Second Natural Capital Report

Taking nature recovery to scale

December 2022

HIGHLANDS REWILDING

Contents

Foreword

It's hard to believe only a year has passed since I was writing the foreword to our first Natural Capital Report. That report shared with the world the work we had been doing to understand the carbon and biodiversity at our Bunloit estate overlooking Loch Ness. The response to that report was far beyond any prior hopes or expectations I had. Charlie Burrell, co-founder of Knepp Wildland described the report as "Ground breaking"; Jason Beedell, Director of Research at Strutt and Parker said "Extraordinary - we have never seen anything like this", and according to Louise Alexander, Head of Forestry, Galbraith it was "The talk of the town". But we haven't rested on our laurels; in the last year our progress has been rapid on many fronts.

The team has grown to 22 (including a world-class science team and our first apprentice ranger), taken on a second estate, and firmly established itself as a driving force in finding a solution to the biodiversity crisis in Scotland. We now have an expert board of 6 directors with experience across Scottish industry and academia.

Our second estate, Beldorney, beside the River Deveron in Aberdeenshire, is different in character to Bunloit. Its previously heavily-grazed grasslands are interspersed with mainly coniferous plantations.

The work we've done to understand the baseline for carbon and biodiversity at Beldorney, presented in this report, paints a picture of tremendous potential for increasing both carbon storage and biodiversity.

Small biodiverse pockets within the estate, for example the strip of ancient broadleaved woodland along the river and small areas of wetland, heathland and species-rich grassland, provide nuclei which we hope to see expand as nature recovers across the whole estate.

Regenerative agriculture forms an important part of our plans for Beldorney, demonstrating that food production can go hand in hand with nature benefits as animals graze on parts of the estate.

I'm immensely proud of the team and what they've achieved in such a short time and it's great to see this being recognised more widely by our recent wins of two prestigious awards; the Business for Nature award at the Nature of Scotland Awards, and the Adapting Scotland award at the 2022 VIBES - Scottish Environment Business Awards.

At Highlands Rewilding our purpose is to enable nature recovery and community prosperity through rewilding taken to scale, as a mass ownership company. We've recently taken a massive step towards the latter part of that mission with the launch of our crowdfunding campaign, which runs until the end of February. By investing as little as £50 the public have the opportunity to be part of our journey to help halt biodiversity loss and climate meltdown. We are delighted by the number of people wanting to be involved. Within 5 days we had reached over 40% of our crowd-funding target. This support gives us confidence we're heading in the right direction, but to tackle the twin crises of climate and biodiversity collapse, rapidly scaling up our activities must be the focus of our next 12 months.

Jeremy Leggett

Founder and CEO of Highlands Rewilding

Executive Summary

Highlands Rewilding Limited (formerly Bunloit Rewilding) exists to help take nature recovery and community prosperity to scale in the Scottish Highlands and uplands. Since our last Natural Capital Report, published in November 2021, the company has developed rapidly, including through the purchase of a second estate, Beldorney, in Aberdeenshire. The baselining work on Beldorney is the focus of this second Natural Capital Report.

Our team of 22 people (and counting) are responsible for managing 852 hectares of land on both estates to boost biodiversity, carbon sequestration and job creation.

16 of the team are local to the estates and neighbouring areas, and all three of the staff employed on Beldorney were retained when the estate was bought, with two more locals joining them since.

Our board of directors is made up of six people from, resident in, or with long-term experience of the Highlands, and are responsible for ensuring that we create sustainable community prosperity.

During 2022 our community engagement programmes have grown steadily, with weekly high school classes and 'walk-and-talk' events being particularly successful in boosting access and feedback.

As we enter a new phase of mass ownership, we aim to create ethical returns for our shareholders and so encourage other landowners to pivot to net-zero carbon and nature positive practices. In doing so, we hope to help Scotland become a global leader in achieving ambitious biodiversity and climate targets.

Natural capital overview

Once again, Highlands Rewilding has worked with a range of innovative organisations using cutting-edge methods to assess biodiversity and carbon stocks. The results give an unprecedented insight into our Bunloit and Beldorney estates, and the methods we can use to maximise benefits for the environment and people.

For Beldorney, results suggest that the estate as a whole holds less carbon and biodiversity than we would expect for typical ecosystems of that kind.

View across the River Deveron towards Craig Dorney

Some areas stand out for their ecological value, particularly the remaining patches of ancient semi-natural woodland and wetland that have survived near the estate's boundaries.

Not only are these highly distinctive and rare habitats in their own right, but they also contain by far the greatest reserves of rare species and stored carbon, including multiple species listed in the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species.

The presence of these patches and the species persisting in them gives us an invaluable opportunity to restore and expand semi-natural habitats across the estate, monitoring methods and outcomes, and generating uplift with relevance for carbon and biodiversity on many other Scottish estates.

For Bunloit, last year's natural capital baseline has been extended with surveys of birds, fungi and insects. These have revealed the presence of additional rare species, and also helped us to distinguish the most significant areas of the estate for biodiversity.

These findings are directly informing our ongoing work to restore degraded areas, with further monitoring underway to capture the effects of this activity.

Beldorney baseline: carbon

Unlike Bunloit, Beldorney does not have a large area of deep peat in which huge quantities of carbon are stored.

Estimates of carbon storage on the estate, partly based on measurement and partly on modelling, suggest a total in the range of 114,044 to 178,585 tonnes of CO_2equivalent (tCO_2 e). The largest share of this total is in the 240 hectares of grassland soils, which have a measurement-based stock of 85,536 tCO_2 e (equivalent to around 3,700 mature oak trees).

However, established figures and models suggest that we might expect up to 80% more carbon in typical soils of these kinds, indicating strong potential for increasing the grassland carbon sink.

Bunloit, on the banks of Loch Ness

A separate model-based analysis of one future management scenario suggests that a further 85,504 tCO_2e could be sequestered across the estate over the next 100 years; a 48% increase on current modelled stocks.

The carbon stored across approximately 65 hectares of plantation and semi-natural woodland at Beldorney is more uncertain, but may be of a similar magnitude to that in grassland soils.

We estimate the woodland biomass (of around 32,000 trees) to contain between 11,980 and 16,124 tCO_2e, with an additional 5,027 to 54,201 tCO_2e in woodland soils, depending on their depth. Modelling suggests that total woodland carbon storage could be as high as 1,688 tCO_2e per hectare, 7.5 times greater than the lowest grassland values. The future sequestration potential of the trees themselves is estimated at 15,569 tCO_2e over 100 years in the absence of further interventions.

Finally, the small area of peat in Beldorney indicated by Scottish soil maps was found to extend further than thought (covering at least 4.8 hectares, rather than 4.2).

We do not yet have direct measurements of carbon storage in this area of peat, but figures from elsewhere in the UK suggest something in the range of 11,501 to 22,724 tCO_2e; a figure very similar to that for the entire woodland biomass of Beldorney.

Historical disturbances mean that Beldorney's peat is almost certain to be a net source of carbon, but if we can achieve a near-natural restoration of this peatland we can expect a carbon sink of 7.0 to 16.6 tCO_2e per year.

Beldorney baseline: biodiversity

We have studied biodiversity at habitat, species and genetic levels, using field observations, camera traps, acoustic monitoring and environmental DNA (eDNA) sampling, amongst other techniques.

Walking along the River Deveron

Together these give a rich and often surprising picture of diversity on the estate, with some areas having enormous value for many different species, and others being notably lacking. The most highly diverse parts of the estate are those containing wetland and native woodland.

Our bat surveys detected over 10 times as many calls along the River Deveron as elsewhere (703 compared to a maximum of 63 at other locations), while eDNA from watercourses revealed eight vertebrate species of conservation concern, including one (the European eel) that is Critically Endangered. One of these species, the European water vole, was detected frequently, suggesting that Beldorney is one of their few remaining strongholds. Insects associated with wet habitats included the Nationally Scarce fly *Dolichopus cilifemoratus.*

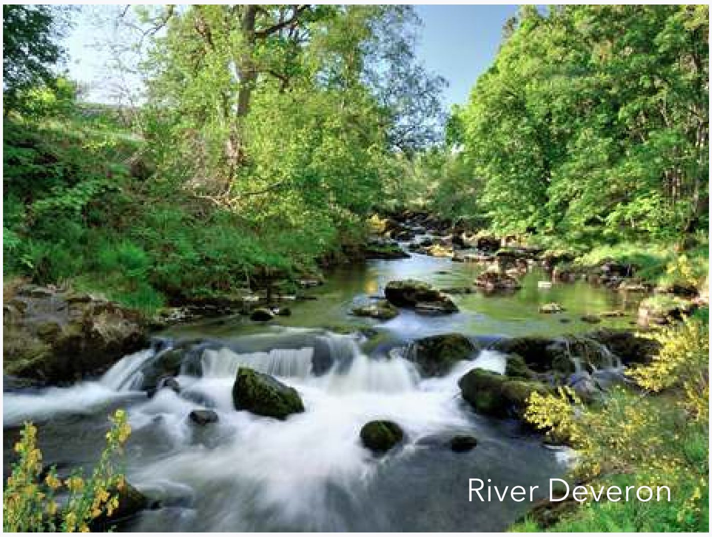
In the woodlands, we found the Endangered glistening waxcap fungus *(Gloioxanthomyces vitellinus)* next to Tammie's burn, and most of the estate's 194 lichen species in ancient woodland by the Deveron. These lichens included several of international and national importance.

Bird species diversity was also highest in riverine and native woodland areas. In total, the estate has ten species (out of 70) on the Red List, including Curlew, Grasshopper Warbler, Skylark and Yellowhammer, as well as 15 (out of 103) on the Amber List. Five of these species are classified as Endangered internationally and three are Vulnerable.

Among insects, the Nationally Scarce Mayfly *Rhithrogena germanica* and several other species of caddisflies, mayflies and stoneflies associated with coarse woody debris were found in wet, wooded areas, as was the Nationally Scarce woodland beetle *Parabolitobius inclinans*. We also detected deadwood indicator species including the Nationally Scarce beetle *Anaspis thoracic*.

In total, eDNA analyses across the estate detected 588 terrestrial invertebrate taxa, 1,583 soil taxa (1,203 soil fungi and 380 soil fauna) and, from water samples, 39 vertebrate taxa and 407 macroinvertebrate taxa. Despite these very encouraging findings, most of Beldorney was found to be substantially less diverse than the relatively small areas identified above.

Several wetland areas contained mainly midges and appear to have poor water quality, while the grasslands and conifer plantations contained limited diversity in most of the survey results. Notable exceptions were among soil fauna, which were most diverse in species-rich and acid grassland. Perhaps most contrary were Beldorney's earthworms, which were extremely common in the otherwise species-poor improved grasslands.


River Deveron

Bunloit year 2

On Bunloit, this second year has focused on management and planning, with peatland restoration being a key priority. Meanwhile, we have initiated low-intensity regenerative grazing on Bunloit's pastures, continued fence removal and bracken control, and started to establish a 'food forest' for sustainable production of fruits, nuts and herbs. We have also continued to develop our natural capital monitoring and research.

Recent findings include detection of 53 bird species from more than 50,000 calls recorded by audio sensors, including 9 species that are Red List species of conservation concern. Fungi surveys have revealed 48 different species, including the Endangered *Pseudocraterellus undulatus* **and Old Man of the Woods** *(Strobilomyces strobilaceus).*

Water vole surveys suggest that this near-threatened species may be present on Bunloit as well, and we await confirmation from aquatic eDNA surveys.

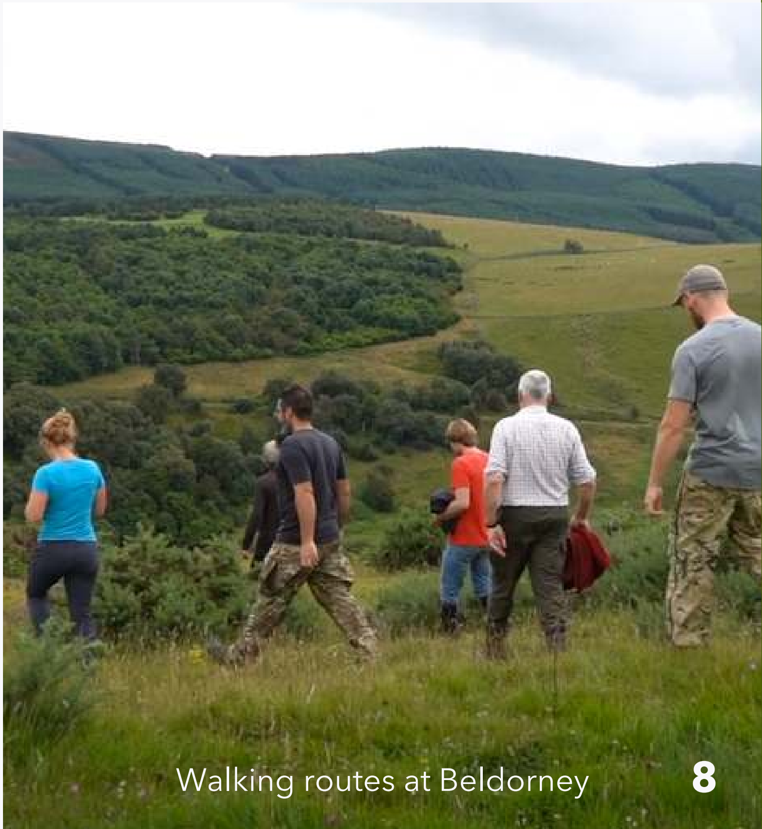
Outlook and next steps

By thoroughly assessing the current state of the estates that we manage, we hope to show measurable changes as they become wilder and more natural. The differing characteristics of Bunloit and Beldorney provide us with a rich source of data covering a variety of habitats. We intend these estates to become a world-class open laboratory for natural-capital verification science, where we and others can develop new methods to track changes in biodiversity and carbon stocks over time.

We continue to engage with experts from our academic research partners and more widely to understand when interventions, such as peatland restoration and tree planting, are useful to help fast-forward nature recovery. In Beldorney the planting of a 'Forest of Hope' will serve to extend the existing broadleaved woodland along the River Deveron and provide valuable riparian woodland habitat, while regenerative agriculture will help to restore grasslands and maintain food production on the estate.

We believe that community prosperity can go hand in hand with nature recovery, and have continued our community engagement to find ways to co-develop such benefits.

We aim to play a part in helping Scottish Government achieve its targets of net-zero carbon by 2045, reversing nature loss by 2030 and substantially restoring and regenerating biodiversity by 2045, as well as tackling land inequality through rewilding paired with re-peopling and mass-ownership of land. As this work progresses, we will continue to communicate our findings to ensure that Scotland can benefit from robust nature-based solutions as quickly as possible.


Walking routes at Beldorney

Highlands Rewilding Update

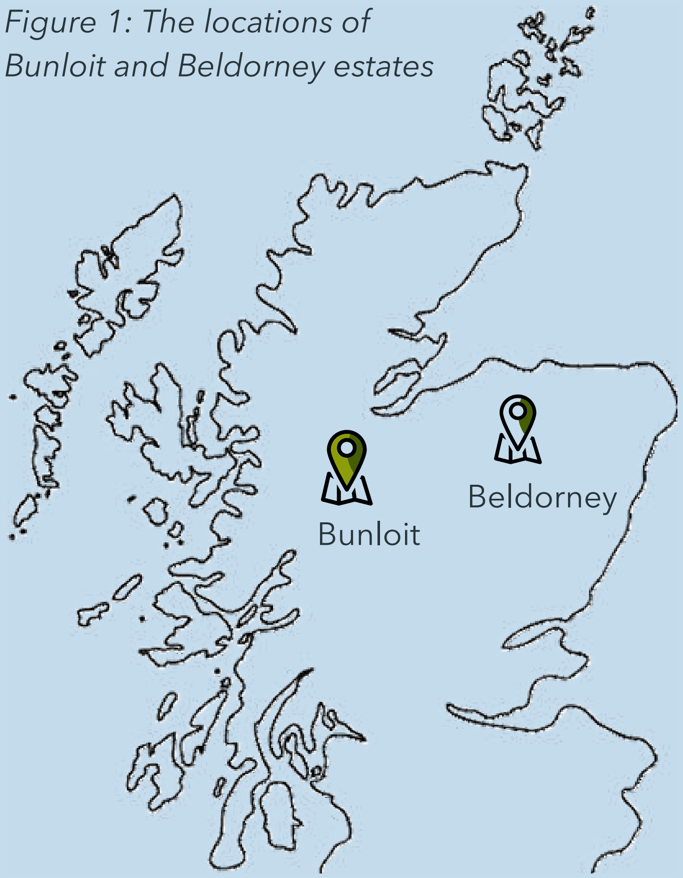
The company

Highlands Rewilding exists to help take nature recovery and community prosperity to scale in the Scottish Highlands and beyond.

We currently own two estates: Bunloit, on the west slope of Loch Ness, and Beldorney, along the west side of the River Deveron in Aberdeenshire.

We manage 852 hectares of land on these estates to boost biodiversity, carbon sequestration and job creation, implementing a form of rewilding designed to revatilise forest, peatlands and pastures, providing space for wildlife and flora to flourish and communities to thrive.

Figure 1: The locations of Bunloit and Beldorney estates



As we enter a new phase of mass ownership, we aim to create ethical returns for our shareholders and so encourage other landowners to pivot to net-zero carbon and nature positive practices. In doing so, we hope to help Scotland become a global leader in achieving its ambitious biodiversity and climate targets.

After two and a half years of operation in our startup phase, we have a strong and growing team, deep roots in our local communities, and a rapidly expanding core of cutting-edge science. We are already generating and analysing huge amounts of natural-capital data generated by satellites, drone-based sensors, ground-based sensors, eDNA analysis, and detailed observational work by ecologists.

We have multiple collaborators in Scotland's leading Universities, spanning several departments at the University of Edinburgh, SRUC, the University of the Highlands and Islands, the University of Stirling and the University of Aberdeen. We also have a special relationship with the University of Oxford, where a large team is collaborating on our natural capital research in a ten-year programme at the university's new Leverhulme Centre for Nature Recovery. International collaborations are also developing quickly, with researchers from a number of European universities planning courses and research projects with us.

Our work has been recognised at the recent Nature of Scotland Awards where we won the Business for Nature Award category, and we were also winner of the Adapting Scotland category of the 2022 VIBES - Scottish Environment Business Awards.

People and community

Highlands Rewilding has grown quickly during the last year, and we now have a team of 22 people (full-time and part-time), 16 of whom are from the local areas of the estates or the Highlands. The company's board of directors is made up of six people from, resident in, or with long-term experience of the Highlands, and they are responsible for ensuring that we create sustainable community prosperity.

All three of the staff employed on Beldorney were retained when the estate was bought, and two more locals have since joined them. Across the two estates, seven tradespeople are also regularly employed.

Some of our most active outreach to date has been educational. We have been running Outdoor Education and Environmental Science classes for Glen Urquhart High School, which have been very well-received.

We have also provided one paid position for a local apprentice, one forestry school student placement, five undergraduate summer placements and four summer fieldwork positions.

Our 'open air laboratory' is hosting a rapidly growing number of BSc, Masters, PhD and Post-doctoral research projects, as well as departmental collaborations with a variety of higher education institutions. Our research also involves close collaboration with local groups including the UHI and the Highland Biological Recording Group.

These developments are happening with increasingly frequent inputs from members of our local communities, 107 of whom have personally engaged online or, more commonly since the Covid lockdowns ended, in person. Community events have included an open evening at Beldorney and a series of 'walk and talk' events at both estates. We are also in frequent touch with neighbouring landowners. At Bunloit, we have built a hide and other access points for public use, and further developed eco-tourism at the estate's existing holiday cottages. We plan to increase community engagement over the coming year.

Outdoor Education classes for Glen Urquhart High School

Science and policy

Highlands Rewilding seeks to operate at the frontiers of natural capital science and marketisation, to establish nature-based solutions to the climate and biodiversity crises. This is an area of intense interest in research and policy sectors, and rewilding is one of the most promising ways of generating such solutions[1-5]. Debates continue about the exact definition and potential of rewilding, and so we have the opportunity to demonstrate one practical form, tailored to our Scottish upland context, and rapidly upscale its benefits[6-8]. In doing so, we need to be sure that these benefits are genuinely additional, long-lasting, and without indirect impacts in other places.

We prioritise benefits relating to carbon sequestration, biodiversity recovery and socio-economic gains. The former two benefits are well established in principle. It is estimated that nature-based solutions, such as rewilding, have the potential to sequester 23.8 billion tonnes of CO_2 equivalent per year[9], with rewilding having further potential beneficial impacts on nutrient cycles, fire regimes and soil health[10].

By definition, rewilding is dedicated to recovering some of the precipitous recent losses of global biodiversity, particularly those affecting megafauna and 'keystone species' that have disproportionate benefits for ecosystem structure and function[5].

Benefits for people are, so far, less well-demonstrated. Rewilding has sometimes been controversial in Scotland because of perceived incompatibility with traditional livelihoods and cultural landscapes, and because of fears that investment in nature-based solutions is driving increases in land prices, worsening one of the world's most unequal distributions of land ownership[11,12].

We regard it as essential to make rewilding work for local people. We aim to generate direct local benefits through, for example, 're-peopling' and achieving mass ownership of our estates as one of our core principles.

Our scientific approach is becoming increasingly well-established, following the publication of our first Natural Capital Report and an accompanying peer-reviewed scientific article[13]. We are also developing collaborations with some of the best universities in Scotland, the UK and internationally, as outlined above. These are being supported by our co-Chief Scientists and Chief Data Scientist, all three of whom have been employed in the last year.

Meanwhile, policies to facilitate nature-based solutions at scale are also under development. Some of the most important of these relate to biodiversity. In Scotland there is an estimated £20 billion funding gap for Nature Restoration[14] and there is currently no functioning mechanism for direct private investment in biodiversity. Biodiversity (or nature) credits are one potential solution to this, acting as an economic instrument to finance actions that result in measurable nature-positive outcomes and leverage responsible private investment.

However, the development of such credits is reliant on the quantification of nature positive outcomes through biodiversity metrics. The difficulty is that biodiversity is, by its very nature, extremely complicated to accurately measure and quantify.

For instance, it is essential that we account for both the number of different species (species richness), as well as the population sizes (or abundances) of these species, especially if they are rare or threatened. Functional and genetic diversity should also be accounted for, as they are essential for healthy ecosystems.

Through our research, we aim to contribute to the development of repeatable, trustable methods to measure these different aspects of biodiversity. We are engaging and collaborating with NatureScot, the Scottish Government and others, including the Cairngorms National Park Authority, on this topic.

Peatland depth surveys

As with our first year report on baselining at Bunloit, we use this report to summarise what we have discovered about carbon and biodiversity in our estates to date, and how they can effectively be measured.

Our aim is to demonstrate that natural capital can be grown verifiably for planet, people, and profit, both in wild land and actively managed land. Our work aims to produce high-quality, evidence-based data on natural capital quantification, which can be fed into the ongoing policymaking process within government to help to generate the best possible outcomes.

Ringing a long-tailed tit

Badger captured on a camera trap

Beldorney

Overview of the estate

Beldorney is a 349-hectare grassland-dominated estate in Aberdeenshire.

The eastern edge of the estate is bordered by approximately 2.7km of the River Deveron, which is well known for its Atlantic salmon, sea trout and brown trout and, in fact, still holds the UK record for a salmon caught on a fly by Mrs 'Tiny' Morison back in 1924 (61lb!)

The river rises in the hills above the Cabrach, to the North-East of the Cairngorms, and its catchment covers an area of 1,266 km².

This provides many opportunities for collaboration at a landscape scale with neighbouring estates along the river, which we hope to develop in the coming months.

History

Beldorney estate has a rich history, with evidence of habitation at Craig Dorney hill fort stretching back to 430-565 AD, in the Early Medieval period[15]. At this time, the effects of Roman withdrawal further south were being felt in Scotland, identifiable Pictish kingdoms were developing in the area, and Christianity was spreading from the west. The climate was also changing, with much of the country becoming colder, wetter and less productive, putting pressure on upland settlements of the kind that might have been found at Beldorney.

After this period, there is little to indicate how life in the area developed, until records emerge of the construction of Beldorney castle in the mid-16th century by the Gordon family. In the following decades the castle changed hands several times (sometimes as the result of murder), was confiscated by Mary, Queen of Scots, and pillaged by the Jacobites. But it was not until 1790 that the Gordons finally sold the castle, to Thomas Buchan, who sold it on to Sir William Grant, the MP for Banffshire at the time.

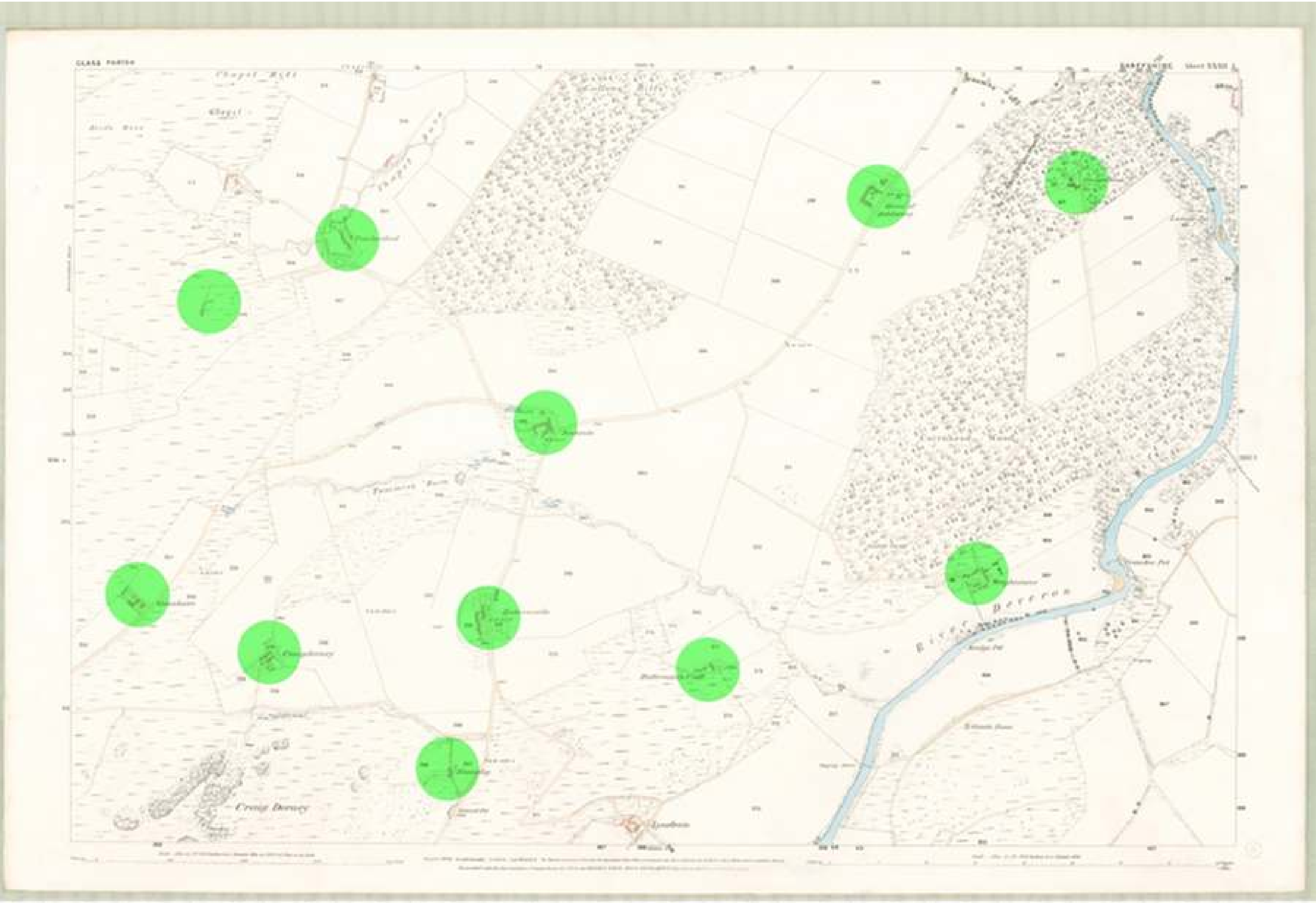


Figure 2: Central Beldorney in 1870, with locations of buildings highlighted in green. Forested areas are also shown, with the central and southern areas of the estate being predominantly grassland. Reproduced with the permission of the National Library of Scotland.

It was in Grant's time that Ordnance Survey Name Book records were collected, and we begin to get glimpses of the ordinary tenants of Beldorney. At first, these glimpses are fleeting – records of the surnames and addresses of male tenants, with little else about them or their families. Nevertheless, it is clear that Beldorney at this time hosted a large and active community.

The Name Book of 1867-70 records 29 buildings associated with the estate, including two large farm steadings, two medium sized farm steadings, 15 small farm steadings, five crofts and two small cottages. 15 built areas are clearly labelled on the 1869/70 maps (Figure 2), and in 1901/02 they are joined by a school, Tighnaird.

By 1970, however, when the newly built Beldorney cottages appear near the castle, the vast majority of steadings are no longer on the map.

Population decline continues, and by 2022 there are only scattered private residences at the sites of Tighnaird and Backside, with no one living permanently on the estate. The castle and two cottages are in excellent, habitable condition, but two more estate cottages are in a state of disrepair.

Ruined remains of farm steadings and crofts dot the estate, including the previously inhabited Blacklug, Craigdorney, Timberford and Glackshalloch. Meanwhile grazing levels have increased, with the grassland areas of the estate expanding into forests shown on historical maps.

As a result, the Beldorney of 2022 is a very different estate, with far fewer people and trees than it has had for most of its recorded history.

Beldorney today

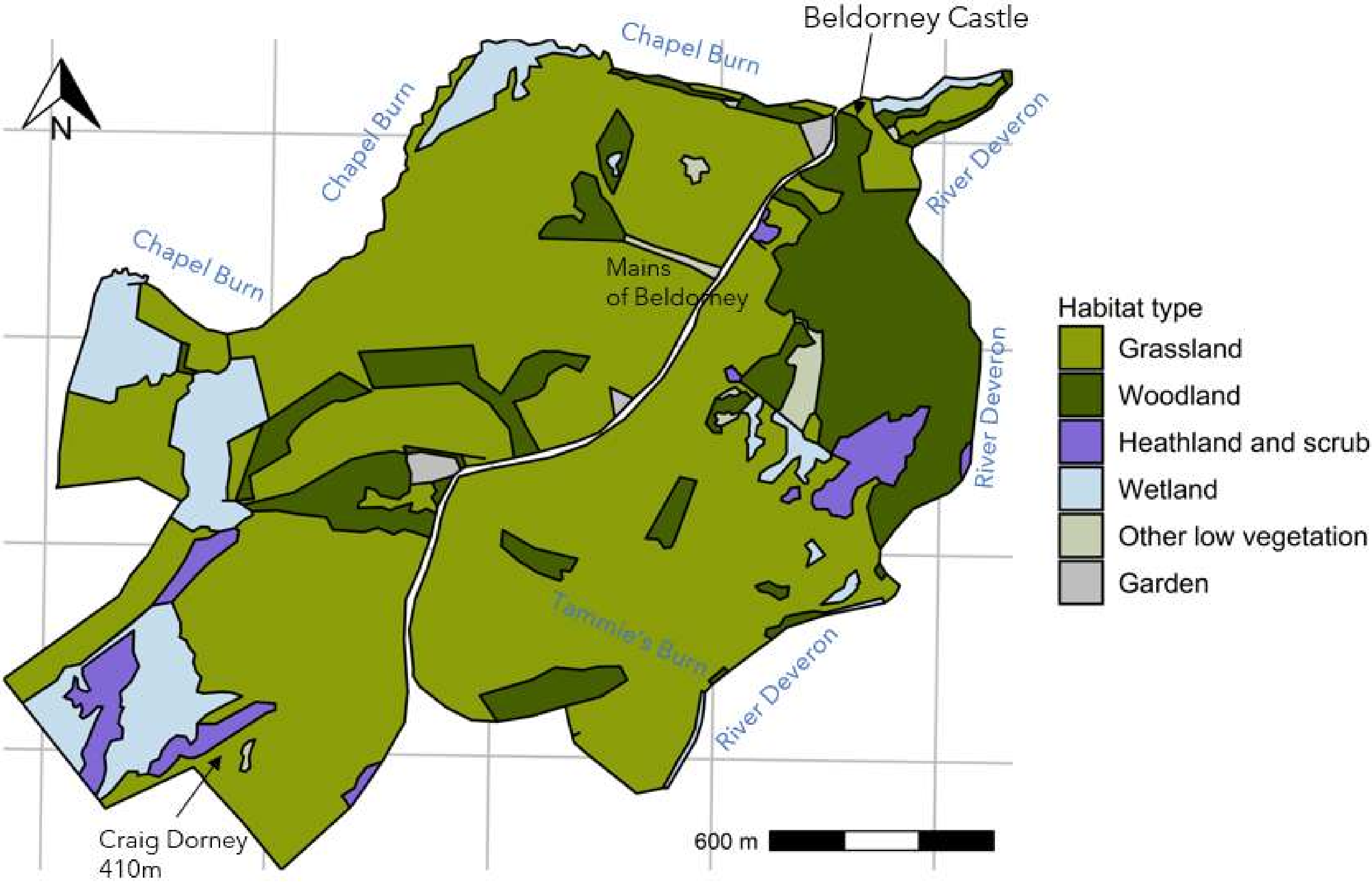
Beldorney is now a relatively typical, grassland-dominated upland estate with few inhabitants. Its grasslands were heavily grazed by sheep and cows until March 2021, but then rested until April 2022, when Highlands Rewilding began our active management of the estate.

Currently, alongside the extensive grassland, Beldorney has several blocks of conifer plantations and an area of native woodland between Beldorney castle and the River Deveron.

There was clear potential from the outset to restore native woodlands, species-rich grasslands and riparian and other wetland vegetation across the estate. The findings below represent what we have discovered about these habitats in detail.


Cows grazing at Beldorney

Figure 3: Map of Beldorney Estate



Carbon

Unlike Bunloit, Beldorney does not have substantial areas of deep peat. Commercial conifer plantations have sequestered carbon as they have grown, but may have increased soil emissions in some areas. Beldorney's grasslands and native woodlands also store carbon, but historical grazing pressure has limited the stocks here too. To better understand carbon stocks and flows on the estate, we have investigated each of these areas in turn.

The National Soil Map of Scotland[16] shows that the estate is primarily underlain by podzols and gleys, particularly Humus-iron podzols. Brown magnesian soils are also common,with some Mineral alluvial soils by the River Deveron. There is also some Dystrophic blanket peat in the northwestern corner of the estate. While many of these soils are acidic and relatively unproductive, they do have the potential to sequester significant amounts of carbon. Our initial findings, described below, suggest that we can improve current carbon stocks through careful management of these soils and their vegetation. We give these findings in terms of tonnes of carbon (tC) or equivalent tonnes of carbon-dioxide (tCO_2e), often as values per hectare (ha^{-1}) and per year (yr^{-1}).

Grasslands

Agricarbon measurements

As we did on Bunloit estate, we used the company Agricarbon to sample the soils in Beldorney's pastures and determine their organic carbon stocks. This process involves extracting multiple soil samples from each field and directly measuring their bulk density (how much soil is found per unit volume, telling us how compacted the soils are) and the percentage of Soil Organic Carbon within them.

Because Beldorney is mainly pasture, Agricarbon were able to sample most of the estate, taking 460 soil cores from a total area of 241 hectares, in late April 2022. These cores were then divided into samples according to depth levels of 0-15cm, 15-30cm, 30-60cm and 60-100cm. Many areas of soil were shallower than a metre, with an average depth of just under 50cm. In total, we gathered 1,372 different samples to analyse (Table 1).

Results show overall carbon stocks in Beldorney's fields of 23,307 tonnes of Carbon, equivalent to 85,536 tonnes of CO_2 (tCO_2 e), or around 3,700 mature Oak trees.

The average carbon stock was just under 100 tonnes per hectare, with some variation from field to field (as shown in Figure 4), and sometimes large differences between samples from the same field (Figure 5). Overall, 'field 13' had far higher values for soil organic carbon than the others, and ‘field 4’ had highly variable results. This is likely to be because field 13 is a paddock next to the castle that receives a lot of leaf litter from surrounding trees, while field 4 covers an elevation range from a heathery hill down to a partially drained wetland area.

Table 1: Summary of soil carbon results. % SOC is the percentage of Soil Organic Carbon in the samples.

Soil extraction dates	26 Apr - 27 Apr 2022
Total core extractions	460
Average core density	1.9 per hectare
Average core depth	498mm
Total sample number	1372
Average sample density	5.7 per hectare
Total Carbon Stock	23,307 tonnes Carbon
Average tonnes Carbon per hectare	96.7t C/ Ha
Depth 1: % SOC levels (0-15cm)	5.07%
Depth 2: % SOC levels (15-30cm)	2.73%
Depth 3: % SOC levels (30-60cm)	1.45%

Model-based results

For comparison with the Agricarbon results, we also modelled grassland carbon using national figures taken from the 2007 Countryside Survey[17]. This survey is recommended by Natural England as "the most comprehensive survey of carbon storage in the UK's grassland habitats" and is based on national samples of vegetation and soils taken between 1978 and 2007[18]. The values we used dealt with the 0-15cm soil depth class, and so we compared these with the relevant subset of the Agricarbon results.

The Countryside Survey values include acid and neutral grasslands, with figures of 87 and 60 tonnes of carbon per hectare (tC ha^{-1}), respectively. According to our habitat mapping, Beldorney is divided approximately 44%-56% between acid and neutral grassland, implying an average soil carbon content of 72 tC ha^{-1}, and a total of 17,322 tC, in the first 15cm of soil. The equivalent Agricarbon measurements give an average of 40.6 tC ha^{-1} and a total of 9,785 tC.

This means that soil measurements are detecting only a little more than half of the carbon stock that might be expected in typical grasslands of the types found at Beldorney.

There are a number of reasons why this could be the case, but Beldorney's history of heavy grazing could well have left soil carbon stocks depleted, a possibility that is reinforced by relatively high bulk densities in some fields suggesting soil compaction. If this is the case, there is substantial scope for further carbon sequestration in Beldorney's grasslands, and monitoring this as we restore the pastures will be a focus of our future research.

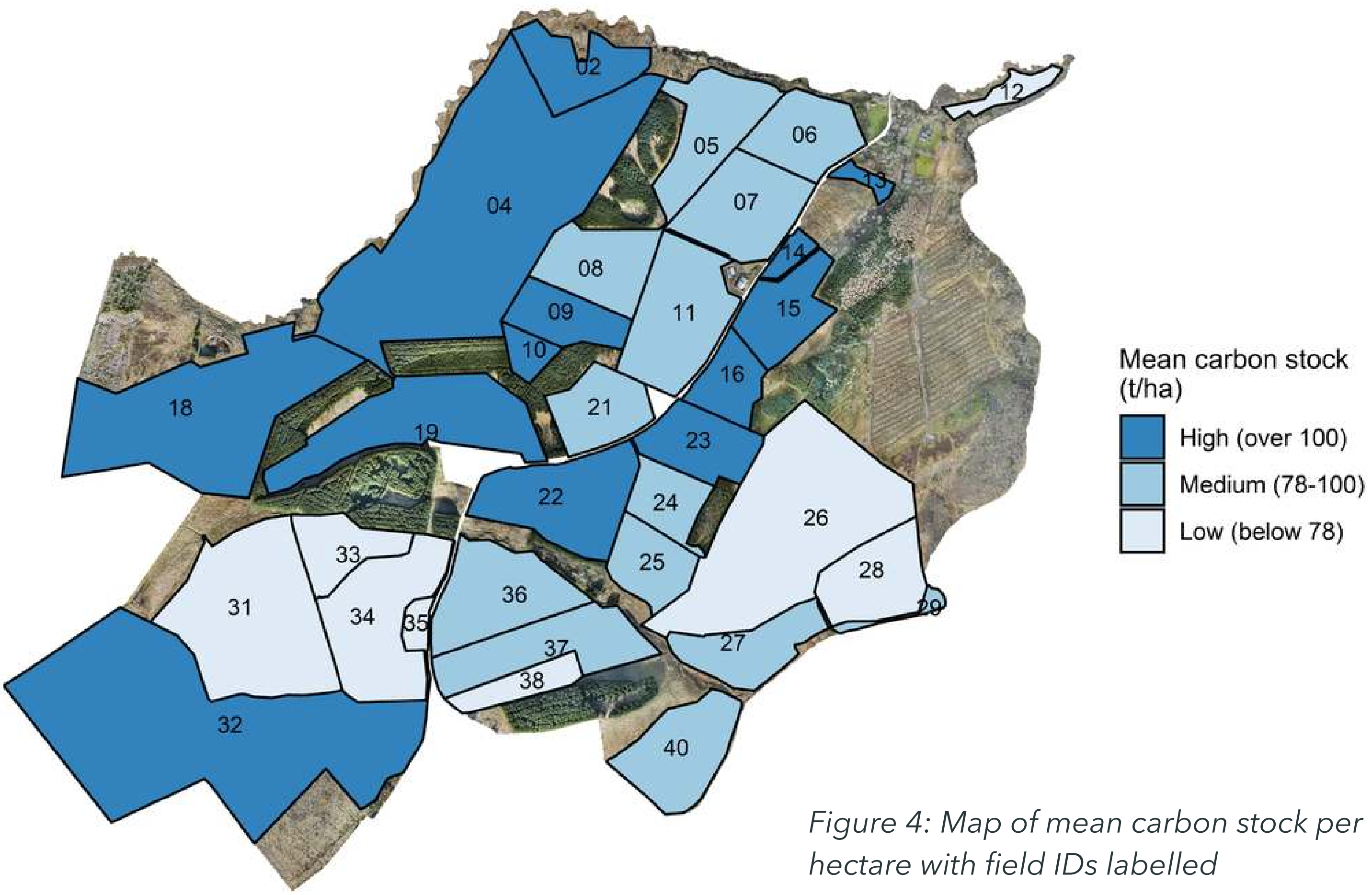
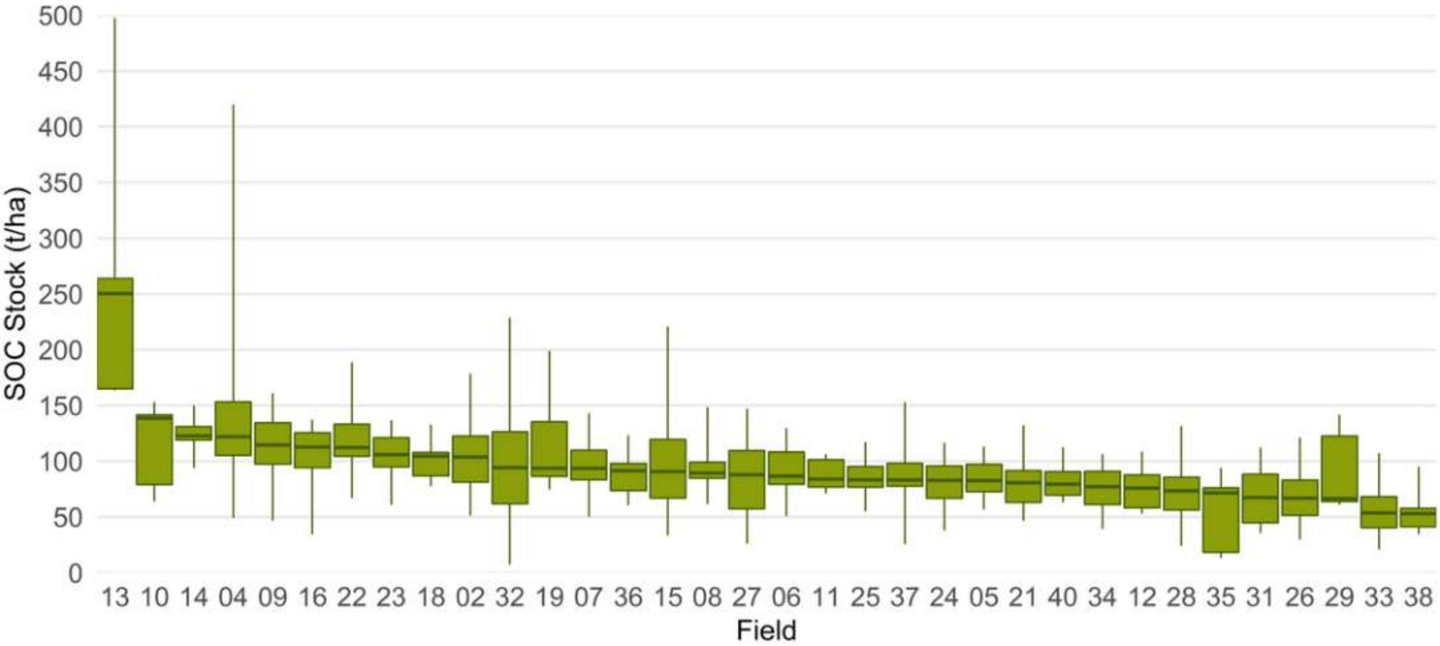


Figure 4: Map of mean carbon stock per hectare with field IDs labelled

Figure 5: Box plots showing the median, interquartile range, minimum and maximum for soil organic carbon for each field

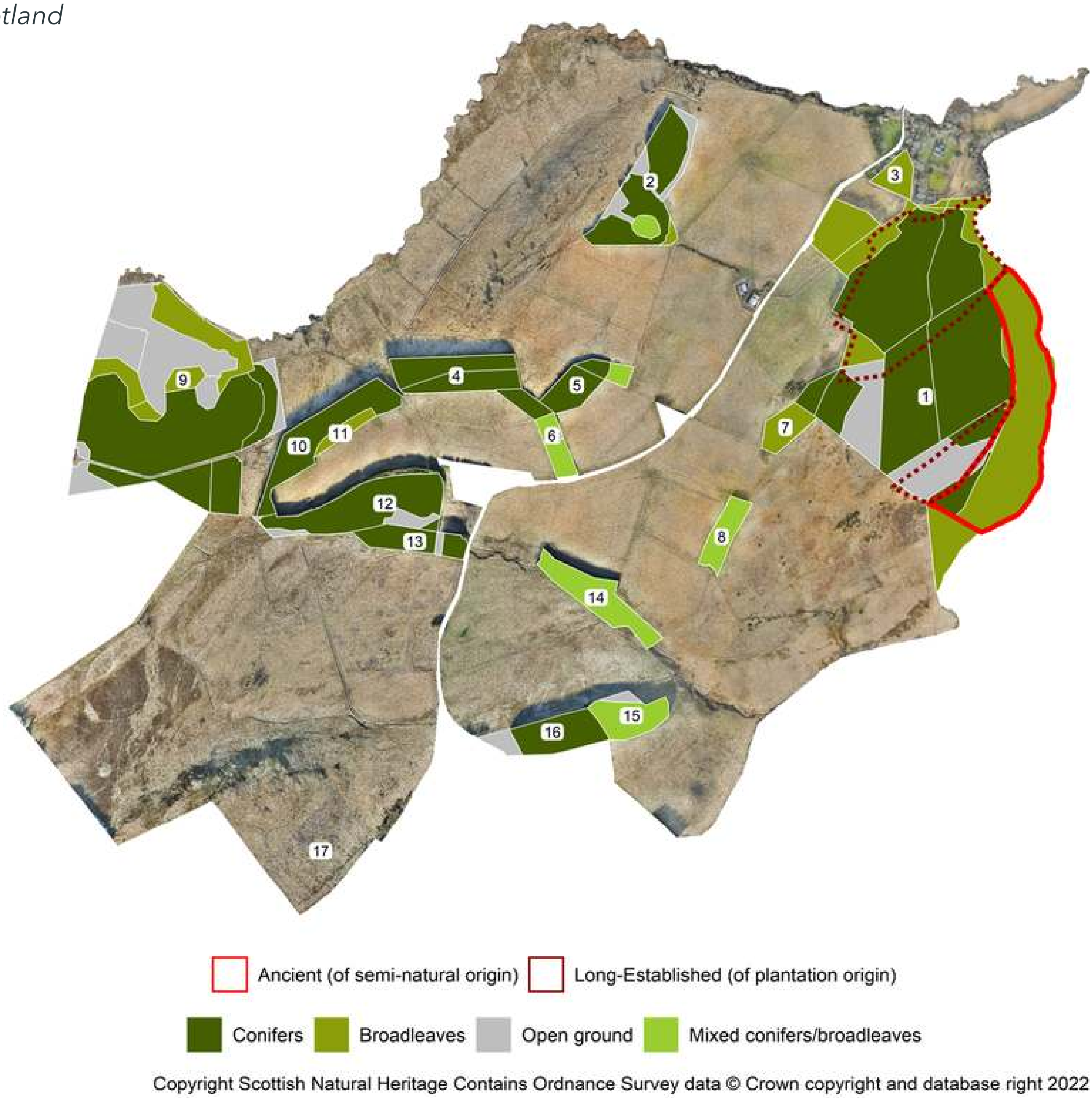


Woodlands

Historical maps show large areas of woodland persisting at Beldorney until at least 1870. Since then, substantial parts of these woodlands have been lost. The areas that remain are now classified as Ancient (of semi-natural origin) and Long-established (of plantation origin)[19], which cover 7.9 and 13.2 ha respectively (Figure 6). These fragments have important benefits for biodiversity, but can also represent large carbon stores.

In more recent times, new woodlands have been created through planting, and a total of 87 ha are now in forest compartments. Just under 19 ha are broadleaved, 6 ha are mixed conifer and broadleaf, and nearly 50 hectares are conifer plantations. The remaining 12 hectares are open ground within forest compartments.

Figure 6: Map of the forestry compartment and the areas on the Ancient Woodland Inventory for Scotland



Biomass: WCC modelling

We modelled the existing woodlands in Beldorney using the Woodland Carbon Code (WCC). The WCC is a credit-based methodology for predicting future carbon stocks and is used in the creation of WCC accredited carbon credits in the UK. In the table below, the WCC standard project calculator has been used to provide an estimate of the carbon currently held in the woodland areas of the Beldorney Estate, by plantation name and planting year. This was created by using species maps from our existing forestry plan, and estimates of yield class and spacing provided by our Head of Forestry.

The current stock was estimated at 16,124 tonnes of CO_2 equivalent (tCO_2e), with an estimate of future sequestration at 15,569 tCO_2e over 100 years, should there be no intervention.

Carbon stock was calculated using the 'Cumulative Carbon Sequestration from lookup tables (tCO_2e) column from each WCC spreadsheet. This provides a 5-yearly estimate of carbon sequestration from planting, between Year 5 and 100, before any buffers are removed.

The real age of each Beldorney compartment was rounded to the nearest 5 and, for woodland areas over 100 years old, the maximum sequestration is assumed and so the Year 100 figure is used. To calculate the future sequestration (tCO_2e) for each compartment, the current stock was subtracted from the Year 100 figure, assuming that by 100 years the emissions from woodlands are equal to any further sequestration and so create a net-zero balance.

Table 2: Summary of Woodland Carbon Code Calculations

Forestry compartment	Forest type	Year	Age	Hectares	Current stock (tCO2e)	Future sequestration (tCO2e over 100 years)
1a1, 1a2	Conifer	1964	58	9.67	Felled	NA
1b1	Conifer	1968	54	5.54	Felled	NA
1b2	Conifer	1968	54	2.46	767	377
1c	Broadleaf	1900	122	9.41	5599	0
1c2	Broadleaf	1900	122	0.27	161	0
1e	Broadleaf	2010	12	1.50	7	357
1f	Broadleaf/open ground	1900	122	1.05	387	0
1g	Conifer	1968	54	1.04	562	282
1i, 1l1	Broadleaf	1900	122	0.70	416	0
2a, 2b	Conifer	1997	25	3.39	666	2085
2e	Conifer/Broadleaf	1997	25	0.32	41	113
2g	Broadleaf	1997	25	0.13	13	19
3a	Broadleaf	1900	122	0.74	440	0
4a, 4b	Conifer	1972	50	2.76	913	362
5a, 5b, 5c	Conifer/Broadleaf	1977	45	1.58	628	495
6a, 6b, 6d	Conifer/Broadleaf	1989	33	1.23	344	449
7a	Broadleaf	1988	34	0.96	144	89
8a	Conifer/Broadleaf	1989	33	1.08	261	308
9a, 9b, 9d	Conifer/Broadleaf	2020	2	14.65	62	7669
10a	Conifer	1972	50	2.89	1075	413
11a	Broadleaf	1994	28	0.48	61	55
12a, 12b	Conifer	1980	42	3.82	1148	819
13a, 13b	Conifer	1980	42	1.42	427	304
14a	Conifer/Broadleaf	1980	42	2.11	887	585
15a	Conifer/Broadleaf	1989	33	1.47	532	502
16a	Conifer	1967	55	1.87	583	287
				Total	**16,124**	**15,569**

Biomass: Treeconomy photogrammetry modelling

To generate an observational comparison with the WCC calculations, we used the startup company Treeconomy to assess aboveground biomass in Beldorney's woodlands. Treeconomy gathered data using Photogrammetry; the precise three-dimensional measurement of objects (in this case trees) from two-dimensional photographs. Photogrammetry data was collected by drone in February and August 2022, with the second survey used to capture the broadleaf trees with their leaves.

These data points were processed into a 3-D point cloud, a 3.5 cm geo-referenced orthophoto, a Digital Terrain Model (DTM), a Digital Surface Model (DSM) and, by combining the DTM and DSM, a Canopy Height Model (CHM).

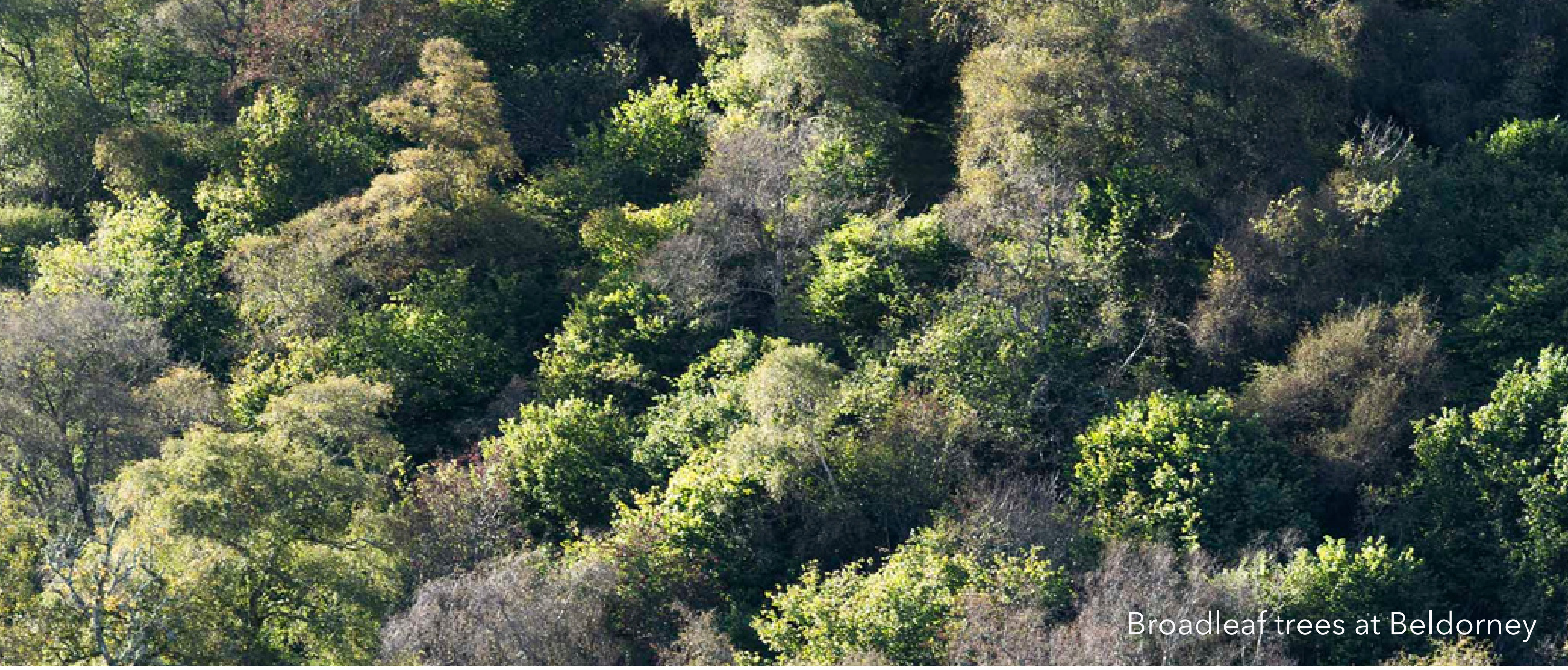
The CHM shows the height of all features on the ground in metres, and allows the calculation of tree heights.

The merged orthophoto layer was then run through a Convolutional Neural Network (CNN) machine learning model trained to delineate crowns of live trees from high resolution drone imagery.

Each detected tree was assigned to a representative species of spruce, pine or birch, based on a forest map of Beldorney, to take advantage of good-quality allometric field measurements for predicting their biomass.

A further variable, Diameter at Breast Height (Dbh), was necessary to predict biomass levels, and because this is not possible to measure remotely it was calculated from tree species and height, and subsequently validated by on-the-ground measurements.

Figure 7: Sample images of bounding boxes over tree detections. The left image shows spruce detections in sub-compartment 12a (Sitka spruce). The top-right image shows birch detections in 1c (birch), and the bottom-right shows saplings in 9h, with the automatic detection struggling to identify all the smaller birches in particular.



Broadleaf trees at Beldorney

After corrections, trees were divided into saplings (692 of which were detected for conifers, and 3,408 for broadleaves) and adults, and the carbon in their roots, stem and crown were estimated using species-relevant calculations in the Woodland Carbon Code's Carbon Assessment Protocol.

A total of 31,918 trees were detected, and these were estimated to contain the equivalent of 11,980 tonnes of CO_2 (tCO_2 e).

The per-tree result ranged from 0.004 to 2.65 tCO_2e, with the distribution being concentrated towards lower values. The Sitka spruce plantations, being comprised largely of mature trees, had the highest per-tree average of 0.627 tCO_2e.

This total is notably different from the Woodland Carbon Code calculation presented above, which gave a total of 15,423 tCO_2e when corrected for differing boundaries used in each case. This means that the Woodland Carbon Code values are around 29% greater than those produced by Treeconomy. There are several reasons for this discrepancy.

The most substantial is mis-classification of birch and hazel woodland in forest compartment 1. Here, Treeconomy's tree detection model struggles to distinguish individual trees within patches, and results in an estimate of stored carbon one fifth the size of that suggested by the WCC calculations, which are based on a more accurate number of trees. Differences are also large in other broadleaved or mixed compartments, where trees may not be reliably detected by Treeconomy's model (overall, the model was found to have an accuracy of 85% compared to detecting trees by eye).

The results were far more similar in mature monoculture compartments, where the Treeconomy values actually exceed the WCC calculations. Here, evaluation of the Treeconomy model using height and Dbh values shows that it is performing well, suggesting that more training data from semi-natural broadleaf forests in summer would be very useful in improving the model's scope and establishing an independent, data-driven point of comparison with the WCC.

Woodland Soils

The carbon stock in woodland soils has not yet been directly measured at Beldorney, but is likely to represent another important carbon store. While site-specific estimates are not available, national figures do exist and give a guide to the levels we can expect. A Scotland-wide average equivalent to 623 tonnes of CO_2 per hectare (tCO_2e ha^{-1}) in the first 30cm of woodland soils [20] implies 54,201 tCO_2e lying under Beldorney's woodlands, if the soil depth is consistent.

A recent extensive survey of British forests (BioSoil[21]) found that organic carbon stocks in the forest litter and top organic layer alone averaged 56.3 and 63.1 tCO_2e ha^{-1} for conifers and broadleaves respectively. These layers are certainly present in Beldorney, even though we do not yet know whether our forest soils are more or less than 30cm deep on average.

Therefore we have a reasonably reliable total of 5,027 tCO_2e in the litter and top organic soil levels (1,199 tCO_2e in our 19 ha of broadleaves, and 3,828 tCO_2e in the remaining forested areas, assuming the lower value for conifers holds here), with the potential for tens of thousands more tonnes further down in the soil. While the uncertainty on these values is large, they are comparable in magnitude to woodland biomass, and could be much larger.

Peatlands

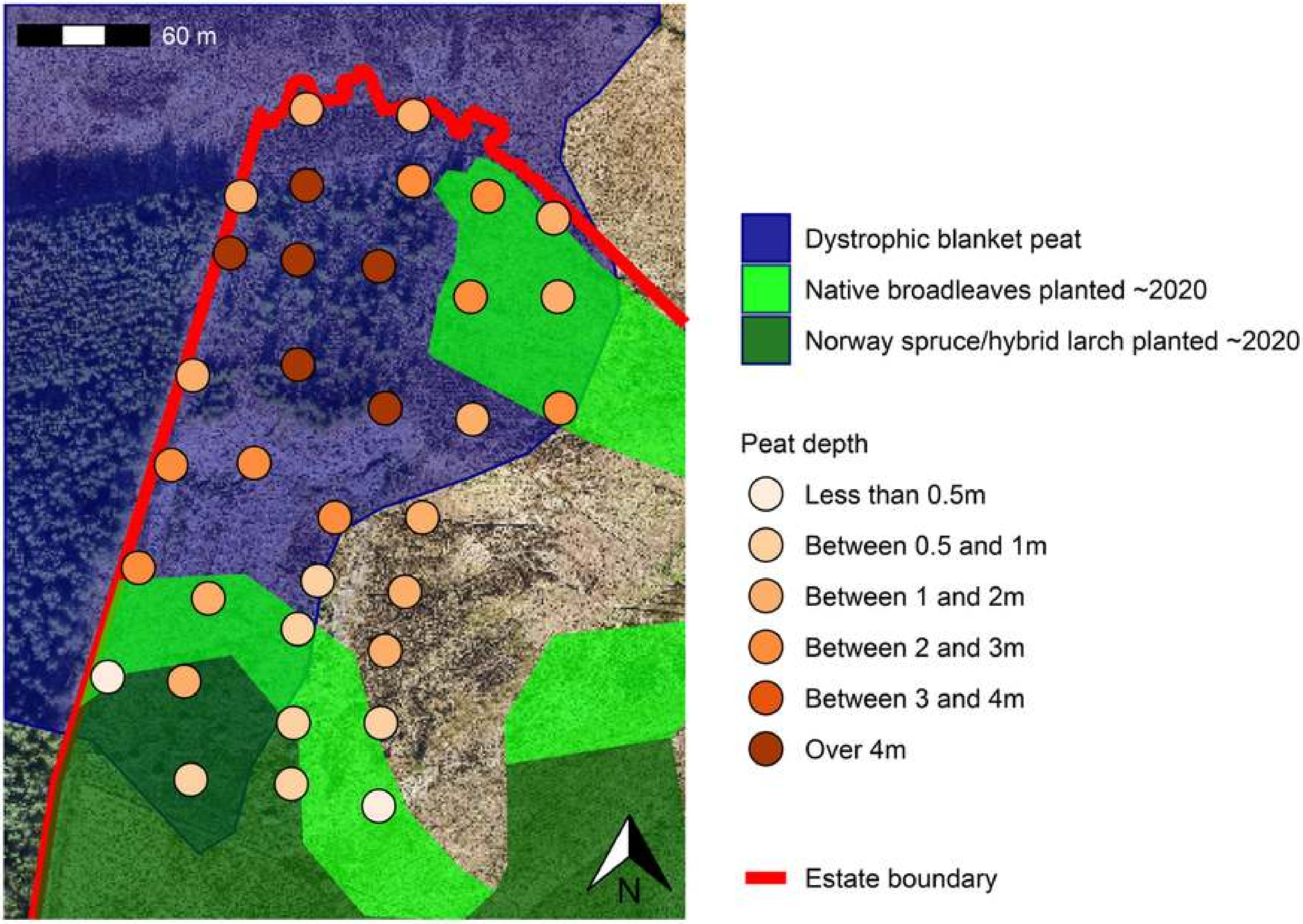
The Soil Map for Scotland[16] shows a small amount of Dystrophic blanket peat in the northwestern corner of the estate. We conducted peat depth surveys in this area, finding that some of this peat is over 4 metres deep. We also found that the peat extends beyond the 4.2 hectares indicated on the soil map, with 4.8 hectares recorded to date. Across this area, we found an average peat depth of approximately 2 metres, which, if representative, gives a total peat volume of 96,240m^3.

The carbon stored in this peat cannot be precisely estimated without on-the-ground measurements, but previous research gives us a range of potential values. Of these, we use low values of 653-904 tonnes of (organic) carbon per hectare (tC ha^{-1}, to a depth of 2 metres) from research based on ground-penetrating radar and core samples on UK peatlands[18, 22] and high values of 1,290 tC ha^{-1} (again calculated for 2m depth) based on a separate review[23] of peatland carbon stocks that was also used as an upper bound in our first Natural Capital Report for Bunloit.

These give us a range of 11,501 to 22,724 tCO_2e stored in Beldorney's small area of peat; a value similar to the above-ground biomass in the 65 ha of standing forest on the estate.

Peatland area in the northwest corner of Beldorney

Figure 8: Map of peat depths



Soil Survey of Scotland Staff (1970-1987). Soil maps of Scotland (partial coverage). Digital version 10 release. James Hutton Institute, Aberdeen. DOI 10.5281/zenodo. 6908156.

While this is a substantial carbon stock, much of the peatland has been affected by planting and drainage over the years. A Sitka spruce plantation from 1971 was harvested and then partially restocked with native broadleaves in 2020, and Norway spruce and hybrid larch have also been planted on part of the peat.

The remainder has clear signs of ground disturbance and drainage, with sparse pine regeneration in the north-west corner.

These disturbances mean that Beldorney's peatland is almost certain to be a net carbon source.

Again, exact figures are not yet available, but using established figures for greenhouse gas fluxes on degraded peat in the UK[24], we can estimate carbon fluxes of somewhere between 0.85 and 7.39 tCO_2e $ha^{-1} yr^{-1}$ for eroded and forested areas respectively. If we are able to restore these areas to near-natural condition, we can expect a net saving of 1.46-3.46 tCO_2e $ha^{-1} yr^{-1}$, eventually making this part of the estate a net carbon sink once again.

A key research area for the coming year is to investigate the extent, depth and condition of peat, including whether any extends to other parts of the estate classified as heathlands and wetlands on peaty gley soils.

Planting the Forest of Hope

Whole estate

In addition to the results above, an independent carbon modelling exercise was carried out as part of a Master's degree project at Kings College London[25]. This project used land cover maps and the commonly-applied ecosystem services model InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) to assess current and potential future carbon stocks. Results indicate a total carbon stock across the estate's soils, above- and below-ground biomass and litter/woody debris of 169,165 tCO_2e.

This total was dominated by carbon in the soils (of all types), which represented 77% of the total.

The highest carbon densities were located in woodlands, where the average stock was 1,009 $tCO_2e\ ha^{-1}$ and reached a maximum of 1,688 $tCO_2e\ ha^{-1}$, compared to average of 495 $tCO_2e\ ha^{-1}$ on the rest of the estate. Modelling of an example scenario of future management gave a total sequestration potential of 85,504 tCO_2e over the coming century, with broadleaf woodland expansion having the greatest potential uplift in carbon density of 866 $tCO_2e\ ha^{-1}$.

Carbon summary

Combining the above results for carbon storage in grassland soils, woodland biomass, woodland soils and peat, we estimate that the total carbon storage for the estate is currently equivalent to 114,044 to 178,585 tonnes of carbon dioxide (tCO_2e). This is broken down as shown in Table 3.

Table 3: Carbon totals according to measurements and models of each carbon pool.

Category	Estimated carbon storage (tCO_2e)
Grassland soils	85,536
Woodland biomass	11,980 - 16,124
Woodland soils	5,027- 54,201
Peat	11,501 - 22,724
Total	**114,044 - 178,585**

The largest single carbon store is in grassland soils because they cover such a large area, while the greatest carbon density is thought to be in the woodlands (biomass, litter and soil). Grassland measurements find only 56% of the soil carbon we would expect on the basis of national figures; perhaps a consequence of historical over-grazing.

As it stands, the far smaller area of woodlands (65 ha of standing trees, as opposed to 240 ha of grassland) may contain a similar total carbon stock when biomass and soils are taken into account. There is substantial uncertainty in this figure because we do not yet have reliable measures of woodland soil depth; a priority for upcoming research. We also find differences between methods in estimating woodland biomass, with the photogrammetry-based method identifying only 78% of the carbon we expect from Woodland Carbon Code calculations. This discrepancy needs to be explored further, but is not unexpected as the photogrammetry method is still under development and is known to miss biomass in broadleaf saplings in particular.

Nevertheless, the far smaller area of peatland (just 4.8 ha) contributes a similar amount to total carbon stores as the woodland biomass.

Currently, many of these areas are thought to be emitting rather than sequestering carbon, and management to restore and increase carbon sinks is already underway. Through this management, we can hope to reach more typical values of carbon storage in grassland soils, and ensure long-term sequestration equivalent to tens of thousands of tonnes of CO_2 in woodland and restored peatland. Modelling gives us an estimate of 85,504 tCO_2e sequestration potential across the estate over the next 100 years, with new broadleaf woodlands contributing 866 $tCO_2e\ ha^{-1}$. While minor in absolute terms, this sequestration will provide an important example for other upland estates, and is likely to be consistent with substantial uplift of biodiversity.

Biodiversity

We investigated the current biodiversity on the estate by looking at habitat, species and genetic levels, using field observations, camera traps, acoustic monitoring and environmental DNA sampling, amongst other techniques. We summarise our methods and initial findings in the following section.

Habitats

We mapped the habitats of the estate using high resolution satellite imagery paired with ground-truthing by experts.

Satellite classification

We collaborated with the satellite analytics company Spottitt. Spottitt used an Airbus Pleiades multispectral image (R, G, B, NIR and Pan bands) taken in May 2022 to assess Beldorney land cover using their hybrid spectral response and artificial-intelligence based-algorithms.

Outputs included a Level 2+ UK Habitat Classification (Figure 9) and Normalized Difference Vegetation Index (NDVI; Figure 10) both at 50cm resolution. The NDVI was calculated from the satellite images using near-infrared (NIR) and visible red measurements. NDVI essentially provides a measure of 'greenness', indicating the presence and density of vegetation, but also areas where fertiliser and other inputs have been used to improve the ground. The NDVI map of Beldorney (Figure 10) shows higher values in the fields that have been most grazed, and lower values in the heathland and wetland areas. This does not indicate plant health, but provides a useful basis for comparison with flora surveys described later in the report.

Figure 9: Habitat classification generated from satellite imagery

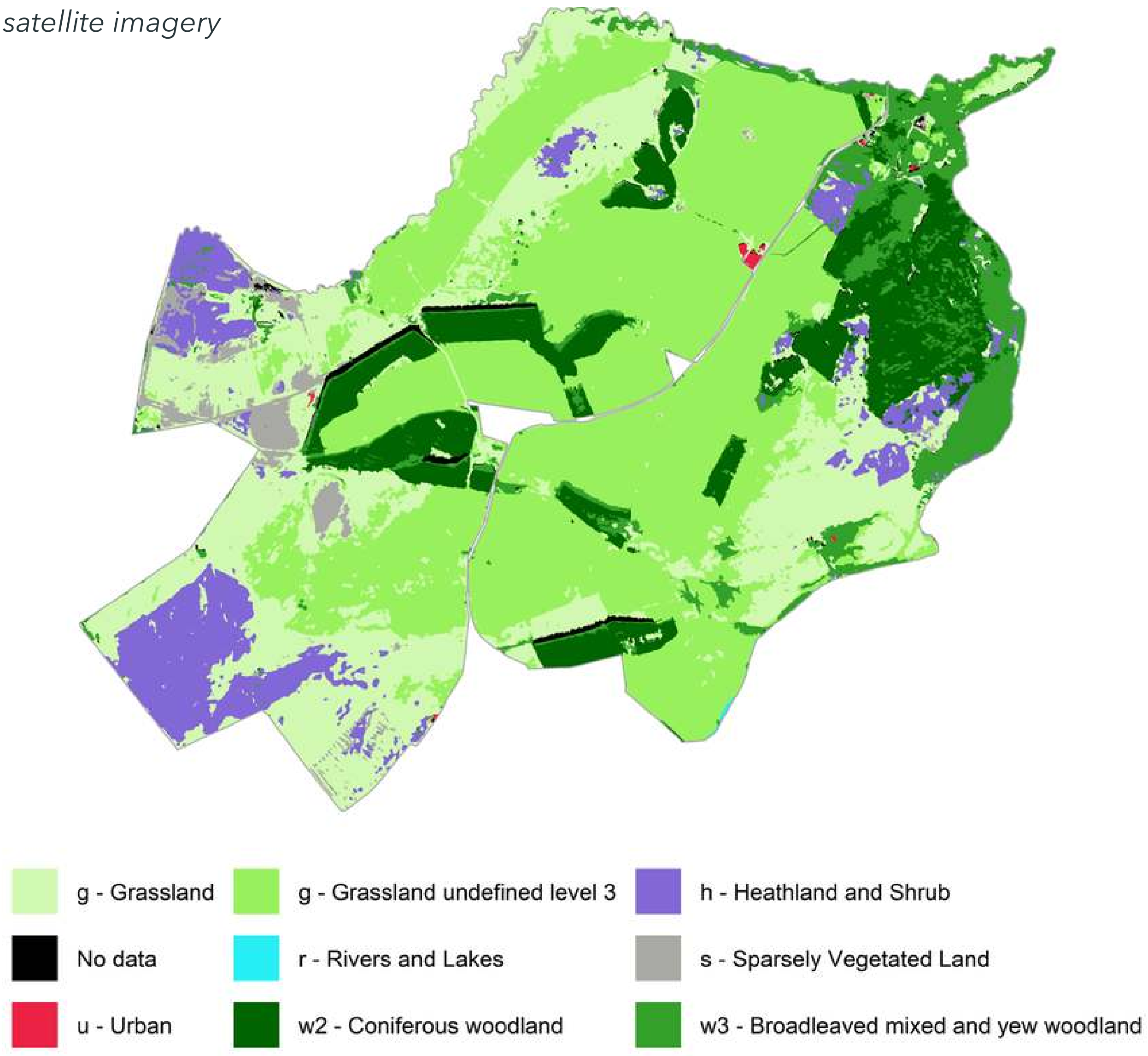
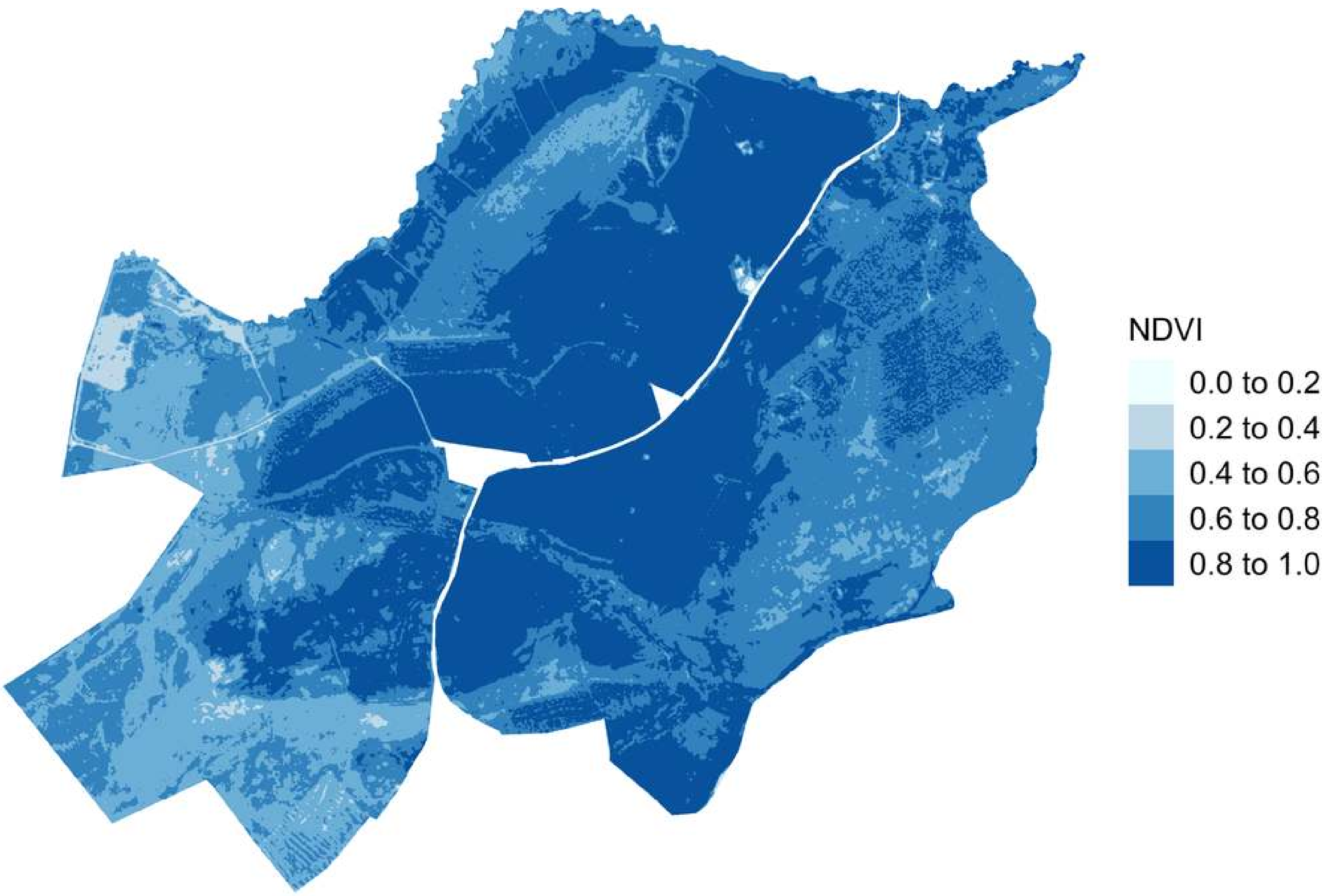


Figure 10: NDVI map generated from satellite imagery



In-field/ground classification

An expert ecologist (Broadview Ecology Ltd.) was commissioned to provide on-the-ground habitat classifications by converting the results from the National Vegetation Classification (NVC) survey (detailed in the following section) into the official UK Habitat Classification (UKHab) categories. This allowed us to make a comparison between the satellite-based and field-based results (Table 4).

The detail included in the UKHab classification makes it difficult to interpret on a map, and so we present these results in tabular form (Table 4). These confirm that a large part of the site is covered by neutral grassland, dominated by Yorkshire Fog (*Holcus lanatus*), and upland acid grassland. Other main habitats present are coniferous plantation, broadleaved woodland of varying types, wet and dry heath, rush-dominated pastures, sedge swamps and blanket bog.

The UKHab categories were also entered into the Defra Biodiversity Metric 3.1 to gain a baseline score for the habitat units present. This metric is a biodiversity accounting tool used in the implementation of the Biodiversity Net Gain policy in England and Wales. While it does not apply under Scottish policy, it is a useful guide to recognised levels of biodiversity and is likely to have some similarities to future metrics in Scotland. Under this metric, 61.66 hectares of the estate are classified as having high or very high distinctiveness (29.24ha high including upland birchwoods, dry heaths and wet heathland; 32.42ha very high including purple moor grass and rush pasture, blanket bog, other swamps and lowland hay meadows) (Figure 11). The Defra Metric also requires each habitat to be scored by its condition, which has not yet been done in the field. For now, conditions scores were standardised as 'Moderate' for all habitats, giving a preliminary score for Beldorney of 3,188.616.

This value is unitless and difficult to compare among sites, but is very sensitive to habitat distinctiveness and condition, giving a basis for calculating biodiversity uplift in the future.

Figure 11: Map showing the areas of habitats classified as having high and very high distinctiveness for the Defra biodiversity metric

Table 4 shows that the grassland and coniferous woodland are classified similarly by the satellite and on-the-ground methods, although the satellite methodology cannot distinguish the many different grassland classes. Unlike on the Bunloit site, Spottitt felt they had insufficient training data for the wetland classes present on Beldorney to be able to attempt accurate wetland classification, leading to the misclassification of wetland areas into woodland, heath and scrub, and sparsely vegetated land.

Ongoing training and development of wetlands classification is important to maximise the value of such methods for future remote habitat classification activities in Scotland.

Table 4: Comparison of satellite-based and ground-based habitat classifications

UKHab code	Description	Area (ha) from satellite	Area (ha) from ground-truthing	
g	Grassland	240.61*	-	242.43
g1b6	Other upland acid grassland	-	82.09	
g1c	Bracken	-	6.03	
g3a5	Lowland hay meadows (H6510)	-	2.01	
g3c	Other neutral grassland	-	94.13	
g3c5	Arrhenatherum neutral grassland	-	6.84	
g3c6	Lolium-Cynosurus neutral grassland	-	10.48	
g3c7	Deschampsia neutral grassland	-	32.47	
g3c8	Holcus-Juncus neutral grassland	-	7.83	
g4	Modified grassland	-	0.55	
w1	Broadleaved mixed and yew woodland	30.00	1.77	19.03
w1a	(Upland oakwood)	-	1.19	
w1b	Upland mixed ashwoods	-	2.22	
w1b6	Other upland mixed ashwoods	-	0.17	
w1d	Wet woodland	-	0.44	
w1e	Upland birchwoods	-	11.71	
w1g7	Other broadleaved woodland types	-	1.16	
w1h	Other woodland; mixed	-	0.37	
w2c	Other coniferous woodland	40.06	41.53	41.53
h	Heathland and shrub	27.04	-	13.19
h1a5	Dry heaths; lowland (H4030)	-	4.64	
h1a7	Wet heathland with cross-leaved heath; lowland (H4010)	-	5.53	
h1b5	Dry heaths; upland (H4030)	-	1.88	
h3d	Bramble scrub	-	0.53	
h3e	Gorse scrub	-	0.61	
f	Wetland	0	-	31.75
f1a5	Blanket bog (H7130)	-	5.83	
f2b	Purple moor grass and rush pastures	-	18.3	
f2b5	Purple moor-grass meadows (H6410)	-	0.15	
f2e	Reedbeds	-	0.55	
f2f	Other swamps	-	6.92	
u	Urban	0.36	-	0
s	Sparsely vegetated land	8.13	-	0
r	Rivers and lakes	0.11	-	0
16	Tall herb	-		2.32
17	Ruderal/ ephemeral	-		1.09
20	Wood-pasture and parkland	-		2.5
230	Garden	-		1.84
	No data	2.48		0
Total		**348.8**		**355.68**

** Of which 151.87 ha is an undefined level 3 class*

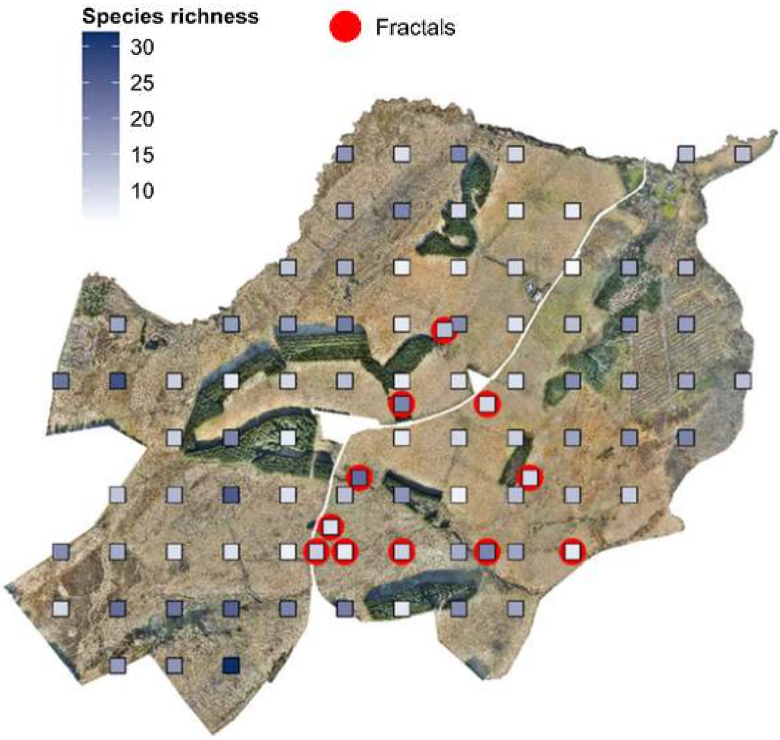
Flora

Plantlife was engaged to carry out a comprehensive botanical survey of Beldorney Estate. Plantlife are a charity dedicated to conserving wild plants and fungi in their natural habitats and helping people to enjoy and learn about them. Their work with us contributes to an ecological baseline prior to restoration and helps to quantify biodiversity on the estate.

Firstly, Plantlife commissioned the experienced upland ecologists, Ben and Alison Averis Consultants, to carry out a National Vegetation Classification (NVC) Survey in September 2022. The NVC is a methodology for very detailed classification of plant communities. Habitats were delineated from aerial photographs as far as possible and then mapped much more precisely in the field. The survey did not use a Minimum Mappable Unit (MMU) but delineated as far as possible individual plant communities and sub-communities. Some habitats did not conform to NVC categories and were described in other terms. A total of 308 polygons were delimited and 60 vegetation and habitat types were found in the survey.

Additionally to the NVC survey, 91 plots (10m^2 quadrats in woodland, 5m^2 elsewhere, at the nodes of a 150m grid) were surveyed and assessed for their plant and structural diversity. 11 of these plots were used to establish a fractal sampling method based on new research that suggests that such an approach can produce accurate results with less surveying effort than traditional grid-based approaches[26].

Figure 12: Map of the species richness within each quadrat



A full species list of the vascular plants and bryophytes found within each plot was recorded, as well as structural features (biotic factors, sward height, percentage of bare ground, and light levels).

The number of species per quadrat ranged between 6 and 32, with a mean of 14. Thatch accumulation was evident in a number of the grassland quadrats preventing a moss layer from developing and reducing the number of species. Future monitoring will detect change in species composition relative to this baseline, and will identify the ecological significance of species as they change over time.

Vascular plants

A total of 177 species of vascular plants were recorded and the site noted as being of moderate importance for vascular plants. Most of the vascular plant species found are widespread and common in Britain, but a few are scarcer or more local in their distributions, for example, Smooth-stalked sedge *(Carex laevigata),* Melancholy thistle *(Cirsium helenioides),* Juniper *(Juniperus communis),* Tea-leaved willow *(Salix phylicifolia)* and Creeping willow*(Salix repens).*

Lichens

A total of 194 species of lichen were recorded, including some species and communities of international and national importance.

Six species are listed in the IUCN Red List and these were found growing in the ancient semi-natural woodland by the River Deveron and in the vicinity of the castle. *Chaenotheca gracilenta* is classified as Endangered, *Bacidia subincompta, Catinaria neuschildii* and *Pyrenula coryli* are classified as Vulnerable and *Collema nigrescens* and *Collemopsidium angermannicum* are classified as Near-Theatened.

Bryophytes

The site is of moderate importance for its bryophyte flora. A total of 108 species were found during this survey, 85 species of moss and 23 species of liverworts. These totals are not particularly high by Scottish Highland standards but indicate a bryophyte flora of moderate richness.

Crimson waxcap
(Hygrocybe punicea)

Hoof fungus
(Fomes fomentarius)

Bitter oysterling
(Panellus stipticus)

Fauna

Camera traps

We purchased ten camera traps from NatureSpy - a non-profit organisation that aims to research and protect wildlife whilst engaging local communities, using the most advanced wildlife watching technology available. We used Browning Spec Ops Elite HP5 camera traps, which we installed across the estate in August 2022, ensuring the different habitats were represented. These camera traps are motion-triggered and record ten seconds of video after each trigger event. Data was collected over a period 12 weeks.

Checking camera traps

Table 5: Number of captures for each species on each camera trap

Species	Camera										Total
	1	2	3	4	5	6	7	8	9	10	
Roe deer	8	28	44	70	75	58	15	81	0	223	602
Red deer	0	0	0	0	0	209	6	39	0	2	256
Wood mouse	195	7	6	0	0	0	0	0	0	0	208
Red squirrel	5	63	3	0	0	0	0	0	0	0	71
Fox	0	1	9	2	0	8	0	9	1	25	55
Badger	17	0	10	0	0	0	0	1	1	7	36
Rat	0	33	0	0	0	0	0	0	0	0	33
Pine martin	19	2	2	0	0	0	0	1	0	0	24
Hare	0	0	0	1	2	0	0	0	0	17	20
Bird sp.	3	6	0	3	1	0	1	0	0	2	16
Pheasant	0	0	0	0	12	0	0	3	0	0	15
Song thrush	0	7	0	0	0	0	0	0	0	7	14
Buzzard	0	0	0	8	0	2	0	0	0	0	10
Otter	9	0	0	0	0	0	0	0	0	0	9
Crow	0	0	0	7	0	0	0	0	0	0	7
Wood pigeon	6	0	0	0	0	0	0	0	0	0	6
Blackbird	0	6	0	0	0	0	0	0	0	0	6
Great tit	1	2	1	0	0	0	0	0	0	0	4
Wren	0	3	0	0	0	0	0	0	0	0	3
Jay	0	0	1	0	0	1	0	1	0	0	3
Barn owl	0	0	0	0	3	0	0	0	0	0	3
Tawny owl	0	0	1	0	2	0	0	0	0	0	3
Robin	1	1	0	0	0	0	0	0	0	0	2
Starling	0	0	0	0	0	0	0	0	0	2	2
Owl sp.	0	0	0	1	0	0	0	1	0	0	2
Rodent sp.	0	0	0	0	0	0	1	0	0	0	1
Chaffinch	0	0	0	0	0	0	0	0	0	1	1
Total											**1,412**

During the 12 week period a total of 1,412 sequences were recorded, which has given us a good initial picture of the larger mammals (as well as a number of bird species) on the estate and where they are broadly located. The most frequently captured animal was the roe deer, with a total of 602 sequences (43% of the total). This species was found on nine of the ten cameras, showing a fairly even distribution across the estate, with a concentration of individuals towards to the north.

Red deer was the second most commonly captured, accounting for 18% of sequences. This species was, however, found on only four of the ten cameras, located to the west of the estate. The third most commonly captured animal was the wood mouse, but 94% of these images were from the same camera and likely to be of the same one or two individuals. This nicely illustrates the complexities of capturing species abundance as well as richness using such visual methods and further work on these issues is planned.

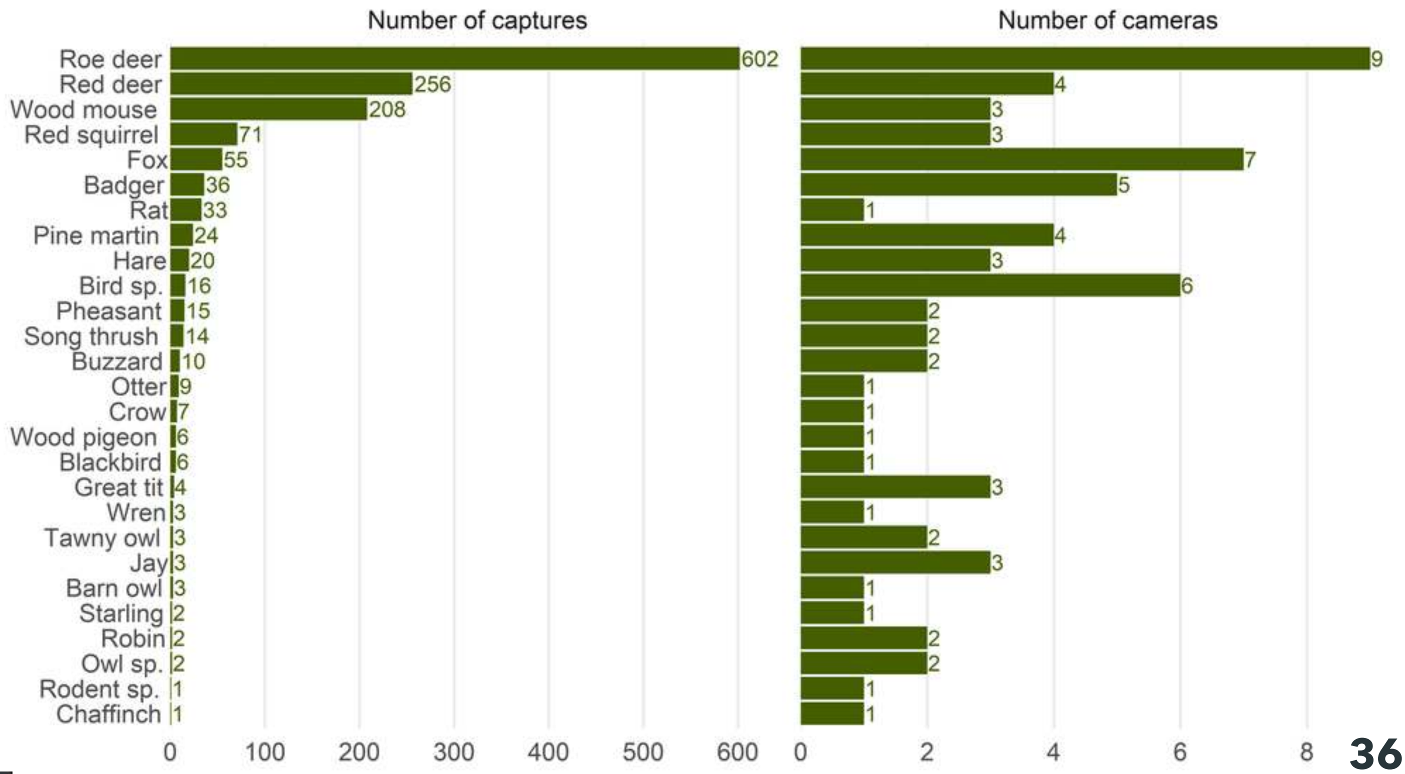

Blue-eyed roe deer


Tawny owl


Fox


Otter

Figure 13: Total number of captures for each species on the camera traps (left) and the number of cameras that each species was captured by (right).



Audio sensors

A bat acoustic survey was carried out on one night - 24th August, 2022. We used five AudioMoths, created by Open Acoustic Devices (OAD)[27]. Each device was set to record from 30 minutes before sunset until 30 minutes after sunrise (20:00 – 06:30), with a sample rate of 384 kHz. The AudioMoths were placed in suitable locations, attached to a tree approximately 2 metres above the ground. Acoustic data was analysed using the BTO Acoustic Pipeline[28] and two sample periods were analysed (20:00 – 00:00 and 04:00 – 06:30).

In total we detected three different bat species – the common pipistrelle, the soprano pipistrelle and the Daubenton's bat (see Table 6). The AudioMoth located on the River Deveron picked up by far the most calls, demonstrating the river's importance as a feeding location. We plan to expand our bat monitoring next year and use ten AudioMoths across the estate and survey throughout the season from May to September.

Table 6: Results by bat species and audio sensor

Bat species	Scientific name	Number of calls: Audio 1	Audio 2	Audio 3	Audio 4	Audio 5	Total calls
Common Pipistrelle	*Pipistrellus pipistrellus*	36	299	14	37	23	**409**
Soprano Pipistrelle	*Pipistrellus pygmaeus*	26	172	2	1	2	**203**
Daubenton's Bat	*Myotis daubentonii*	1	232	0	6	0	**239**
		63	**703**	**16**	**44**	**25**	**851**

Figure 14: Map of total number of bat calls in each sensor location

Birds

Breeding bird surveys were carried out using the BTO's established methodology. Our rangers walked eight transects, each 1km long, which were selected to cover the variety of habitats across the estate. Each transect was divided into five 200m sections and 20 minutes was spent within each 200m section (1 hour 40 minutes for each transect). Birds were identified via sighting or song/call, 50m either side of the central transect line, and the species and numbers were recorded. The early season breeding bird survey was carried out in April, and a late season breeding bird survey in July.

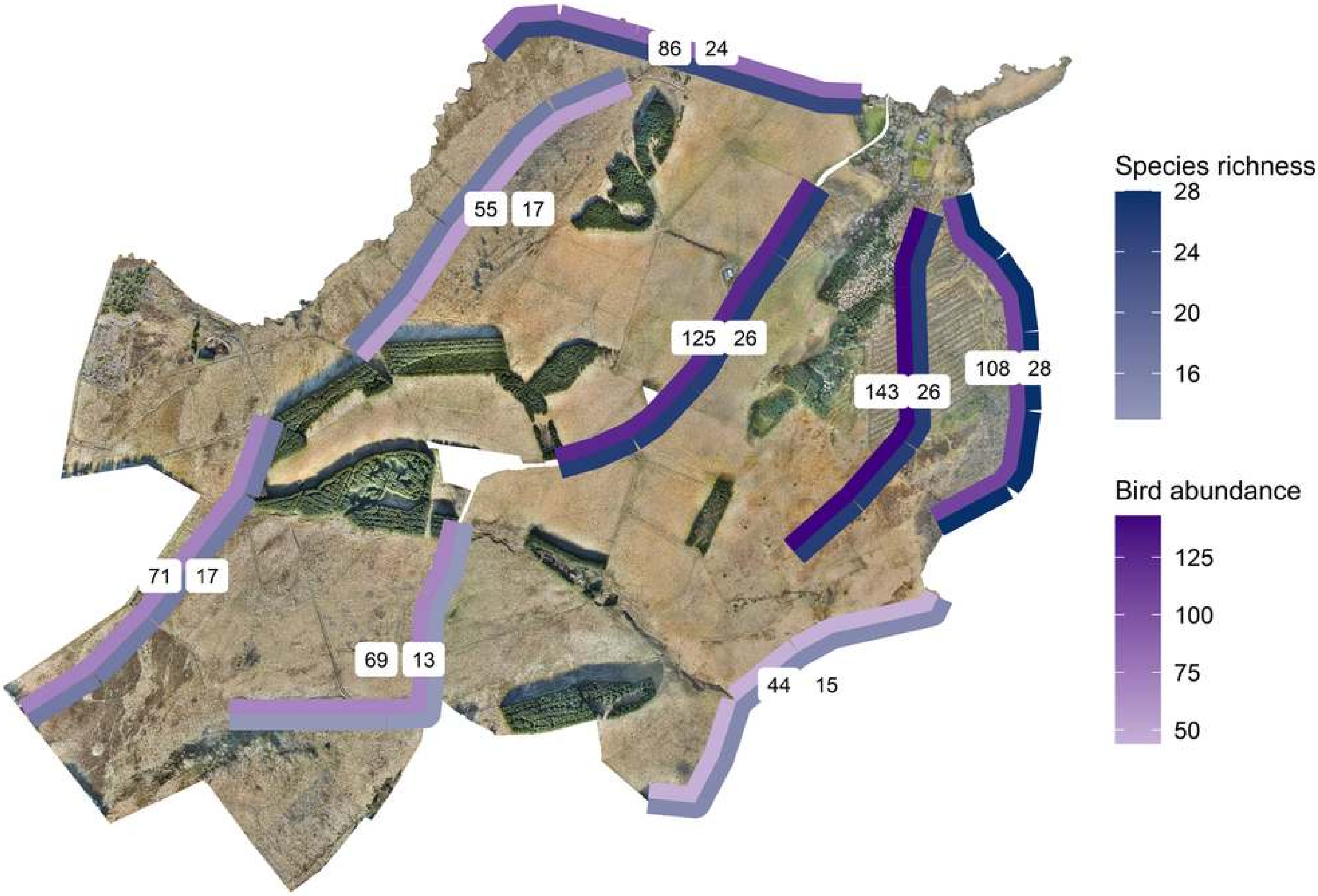
In total, 701 birds were recorded from 51 different species (Table 7 and Appendix 1). According to the UK's Birds of Conservation Concern[29], we have ten species (out of 70) on the Red List, including Curlew, Grasshopper Warbler, Skylark and Yellowhammer, and 15 (out of 103) on the Amber List. Of the remaining 26 species, 24 are on the Green List and the final two are introduced species (Pheasant and Red-legged partridge). Additionally, five of our species are considered endangered internationally and three vulnerable according to the IUCN Red List[30].

Table 7: Results of the breeding birds surveys by transect

Transect	**Species richness**			**Total bird abundance**		
	Early	Late	**Combined**	Early	Late	**Total**
A	24	15	**28**	78	30	**108**
B	13	3	**15**	29	15	**44**
C	16	24	**26**	72	71	**143**
D	18	14	**24**	47	39	**86**
E	19	14	**26**	84	41	**125**
F	16	3	**17**	46	9	**55**
G	15	10	**17**	45	26	**71**
H	13	0	**13**	69	0	**69**


A buzzard's flight caught on camera trap

Figure 15: Map of bird species richness and abundance by transect



Herpetofauna

Artificial refugia were set up along five transects to survey the herpetofauna (reptiles and amphibians) across the estate. Twelve artificial refugia, made of either roofing felt (1x0.5m) or corrugated iron (0.5x0.5m), were placed 20m apart along each transect, in unshaded areas where possible. Two of the refugia in each transect (in positions six and 12) were corrugated iron and the rest were roofing felt. Every refugia was checked 10 times between 18th July and 10th August 2022.

In total, two species were found; common toad and common lizard. Only four individuals were found in a total of 600 inspections. Two of the transects had no herpetofauna, one transect had one common toad on one inspection, and another had one common lizard on one inspection. The final transect, in the acid grassland, had one common toad and one common lizard.

Invertebrates

Butterfly transects

Five transects, each approximately 1km long, were surveyed once a week for four weeks from July 18th to August 9th 2022. Each transect was walked slowly and any butterflies observed within approximately 5m of the surveyor were recorded. A butterfly net was used to catch any butterflies not identified in flight, and these were promptly released after identification.

In total 171 butterflies were recorded from 13 different species. Of the 171 butterflies found, over half (92) were Ringlets.


Meadow Brown buttterfly

Table 8: Abundance by species from butterfly surveys

Species	Scientific name	Total number
Ringlet	*Aphantopus hyperantus*	92
Meadow Brown	*Maniola jurtina*	32
Scotch Argus	*Erebia aethiops*	16
Speckled Wood	*Pararge aegeria*	9
Small White Butterfly	*Pieris sp.*	8
Orange & Black Butterfly	*Butterfly sp. (unidentified)*	4
Large White	*Pieris brassicae*	3
Small Tortoiseshell	*Aglais urticae*	2
Burnished Brass	*Diachrysia chrysitis*	1
Green-veined White	*Pieris napi*	1
Orange Large Butterfly	*Fritillary sp.*	1
Peacock	*Aglais io*	1
Pearl-Bordered Fritillery	*Boloria euphrosyne*	1

Figure 16: Map of butterfly survey transect results

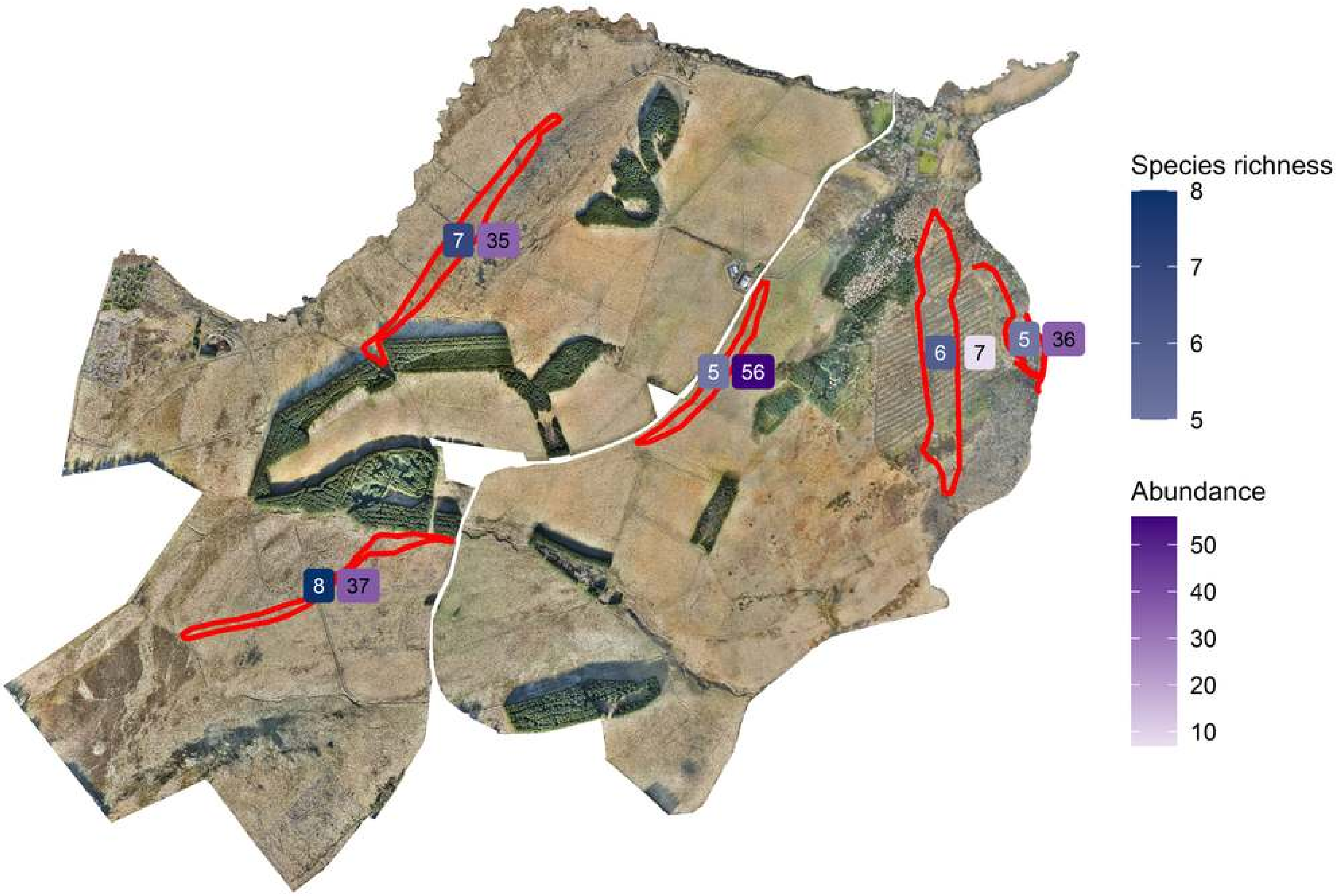


Table 9: Results of the butterfly surveys by transect

Transect	Species richness	Number of butterflies found
1	6	7
2	5	36
3	5	56
4	8	37
5	7	35

The highest species richness was found on the transects on acid grassland (4 and 5). The lowest in the woodland along the river (2) and the improved grassland (3).

The highest number of butterflies was found in the transect in the improved grassland (3), but 47 of the 56 butterflies found on this transect were Ringlets.

Moth trapping

We carried out one night of moth trapping on 2nd-3rd August 2022, with expert help from the local county moth recorder; the start of much more regular surveys.

We have been informed that the 10km recording square (NJ43) within which Beldorney falls is to date very unrecorded and the new species records are therefore beneficial data for species distribution knowledge.

We set up four light traps in different habitats (one homemade bucket trap with LED light and three Heath traps with Actinic light).

Table 10: Results of moth trapping

Trap	Total species richness	Total number of moths found
A	34	113
B	17	119
C	11	33
D	17	90

In total we found 45 different species of moth (see Appendix 2) but four of these species await future verification as they are fairly unusual or rare in the area (Chestnut-coloured Carpet, Slender Brindle, Brown-line Bright-eye and Plain Clay). In future, voucher photos will be taken for verification by experts of each species captured to ensure accuracy of identification and all records will be sent to the local county moth recorder.

Moth trapping




Figure 17: Map of the moth trapping results

Biodiversity monitoring with DNA

We worked closely with NatureMetrics – an innovative UK biotech company that provide commercial sampling kits to monitor biodiversity via DNA - to design a sampling plan to adequately capture the diversity of terrestrial and aquatic invertebrates across the estate. We collected three different types of sample. Firstly, Malaise and pitfall traps were used to collect terrestrial invertebrates and these bulk samples were sent to NatureMetrics for species identification using DNA metabarcoding.

Secondly, we collected soil samples for identification of soil invertebrates and fungi again through DNA metabarcoding. Thirdly, water samples were collected for eDNA analysis to provide a species list of aquatic invertebrates. Detailed methodologies are provided below.

Invertebrate metabarcoding

Malaise traps, with their tent-like structure, are designed to capture flying insects, which are funnelled towards a collection bottle. We sent off our invertebrate samples to be identified through DNA metabarcoding with NatureMetrics, and so used collecting bottles filled with 200ml of propylene glycol. Fifteen Malaise traps (purchased from Watkins & Doncaster) were set up across the estate, covering the key habitats.

Each Malaise trap was supported by three pitfall traps, which are designed to capture ground-dwelling invertebrates. The pitfall traps were situated two metres equidistant from each other and centred on the Malaise trap. Our design, following Brown & Matthews, 2016[31], consisted of two 500ml biodegradable cups buried flush to the ground (the double cup enabled easy emptying) and filled with 100ml of propylene glycol. Above the cups, guidance barriers were placed in a cross design to encourage invertebrates towards the cup, and each was covered with a 25cm x 25cm square of roofing felt.

Malaise trap

All Malaise and pitfall traps were in place for two weeks from mid-July 2022 (starting dates were slightly staggered for logistical reasons).

After two weeks, each trap was emptied, the invertebrate sample was drained of propylene glycol, and the total biomass (wet weight) of each catch was determined. The three pitfall samples from each location were pooled, to give a total of 15 pitfall samples, as well as 15 Malaise samples. After weighing, all samples were transferred to ethanol and delivered to NatureMetrics for DNA metabarcoding.

In total, 588 terrestrial invertebrate taxa were detected

Of the taxa detected, 61.1% (359) could be identified to species level. The remaining taxa were identified to the lowest possible taxonomic level (for example, 128 could be identified to genus level and 71 to family level). Because of these variations in identifiability, we present results below in terms of Operational Taxonomic Units (OTU); a proxy for species where undefined genetic relationships are measured. The average taxon richness across the different traps was 62.6 and ranged from 17 (in Pitfall trap 11) to 144 (in Malaise trap 1). The most commonly detected species included the moth, Dark Arches *(Apamea monoglypha),* a species of harvestman *(Mitopus morio)* and the larch ladybird *(Aphidecta obliterate).*

The Malaise trap in the ancient broadleaf woodland (M2) contained some species typical of this more varied habitat, including *Bryotropha galbanella,* a notable forest moth whose larvae feed on mosses. However, species associated with deadwood were lacking here. Site M3, in a rather neglected forestry compartment with a mix of conifers and broadleaves, did contain better deadwood indicator species, including the Nationally Scarce deadwood beetle *Anaspis thoracica.* Other interesting species found include the Nationally Scarce fly *Dolichopus cilifemoratus,* a species associated with wetter habitats, and the moths Dusky Brocade *(Apamea remissa)* and Double Dart *(Graphiphora augur)* both UK BAP species.

Overall, there were some interesting species but the results indicate a general lack of niches including deadwood, edges and rides within woodland.

The pitfall trap results yielded an overall lower species richness with limited species of conservation interest. Site P3 contained *Parabolitobius inclinans,* a nationally scarce woodland beetle, which relies on fungi, demonstrating again the benefits of forests containing deadwood. Most samples contained a mix of open and woodland species, with a few wetland specialists. Site P15, which has been mob-grazed by cattle, contained some dung beetle species.

Figure 18: The proportion of the sequencing output allocated to the different orders (rows) within each sample (columns) for invertebrate samples. Each bubble per sample represents the proportion of DNA for each order for that sample. Samples M1-M15 are from Malaise traps, samples P1-P15 are from Pitfall traps (Figure from NatureMetrics)

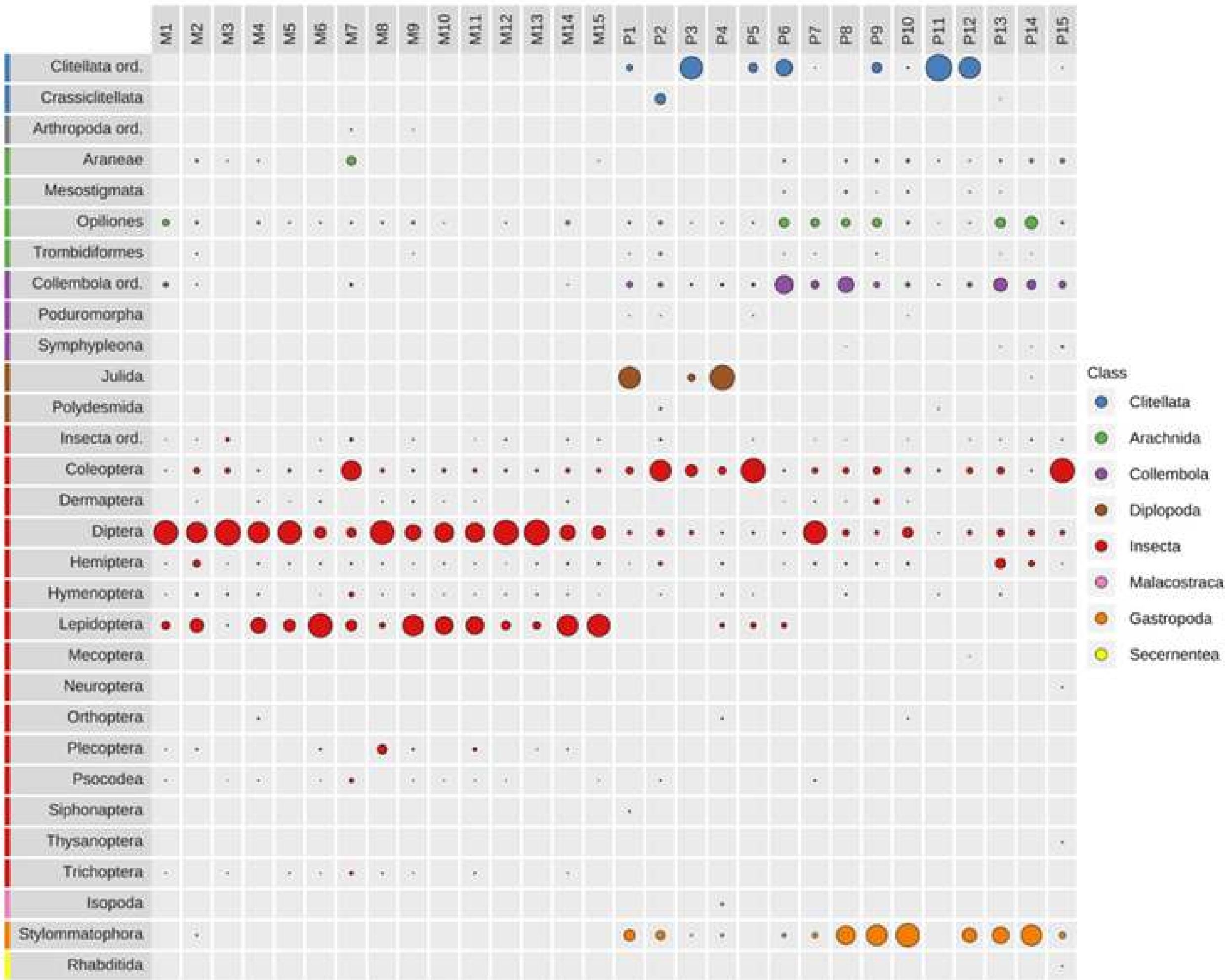


Figure 19: Map of the Operational Taxonomic Unit (OTU) richness from the malaise and pitfall traps

Soil fungi and invertebrates

In each of the 15 Malaise/pitfall sampling locations, three soil samples were collected, at least 20m apart. Each of these three soil samples consisted of five sub-sample cores, collected with a 10ml syringe, to form one combined sample.

In total, we collected 45 soil samples across 15 habitats, and a total of 225 sub-samples across the whole estate. The soil samples were kept refrigerated after collection and then delivered to NatureMetrics for DNA metabarcoding to identify soil fungi and invertebrates.

A total of 1,583 taxa were detected, including 1,203 soil fungi (14% of which could be identified to species level) and 380 soil fauna (18.2% to species level).

The ancient woodland site by the River Deveron (site B) had the highest soil fungal taxa richness, closely followed by site J, which is a grassland area enclosed by coniferous plantations. In contrast, site G (a coniferous plantation) and site D (a clearfell) had the lowest levels of fungal taxa richness. One species of conservation concern, the glistening waxcap *(Gloioxanthomyces vitellinus),* was found in the mixed plantation along Tammie's Burn – this species is listed as Endangered on the IUCN Red List of Threatened Species.

The soil fauna showed a contrasting picture, with grassland sites, particularly the areas of more species-rich or acid grassland, having a higher taxa richness. Further work is required to establish the functional roles of all these soil fungi and fauna

Figure 20: A taxonomic heat tree showing the number of Operational Taxonomic Units (OTUs) across all samples for soil fungal taxa down to the order rank

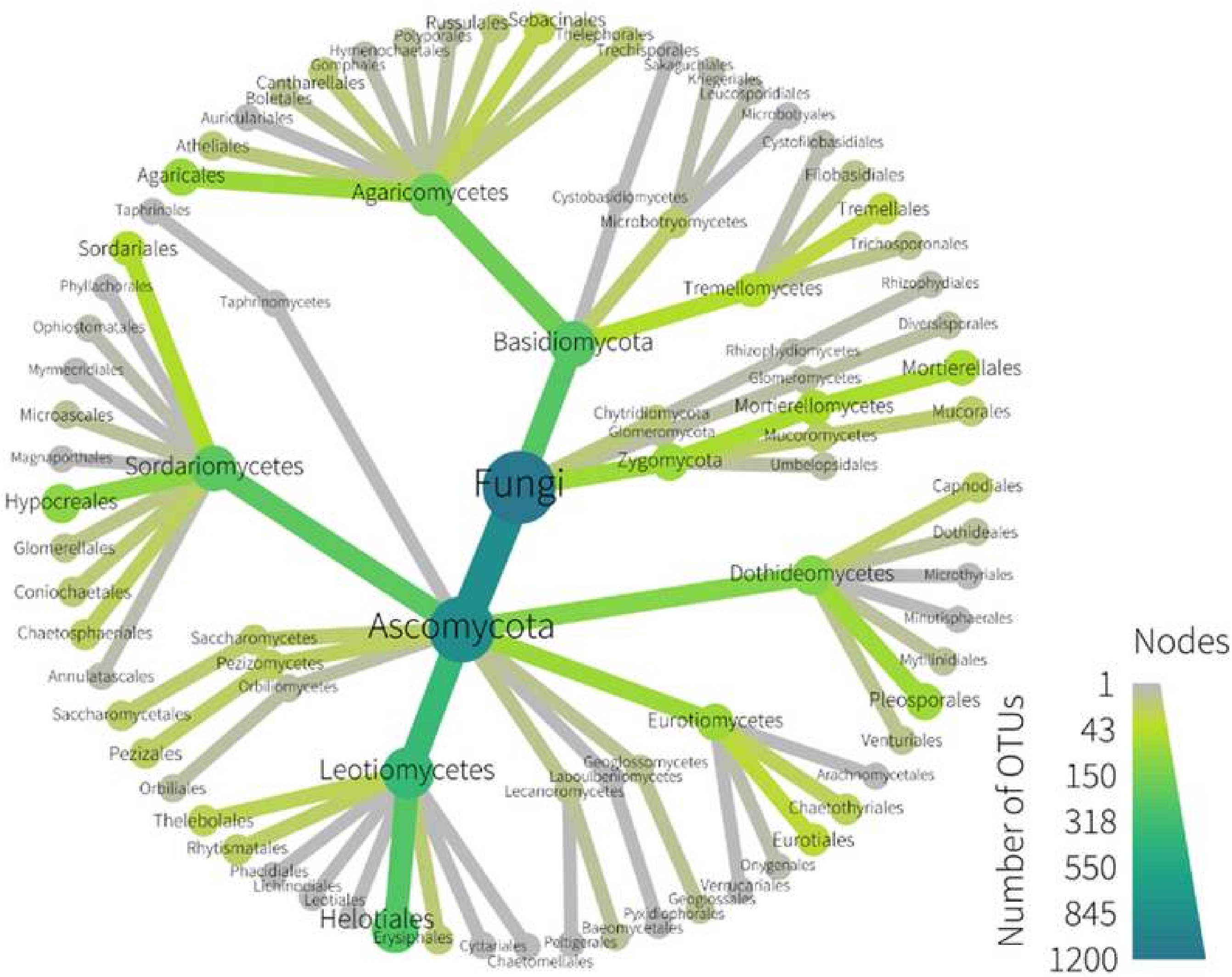
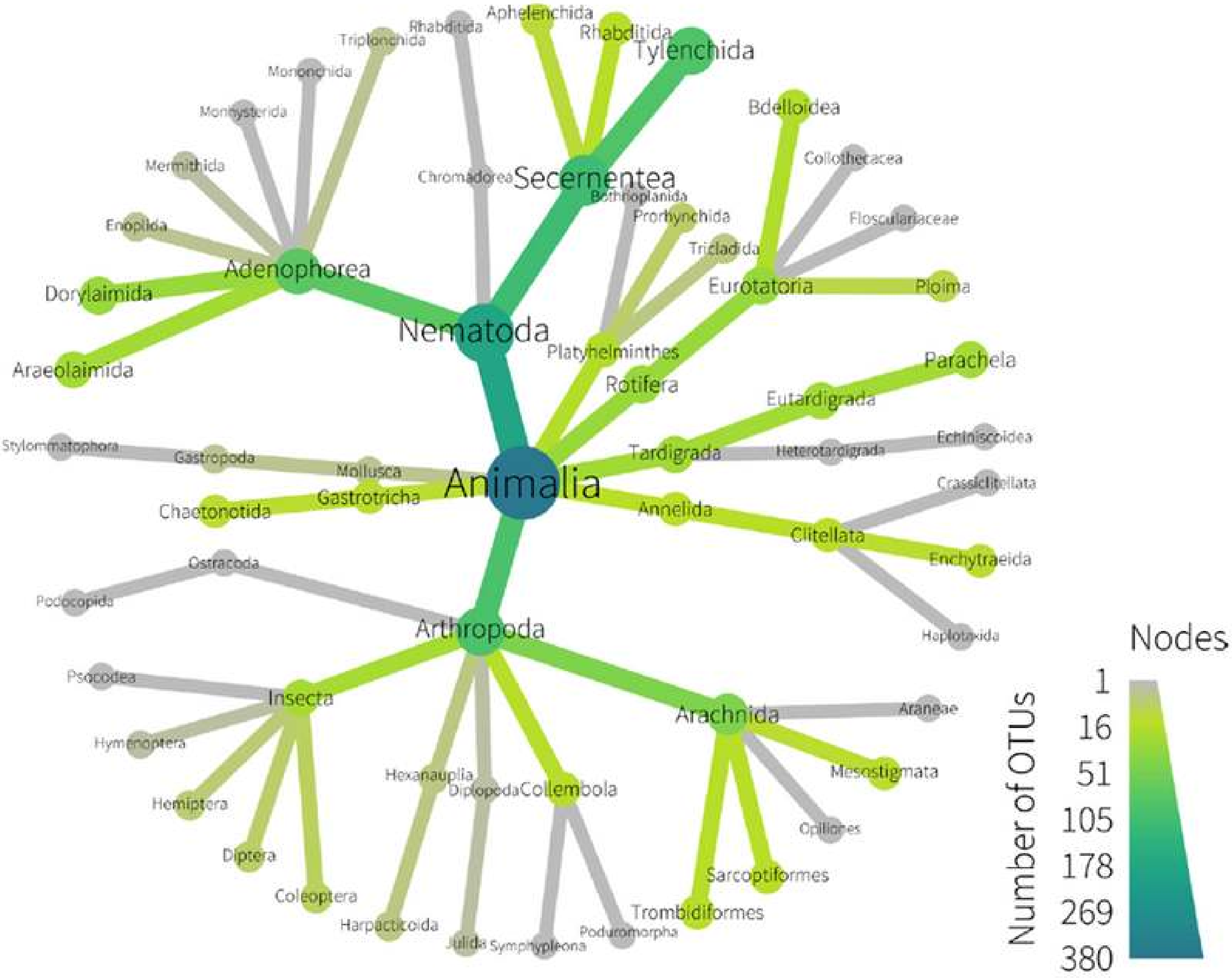


Figure 21: A taxonomic heat tree showing the number of Operational Taxonomic Units (OTUs) across all samples for soil fauna taxa



Soil macroinvertebrates

The eDNA soil surveys, while fantastic at measuring species richness, do not measure the abundance of invertebrates. It is crucial to take account of abundance when measuring biodiversity, as it enables us to understand how species are distributed within an ecosystem and also to monitor the populations trends of species over time. To assess the abundance of soil macrofauna (invertebrates larger than 2mm), we dug soil monoliths (25 x 25 x 10cm) from each sampling location (the same 45 locations where eDNA samples were collected) at 0–10 cm and 10–20 cm depths. Soil was placed on plastic trays and the macrofauna from each depth was sorted from the soil by hand and counted. Biomass was also determined as the fresh, dabbed-dry weight at each species/family level, using a microbalance with an accuracy of 0.01mg.

A total of 747 macroinvertebrates were counted, the vast majority of which were earthworms (millipedes were the other taxa recorded and only six were found).

The counts ranged from one or two in samples C, D and G (coniferous plantations and clearfell) up to 134 and 135 in samples L and O respectively (grasslands). Interestingly, these latter sites are in the fields close to the Mains of Beldorney, which are historically more improved, and less species-rich grasslands.

Figure 22: Map of the 3 sample points for each location for eDNA and macroinvertebrates

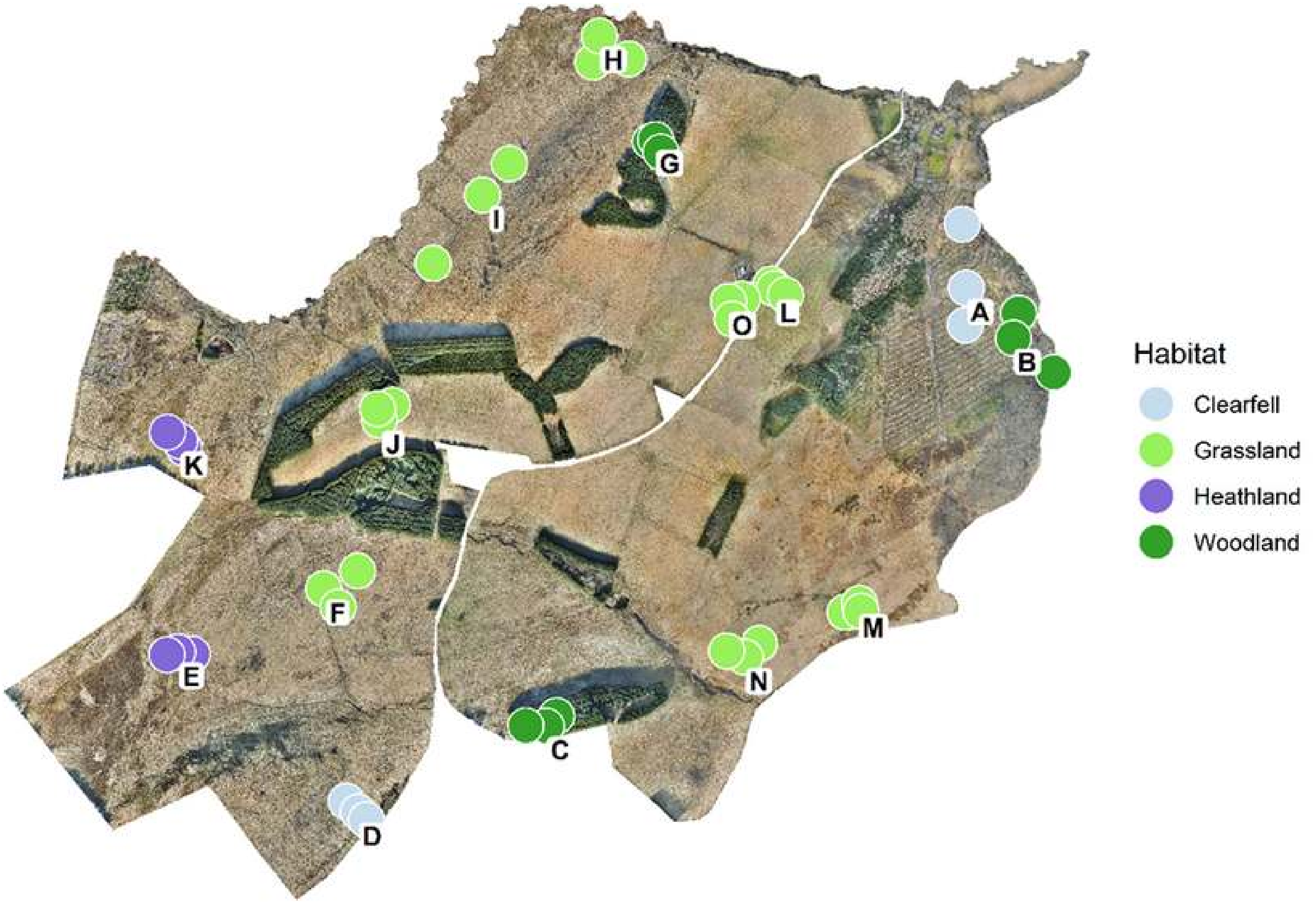
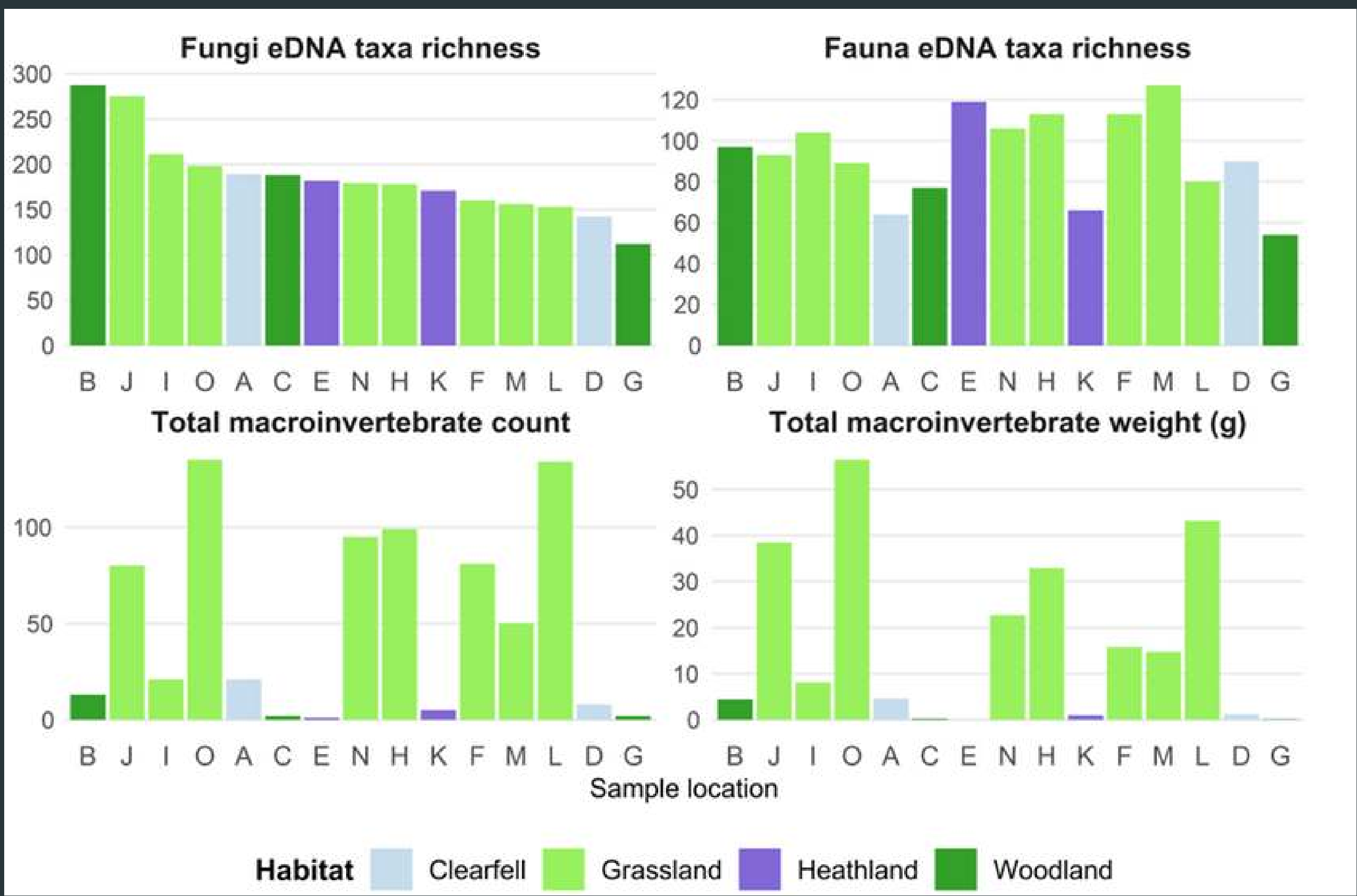


Figure 23: Results from soil sampling locations, ordered by fungi taxa richness



Water samples for vertebrates and aquatic invertebrates

15 water samples were collected from all water body types (burns, ditches, wetlands and rivers) across the estate (see Figure 25). Water was collected in a bag, then syringed through a filter, and these filters were sent to NatureMetrics to analyse the eDNA collected. This analysis detected the presence of vertebrates (those that live in water, such as fish and otter, as well as animals that just pass by, such as deer) and aquatic invertebrates.

A total of 39 taxa of vertebrates were detected from the water samples, including three fish species, three amphibian species, 22 birds and 11 mammals.

The most commonly detected taxa were the short-tailed field vole *(Microtus agrestis),* the European water vole *(Arvicola amphibius)* and the common toad *(Bufo bufo).* The frequent detection of the latter species illustrates the utility of using various methods to survey species, as the herpetofauna surveys were not so successful at detecting toads. In total, seven species of conservation importance were detected: European eel *(Anguilla anguilla;* Critically Endangered, UK Biodiversity Action Plan listed (UKBAP)), Atlantic salmon *(Salmo salar;* UKBAP, SAC), trout *(Salmo trutta;* UKBAP), common toad *(Bufo bufo;* UKBAP), common frog *(Rana temporaria;* SAC), dunnock *(Prunella modularis;* UKBAP) and Eurasian wren *(Troglodytes troglodytes;* UKBAP).

A total of 407 taxa of macroinvertebrates were detected from the water samples, with an average taxon richness of 65.71, ranging from 3 to 147.

The most commonly detected species were the Large Dark Olive Mayfly *(Baetis rhodani),* and non-biting midges *(Macropelopia nebulosa* and *Trissopelopia longimana).* Overall, the species found demonstrated that there are some key aquatic invertebrate niches in Beldorney, for example some good woody debris sites, Exposed Riverine Sediment (ERS) and a few seepage habitats. The samples taken from the River Deveron (Aqua-8, 10 and 15) contain species that indicate a moderate to good water quality, and also reveal the Nationally Scarce Mayfly *Rhithrogena germanica,* albeit with a limited beetle fauna. Both samples taken from Chapel Burn (Aqua-4 and 11), which runs along the northern estate boundary, contain species that indicate a high water quality; this is the best aquatic site on the estate.

Here, there are a number of species associated with coarse woody debris, for example the fly *Dicranota robusta* and other caddis, mayflies and stoneflies. There are also quite a few marshland, mire and seepage species here.

Sites with poorer assemblages include a section of Tammie's Burn flowing through a coniferous plantation (Aqua-2), which contains only midges and a very common mayfly, indicating poor water quality. Also a pond to the north of the estate (Aqua-5) contains species that suggest it is of poor water quality; mainly midges, a common mayfly and a marsh stonefly. Overall, Beldorney contains a few aquatic invertebrates of conservation priority but there are certainly opportunities to increase this number with habitat improvements.

Figure 24: The proportion of the sequencing output allocated to the different taxa (rows) within each sample (columns) for water samples. Each bubble per sample represents the proportion of DNA for each taxon for that sample (figure from NatureMetrics).

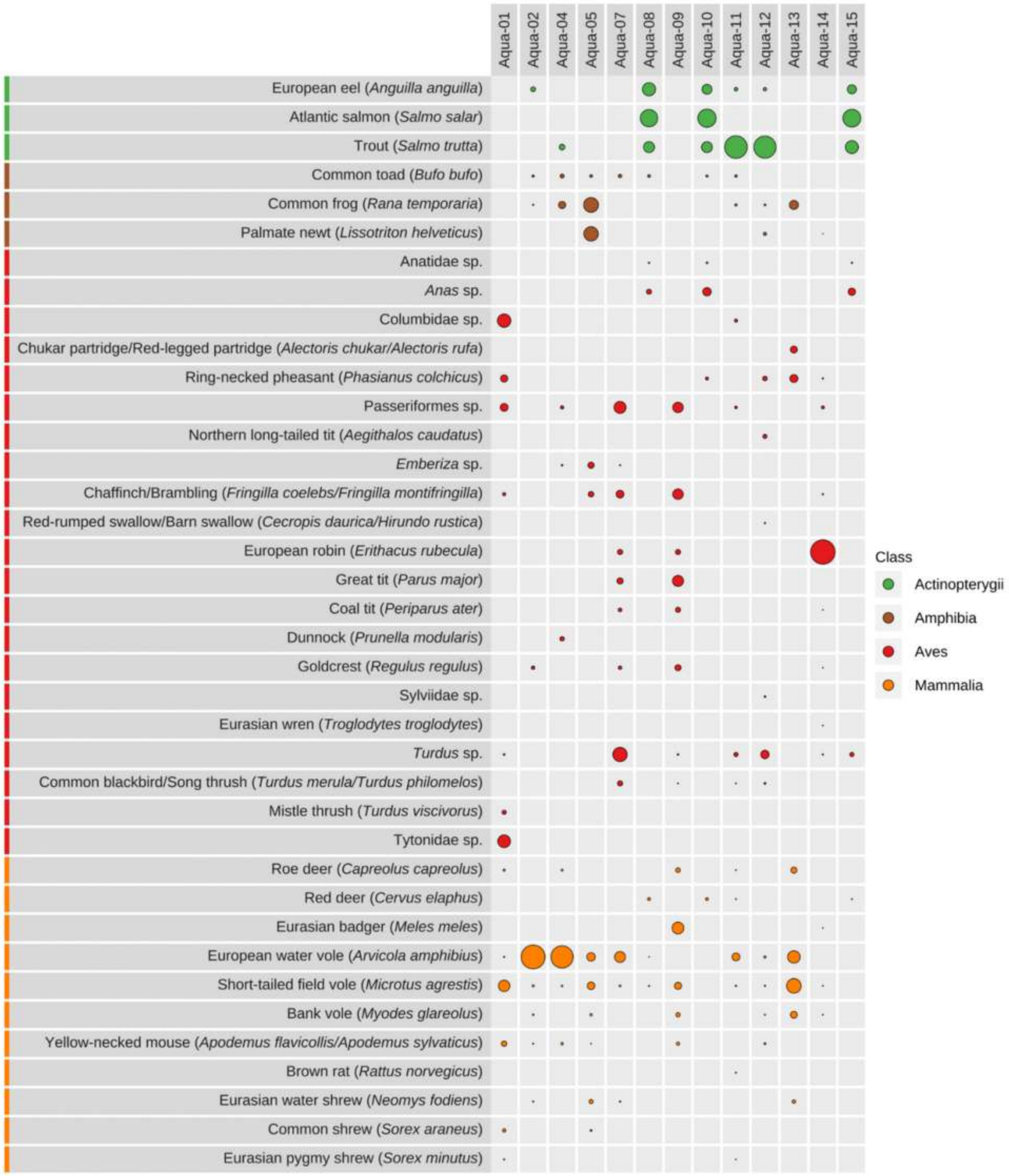
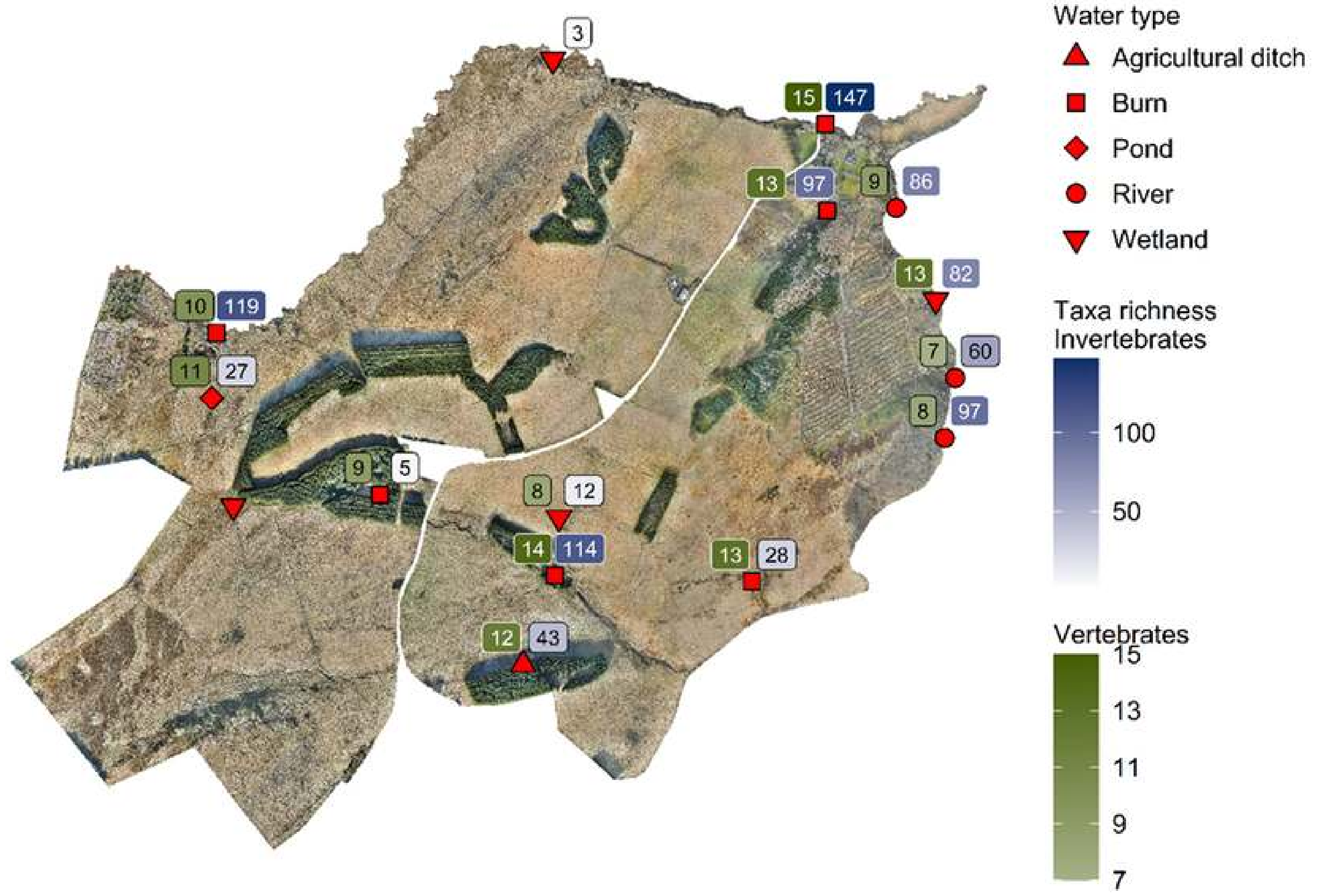


Table 11: Summary of taxa richness across eDNA results from water samples

Sample ID	Habitat	Vertebrate taxa richness				Invertebrate taxa richness
		Fish & amphibians	Birds	Mammals	Total	
Aqua-1	Burn	0	7	6	**13**	28
Aqua-2	Burn	3	1	5	**9**	5
Aqua-3	Wetland	Sample failed				
Aqua-4	Burn	3	3	4	**10**	119
Aqua-5	Pond	3	2	6	**11**	27
Aqua-6	Wetland	Too few target sequences				3
Aqua-7	Burn	1	9	3	**13**	97
Aqua-8	River	4	2	3	**9**	86
Aqua-9	Wetland	0	8	5	**13**	82
Aqua-10	River	4	3	1	**8**	97
Aqua-11	Burn	4	5	6	**15**	147
Aqua-12	Burn	4	6	4	**14**	114
Aqua-13	Wetland	1	2	5	**8**	12
Aqua-14	Agri ditch	1	8	3	**12**	43
Aqua-15	River	3	3	1	**7**	60

Figure 25: Aquatic sample invertebrate and vertebrate taxa richness



Biodiversity conclusions

Our suite of survey methods revealed that the most highly diverse parts of the estate are those containing wetland and native woodland, for example the strip of ancient woodland along the River Deveron and the Chapel Burn on the northern boundary. There are also areas of species-rich grassland and heathland that support a wide range of species. These pockets of diversity would score highly by any biodiversity metric, and we will focus on conserving but also restoring, extending and connecting these areas to create further niches and significantly boost biodiversity across the estate.

Our findings have also illustrated how the species recorded can vary from method to method. For example, the vertebrate eDNA analysis of water samples captured a good range of small mammals, such as water voles and three species of shrew. However, eDNA results did not include species such as otter, hare, squirrel and fox, which have been detected on the camera traps. Other species have not been recorded through any formal method but are known to be present; for example a hedgehog left footprints, and hen harriers and a golden eagle have been spotted in passing. We await to see if these species appear in future surveys, especially if their numbers increase as a result of improved habitats, as we hope.

Results also differ at habitat level. Habitat classification using satellite imagery provided an initial overview, but misinterpreted some habitat types and inevitably could not distinguish some important sub-categories. Here, ground-based plant surveys proved crucial for accuracy as well as to identify high priority habitats on the estate. This habitat information was further complemented by DNA metabarcoding results. For instance, we found numerous species of invertebrate fauna, including some of conservation priority, but also a lack of those requiring specific niches, such as deadwood within woodlands.

Overall, biodiversity findings were consistent and convincing, providing a strong basis for continued monitoring as we work to improve habitats. These findings also give valuable information about where our efforts should focus, revealing where the most and least diverse areas are, and with which species they are most associated. Implications for future management are discussed in the next section.

Management

The findings above provide invaluable information for our management of Beldorney.

From both carbon and biodiversity assessments, it is clear that the native woodlands and wetland areas are the most important parts of the estate, and also have some of the greatest potential for future carbon sequestration and biodiversity gain.

Despite their ecological value, these areas are partly degraded and need to be restored and, where possible, extended.

Beldorney's grasslands are poorer than expected in carbon and biodiversity, and therefore also have enormous scope for restoration.

The existing areas of species-rich and semi-natural grassland provide an example and a basis for this restoration.

Our initial management activities focus on two main elements:

- **Extending native and riparian woodlands by planting the 'Forest of Hope' along the Deveron and controlling deer numbers to allow regeneration elsewhere**
- **Restoring grassland biodiversity and carbon using regenerative agriculture, which also supports the development of scrub and silvo-pasture alongside regenerating woodlands**

Combined with these current activities, we are also developing plans for peatland restoration, wetland restoration, and sustainable harvesting of commercial timber plantations. The existence of these plantations allows us to consider the scope for woodland expansion that retains some element of timber production.

Regenerative agriculture

The scope for applying and evaluating regenerative agriculture at Beldorney is significant. We aim to produce an upland agroecological model that produces useful products for people (like fibre and nutrient-dense food), while rapidly improving ecosystem functioning and biodiversity. Grassland is currently the dominant habitat at Beldorney, offering an exciting opportunity for species-rich grassland (SRG) restoration alongside increasing woodland cover. Over 97% of species-rich grassland has been lost in the UK in less than a century, and 40% of Scotland's has been lost since the 1980s.

Grassland management is now being undertaken through adaptive grazing and livestock management with small herds of cattle, infrequent and rotational hay cutting and bale grazing. This year 86 bales (four feet around) were cut from Mains North field, leaving wide field margins. Another 76 bales of species-rich hay were brought in from the RSPB reserve at Loch of Strathbeg. These bales will feed the cattle over the winter and regenerate diverse seed sources in the fields.

A bale grazing research programme has already been initiated, with protocols under development to assess the impact on soil and plants of bale grazing over a four-year period. This research has not been undertaken in the UK before and, working with FAI farms in Oxford, we are creating comparative data sets for upland and lowland farms. Soil and grassland health will be monitored and recorded using the Soilmentor app. We are also recording grazing intensity in the areas where cows have been used, to contribute to our research into the impact of regenerative agriculture on biodiversity.

Cattle, owned and managed by Grampian Graziers, are currently the only livestock on Beldorney Estate. These animals can play an important role as ecological engineers, cycling nutrients and creating a varied sward structure with adaptive multi-paddock grazing. They are also historically and culturally appropriate in this upland landscape, allowing a continuation of traditional forms of management, albeit at lower intensities than in recent years.

Cows grazing at Beldorney

Forest of Hope

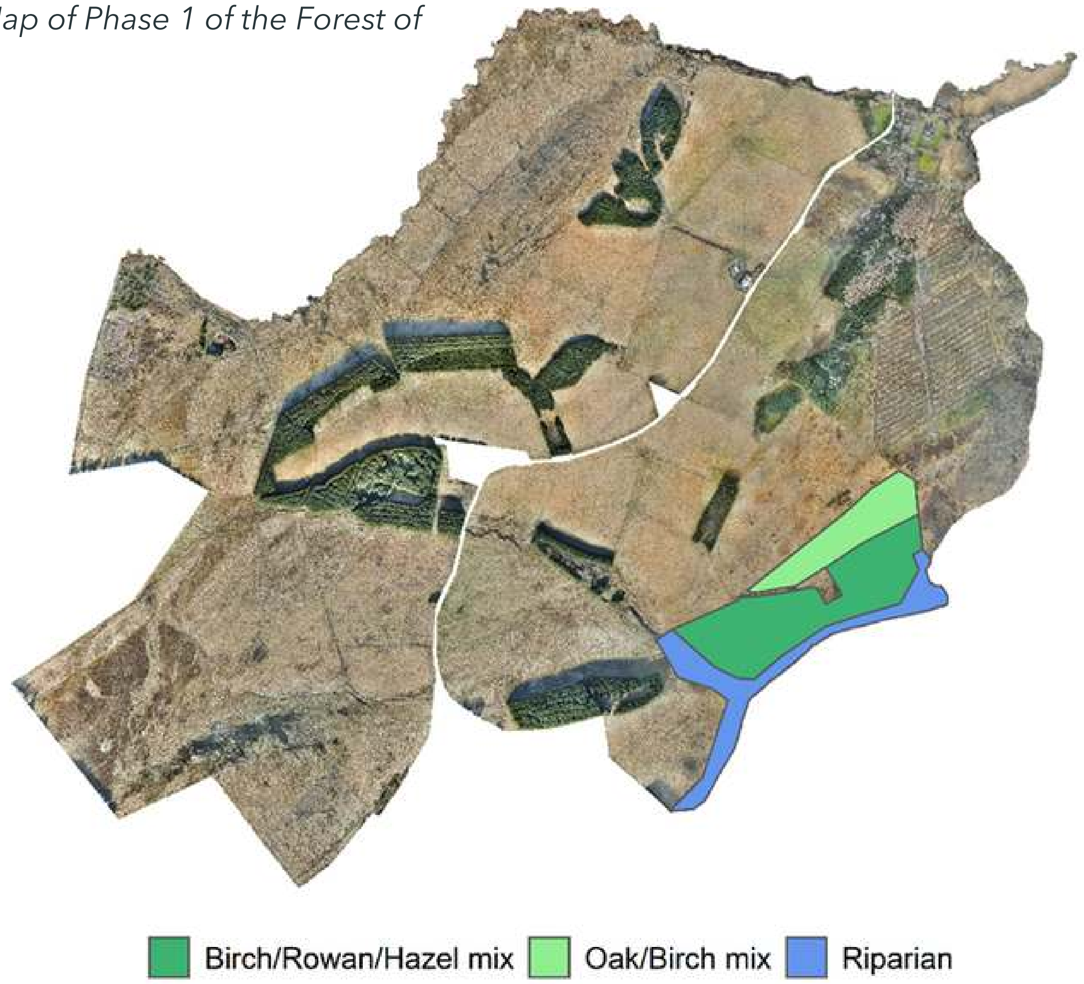
The Beldorney 'Forest of Hope' is a carbon-negative, biodiversity-positive afforestation project, with initial planting of 18.96 hectares as a legacy from the COP26 Innovation Zone. The planted area will extend from the ancient, semi-natural broadleaf woodland that sits in the north-east corner of the estate, on a southeast facing slope along the River Deveron. Woodland Carbon Code calculations estimate that this area will sequester approximately 11,280 tCO_2e over the next 100 years.

We are planting a mix of young native broadleaves sourced from local tree nurseries, suitable for the local climate, elevation and soil. The tree mix includes birch (*Betula pendula*), sessile oak (*Quercus petraea*), hazel (*Corylus avellana*), alder (*Alnus glutinosa*), rowan (*Sorbus aucuparia*), goat willow (*Salix caprea*), and hawthorn (*Crataegus monogyna*).

In late April 2022, we planted 1,400 tea-leaved willows and in late October 2022, we planted 10,000 more trees including alder, hazel, aspen, oak and willow. All the young trees came from the Dundreggan Trees for Life nursery and a further 20,000 trees are due to arrive in early spring 2023.

The planting of the Forest of Hope has given us the opportunity to establish some experimental plots, in collaboration with the University of Oxford's Leverhulme Centre for Nature Recovery. A total of 17 40m x 40m plots of planted trees are being compared to neighbouring unplanted areas (a total of 34 plots). These plots will be monitored and measurements of soil carbon taken, to assess the difference between planting and natural regeneration in an afforestation site.

Figure 26: Map of Phase 1 of the Forest of Hope



Bunloit

Gorse flowering at Bunloit

Update for Year 2

Since the Bunloit Natural Capital Report was published in November 2021 work has continued on the estate.

Our partnership with Glen Urquhart High School has continued.

Two different groups from the high school come once a week for classes led by the rangers.

The Outdoor Education class is an 8-week programme and activities have included the building of mink rafts. These will help to detect if mink are present on the estate, which we need to understand for water voles, by capturing footprints. The class has also helped control the regeneration of Sitka spruce by pulling up and cutting down seedlings.

The Environmental Science class started in August and runs for the whole school year. The class have explored the four main habitats on the estate and will shortly be helping with surveys.


Outdoor education class


Flowering heather

Community walk-and-talks

Over the summer we invited the local community to walk-and-talk events to show them what we've been doing on the estate and discuss ideas for what comes next.

Peatland

Peatland

We are continuing to work with Peatland Action to restore degraded peatlands on Bunloit. Recent work has focused on an area of deep peat that we are restoring from conifer plantation. This plantation has been felled, with ground and watercourse restoration currently being designed to ensure recovery of the site.

Camera Traps

We're continuing to use camera traps throughout the estate to monitor the species present. Highlights include otters being captured on one of the cameras for the first time in spring, a goshawk having a bath, and interactions between deer and boar. The cameras are also helping to give us a general picture of the boar on the estate and what size of litters they had. We are planning further research in this area, to gain accurate estimates of their population size.

Camera trap

Timber

Forestry

The forestry works described in the first Natural Capital Report have been completed and most of the logs collected and taken to the timber mill.

Water voles

We have carried out a number of water vole surveys to establish whether they are present on the estate. We surveyed seven 1km stretches of streams, focussing on the most likely habitat, Allt Dhuan, to the north of the estate. We found a few potential signs of feeding and burrow sites but no definitive evidence. We will survey again in spring and share any findings with the National Water Vole Monitoring Programme (NWVMP). We also await the results of our aquatic eDNA surveys, which may well provide the evidence we need – or perhaps reveal the presence of American mink, which might explain the water vole's absence!


Walking through Bunloit woodlands


Sika deer

Wildlife management

Deer management has continued with the aim of maintaining densities at 2-6 deer per 100 hectares; a level thought to be consistent with woodland regeneration.

Boar populations and their impacts are being carefully monitored and we are developing methods to do this more accurately. Interactions between the two are also being assessed as part of a university research project, and findings so far suggest that boar are concentrated in certain areas of the estate while sika deer in particular are found across the site.


Cows grazing above Loch Ness

Highland cows have returned to undertake low intensity regenerative grazing to help maintain our species-rich grasslands.

We have been experimenting with rolling patches of bracken to reduce its spread and vigour where it is covering large areas and reducing species diversity.

Removal of fences where they're not needed on the estate is continuing to encourage the free flow of wildlife.


Bunloit pastures


Dark Green Fritillary
(Speyeria aglaja)

Butterflies

In the summer annual butterfly surveys were carried out on four transects covering the different habitats on the estate. In addition to more common species like Meadow Brown, Green-veined White and Scotch Argus, various types of Fritillary (including Dark Green Fritillary, Small Pearl-bordered Fritillary, and Pearl-bordered Fritillary) were again identified.

Daniel, one of our rangers, has started a detailed fungi survey on the estate recording the species, location and date of observation. Over 48 different species have been identified so far, including endangered species such as *Pseudocraterellus undulatus*, and Old Man of the Woods (*Strobilomyces strobilaceus*).


Orange Peel Fungus (*Aleuria aurantia*)


Wildlife hide

A small food forest is being created close to the Bunloit farm buildings. This is a sustainable form of local food production with high diversity of crops to make it more resilient to climate change and pests. Initial planting was carried out with last year's Outdoor Education group and included raspberries, gooseberries, currants, strawberries, 'walking' onions, mint, marjoram, and comfrey. 40 fruit and nut trees have been ordered and will be planted this winter.

We've installed a weather station as part of our scientific research, to monitor conditions and compare them to survey findings.

Our rangers have built a hide for visitors to the estate to observe wildlife. The hide was built with timber from the estate and has a green roof of native plants.


View from the hide

Birds

To build up a better understanding of the birds on the estate, in addition to an annual breeding birds survey, we deployed audio sensors to detect bird calls, and carried out bird ringing. The results from these different approaches will be analysed as part of our research into the development of biodiversity metrics, as well as to inform management plans.

Breeding birds surveys

In April and July breeding bird surveys were carried out using the same method as described for Beldorney. The number of birds of different species along ten transects of roughly 1 km was recorded, and the same transects will be used for a winter birds survey.

Audio sensors

We contracted the start-up company Carbon Rewild to survey the birds on Bunloit, using cutting-edge acoustic monitoring technology. Carbon Rewild 3-D print their own weather-proof, acoustic monitors in-house, and then analyse audio data collected by the monitors to identify which species are present. We deployed 11 audio sensors across the estate for four weeks, covering the different woodland habitats, as well as the open peatland areas (for locations see Figure 27). The sensors recorded bird sound for 22 hours within every 24 hour period.

A total of 50,267 bird calls were analysed, which were identified to come from 53 bird species.

Several of the identified species are of conservation importance and have experienced population loss in recent years, with nine species (Spotted Flycatcher, Tree Pipit, Lesser Redpoll, Mistle Thrush, House Martin, Greenfinch, Swift, Ring Ouzel, Whimbrel) on the red list species of conservation concern (BoCC5).


Audio sensor on a clearfell site


Audio sensor by grassland

Figure 27: Carbon Rewild audio sensor locations with the total number of species detected

Figure 28: Summary of Carbon Rewild's acoustic bird survey

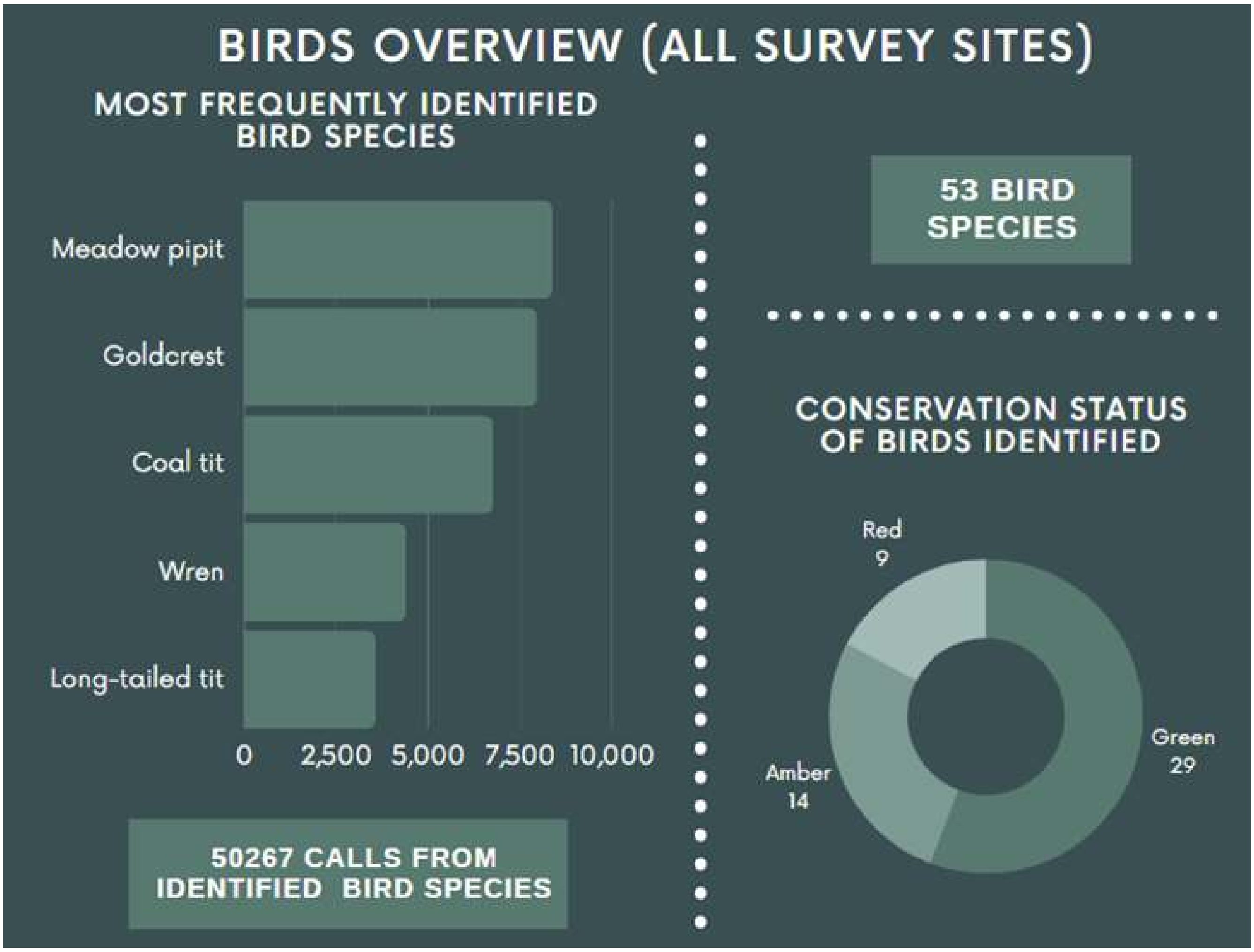


Table 12: The top ten most frequently-identified bird species from Carbon Rewild's acoustic sensors

Species	Identification Frequency*	Conservation Status (BoCC5)
meadow pipit	8350	Amber
goldcrest	7946	Green
coal tit	6743	Green
eurasian wren	4387	Green
longtailed tit	3555	Green
european robin	3213	Green
eurasian treecreeper	3144	Green
spotted flycatcher	1677	Red
willow warbler	1542	Amber
common chiffchaff	1068	Green

The frequency of calls is not an automatic measure of abundance due to differing call behaviour between species, and acoustic characteristics of different habitats.

We will carry out further research into how the acoustic data could be used in future years to understand how the bird populations are changing.

Bird ringing

The rangers on the estate have worked with a local expert bird ringer, John Owen, to carry out ringing on three occasions so far this year. Birds are captured and the species, age, sex, weight, wing measurements and condition recorded before they are ringed and released.

By repeating this over multiple years we will be able to compare aspects such as the species mix, and number of juveniles. If we recapture the ringed birds in future years it will help us to understand patterns of age and diversity. Data is shared with the British Trust for Ornithology to feed into a wider picture of birds in Scotland.


Crested tits


Great spotted woodpecker


Goldcrest

Biodiversity monitoring with DNA

We worked with NatureMetrics to use DNA to continue to monitor biodiversity of the terrestrial and aquatic invertebrates, vertebrates and fungi across Bunloit using the same approach as at Beldorney. We expect to receive the results of this testing soon and will present them, and the comparisons between the estates, in our next report.


Collecting a water sample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Conclusions

We hope this report provides an interesting introduction to the Beldorney estate and the approaches we've used to investigate the carbon and biodiversity there, building on our previous work on the Bunloit estate which was presented in the Natural Capital Report published in November 2021. By thoroughly assessing the current state of the estates we hope to show measurable changes as they become wilder and more natural.

The differing characteristics of the two estates provides us with a rich source of data covering a variety of habitats. Being able to compare the results from different parts of the estates provides valuable insights into how the species present and their abundance may change as the areas rewild.

We intend these estates to become a world-class open laboratory for natural-capital verification science, where we and others can develop new methods to track changes in biodiversity and carbon stocks over time.

Work continues on the data we've collected on both estates as we develop our understanding of the various measures and explore how they can be combined to track biodiversity change over time. We hope this research will help to drive the development of high quality and consistent biodiversity monitoring across Scotland.

We continue to engage with experts, from our academic research partners and more widely, to understand when interventions such as peatland restoration and tree planting are useful to help fast-forward nature recovery. In Beldorney the planting of the Forest of Hope will serve to extend the existing broadleaf woodland along the River Deveron and provide valuable riparian habitat. In Bunloit, removing conifers planted on deep peat will allow large quantities of carbon to be sequestered again.

We believe community prosperity can go hand in hand with nature recovery. We have continued our community engagement including "walk and talk" events at both estates, and welcome the local high school to Bunloit to run open-air classes on an on-going basis. At Bunloit we also are delighted to have our first apprentice ranger join the team and hope his will be the first of many such positions we can offer.

Highlands Rewilding exists to help take nature recovery to scale. We believe we can play a part in helping Scottish Government achieve its targets of "reversing nature loss by 2030" and "substantially restoring and regenerating biodiversity by 2045".

In the report we publish next year we will present more of the cutting-edge science that is at the heart of our mission as we manage our land for carbon and biodiversity uplift and community prosperity.

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View over Loch Ness from Bunloit

Annexes

Annex 1 – Beldorney species list from breeding birds survey

Common name	Scientific name	BoCC5	IUCN2	Total number
Meadow Pipit	*Anthus pratensis*	Amber	LC	119
Chaffinch	*Fringilla coelebs*	Green	EN	63
Willow Warbler	*Phylloscopus trochilus*	Amber	LC	49
Coal Tit	*Periparus ater*	Green	LC	34
Skylark	*Alauda arvensis*	Red	LC	33
Woodpigeon	*Columba palumbus*	Amber	LC	33
Wren	*Troglodytes troglodytes*	Amber	LC	31
Robin	*Erithacus rubecula*	Green	LC	27
Blue Tit	*Cyanistes caeruleus*	Green	LC	26
Song Thrush	*Turdus philomelos*	Amber	LC	25
Blackbird	*Turdus merula*	Green	LC	21
Goldfinch	*Carduelis carduelis*	Green	LC	20
Goldcrest	*Regulus regulus*	Green	LC	19
Buzzard	*Buteo buteo*	Green	LC	17
Great Tit	*Parus major*	Green	LC	17
Mallard	*Anas platyrhynchos*	Amber	VU	13
Carrion Crow	*Corvus corone*	Green	LC	11
Jackdaw	*Coloeus monedula*	Green	LC	10
Chiffchaff	*Phylloscopus collybita*	Green	LC	9
Common Whitethroat	*Curruca communis*	Amber	LC	9
Swallow	*Hirundo rustica*	Green	VU	9
Curlew	*Numenius arquata*	Red	EN	8
Pheasant	*Phasianus colchicus*	NA	NA	8
Yellowhammer	*Emberiza citrinella*	Red	LC	8
Bullfinch	*Pyrrhula pyrrhula*	Amber	LC	7
Dipper	*Cinclus cinclus*	Amber	LC	7
Greenfinch	*Chloris chloris*	Red	EN	7
Grasshopper Warbler	*Locustella naevia*	Red	LC	6
Great Spotted Woodpecker	*Dendrocopos major*	Green	LC	6
Grey Wagtail	*Motacilla cinerea*	Amber	NT	5
Herring Gull	*Larus argentatus*	Red	EN	5
Oystercatcher	*Haematopus ostralegus*	Amber	VU	5
Dunnock	*Prunella modularis*	Amber	LC	4
Siskin	*Spinus spinus*	Green	LC	4
Common Sandpiper	*Actitis hypoleucos*	Amber	NT	3
Pied Wagtail	*Motacilla alba*	Green	LC	3
Treecreeper	*Certhia familiaris*	Green	LC	3
Crossbill	*Loxia curvirostra*	Green	LC	2
Red Legged Partridge	*Alectoris rufa*	NA	NA	2
Swift	*Apus apus*	Red	EN	2
Barn Owl	*Tyto alba*	Green	LC	1
Blackcap	*Sylvia atricapilla*	Green	LC	1
Collared Dove	*Streptopelia decaocto*	Green	NT	1
House Martin	*Delichon urbicum*	Red	NT	1
Jay	*Garrulus glandarius*	Green	LC	1

Long-Tailed Tit	*Aegithalos caudatus*	Green	LC	1
Mistle Thrush	*Turdus viscivorus*	Red	NT	1
Rock Pipit	*Anthus petrosus*	Green	LC	1
Sedge Warbler	*Acrocephalus schoenobaenus*	Amber	NT	1
Tawny Owl	*Strix aluco*	Amber	NT	2
Tree Pipit	*Anthus trivialis*	Red	LC	1


Beldorney in the snow

Annex 2 - Beldorney species list from moth trapping

Scientific name	Common name	Total number
Mesapamea secalis agg.	Common Rustic agg.	59
Noctua pronuba	Large Yellow Underwing	58
Xestia sexstrigata	Six-striped Rustic	54
Mythimna impura	Smoky Wainscot	47
Xestia xanthographa	Square-spot Rustic	20
Eudonia truncicolella	-	18
Xestia baja	Dotted Clay	13
Apamea monoglypha	Dark Arches	9
Noctua janthe	Lesser Broad-bordered Yellow Underwing	9
Eudonia lacustrata	-	7
Argyresthia goedartella	-	6
Diarsia rubi	Small Square-spot	6
Diachrysia chrysitis	Burnished Brass	4
Udea lutealis	-	4
Eugnorisma depuncta	Plain Clay	3
Hydriomena furcata	July Highflyer	3
Xanthorhoe designata	Flame Carpet	3
Yponomeuta evonymella	Bird-cherry Ermine	3
Dysstroma citrata	Dark Marbled Carpet	2
Litoligia literosa	Rosy Minor	2
Agriphila tristella	-	1
Alcis jubata	Dotted Carpet	1
Alcis repandata	Mottled Beauty	1
Apamea remissa	Dusky Brocade	1
Apamea scolopacina	Slender Brindle	1
Celypha lacunana	-	1
Cerapteryx graminis	Antler Moth	1
cnephasia sp.	Cnephasia species	1
Cosmorhoe ocellata	Purple Bar	1
Crocallis elinguaria	Scalloped Oak	1
Diarsia mendica	Ingrailed Clay	1
Epinotia ramella	-	1
Epirrhoe alternata	Common Carpet	1
Eulithis populata	Northern Spinach	1
Gandaritis pyraliata	Barred Straw	1
Geometra papilionaria	Large Emerald	1
Graphiphora augur	Double Dart	1
Idaea aversata	Riband Wave	1
Lacanobia oleracea	Bright-line Brown-eye	1
Lycophotia porphyrea	True Lover's Knot	1
Mythimna conigera	Brown-line Bright Eye	1
Thera cognata	Chestnut-coloured Carpet	1
Thera obeliscata	Grey Pine Carpet	1
Ypsolopha parenthesella	-	1
Zeiraphera ratzeburgiana	Spruce Bud Moth	1