCC and applies those to all habitats, as a proxy.

The IPCC equations used have been primarily derived and calibrated using measurements from productive systems. Even where improvements to the input values of forage crude protein and digestibility can be attained, the overall suitability of the IPCC equations for application to conservation grazing systems should be assessed using measured greenhouse gas fluxes. The IPCC equations include many other assumptions to derive coefficients that may not be applicable or optimal for conservation grazing systems. Variation in rumen microbiome, diet selectivity, grazing and browsing behaviour in response to a more varied diet and differences in the ecosystems themselves, such as efficiency in soil nutrient cycling could impact livestock derived greenhouse gas emissions from conservation grazing systems. This data is not specifically available for the species in these habitats and therefore could not be modelled at this stage.

There was limited data available for water buffalo, with most based on either intensively produced commercial European water buffalo (e.g. used for milk), or extensive production in developing countries. There was no specific data available for European Bison.

Habitat data

The two reference documents (Gregg et al. 2021; Thom & Doar 2021) provided data and ranges of GHG fluxes for six of the eight habitats; these are based on a variety of sources, including modelled data as well as measurements. However, no data were available for wood pastures or rush pastures. Where data were available for the other habitats, it is important to recognise that often those data points are based on sets of limited studies that represented a small sample of that habitat type, and that different researchers used different conventions to classify the habitats studied. Therefore, the habitat data are considered to be highly uncertain and as a result was not included within the main modelling process, due to the risk of misinterpretation of the results.

Disclaimer on the accuracy of the model

Based on the data gaps, this model can be used to provide an estimate of the livestock emissions produced through conservation grazing and give an understanding of how changing species and size (as proxy for breed) mixtures on a site will impact on total livestock emissions. It is not currently possible to compare the impacts of different habitat type on livestock emissions as the model currently uses the same input values and emissions factors for all habitat options. One way to address this limitation would be to obtain more accurate data on the digestibility and crude protein content of the forage from the habitats within the model.

Results

Three case study examples were modelled to investigate three key research questions around GHG emissions from conservation grazing. The questions were:

1. Which species of livestock has the lowest emissions per livestock unit?
2. How does size (as a proxy for breed) impact on emissions per livestock unit?
3. When grazed at low stocking rates, as is typical in conservation grazing systems, how do the emissions compare to the potential removals that the habitat can deliver when well managed?

The outcomes of these cases studies are presented below.

Case Study 1: Comparing carbon emissions from different livestock species grazing the same habitat

A primary aim of this project was to investigate the differences in GHG emissions between different livestock species used in conservation grazing systems. To address this, the model was used to compare the annual emissions in CO_2e per livestock unit for all featured species (Table 7).

Based on the species that were modelled (indicated in Table 7) the lowest emissions were found in the grazing of medium sized ponies, (0.66 tonnes $CO_2e\ LU^{-1}\ yr^{-1}$), while the greatest emissions per livestock unit relate to the small sheep breeds (up to 3.6 tonnes $CO_2e\ LU^{-1}\ yr^{-1}$). The same outcome was found in both the results presented here (a combination of Tier 1 for ponies and Tier 2 for sheep and cattle) and when considering Tier 1 results for all livestock types; this comparison was undertaken as a cross check to ensure that the results were not driven by methodological differences. The result is due to the fact that, unlike the other species in the model, ponies are monogastric rather than ruminants. This means that their digestive system does not utilise the anaerobic rumination phase, and therefore has far lower enteric methane emissions than the equivalent livestock units of ruminant animals.

The modelled outputs also indicated differences in emissions between different sized breeds of the same species, with larger cattle, sheep and pony breeds being more efficient than smaller breeds of the same species in terms of GHG emissions; this outcome is discussed in greater detail within

Case Study 2: Comparing carbon emissions from breeds of the same livestock species grazing the same habitat below. Large sized horses were not included in the model as these are unlikely to be used for conservation grazing purposes.

Table 7 – Typical greenhouse gas emissions per one livestock unit (LU) for different species and breeds in tonnes CO_2e per LU.

Livestock species	Livestock breed size class	Number of animals	Livestock emissions (tonnes CO_2e LU^{-1} yr^{-1})
Cattle	Small: e.g. Galloway	1.62	3.5
	Medium: e.g. Longhorn	1.30	3.3
	Large: e.g. Continental Cross Breed	0.93	3.1
Sheep	Small: e.g. Black Soay	13.00	3.6
	Medium: e.g. Southdown	10.00	3.4
	Large: e.g. Blue-faced Leicester	6.85	3.2
Equine*	Small: e.g. Exmoor	1.25	0.73
	Medium: e.g. Konik	1.00	0.66
Bison	Standard: European	0.96	3.0
Water buffalo	Standard: N/A	1.45	3.4

*Equines are calculated using Tier I methodology where the weight of the animal is not considered in the emissions calculations. Large horses were not included in the model as these are unlikely to be used for conservation grazing purposes.

A worked example was modelled to further explore the differences between species selection when set with stocking densities intended for habitat restoration. The outputs of this example are presented below.

The model was set to compare the emissions from small cattle, small sheep, and small ponies. The habitat inputs were kept consistent to facilitate the comparison, with 100 ha of habitat entered in the model, assumed to be grazed all year round. The number of adults was set to be equivalent to 12.5 livestock units for each species across the 100 ha; based on indicative stocking rate guidance (Table 4), this is equivalent to 0.125 LU ha^{-1}. However, to achieve consistency between the different species in livestock units, the number of adult animals needed to be entered in fractions of animals (Table 8); these have been entered for illustrative purposes and do not represent a real-life scenario. Nevertheless, the model inputs show that this would be equivalent to about 162.5 small sheep, compared to 20.16 small cattle and 15.62 small ponies would be required to achieve a similar stocking density.

Table 8 – Number of animals modelled to achieve a low stocking density suitable for restoration conservation outcomes. Modelled for 100 ha of habitat, representing 12.5 livestock units for each species, to give a stocking density of 0.125 LU ha^{-1}.

Livestock species	Livestock breed size class	Number of animals (adults)
Cattle	Small (e.g. Galloway)	20.16
Sheep	Small (e.g. Black Soay)	162.5
Equine	Small (e.g. Exmoor)	15.62

The outputs of this modelled scenario provide further detail for the differences in emissions between different species grazing at the same stocking density (Table 9, Table 10). As demonstrated in Figure 1**,** the majority of emissions (almost 90%) are derived from methane (enteric and manures), which are produced in greater quantities by ruminant species (i.e. cattle, sheep) than monogastric animals (e.g. ponies). Sheep and cattle tend to have similar enteric emissions. On a per animal basis, small adult cattle produced 7.8 times the amount of enteric methane compared to small adult sheep in this scenario. However, the livestock units indicated that 8 times more sheep needed to be grazed than cattle to achieve the same stocking density. This meant that the final emissions were very similar.

The results showed that just over 10% of the emissions for each species type are derived from nitrous oxide following manure deposition. Here, the nitrous oxide is produced from soil microbes breaking down the manure following deposition (Rivera & Chará 2021).

Table 9 – Annual livestock emissions per species for the site (tonnes CO_2e yr^{-1}) with percentage of total emissions given in brackets. Modelled for 100 ha of habitat, representing 12.5 livestock units for each species.

Livestock species	Livestock breed size class	Methane (enteric and manures)	Nitrous oxide (manures)	Total livestock emissions
Cattle	Small (e.g. Galloway)	38.3 (88%)	5.2 (12%)	43.5
Sheep	Small (e.g. Black Soay)	39.9 (89%)	4.7 (11%)	44.6

Livestock species	Livestock breed size class	Methane (enteric and manures)	Nitrous oxide (manures)	Total livestock emissions
Equine	Small (e.g. Exmoor)	8.0 (87%)	1.1 (12%)	9.2

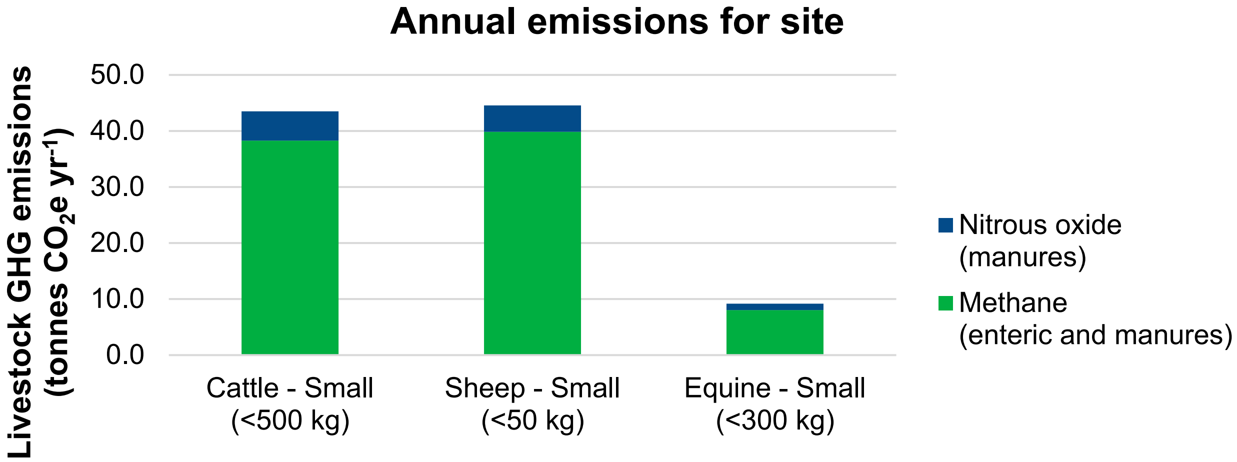

Figure 1 – Annual livestock emissions compared between species for the site (tonnes CO_2e yr^{-1}). Modelled for 100 ha of habitat, representing 12.5 livestock units for each species.

Table 10 – Annual livestock emissions per species per hectare (tonnes CO_2e ha^{-1} yr^{-1}). Modelled for 100 ha of habitat, representing a stocking density of 0.125 livestock units for each species per hectare.

Livestock species	Livestock breed size class	Methane (enteric and manures)	Nitrous oxide (manures)	Total livestock emissions
Cattle	Small (e.g. Highland)	0.38	0.05	0.43
Sheep	Small (e.g. Black Soay)	0.40	0.05	0.45
Equine	Small (e.g. Exmoor)	0.08	0.01	0.09

Case Study 2: Comparing carbon emissions from breeds of the same livestock species grazing the same habitat

The second case study aimed to explore and compare differences in emissions from different breed sizes from the same species, when all other aspects are kept consistent. The model was set to compare the emissions from small (e.g. Highland), medium (e.g. Longhorn) and large (e.g. Continental Cross Breed) cattle. As in case study 1, the habitat details were set with 100 ha of habitat, assumed to be grazed all year round for all breeds. The number of adults was set to be equivalent to 12.5 livestock units for each size class of cattle. This also required the number of animals to be entered in non-integers, with greater numbers of smaller breeds required to reach the same stocking density (Table 11).

Table 11 – Number of animals modelled to achieve a stocking density of 0.125 livestock units. Modelled for 100 ha of habitat, representing 12.5 livestock units for each cattle breed size class.

Livestock species	Livestock breed size class	Number of animals (adults)
Cattle	Small (e.g. Galloway)	20.16
Cattle	Medium (e.g. Longhorn)	16.25
Cattle	Large (e.g. Continental Cross Breed)	11.61

The outputs of this modelled scenario provide comparisons between the emissions of different size classes of cattle grazing on the same habitat (Table 12, Table 13). Where different sizes of the same species were considered on a per livestock unit basis, it was found that larger cattle had lower emissions than smaller cattle. This is because more animals were needed to reach the same livestock units when the animals were smaller. Each animal produces emissions through enteric fermentation. Larger animals produce more enteric methane than smaller animals, however, they produce slightly less methane per kilo of body weight. This means that when compared on a per livestock unit basis (i.e. the same total body weight) larger cattle will produce slightly lower emissions. Breed size selection also has potential impacts for conservation outcomes – more mouths and lighter footsteps will create different habitats to fewer mouths and heavier footsteps. Greater mouths might also mean less time spent on a habitat to deliver the conservation outcomes for the habitat.

Table 12 – Annual livestock emissions per cattle breed size class for the site (tonnes CO_2e yr^{-1}). Modelled for 100 ha of habitat, representing 12.5 livestock units for each species.

Livestock species	Livestock breed size class	Methane (enteric and manures)	Nitrous oxide (manures)	Total livestock emissions
Cattle	Small (e.g. Galloway)	38.3 (88%)	5.2 (12%)	43.5
Cattle	Medium (e.g. Longhorn)	36.5 (88%)	5.0 (12%)	41.4
Cattle	Large (e.g. Continental Cross Breed)	33.5 (88%)	4.6 (12%)	38.1

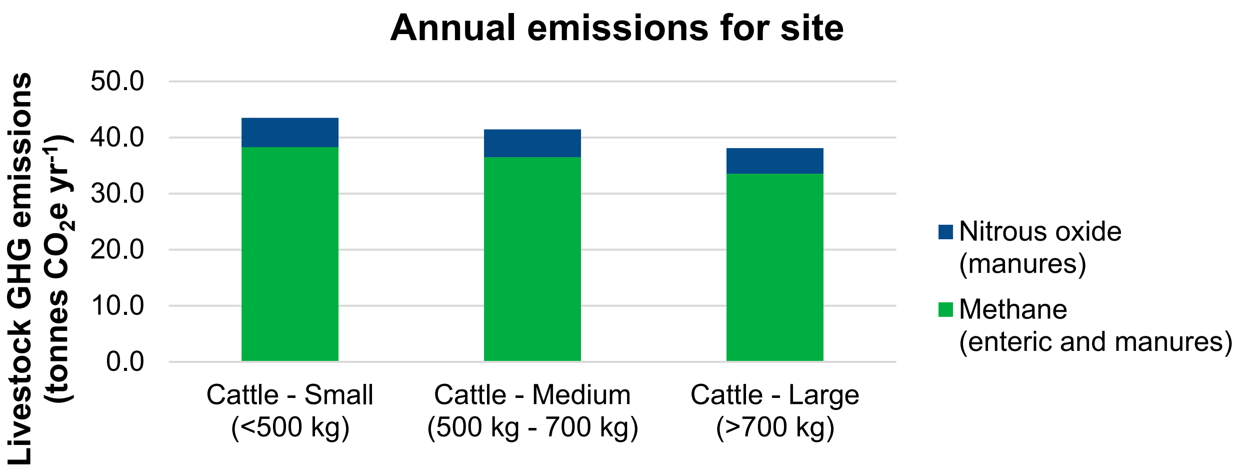

Figure 2 – Annual livestock emissions compared between cattle breed size classes for the site (tonnes CO_2e yr^{-1}). Modelled for 100 ha of habitat, representing 12.5 livestock units for each cattle breed.

Table 13 – Annual livestock emissions per cattle breed size class per hectare (tonnes CO_2e ha^{-1} yr^{-1}), representing a stocking density of 0.125 livestock units for each species per hectare.

Livestock species	Livestock breed size class	Methane (enteric and manures)	Nitrous oxide (manures)	Total livestock emissions
Cattle	Small (e.g. Galloway)	0.38	0.05	0.43
Cattle	Medium (e.g. Longhorn)	0.36	0.05	0.41
Cattle	Large (e.g. Continental Cross Breed)	0.34	0.05	0.38

Case Study 3: Comparing emissions from the same livestock type grazing the different habitats

The third case study aimed to compare the balance between emissions and carbon sequestration rate between three different habitats: calcareous grassland, salt marsh and heathland. The habitat inputs were kept consistent to facilitate the comparison, with 100 ha of each habitat entered into the model, which were all assumed to be grazed all year round by small sheep. To achieve a low stocking rate level suitable for habitat restoration (in line with guidance for Higher Level Stewardship) on a previously overgrazed habitat the number of adult sheep was set to be equivalent to 12.5 livestock units for calcareous grassland, 5.0 livestock units for fen, and 3.65 livestock units for heathland. This was calculated for the entered number of hectares based on indicative stocking rate guidance (see Table 4). However, to achieve consistency between the different species in livestock units, the number of adult animals needed to be entered in non-integers (Table 14); this was entered for illustrative purposes and does not represent a realistic scenario. The table also shows the emissions for the livestock across the whole 100 ha. The calculated emissions scale directly with the stocking density (number of sheep) due to the model applying the same input values and emissions factors for all habitat types.

Table 14 – Comparison of low stocking densities and associated emissions on 100 ha of three different habitats – using small sheep.

Habitat	Livestock units per 100 ha	Number of sheep	Total livestock emissions (tCO_2e yr^{-1})
Calcareous grassland	12.5	162.5	44.6
Salt marsh	12.5	162.5	44.6
Heathland	3.65	47.4	13.0

The condition of the habitat is important for determining its ability to sequester carbon or produce emissions. Where a habitat is in a poor condition it is likely to be producing more emissions as a result of erosion or degradation of soils or peat and have a lower carbon in the habitat (referred to as a high climate impact). On the other hand where the habitat is in a healthy condition depending on the type of habitat it can be at near equilibrium (no net change in carbon stocks) or for some habitats there is the potential for sequestration to occur (Table 5) with higher amounts of stored carbon. The creation of a new semi-natural habitat on formerly intensively managed land, for example arable reversion to species rich grassland, will typically lead to carbon sequestration (Gregg et al. 2021) due to the fact that the previous land use would have lowered the amount of carbon stored in the soil.

In an established calcareous grassland the evidence indicates that emissions could range from no emissions (equilibrium) through to 4.0 $tCO_2e\ yr^{-1}$ across the 100 ha. This means that at best the sheep will create a positive emission where there were previously no emissions, and at worst they will add to emissions from the land itself. In this scenario, the indications are that emissions from the sheep would be expected to be more than the habitat is able to sequester. Estimated emissions from the sheep are an order of magnitude greater than the maximum estimated emissions from the habitat.

In the salt marsh scenario, the situation is slightly different. The limited information that is available on GHG fluxes from salt marshes indicates that they tend to sequester carbon, with removals estimated to range from -235 to -600 $tCO_2e\ yr^{-1}$ across the 100 ha. This means that, even with the higher stocking density of sheep, they are expected to still be able to sequester substantially more carbon than the sheep emit. There are however uncertainties about the extent to which salt marsh is sequestering carbon directly from the atmosphere or by trapping sediment from elsewhere.

The evidence for heathland indicates that these habitats are typically emitting carbon, with estimates for 100 ha ranging from 20 to 560 $tCO_2e\ yr^{-1}$. This means that the livestock on the habitat again produce additional emissions that are not balanced by removals from the habitat.

Discussion

Conservation grazing is an effective management strategy for maintaining and improving biodiversity in many habitats. Using livestock at low grazing pressures can ensure that habitats remain open, with the livestock preventing the encroachment of shrubs or trees, maintaining a steady state so grassland remains grassland and heathland continues as heathland. Using a diversity of livestock species can help maintain habitat diversity and careful planning of grazing regimes can maintain or restore the conditions needed to support desired plant species. However, as well as having the potential for improving biodiversity, livestock also produce GHG emissions. This can create challenges when deciding how to develop a sustainable management plan to achieve both biodiversity goals and climate emission reductions.

Climate emissions can be impacted by conservation grazing practices through both emissions production and emissions removal, or sequestration. Livestock produce emissions through different pathways. For example, enteric methane is produced during digestion (Rivera & Chará 2021), enteric methane emissions are much greater from ruminants like cattle or sheep than from monogastric animals such as ponies. This is due to ruminants using enteric fermentation for digestion. Livestock also produce GHG emissions from manure deposition. Here methane and nitrous oxide are both produced from soil bacteria breaking down the organic matter in the manure (Rivera & Chará 2021). Nitrogen from manure can also reach waterways, in the form of nitrate, through leaching or be turned into ammonia by soil bacteria (Rivera & Chará 2021). This nitrate and ammonia is then deposited elsewhere and results in indirect emissions of nitrous oxide.

Habitats can either produce or sequester carbon, depending on the micro-climate, vegetation type and soil bacteria, and also overall condition of the habitat (Gregg et al. 2021). Carbon sequestration is the result of fixation in growing vegetation or the building of soil carbon. The relatively low stocking densities used for conservation grazing mean that, in theory, on certain habitats where sequestration is occurring, there is the potential that the site can remain a net carbon sink (as in sequestering more carbon than is emitted) even when grazed by livestock.

The model

ADAS created a model for Natural England that is designed to assist in making decisions for conservation grazing by providing estimated GHG emissions for different grazing patterns (species, breed size, density) and putting them into context of the potential scale of emissions or removals from a range of different habitats. This means that land managers can input their desired grazing scenario into the model and get estimates of GHG emissions, for those livestock, out of the model. Up to three different size classes or species can be included in the grazing plan, and the separate contributions from each assessed. This allows the land manager to do an assessment of their site if a more diverse set of livestock are being used. Livestock units are given for each species to help the grazing manager compare on a like for like basis if required.

The model allows up to three habitats to be selected allowing a more holistic assessment of simple landscapes, rather than sites being broken up by artificial habitat boundaries.

Sequestration and emissions from habitats are considered within the report, but not within the main model, as the highly variable nature of sequestration and emissions, plus the weakness of the evidence base were not considered to provide a sufficiently robust basis for the model. The single net GHG flux values generated for each conservation grazing system applied to each specific habitat was considered to be of interest from a scientific perspective but potentially misleading if applied to practical land management decisions.

Limitations of the model are covered in detail below. To summarise, the main limitation of the model was a lack of data. There were multiple sections within the model calculations which would have benefitted from more data. Firstly, the IPCC equations have been primarily designed for productive agricultural systems, as opposed to conservation grazing systems. While some coefficients are provided for extensive systems (e.g. activity coefficients for grazing hilly pastures) it is unclear how relevant the values are to UK conservation grazing scenarios. Secondly, to keep the model simple, the user was not asked to add in information about milk production or wool production. This meant that equations concerning net energy needed for lactation, pregnancy and wool production were not included in the estimates of gross energy; this simplifies the assumptions but reduces granularity and accuracy of IPCC equations. Thirdly, there was a considerable amount of specific data on nutritional composition missing from the habitats that the animals grazed. It would be expected that the habitats varied in digestibility and crude protein based on the different kinds of vegetation growing there. This would provide greater variation in livestock emissions between the different habitats. The model would benefit from more specific data from conservation grazing systems.

Case study results

Three case studies were designed to show the impacts of different types of conservation grazing species and habitat interactions. These case studies looked at:

- The difference in emissions between livestock species.
- The difference in emissions between size classes within a livestock species.
- The potential for habitat sequestration to balance estimated livestock emissions for different habitats grazed at different stocking densities.

These modelled outcomes will enable conservation practitioners to have better understanding about species selection and their potential impact upon emissions, thereby allowing them to make more informed decisions.

The results of case study 1 indicate that on 100 ha of habitat, using a stocking density of 12.5 livestock units of ruminant animals, such as small cattle (e.g. Galloway) or small sheep (e.g. Black Soay) would result in similar carbon emissions of 43.5 and 44.6 tCO_2e yr^{-1} respectively for each species. Whereas for small ponies (e.g. Exmoor), which are not ruminants and therefore produce less enteric methane, the resulting emissions would be around a fifth of the emissions at 9.2 $tCO_2e\ yr^{-1}$. These results are expected to vary slightly when juveniles are included in the model because the calculations for energy requirements from growth are different for sheep and cattle.

For case study 2, a stocking density of 12.5 livestock units of different sized breeds of cattle on 100 ha of habitat was used. The results demonstrate that large cattle breeds (e.g. Continental Cross Breed) would produce emissions of 38.1 $tCO_2e\ yr^{-1}$, whereas small breeds (e.g. Galloway) would produce more enteric methane for the same number of livestock units, thereby increasing the total emissions by 14% to 43.5 $tCO_2e\ yr^{-1}$. This is due to a greater number of small cattle being used compared to larger cattle to achieve the same stocking density, which results in an increase in enteric methane produced due to their slightly lower conversion efficiency.

Case study 3 recognises that different habitats are often grazed at different stocking densities due to their fertility and needs. We therefore used values derived from indicative stocking rate guidance for three habitats, calcareous grassland, salt marsh and heathland to compare estimated emissions from livestock to potential habitat emissions or removals. We selected small sheep (e.g. Black Soay) as our grazing species / size class. The habitat emissions and removals were presented in a range based on possible likely stocking levels and to take into account that habitats vary in condition. Calcareous grassland (based on evidence collated in Thom & Doar 2021) was identified to be either in equilibrium or a net emitter of carbon, with emissions ranging from no emissions to 4.0 $tCO_2e\ yr^{-1}$ across 100 ha. Here, adding sheep to calcareous grassland in any condition would cause the site to either shift from equilibrium to become a net emitter, or increase existing emissions further. In contrast, salt marsh habitats were assumed to be carbon sinks with sequestration rates ranging from -235 to -600 $tCO_2e\ yr^{-1}$ across the 100 ha. Even with the addition of a low stocking density of sheep included as part of a conservation grazing program, these habitats were able to remain net sinks, with sequestration still exceeding the emissions from the sheep. Heathland was a net source of emissions, with estimates ranging from 20 to 560 $tCO_2e\ yr^{-1}$. This meant that the habitat would always emit carbon, regardless of livestock number added to the site.

Limitations

It is important to realise that as this is a modelling exercise it is always inherently uncertain and is reliant on the quality of the data that is available. For example, the emissions factors and equations used to estimate the emissions from livestock are based on productive agricultural systems rather than animals specifically grazed in conservation systems. It was possible to define different size livestock by weight groups and determine emissions estimates. The aspiration had been to capture differences in digestibility of the different habitats to enable more detailed calculation of enteric emissions. However, there was insufficient, robust, data to allow for reliable distinctions to be made between habitats and as a result it was assumed that all habitats have forage with the same digestibility.

The livestock module in the model is relatively simple, as it only requires data for species, size, number, and length of grazing period. It assumes that animals are either adults or juveniles but has no nuance of age category (to keep data entry simple). It assumes that there is no supplementary feeding and does not capture any data on fuel usage for managing the livestock.

Livestock units were incorporated into the model to help grazing managers compare species on a like for like basis. We used Martin et al. (2013) as the source for livestock units and livestock weights, with livestock units being calculated based on animal weights. These then informed the model as to the stocking rate for different livestock numbers entered on the data entry page. The model uses the same animal weights for the different livestock as the livestock units calculations do. The model then calculates gross energy intake and enteric methane based on the livestock weights and the assumed digestibility of the habitat.

The habitat data available gave an indication of whether habitats were a source of carbon emissions or a natural sink of carbon emissions. It was also determined that there was such a high level of variability in the data available, and often very limited data sets from some habitats (such as single studies) that it was not possible to provide a robust average emission from the habitat to allow for reliable inclusion in the model. For this reason, although the habitat data are discussed in the case studies they were not included in the main model. There were also a number of habitats for which data were missing. The quality and quantity of the habitat data available meant that it was not possible to set the model up to be used to see whether habitat sequestration could be used to offset livestock emissions accurately at low stocking densities.

Another clear limitation of the model is that it only focuses on grazing and not productivity. It does not capture what value the different livestock species provide in terms of food production or wool that can be used to earn an income from the animals; this was outside the scope of the modelling process.

Conclusions

This modelling exercise has highlighted a lack of data relevant to conservation grazing systems, both for determining livestock derived emissions and net habitat greenhouse gas flux. Based on available data the model output suggests, it is possible to reduce livestock emissions through adjusting the grazing livestock that are on the land. For example, introducing ponies into a grazing program would reduce emissions by about three quarters for every livestock unit swapped. Switching size class within a species can have an effect on emissions, with larger size classes tending to be more efficient than smaller ones in terms of emissions. However, it is important when looking at a conservation grazing management system that you do not just look through the single lens of climate impact, as these animals are being used to graze the habitat for conservation purposes. Careful consideration goes into the selection of grazing species and breeds, based on things such as the grazing selectivity and number of mouths and hooves needed to achieve conservation outcomes, the resilience of the breed in harsh conditions (large sheep and cattle are rarely suited to grazing many of these habitats) and also, for some systems, the economic return from the stock is also important, i.e. having a meat value.

The modelling process highlights that where there is significant sequestration occurring in a habitat, there is the potential for this to exceed the level of emissions produced by the relatively low stocking densities used for conservation grazing. This may therefore allow the grazing manager greater flexibility in the choice of breed and species when looking to balance emissions, removals, biodiversity outcomes and economics, whilst still delivering net zero goals. Where a habitat is a net source of emissions, greater care is likely to be needed in selecting grazing species if there is an ambition to minimise emissions from that habitat whilst also managing the biodiversity outcomes.

As with all modelling it is important to recognise the limitations of the model, and the fact that it is built on simplified assumptions about complex systems. Therefore, the model should be used as a tool to inform decision making, but not as a source of categorical answers. A grazing manager could use the tool to see what impact changing the mix of grazing species might have on overall emissions, to help optimise the system to meet multiple objectives.

Next steps

The model has a lot of opportunities for future use given the development of more robust datasets. Functionality has been incorporated into the model to allow it to capture several additional nuances that are not currently possible with available data. Additional data that could enhance the model are set out below;

- Obtaining more robust (accurate and precise) data on the average percentage digestibility of diets in different habitats. Increasing the digestibility of feed would reduce the enteric emissions from the animals. The rate of this reduction depends on the livestock type and is non-linear. The digestibility of feed may vary between sites. Securing these data would allow greater understanding of how species interact with the vegetation in the habitat being grazed, which could be linked to more specific biodiversity goals.
- Obtaining more robust (accurate and precise) crude protein data for different habitats. The crude protein content would be expected to vary between the different forage species growing in the different habitats – this would change the nitrous oxide emissions produced by the livestock, with an increase in crude protein causing an increase in emissions.
- More robust carbon sequestration or emissions data for the individual habitats (especially grazed habitat such as grasslands and heathlands) would allow for a better understanding of how much sites can sequester carbon and how much they can offset livestock grazing on the site.
- A high degree of uncertainty remains around the use of IPCC methodology and standard input values for conservation grazing systems. Future work should aim to address these knowledge gaps and adjust the model appropriately.

Other considerations for the model are to look at how it might capture aspects of productivity (kg meat produced) or look to develop a way of capturing the biodiversity outcomes in greater detail. At present the model relies on the user being knowledgeable in the biodiversity outcome that they are aiming to achieve and how the different grazing species would deliver these outcomes. These scenarios can then be entered into the model to calculate the associated emissions.

References

AHDB (n.d.) Calculating dry matter intakes for rotational grazing of cattle. Available at: https://ahdb.org.uk/knowledge-library/calculating-dry-matter-intakes-for-rotational-grazing-of-cattle [Accessed: 02/03/2023].

AHDB (2023) Monitoring dairy calf growth. Available at: https://ahdb.org.uk/knowledge-library/monitoring-dairy-calf-growth#:~:text=A%20calf%20has%20a%20birth%20weight%20of%2036%20kg [Accessed: 02/03/2023]

Chapman, P. (2007) Conservation Grazing of Semi-Natural Habitats. SAC Technical Note ISSN 0142 7695.

Chapman, P. (2017) Conservation Grazing for Semi-Natural Habitats. FAS Technical Note TN686.

Crofts, A. and Jefferson, R. G., (1999). The lowland grassland management handbook. English Nature/The Wildlife Trusts.

Eustat (n.d.) *Units of measurement.* Available at: https://en.eustat.eus/documentos/elem_6339/definicion.html [Accessed: 02/03/2023].

Gavrilova, O., Leip, A., Dong, H., MacDonald, J.D., Gomez Bravo, C.A., Amon, B., Barahona Rosales, del Prado, A., de Lima, M.A., Oyhantcabal, W. and Van der Weerden, T.J. (2019). *Chapter 10: Emissions from livestock and manure management.* In: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.

Gregg, R., Elias, J.L., Alonso, I., Crosher, I.E., Muto, P. & Morecroft, M.D. (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York.

Hergoualc'h, K., Akiyama, H., Bernoux, M., Chirinda, N., del Prado, A., Kasimir, Å., MacDonald, J.D., Ogle, S.M., Regina, K. and Weerden, T.J.V.D., (2019). *Chapter 11: N2O emissions from managed soils, and CO2 emissions from lime and urea application.* In: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.

IPCC, (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A.

Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2019) Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 Agriculture, Forestry and Other Land Use. *Switzerland: IPCC.*

IPCC (2021) Chapter 7: The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity. Table 7.15: Emissions metrics for selected species: global warming potential (GWP), global temperature-change potential (GTP).

Martin, D., Fraser, M.D., Pakeman, R.J. & Moffat, A.M. (2013). Natural England Review of Upland Evidence 2012 - Impact of moorland grazing and stocking rates. Natural England Evidence Review, Number 006.

Pan, H., Feng, H., Liu, Y., Lai, C.Y., Zhuge, Y., Zhang, Q., Tang, C., Di, H., Jia, Z., Gubry-Rangin, C. and Li, Y. (2021). Grazing weakens competitive interactions between active methanotrophs and nitrifiers modulating greenhouse-gas emissions in grassland soils. ISME communications, 1(1), p.74.

Payne, F. (2020) Conservation grazing – What is it and why do we do it? Leicestershire & Rutland Wildlife Trust. Available at www.lrwt.org.uk/blog/fran-payne/conservation-grazing-what-it-and-why-do-we-do-it [Accessed 30/03/2023].

Rivera, J.E. & Chará, J. (2021) CH4 and N2O emissions from cattle excreta: a review of main drivers and mitigation strategies in grazing systems. *Frontiers in Sustainable Food Systems*, p.370.

The Wildlife Trusts (2016) Managing Grasslands for Nature: A Guidance Note for Farmers and Landowners. The Wildlife Trusts, Newark.

The Wildlife Trusts (n.d.a) *Lowland calcareous grassland.* Available at: www.wildlifetrusts.org/habitats/grassland/lowland-calcareous-grassland [Accessed 30/01/2023].

The Wildlife Trusts (n.d.b) *Saltmarsh and mudflats.* Available at: www.wildlifetrusts.org/habitats/coastal/saltmarsh-and-mudflats [Accessed 30/01/2023].

The Wildlife Trusts (n.d.c) *Sand dunes.* Available at: www.wildlifetrusts.org/habitats/coastal/sand-dunes [Accessed 30/01/2023].

The Wildlife Trusts (n.d.d) *Lowland heath.* Available at: www.wildlifetrusts.org/habitats/heathland-and-moorland/lowland-heath [Accessed 30/01/2023].

The Wildlife Trusts (n.d.e) *Heathland and moorland.* Available at: www.wildlifetrusts.org/habitats/heathland-and-moorland [Accessed 30/01/2023].

The Wildlife Trusts (n.d.f) *Purple moor-grass and rush pasture.* Available at: www.wildlifetrusts.org/habitats/grassland/purple-moor-grass-and-rush-pasture [Accessed 30/01/2023].

The Wildlife Trusts (n.d.g) *Blanket bog.* Available at: www.wildlifetrusts.org/habitats/wetlands/blanket-bog [Accessed 30/01/2023].

The Wildlife Trusts (n.d.h) *Lowland fen.* Available at: www.wildlifetrusts.org/habitats/wetlands/lowland-fen [Accessed 30/01/2023].

Thom, T.J. & Doar, N. (2021). Quantifying the potential impact of Nature Based Solutions on Greenhouse Gas Emissions from UK habitats. Version 2. Revised January 2022. The Wildlife Trusts, Newark.

Woodland Trust (n.d.) *Wood pasture and parkland.* Available at: www.woodlandtrust.org.uk/trees-woods-and-wildlife/habitats/wood-pasture-and-parkland/ [Accessed 30/01/2023].

Glossary

Terminology / abbreviation	Definition
Carbon removals / sequestration	This is the annual removal of carbon from the atmosphere and long term lock up into either soils or vegetation (carbon stores)
Carbon sink	A carbon store that is actively increasing in size as a result of sequestration
Carbon source	A carbon store that is actively depleting in size as a result of erosion or oxidation of stored carbon, resulting in a release to the atmosphere.
Carbon stores	The level of carbon exchanged between carbon stores over a period of time. In relation to the habitats a positive flux is a net emission to the atmosphere, whilst a negative flux is a net removal (or sequestration) from the atmosphere.
CH_3	Methane – greenhouse gas produced as a result of enteric fermentation or from livestock manures.
CO_2	Carbon dioxide – greenhouse gas emitted as a result of burning of fossil fuels and also degradation of peatlands or other carbon containing habitats
CO_2e	Carbon dioxide equivalents – a way of presenting greenhouse gas emissions of different gases (CO_2, N_2O, CH_3) in a single value using their global warming potential over a 100 year period.
GHG	Greenhouse gases – these are gases that when released into the atmosphere have the potential to cause warming of the planet and contribute to climate change.

Terminology / abbreviation	Definition
GHG flux	A GHG flux is the movement of carbon between two stores, e.g. from the soil to the atmosphere or from the atmosphere to the soil.
IPCC	Intergovernmental Panel on Climate Change
LU or Livestock unit	A reference unit which facilitates the aggregation of different livestock species or age groups on the basis of the nutritional feed requirement of each animal type. 1 LU is equivalent to the grazing requirement of one adult dairy cow producing 3000kg milk without additional concentrated feeding stuffs.
N_2O	Nitrous oxide – potent greenhouse gas associated with nitrogen deposition on soils
Nitrous oxide – direct emissions	These are emissions of nitrous oxide that occur on site as a result of nitrogen (in faeces and urine) being deposited on the soil.
Nitrous oxide – indirect emissions	These are indirect emissions of nitrous oxide that arise following the deposition off site of either volatilised ammonia or leached nitrate – that arise as a result of nitrogen being deposited on the soil.

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