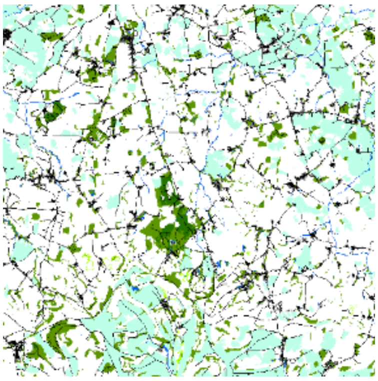
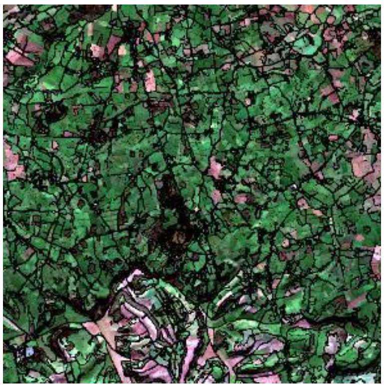
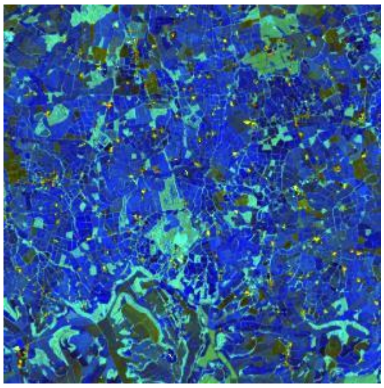
ITT 7471: Long term effectiveness of AES funded bracken control

Final Report



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1 Executive Summary

Bracken, *Pteridium aquilinum,* is a familiar component of the English countryside, especially in upland areas. It is a component of many habitats and is typically found on hill pastures in the uplands (up to 590m), as an understory in woodlands, and on coastal slopes and verges (Grimes *et al* 1989). It is an important component of the 'inbye' habitats on the upland / lowland edge which support a number of scarce and declining bird and animal species. It adds structure and colour to the landscape over the course of the year.

With climate change and the current growth of interest in 'rewilding' and more natural methods of landscape management, there is a risk that bracken could assume a greater dominance in the countryside. This would be to the detriment of agricultural production, biodiversity, damage historic interest features and affect recreational access. This project investigates the effectiveness of bracken control, using remote sensing techniques to investigate the current impact of the agri-environment schemes in England.

AES data from both HLS and CS schemes was evaluated to identify a sample of parcels containing relevant options and capital work. For these parcels, two strands of analysis were undertaken: a remote sensing assessment of changes to bracken cover during the agreement period, and interviewing land managers to gather evidence regarding the effectiveness of the bracken control options in the agri-environment scheme on the holding.

A remote sensing methodology was developed that used optical satellite imagery from the Landsat-8 and Sentinel-2 platforms to evaluate changes to bracken cover over 2014 to 2020. The methodology devised measures to mitigate for cloud cover reducing the temporal frequency of data availability over the 7 years evaluated, and for a lack of spatial information on the exact extent of bracken options within parcels. From a final sample of 134 parcels, it was found that bracken cover had mostly reduced over the evaluation period, and typically covered less than 30% of parcels by 2018-2020. Overall, these results suggest that the bracken control work is having a positive effect on reducing bracken cover for the parcels evaluated.

Comparing the remote sensing findings against environmental factors, the results were strongly influenced by geographic clustering of results, but there was some indication that rate of bracken growth may be affecting outcomes, with areas likely to support faster bracken growth more strongly correlated with increase in bracken cover between baseline and revisit assessments. Detailed case studies also demonstrated the importance of site- and agreement- specific variables for evaluating the success of bracken control measures.

Interviews were conducted for 171 agreement holders and were designed to collect structured information about the effectiveness of the bracken control options and

any additional work that agreement holders has undertaken/is undertaking in addition to elements supported by their AES agreement. In particular, interviews covered the extent of follow up treatments, and how grazing and other environmental factors contributed to controlling bracken re-establishment after any initial treatment. This includes details on grazing animals, such as the type, duration and timing of such interventions.

The interviews showed that a significant proportion of the agreement holders had been managing bracken both within and outside AES agreement for a long time, and there is a sense that bracken management is becoming more challenging. The impacts of bracken are perceived as wide ranging, but centre on the impact on biodiversity and a loss of grazing land. Agreement holders feel that treatments need to be made repeatedly throughout the agreement, especially when using mechanical control measures. The interviews with agreement holders revealed a possible link between grazing and bracken control, but it was not clear that cattle were more effective than other livestock. Further research is needed to assess the effectiveness of different grazing regimes, timing and the type of livestock on bracken control. The issue of bracken control is clearly complex and it could be impacted by local factors, such as altitude or geology. What is clear is that farmers and other agreements holders are innovative in their attempts to reduce the spread of bracken.

The findings of this project suggest that a number of years of control are needed to reduce bracken cover within parcels, but given climate change and increased interest in rewilding, conditions are likely to favour extremely vigorous bracken growth in the future. Therefore, we recommend that bracken control should form part of future agri-environment schemes, especially on historic monuments or other sensitive habitats. Furthermore, we suggest that remote sensing should be used as part of an integrated approach for monitoring the effectiveness of bracken control using a combination of automated classification of bracken at scale with satellite imagery, detailed case studies from manual interpretation of aerial photography, and a program of farmer interviews to understand how the agreements are implemented and perceived.

1 Introduction

Bracken, *Pteridium aquilinum* is a familiar component of the English countryside, especially in upland areas. It is a component of many habitats typically being found on hill pastures in the uplands, to 590m; as an understory in woodlands on coastal slopes and verges (Grimes *et al* 1989). It is an important component of the 'inbye' habitats on the upland / lowland edge which support a number of scarce and declining bird and animal species. It adds structure and colour to the landscape over the course of the year.

Whereas bracken is a common feature of many of England's finest areas of countryside it can spread rapidly. It possesses an extensive system of underground rhizomes and is an extremely competitive plant that can form dense mono-species stands which reduce grazing land and form a barrier to stock moving from one area to another. It can also harbour ticks, posing an increase animal health risk (Burge and Kirkwood, 1992), and can invade other priority habitats reducing biodiversity. The rhizomes can also damage archaeological features, causing damage to underground structures and smothering features above ground. It therefore requires management to keep it in check. Historically bracken would have had many uses: livestock bedding, domestically for fuel, bedding and roofing material and in industry to produce ash for soap and glass production. These farming practices kept areas it dominated under control, but have since largely died out and therefore bracken spread has increased.

Deposition of atmospheric nitrogen and Increase temperatures due to climate change have also favoured bracken dominance (Werkman *et.al.*, 2006). There has also been an Increase in sheep numbers and a decrease in cattle in the uplands and this has led to less trampling of bracken and therefore let it become more dominant. All these factors have led to an increased growing season and greater vigour of the plants.

Because of the damage unmanaged bracken can do to priority habitats, grazing land and archaeological features, bracken control has featured in all Agri-environment schemes in England (AES). There are several management options involving bracken control in the current Environmental Stewardship scheme (within the Higher Level (HLS)) and since 2016 in the Higher Tier of Countryside Stewardship (CS).

Chemical application is generally the favoured method of control on steep slopes where soil erosion and health and safety may be a risk (Natural England Technical Information Note TIN048), although options for mechanical control (such as cutting and bruising) are available on sites with easier access and can be effective in some settings, notably those when chemical use is not possible, or is not botanically appropriate due to the presence of species of conservation Interest which would be vulnerable to the spray. Whilst success may be immediate in the right conditions (in first and second years following the initial treatment) bracken can recover rapidly after this without follow up treatment (Lowday and Marrs,1992). Continuing suppression and follow-up treatments, or effective subsequent grazing regimes, therefore need to be implemented to maintain bracken control long-term.

With climate change and the current growth of interest in 'rewilding' and more natural methods of landscape management, there is a risk that bracken could assume a greater dominance in the countryside, to the detriment of agricultural production, biodiversity, damage to historic interest features and recreational access. This project uses remote sensing techniques to investigate the effectiveness of bracken control and assess the current impact of the associated agri-environment schemes in England.

1.1 Background

Bracken control has been used in a variety of Agri-Environment Scheme (AES) agreements including Environmental Stewardship's Higher-Level Scheme (HLS) and the new Countryside Stewardship (CS), to maintain or restore wildlife value or protect archaeological features. It can also help to maintain and conserve the vegetation mosaics characteristic of upland and heathland landscapes. The main options used are set out in
Table 1-1. These options (including supplements and capital items) are mainly intended for use with lowland heathland and upland options, but could also be used where bracken control is necessary: for example, on dry grassland, in woodland, and on sand dunes.

Table 1-1: Bracken relevant HLS capital payment option codes and descriptions

HLS Code	HLS Name
HR5	Bracken Control Supplement
BMB	Mechanical bracken control – base payment
BMA	Mechanical bracken control – area payment
BCB	Chemical bracken control – base payment
BCA	Chemical bracken control – area payment
BDS	Difficult site supplement for bracken and scrub control

Table 1-2: Bracken relevant CS codes and descriptions

CS Code	CS Name
SB4	Chemical Bracken Control
SB5	Mechanical Bracken Control
SP3	Bracken Control Supplement

1.2 Aims

This project will carry out research to help understand the role that follow up treatments, grazing and environmental factors have in controlling the speed of bracken canopy re-establishment after initial treatment. The project drew on data collected from AES agreements, analysis of multispectral satellite imagery and environmental data sources to establish which factors govern the rate of re-establishment of bracken canopy following bracken control.

Specific objectives are to:

1. Identify a methodology for measuring the extent and vigour of bracken canopy by remote sensing from satellite data.
2. Analyse and determine the value of grazing data collected by land managers as a requirement of an AES in order to gain a view on the effect of grazing on bracken re-establishment.
3. Determine how other environmental data such as soil characteristics, elevation, aspect, region, and climate can be used to provide a broad picture of the range of factors that influence bracken recovery.
4. Identify the significance that varying grazing regimes play in controlling bracken re-expansion across a wide range of English landscapes under a range of different environmental conditions.
5. Provide evidence to underpin advice given to landowners, inform options for future bracken control and follow-up treatments (under AES) and demonstrate the role of grazing in keeping areas bracken free.

The outputs of this study will be presented at a webinar for Natural England and other key interested parties, and will be published on the DEFRA website as a Research Report.

1.3 Context

1.3.1 Bracken Phenology

While originally a woodland species, bracken can be found in a wide range of habitats across the UK including 'inbye' upland pastures, upland heather moorland as well as lowland habitats including dune slacks, lowland grass and heath and woodland. Bracken grows best in well-drained loamy or sandy soils with an acidic pH although it can tolerate a range of soil conditions. Bracken vigour is also reduced by cold, wind and frost (Natural England, 2008).

Bracken grows quickly throughout the spring and summer, exhibiting vigorous vegetation, then dies back in the autumn to form a thick mass of deep red/brown litter (Figure 1-1). This dead litter persists throughout the winter and well into the spring of the next year, when it is replaced, or at least obscured, by new bracken growth (Holland and Aplin, 2012).

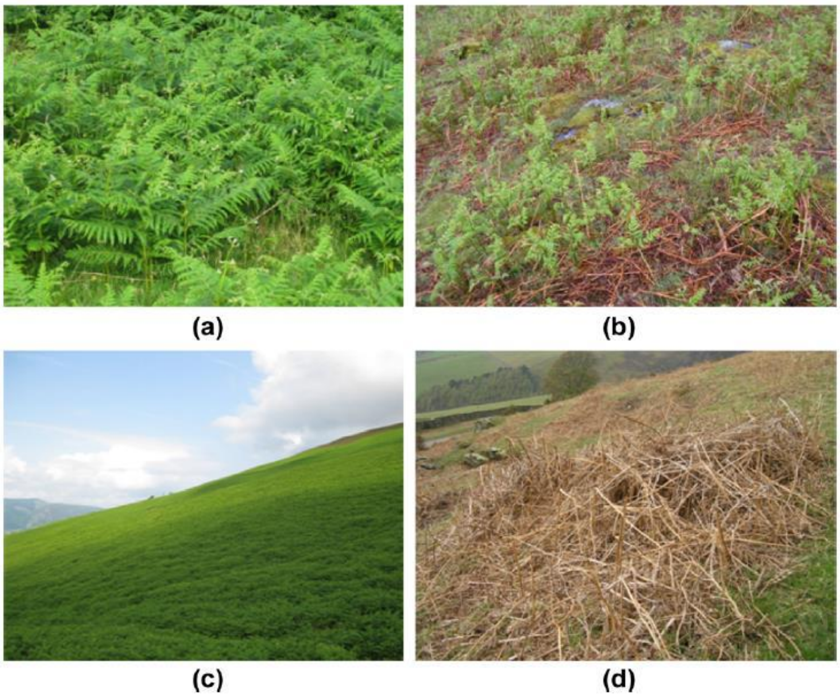

Figure 1-1. Seasonal change in the appearance of bracken. (a) Bracken in full growth, (b) Bracken landscape in spring, (c) Bracken landscape in summer, (d) Bracken landscape in winter

Bracken productivity is site-dependent related to a range of factors from the aspect of slope to the current land management. The rate of bracken growth may therefore, vary considerably between sites, even when only short distances apart (DEFRA, BD1239). The impact of the weather can also influence peak performance, with long hot summers producing peak frond density and colder, wetter summers tending to have lower bracken performance (MAFF, BD1209). This work sets out to investigate which site factors are most significant in ensuring that bracken management activities prove effective in the short and long term. In this project short term refers to year to year changes in bracken canopy, while long-term refers to the 10-year AES time frame evaluated. However, in the context of bracken biology these may represent relatively short time frames as the rhizome structure is resilient and may take many years of repeated treatment to effectively reduce the vigour of large stands.

Furthermore, in this project we assume that monitoring the bracken canopy is a good proxy for evaluating the control of bracken infestation as a whole. This is largely a result of the technologies used, as remote sensing is only capable of evaluating the bracken canopy. However, a note of caution is required here as the vigour of the underlying rhizome network, rather than the canopy, is the key driver of bracken infestation. This network may also extend beyond the visible canopy.

1.3.2 Bracken control

Over the lifetime of HLS bracken control options have been used in over 600 agreements and covering 11,000 ha at an estimated cost of over £4,000,000. Under CS there are currently 258 agreements covering 4,637 ha of land (data derived from the Rural Payments Agency).

The funding for bracken control may be provided by Historic England (where damage is occurring on Scheduled Monuments) or landowners/farmers to prevent encroachment on economic assets such as pasture land and grouse moors. Control efforts are also often supported by volunteers who help to cut and pull bracken by hand on selected sites, especially in National Parks and AONBs.

Irrespective of the initial control method bracken tends to re-establish over time depending on a variety of factors. These include the effectiveness of the initial control, whether follow-up treatment was carried out, environmental factors, and crucially the nature, timing and intensity of grazing over subsequent years.

Asulam is the main chemical used for bracken control in the UK. It is best applied in early summer when the fronds are at full extension. Since European approval to use asulam ended on 31 December 2012, temporary, annual arrangements have been put in place to permit the use of asulam for bracken control to continue in the UK. Approval has been subject to the terms set out in Emergency Authorisations granted by the Chemicals Regulation Division (CRD) of the Health & Safety Executive. There is no guarantee that these annual arrangements will continue. Mechanical control should occur mid- to late June when the bracken fronds are between 50-70cm high. It should be repeated six weeks later and this twice yearly cutting will be required for at least 3 years (Natural England Technical Information Note TIN048).

In order to avoid the unchecked re-expansion of bracken into areas where it causes damage to the natural or cultural environment, a better understanding is needed of the factors which may affect its spread and re-establishment. In addition to this project, there are currently field trials on bracken control and alternative chemical control to Asulam being carried out by Prof Roy Brown in the North York Moors national park, and an ongoing project for Historic England which is looking at mechanical and chemical means of controlling bracken on archaeological features on Ingram Farm in the Cheviot Hills and Challacombe Farm in Devon (Oatway, 2020).

We are on the cusp of significant change in the agricultural economy. One of the trends which is already apparent is a move towards agricultural de-intensification, including an increasing interest in 'wilding' projects and other more 'natural 'approaches to managing the landscape. There is considerable anecdotal evidence that the type of grazing animal, the stocking density and the timing of grazing activity are critical factors which affect the rate of bracken re-establishment after treatment. Cattle and pigs grazing an area after bracken control over winter can help break up bracken litter and expose rhizomes to frost damage (SEARS, 2008) Understandably, it is virtually impossible to construct robust scientific field trials to investigate this, due to the wide range of variables which would need to be controlled and the economic and welfare issues that could arise from such an experiment.

An additional challenge with bracken control is the potential for long-distance translocation of carbohydrates in the rhizome system (Le Duc et al, 2003). This means that mechanical and chemical treatment of small stands may be ineffective as nutrients can be sourced from other nearby untreated stands. A thorough literature review on this topic would be greatly beneficial, but this was beyond the scope of this study.

Records collected under HLS and CS combined with other widely available data (e.g. climate data, topographic data etc.) present a unique opportunity to study this concept in another way. This project uses satellite imagery together with a broad range of data (which was collected for other purposes) to describe the range of conditions that bracken grows under and reflects the grazing practices encountered in the real world. It is hoped the methods trialled here will enable the effectiveness of bracken control in the medium-long term to be evaluated. A broad range of management factors which may influence bracken re-establishment could also be studied at a national scale, and lead to a better understanding that will help inform future AES.

2 Methodology

2.1 Overview

The project methodology was conceived pre-COVID and had to adapt in the face of travel restrictions. In this section we will outline both the original planned methodology and the final methodology that was devised to allow the project to deliver outcomes in COVID-secure fashion.

Original methodology:

Task 1: Evaluation of data

a. Evaluate AES data from both HLS and CS schemes to identify a sample size of 150-200 agreements on which bracken control has taken place under the applicable HLS/CS options and capital work. These identified agreement holders were then approached to take part in an interview.
b. Contact a representative sample of agreement holders to determine the likelihood of them providing records on bracken control and grazing.
c. Through conversations with land managers, establish the most appropriate method of gathering data on grazing and timing of bracken work.
d. Establish the availability of suitable satellite imagery at an appropriate temporal and spatial resolution for the classification of bracken extent. Develop a bracken classification methodology and test its accuracy from a series of field visits.
e. Evaluate the availability of other data sources to assess variables such as habitat type, soil, elevation, aspect, slope, region and climate which affect bracken re-establishment after initial control.
f. Produce report detailing outcomes of data evaluation for a review of project viability.

Task 2: Data Collection

a. Extract relevant data from AES agreements with bracken options and/or capital work. To include: date, type of control, follow-up methods and agreed bracken management plan (if present). Full data review provided in section 0.
b. Contact the identified agreement holders (via phone/e-mail) to confirm the data on bracken control held by Natural England and to obtain additional information on the type of control, timing, and any follow-up that may have taken place.
c. Gather national coverage multi-temporal Landsat-8 and Sentinel-2 satellite data for bracken classification.
d. Collect other relevant environmental data on for example soil, elevation, aspect, climatic conditions and historic features present.
e. Produce a short report outlining data collected and implications this may have for analysis and the final report.

Task 3: Data processing and reporting

a. Assess and summarise the data collated to develop an analysis demonstrating the impact individual variables have on the re-establishment of bracken.
b. Undertake statistical and qualitative analysis of all data to evaluate the relationship between the rate of bracken re-establishment and other factors such as environmental, climatic and management.

The main influence COVID had on the project was that social distancing and regional lock-downs meant that travel to farms was not possible. Consequently, all interviews and data requests from farmers had be done remotely, making provision of bracken control records under task 1b more difficult. Fieldwork to calibrate and validate the methodology planned for task 1d was also not possible, with the result that the bracken classification was restricted to evaluating only the extent of bracken stands rather than their extent and vigour.

The resources that would have been used for field work was reallocated to deliver additional value to Natural England as follows:

- The sample size of agreements evaluated with remote sensing was increased from 150-200 agreements, up to ~600, i.e., the full sample of bracken relevant agreements found during task 2a.
- The effectiveness of bracken control over historic environment features, such as Scheduled Monuments, was evaluated.
- A selection of more detailed case studies that compared remote sensing results against agreement records provided by Natural England was undertaken.

2.2 Data Review

2.2.1 Data from Natural England

Natural England provided spreadsheets containing 425,100 CS and 1,202,549 HLS options, and included both bracken and non-bracken relevant options.

Individual parcels were provided in the form of Rural Land Registry (RLR) Anonymised LIDM Land Parcels. This is a geodatabase of ~3 million land parcels covering all of England.

2.2.2 Satellite imagery

Sensor Overview

Analysis was conducted using imagery captured by Landsat-8 and Sentinel-2 between 2013 and 2020 (Table 2-1). These are optical Earth observation monitoring systems that continuously capture imagery globally at spatial resolutions suitable for sub field scale work. All data from both systems is also available at no cost to the end user, making them among the best data sources available for long-term land cover monitoring work.

The NASA Landsat missions have been capturing imagery for land cover monitoring since 1973, with Landsat 8 beginning operations in 2013. Landsat-8 captures imagery over the UK at least every 16 days, and has a spatial resolution of 30m for visible and near-infrared bands.

Sentinel 2 is operated by the European Space Agency as part of the European Union's Copernicus Programme for Earth observation. The mission currently comprises a pair of satellites launched in 2015 and 2017, with full operations beginning late 2017. The constellation provides a minimum revisit frequency of 5 days, and has visible and near-infrared bands with spatial resolutions of both 10m and 20m, though in this project we were only interested in the 10m bands.

Figure 2-1 provides a comparison of the spatial resolution of Landsat-8 and Sentinel-2 for a potential bracken site captured at the same time of year. In this example you can clearly see that the Sentinel-2 image provides a clearer picture of the parcel than Landsat-8, but they are both capable of picking out similar features such as roads and areas of productive vegetation (e.g. bright green areas).

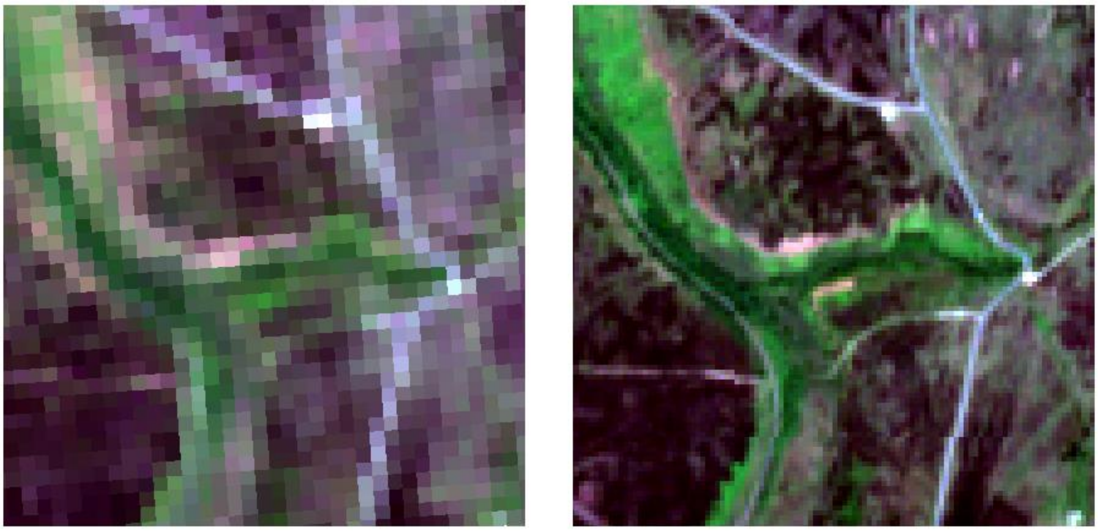

Figure 2-1: Visualising the difference in spatial resolution between 30m Landsat 8 (left) and 10m Sentinel 2 (right) pixels over a potential bracken site.

Table 2-1 provides a summary of the key characteristics of each sensor, including the expected number of captures per year. Note that actual frequency of capture for any particular site may be higher than the minimum due to overlap between satellite orbits.

Table 2-1: Summary of available satellite sensors detailing key characteristics over the UK

Sensor	Operational Period	Spatial Resolution (m)	Swath Width (km)	Min. Frequency of Revisit (UK)	Min. Captures per Year
Landsat-8	2013 - Present	30	185	16 days	22
Sentinel-2	2015 - Present	10	290	5 days	73

Cloud Coverage

Both Landsat-8 and Sentinel-2 are optical sensors, meaning that they capture imagery in the visible and near-infrared portion of the electro-magnetic spectrum, and are affected by cloud cover. If an area is covered by cloud at time of capture, it is impossible to observe features on the ground. Therefore, the theoretical/useable number of captures per year is often greatly reduced, especially during winter months.

To illustrate the effect of cloud upon the total number of datasets available for analysis, we have compared the maximum possible number of images for each season against the number with less than 20% cloud cover (Table 2-2). This table shows that Landsat-8 typically has 10-15% of useable imagery, while Sentinel-2 has typically >20% as a result of it higher revisit time and wider swath width. It's important to note that the figures listed are approximations for England as a whole, and the cloudiness of the land parcels selected for this project will be dependent on the exact conditions at time of capture. Additional mitigation for cloud cover was provided by applying cloud detection algorithms and manual cloud masks to the imagery as section 2.5.1 outlines.

Table 2-2: Summary of available datasets for each time period, to demonstrate the effect on cloud cover on scene availability, and that some years are less cloudy than others.

Period	Sensor	Images with <20% cloud	Max. possible images	Percentage available
Summer 2013	LS8	22	131	16.8
Winter 2013-14	LS8	20	208	9.6
Summer 2014	LS8	20	141	14.2
Winter 2014-15	LS8	25	237	10.5
Summer 2015	LS8	17	147	11.6
Winter 2015-16	LS8	31	236	13.1
Summer 2016	LS8	17	143	11.8
Winter 2016-17	LS8	17	232	7.3
Summer 2017	LS8	29	145	20
Winter 2017-18	S2	511	2594	19.7
Summer 2018	S2	663	1626	40.7
Winter 2018-19	S2	535	2628	20.4
Summer 2019	S2	328	1603	20.4
Winter 2019-20	S2	625	2579	24.2
Summer 2020	S2	266	1599	16.6

2.2.3 Open-source vector layers

Within the RLR parcels there will be areas that are not suitable for bracken growth or mapping, such as water bodies or forestry. In order to omit these from the analysis two open-source vector datasets were used:

- OpenStreetMap water layer.
- National Forest Inventory (NFI) interpreted forest type. In particular the Broadleaf, Conifer, Coppice and Mixed classes were extracted.

These vector layers were used to create masks of ineligible features for each parcel.

2.2.4 Environmental data

It is important to assess associations between detected bracken and environmental characteristics to determine other factors which might influence bracken recovery. Strong correlations with certain environmental factors may suggest that they play a significant role regarding re-establishment (following the initial control), and may help target locations where further control is necessary.

Habitat

A range of datasets that provide information on habitat across England were considered, including Land Cover Map 2015 and the Crop Map Of England. However, these were both discounted as they do not provide sufficient resolution regarding the dominant habitat within which the bracken occurs . When considering the effectiveness of bracken control on regrowth, other environmental factors that are the drivers of habitat distribution, such as soil, aspect or elevation, are likely to be more strongly correlated.

Soil

Bracken can grow on a wide range of soil types; from dune slacks with greater than 90% sand content to shady woods on heavy clay, however evidence suggests it does not tolerate saline or permanently waterlogged soils. Conventionally, it is seen to be an indicator of deep, loamy well-drained or sandy soil as it seems to thrive and often dominate in these conditions. However, it has been found where wet flushes occur and even alongside streams. A principal factor determining presence in wet areas appears to be the oxygen level of the soil[4].

Soil information was extracted from Natural England's National Soil Map which gives the most precise available national-level data. This avoided the need to question land owners on their soil composition.

Because bracken regrowth depends on the recovery of the rhizomes which lie deep within the soil the following layers were determined to be important factors to examine bracken growth: subsoil texture, topsoil texture, and wetness. The subsoil and topsoil texture classify England and Wales into 22 different soil textures. The soil wetness layer classifies land according to six different classes, ranging from least (I) to most (VI) saturated. Figure 2-2 shows soil texture and moisture classes and their distribution across England and Wales.

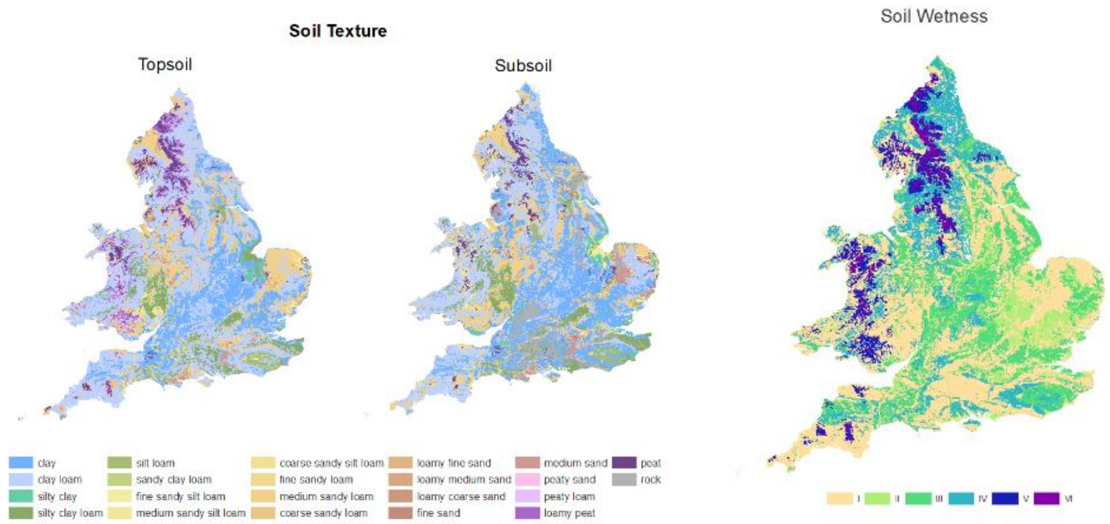

Figure 2-2: Topsoil texture (left), subsoil texture (middle) and soil wetness (right) layers extracted from the Natural England National Soil Map

Elevation, slope and aspect

The degree and the aspect of the slopes on which bracken grows seems to vary with altitude, it generally prefers south-facing slopes as altitude increases. The chief limiting factors seem to be extremes of cold (including high altitude regions) and poorly-drained locations such as marshes and fens. Essentially a temperate climate plant, bracken can be found between sea-level and 3000 metres. However, in the UK, its range is limited to altitudes of below 600 metres (Natural England, SIN011).

Elevation data was derived from the Environment Agency's Integrated Height Model (IHM). This is predominantly based on LiDAR data and provides 2m coverage across England.

Slope and aspect layers were both derived from the elevation layer. Slope represents the rate of change of elevation for each cell in the elevation model, and is expressed in degrees from 0 (flat surface) to 90 (a vertical cliff). Aspect describes the compass orientation of the elevation model cell. Aspect was calculated by categorising the elevation data into eight cardinal directions, as Figure 2-3 shows. Where gradient was less than three degrees, the aspect was classified as 'flat' to avoid drawing false conclusions from noisy aspect data at low gradients.

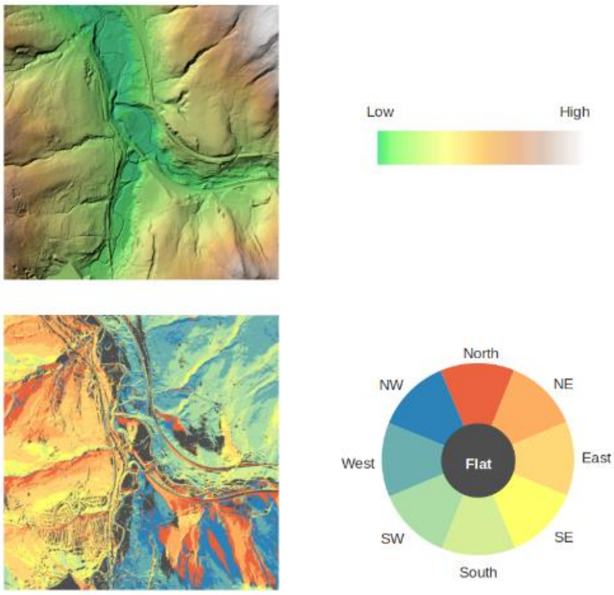

Figure 2-3: Sample from the elevation dataset (top) with the corresponding categorised aspect (bottom)

2.2.5 Climatic data

Regional climatic data was sourced from the Meteorological Office HadUK-Grid data provided by the British Atmospheric Data Centre (https://data.ceda.ac.uk/badc). These are climate variables derived from UK land-surface observations and provided on a range of different spatial and temporal resolutions.

For this project a balance between spatial/temporal resolution and data processing volumes was evaluated, and it was decided to download 5km gridded monthly data for the last decade (January 2010 - December 2019) for the following variables:

- tas: Average of daily mean air temperature.
- tasmax: Average of daily maximum air temperature.
- tasmin: Average of daily minimum air temperature.
- rainfall: Total precipitation amount (mm).
- groundfrost: Count of days when the grass minimum temperature is below 0 ◦C (days).

For each year the following variables were calculated for each 5km grid cell:

- Mean annual temperature.
- Minimum monthly temperature.
- Maximum monthly temperature.
- Total annual rainfall.
- Total annual days of ground frost.

Each variable was then averaged over the 10 years and evaluated to provide a summary of climate that could be intersected with the parcel database. Examples of the 5km grid outputs for ground frost and mean air temperature are provided in Figure 2-4

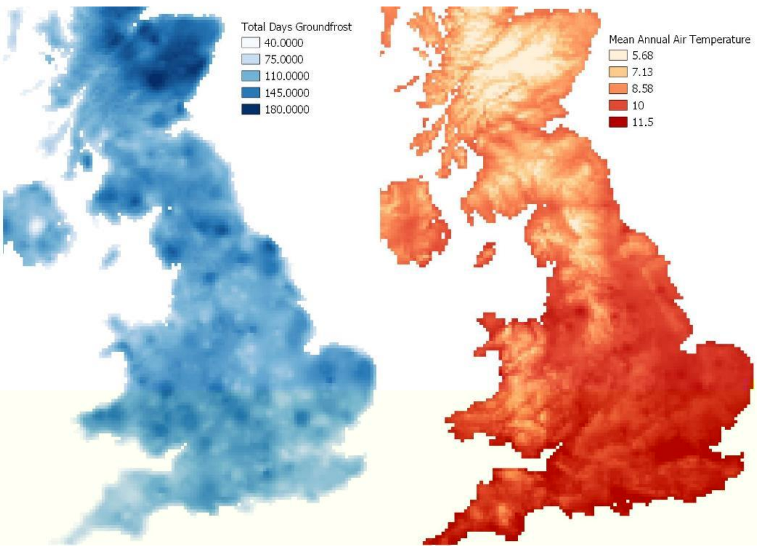

Figure 2-4: 5km grid showing total days of ground frost (left) and mean annual air temperature (right) averaged over 2010-2019

2.2.6 Historic Environment Data

The following Historic environment data was sourced from Historic England (https://historicengland.org.uk/listing/the-list/data-downloads/):

- Battlefields: Polygons showing extent of protected area surrounding ~50 English battlefields.
- Parks and Gardens: Polygons showing extent of Parks and Gardens of special historic interest.
- Scheduled Monuments: Polygons showing the extent of the statutorily protected area associated with scheduled monuments.
- Heritage at Risk 2020: Polygons that provide an indicative understanding of the overall state of England's Heritage assets.

In addition to these publicly available data, Natural England provided a spreadsheet containing details of historic features found on the HLS parcels under evaluation in this project. This dataset provided details and grid locations of ~1000 individual historic features such as barrows or agricultural systems. The grid references of these features were converted into OSGB Eastings and Northings and a spatial point dataset was generated for overlay with the parcel database.

2.3 Selection of Candidate Parcels

The CS and HLS option spreadsheets provided by Natural England required filtering to identify only those options that were relevant to this project. The process of filtering these parcels is shown in Figure 2-5 and detailed below:

A. Natural England advised that Options in the Isles of Scilly were not required as interviews were not possible on the Isles.
B. Options and capital work were filtered to select only those that contained bracken relevant codes. See Table 1-1 and Table 1-2 for relevant HLS and CS codes respectively.
C. CS options with start dates no later than the 31/08/2018 were selected for analysis. This date was chosen as later start dates would not have been in place for long enough to assess the effect of follow-up management.
D. HLS with end dates after 01/01/2020 and work end dates after 31/02/2020 were selected. These dates were chosen to ensure that options were either currently under live agreement, or only recently finished, and thus enable a better interview response rate.
E. The CS and HLS datasets contained attributes that were named differently, but referred to the comparable values. To support further analysis, attributes were standardised between these datasets as follows:
    - AGREF: Unique agreement ID (CSREF or AGREF)
    - STARTDATE: Option start date
    - ENDDATE: Option End Date
    - SCHEME: Level of land management scheme
    - OPTCODE: HLS or CS option code
    - OPTDESC: HLS or CS option name
    - CAPREV: Is option Capital or Revenue
    - QUANTITY: Area of option in Hectares
    - XCOORD: Agreement Easting
    - YCOORD: Agreement Northing
    - PARCREF: Rural Land Register (RLR) parcel id
F. The selected options and RLR parcels were joined using the positions recorded in the XCOORD and XCOORD attributes. This was chosen as, in many cases, the RLR parcel ID recorded for the agreement had changed and was thus not an accurate method for joining the datasets.
G. As parcels could overlap with multiple relevant options, these were filtered to select the appropriate follow up options codes wherever possible (e.g. HR5). The earliest relevant start date and latest end date for each parcel were also selected.
H. To allow for detection of bracken from satellite imagery a minimum mapping unit of 0.25 ha was defined, and all parcels smaller than this rejected.

At the end of this filtering process, the ~1.6 million initial options were reduced to a sample of 107 CS and 506 HLS options suitable for taking forward to landowner interview (Section 2.4) and satellite analysis (section 2.5).

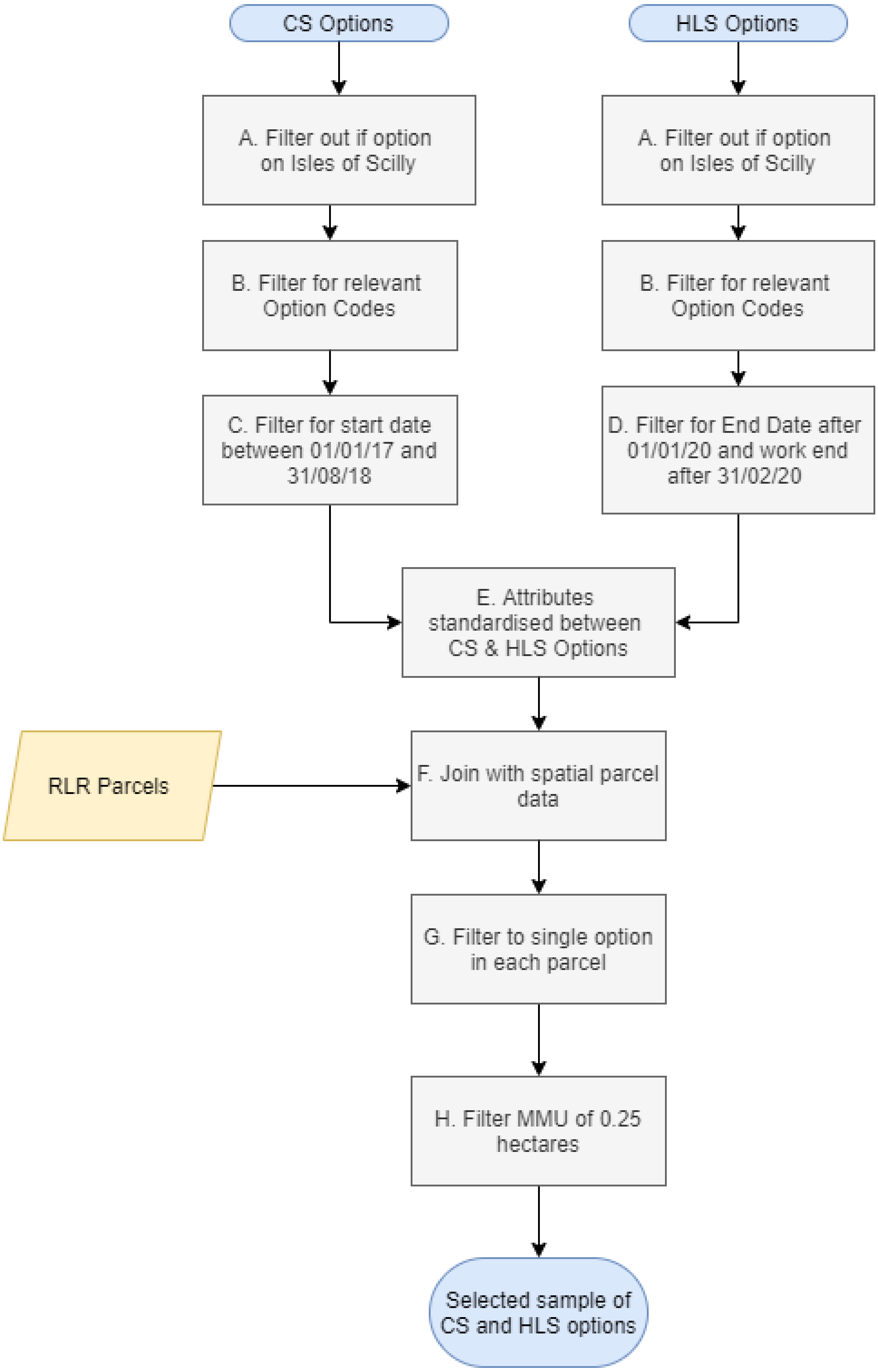

Figure 2-5: Flowchart illustrating CS and HLS options filtering process

2.4 Interview Methodology

The survey of agreement holders was designed to gather evidence regarding the effectiveness of the bracken control options in the agri-environment scheme on the holding. Most agreement holders were participating in Environmental Stewardship (ES), mainly in Higher Level Stewardship (HLS), which were close to the end of the 10 year agreements. A smaller group had recently joined the current scheme, Countryside Stewardship (CS), most under a 5 year agreement but some exceptions have 10 year agreement. Both ES and CS offer options on chemical and mechanical control of bracken as well as various base payments and supplements, such as for difficult to reach sites (ES).

The aim of the survey was to collect structured information about the effectiveness of the bracken control options and any additional work that agreement holders have or are undertaking in addition to elements supported by their AES agreement. In particular, the interview covered the extent of follow up treatments, and how grazing and other environmental factors contributed to controlling bracken re-establishment after any initial treatment. This includes details on grazing animals, such as the type, duration and timing of such interventions.

The landowners to interview were selected from agreements with bracken control options. For CS a focus on selecting all those who signed from 2016-2018 was made in order to focus on agreements where bracken control options had been implemented. A sample of 122 agreements was secured. The second sample was taken from ES agreement holders focusing on those with live agreements. A sample of 371 was secured. The total sample was 493. Ethical approval for the survey was secured from the University of Gloucestershire Ethics Committee and the survey was approved by Defra's Survey Control Liaison Unit.

The agreement holders were sent a letter or email (see Appendix B) outlining the project and indicating that they would be contacted in the coming days. Interviews were conducted over the telephone (see Appendix C) between 6th January and 5th March 2021.

2.5 Bracken Identification from Satellite Imagery

2.5.1 Processing of satellite imagery

The seasonal growth of bracken means that there is a significant change in vigour between summer and winter months. The Normalised Difference Vegetation Index (NDVI) is a simple and widely used method that assesses the vigour of vegetation by comparing reflectance in red and near infra-red (NIR) bands as follows:

$$NDVI = \frac{Red - NIR}{Red + NIR}$$

Productive, healthy vegetation, such as bracken in the summer, absorbs red light through photosynthesis and reflects NIR from spongy mesophyll tissues. This will lead to high NDVI values that approach 1. Senescent/dead vegetation, such as bracken in the winter, will have similar reflectance in Red and NIR, and NDVI values approaching 0. By comparing summer versus winter NDVI on a per-pixel level it is possible to identify bracken in grassland parcels.

The Landsat-8 and Sentinel-2 sensors used in this study have different numbers of bands and, in the case of Sentinel-2, multiple NIR bands. For Landsat-8 NDVI was calculated using the 30m Band 4 (Red) and Band 5 (NIR). For Sentinel-2 the 10m Band 4 (Red) and Band 8 (NIR) was used.

Given cloud cover, it is not possible to guarantee availability of optical images over short time frames. Therefore, images with sufficient cloud-free coverage (typically <40% cloud) were chosen for winter and summer months where bracken should be in a relatively stable condition. Summer captures were collected from June to August when the bracken should have grown and, if untreated, be in a healthy condition. Winter captures were collected from November to March, where the bracken should have broken down, and re-growth not yet started.

Satellite images were atmospherically corrected to provide a stable spectral signature across captures. Images were also masked to identify areas of cloud and remove them from the image. The Landsat sensor includes a thermal band, allowing for very accurate cloud detection. This means that all Landsat scenes under 40% cloud can be processed and masked automatically. A thermal band is not available for Sentinel 2, making cloud classification less reliable. As such, a slightly different approach was used. Owing to the more frequent capture cycle, there is a much greater chance that a region can be captured cloud-free each season. The best dates were selected and masked manually.

For each season the images were combined into a regional composite. Initially a best-pixel approach using the maximum NDVI value for any given pixel was investigated, but this was severely affected by cloud shadow and proved unviable. Instead, cloud masked images were placed in date order and mosaiced into a single image covering the whole study area.

Figure 2-6 shows the flow of data from the capture to the creation of an NDVI composite. Example summer/winter NDVI composites for Landsat-8 and Sentinel-2 are shown in Figure 2-7 and clearly illustrate the problems of cloud within a single season, especially for winter months.

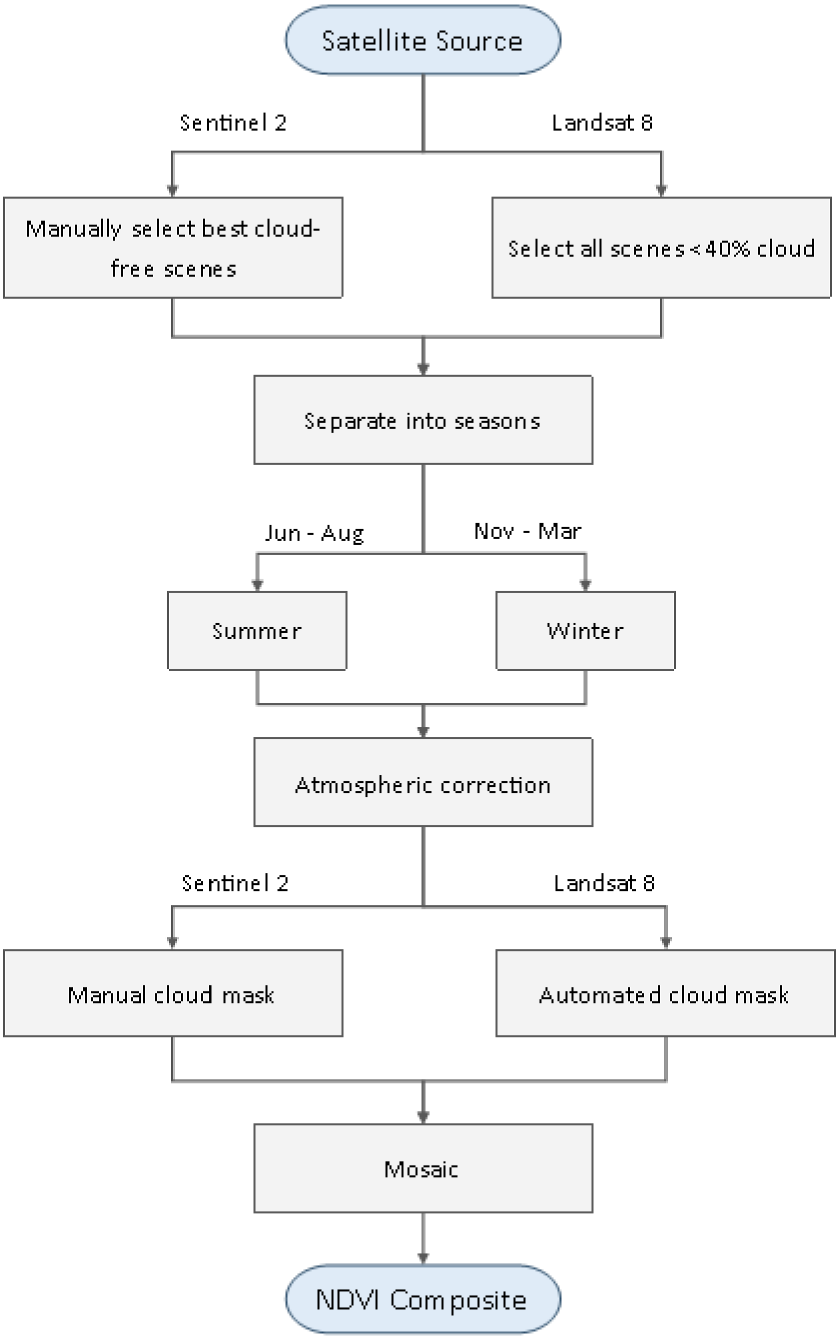

Figure 2-6: Satellite processing workflow, detailing scene selection, correction, and cloud masking to create the final NDVI composites used for identifying bracken

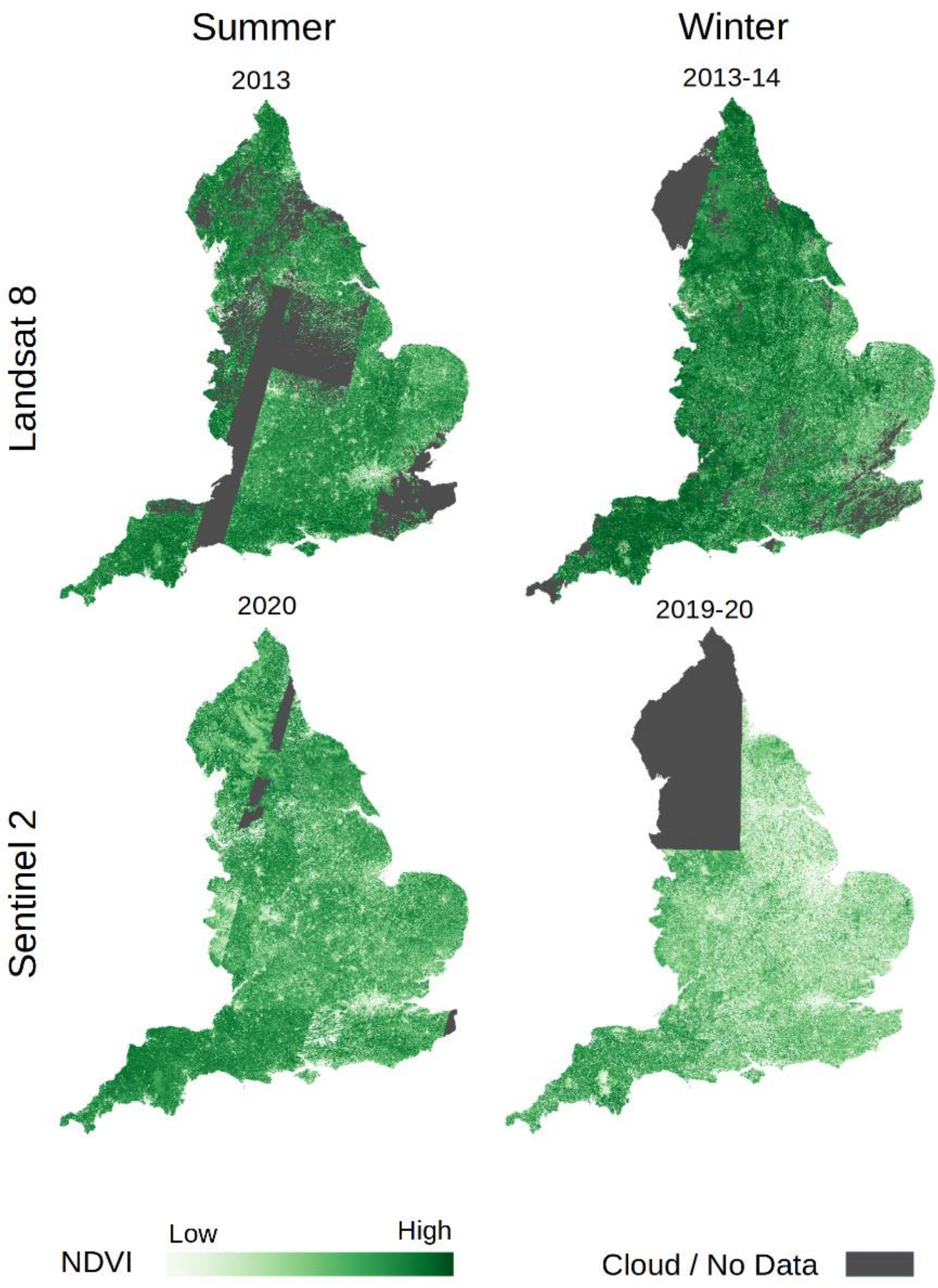

Figure 2-7: Example NDVI winter (left) and summer (right) composites for Landsat-8 (top) and Sentinel-2 (bottom). Images have had a local NDVI stretch applied so are not directly comparable.

2.5.2 Development of classification ruleset

The bracken classification ruleset was initially developed on the south coast of England. This region provided a suitable testbed for development as it consisted of a substantial cluster of parcels (40% of total observed) and included the full range of habitats under observation (coastal, agricultural, wetland, lowland and upland areas such as Exmoor and Dartmoor National Parks).

The classification was developed using eCognition Developer; a powerful development environment for the interpretation of geospatial data for feature extraction and change detection.

The input data consisted of annual summer and winter NDVI raster composite images (section 2.2.2) and OSM water and NFI woodland layers (section 2.2.3). As outlined in section 2.2.2, bracken has a significant change in vigour over the year that can be clearly identified by comparing winter and summer NDVI. In the winter, bracken leaf litter reflects more visible light and less near-infrared light. Areas of bracken leaf litter show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such bracken at its peak growth stage. While similar seasonal changes in NDVI may be also seen in deciduous woodland, the NFI woodland layers help identify and remove this source of confusion. It should be noted that the NFI layer occasionally misses small stands of trees, and this could lead to confusion of deciduous woodland with bracken.

The fieldwork planned under the original methodology was intended to provide:

1. Information on the extent, density and vigour of bracken stands for calibrating the classification ruleset, and;
2. Independent validation data to assess the accuracy of the classification.

In the absence of fieldwork data, the ruleset could only be calibrated by comparison against high-resolution satellite and aerial photography imagery accessed via Google Earth Pro. While this data proved sufficient to determine the extent of bracken patches, the vigour of the canopy could not be determined with any degree of accuracy. As a result, the classification approach was modified to only assess the extent of bracken and not the vigour of individual patches.

2.5.3 The classification workflow

The classification ruleset was based on bracken phenology outlined in section 1.3, whereby both vigorous growth in the summer and the presence of leaf litter in the winter can be detected using a timeseries of NDVI composite images. The use of summer and winter NDVI images combined make it possible to detect and delineate bracken from other surrounding vegetation such as improved grassland.

The rule base was structured into a series of levels, each level representing a bracken season from 2013 to 2020 (Figure 2-8). An initial segmentation of the Open Street Map water and NFI woodland layers was undertaken to exclude areas of open water and woodland from the parcel boundaries, whilst a per-pixel level segmentation of the sensor data was undertaken for all remaining areas within each parcel. A bracken classifier was applied to the remaining areas at each level to provide an annual classification of bracken cover.

Each level of the classification workflow represents a bracken summer season and uses three sets of NDVI images (winter / summer / winter). Figure 2-8 outlines the winter / summer / winter input data in the classification workflow. For the classification to work, a winter and summer image combination is required to produce a classification output per season. By its nature, winter imagery is more susceptible to frequent and extensive cloud cover and as a result it is difficult to achieve stable and complete coverage in the UK.

The winter / summer / winter approach was implemented to minimise the impact of excessive cloud cover. For example, parcels in the bracken 2014 classification are classified using composite NDVI imagery from winter (November, December 2013 / January, February 2014) and Summer (June, July and August 2014).

In cases where parcels are obscured by cloud in winter (i.e. no data), the classification defaults to composite NDVI imagery from the following winter (2014/2015). This approach gives the classification a 'second chance' to return a positive classification for the summer season. In instances where a field has no data in both sets of winter composite images the parcel is classified as 'no data'. Section 2.2.2 outlines how the classifications were processed at the parcel level to mitigate for the influence of cloud cover returning 'no data' results for whole parcels.

The final step before feature extraction is the application of a minimum mapping unit (MMU). This step removes small non-contiguous pixels identified as bracken and fall below the minimum area, set at 900 m^2 (one Landsat pixel). The features are extracted as polygons per field with each season having a bracken classification from 2014 to 2020.

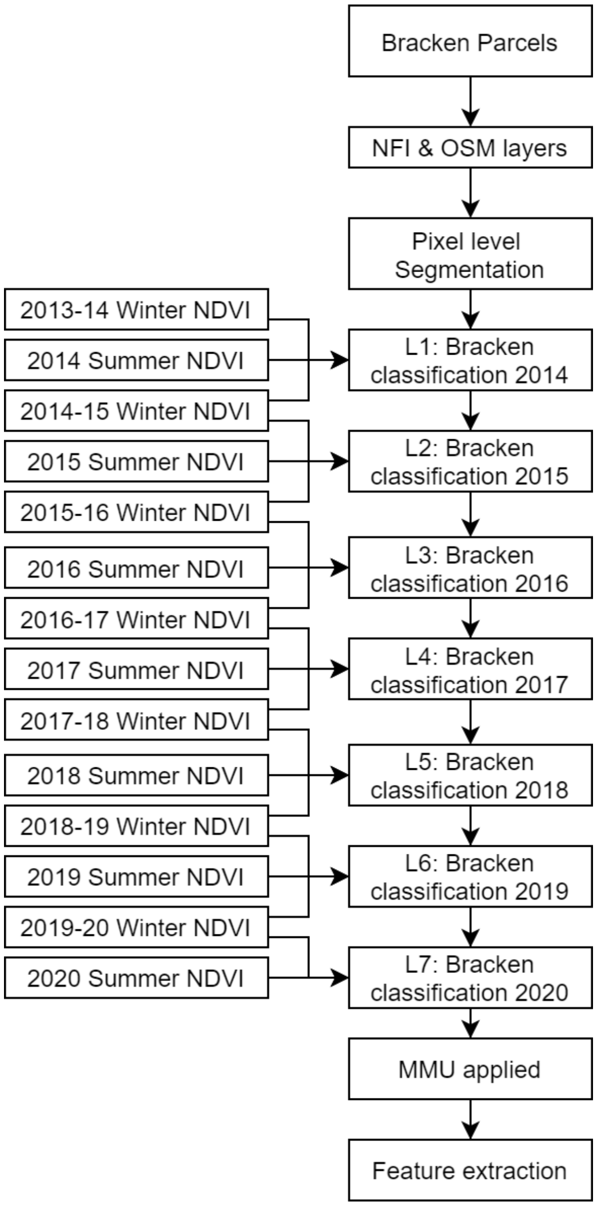

Figure 2-8. Classification workflow showing input raster and vector data and processes required for feature extraction

2.5.4 Classification quality assessment

As outlined in section 2.1, it was originally planned that the accuracy of the classification would be evaluated against field data captured for a representative sample of bracken stands. Travel restrictions due to COVID-19 meant that this data could not be captured, with the result that a formal accuracy assessment cannot be performed.

Instead, a quality assurance process was undertaken during which analysts reviewed the classification for all parcels against high-resolution imagery from Google Earth and Google Street View. Bracken could be readily identified when high-resolution winter and summer imagery was available for the same parcel, and could also be inferred from summer imagery alone based upon a combination of high vigour and canopy structure/shadows. That being said, this data was not consistent across the whole study area in terms of either date or image quality, meaning that the approach could only be undertaken where data allowed

This process highlighted a number of parcels where the classification appeared to be over- or under- classifying bracken. The classification for these parcels was updated by either locally modifying NDVI thresholds or manually updating bracken extents.

Sources of classification error for these parcels were found to include: steep, north-facing slopes where NDVI values were lower than expected due to shadow; stands of deciduous woodland that were not represented by the NFI layer; some confusion with heath and other upland vegetation. It was also found that parcels containing low density and/or small scattered bracken stands did not have enough of vigour difference between summer and winter to be detected by this method. Field data on the extent, density and vigour of the bracken canopy would help better quantify the limitations of optical satellite imagery for bracken monitoring.

It is also possible that the reliance on a vigour differential between summer and winter may be a limitation in very exposed upland areas where bracken litter can be blown away to reveal an understory of grass that would have a higher winter NDVI. In these cases, it would be impossible to distinguish bracken from grassland using NDVI alone. However, there is potential to use Sentinel-1 SAR to evaluate the seasonal biomass change to bracken. While Sentinel-1 was not suitable for this study as it was only available over the second half of the study period (i.e. 2015 onwards), moving forwards this may provide a valuable source of satellite information for bracken monitoring.

2.5.5 Parcel-level bracken evaluation

The annual bracken classifications were summarised by calculating the total area of bracken and cloud for each parcel. Figure 2-9 shows the significant impact cloud had on the results, especially for the years evaluated using Landsat (2014-2017) where cloud cover obscured between 27%-65% of the parcel areas. Typically, the cloud cover was highest in the winter imagery, however the Sentinel-2 imagery for summer 2020 also proved especially cloudy.

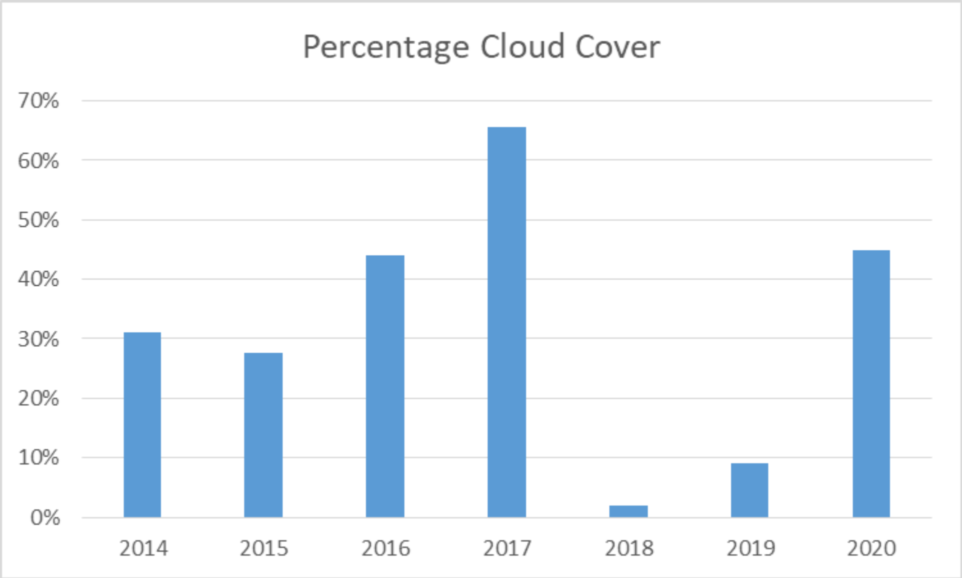

Figure 2-9: Percentage of total parcel area covered by cloud each classification year

Given the significant cloud cover, it was not possible to construct a bracken classification time series covering all years and all parcels. In order to support evaluation of bracken cover change over the largest number of parcels, classifications were aggregated by calculating the union of classifications within two time periods; which we have called the baseline (2014-2016) and revisit (2018-2020) periods. The 2017 classification was rejected due its particularly high cloud cover. An example of the aggregated classification is shown in Figure 2-10. From this example the difference in resolution between the 30m Landsat-8 pixels (2014-2016) and 10m Sentinel-2 pixels (2018-2020) is apparent. In this particular parcel a significant reduction in bracken area has been observed between the two time windows.

A final parcel-level cloud mask was also implemented by calculating the minimum cloud cover across 2014-2016 and 2018-2020. Any parcel with cloud coverage over 40% was rejected, in total this resulted in 89 parcels being rejected, leaving a final subset of 533 parcels for further analysis.

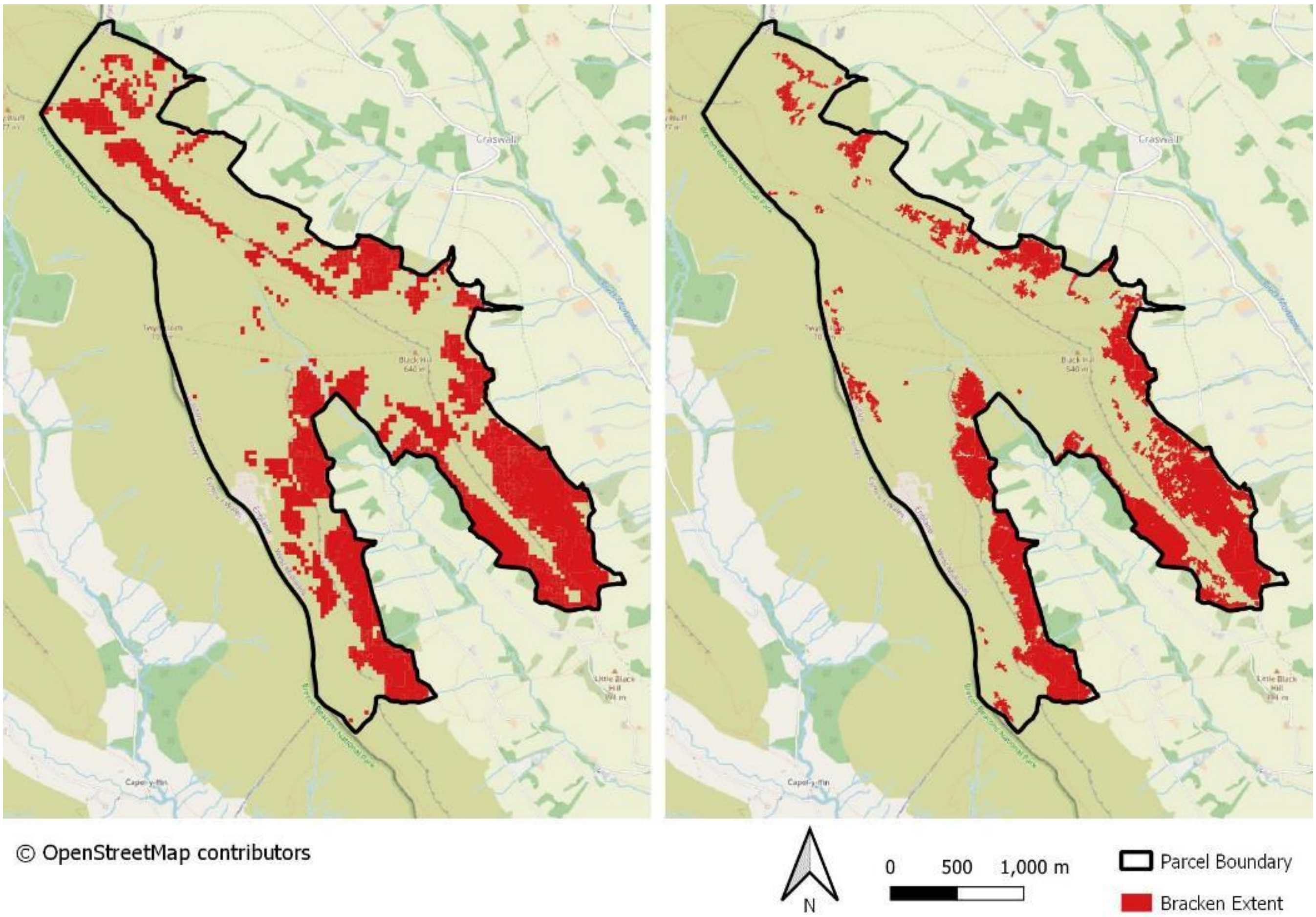

Figure 2-10: Example of aggregated classification showing bracken extent for 2014-2016 baseline (left) and 2018-2020 revisit (right)

2.5.6 Comparison of resolutions between baseline and revisit

In order to cover the observation time period required for this project, it has been necessary to mix data between different platforms, with Landsat-8 providing data for the baseline assessment and Sentinel-2 delivering the revisit. As can be seen from the example classification shown in Figure 2-10, these platforms have different spatial resolutions (30m and 10m respectively) which may introduce biases in the evaluation.

To assess this, we conducted the following evaluation:

- Polygons ranging in area between 0.25 and 1 ha were created to represent simulated bracken areas
- Each polygon was converted to raster datasets with 30m and 10m resolution to simulate Landsat-8 and Sentinel-2 resolutions respectively
- The area of each converted feature was compared against the original polygon

From this analysis we found that the Landsat-8 and Sentinel-2 areas agreed to within +/- 10% of the original. This effect was most marked for the smaller simulated areas (0.25 ha) where the offset of Landsat-8 pixels compared to the simulated features could introduce greater relative over and under estimation of the feature area than Sentinel-2.

From a visual assessment of the classification outputs, we found that while Landsat-8 could over-estimate the extent of bracken in some places, this was balanced by its tendency to miss smaller patches (sub 0.25 ha) that were more reliably picked up by Sentinel-2.

2.5.7 Extraction of parcel-level environmental, climatic and historic environment variables

Each parcel was intersected with the environmental, climatic and historic environment layers described in sections 2.2.4, 2.2.5, and 2.2.6. These datasets represent a mixture of categorical and continuous variables, and thus required different strategies to summarise per parcel. These strategies are summarised as follows:

- Slope, elevation, climatic (continuous raster data): The parcel mean for each variable was calculated using zonal statistics.
- Topsoil texture, subsoil texture, soil wetness, aspect (categorical raster data): The most frequent value found in the parcel for each variable was calculated using zonal statistics.
- Historic environment (categorical vector data): For each parcel and each designation category the number of intersecting historic features was calculated using vector overlay operations. A count of the different types of designations overlapping each parcel was also calculated.

3 Results

3.1 Bracken classification

In order to evaluate the effectiveness of bracken control from the remote sensing approach used in this study, it is important to directly compare the area under option against the bracken extent identified from remote sensing. The most granular spatial data available in this project was the RLR parcel database. Comparing the option and the RLR parcel areas (Figure 3-1), we can see that in the majority of cases the option only covers a portion of the parcel, with 60% of parcels falling in the 0-50% percentage cover categories. The < 10% cover category also contains the majority of the parcel area (Figure 3-2), as this category includes a number of large upland parcels that are greater than 500 ha in size.

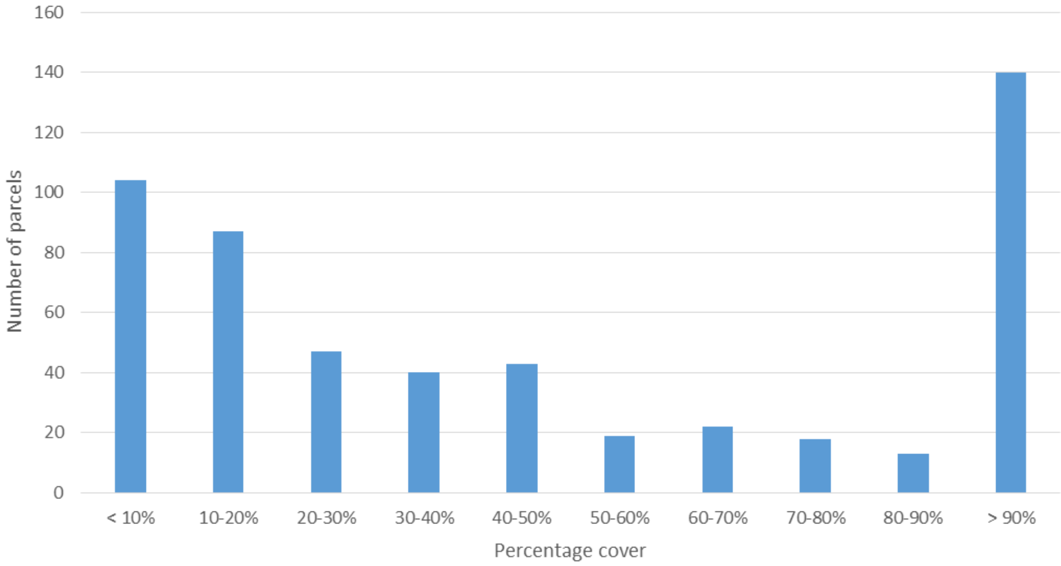

Figure 3-1: Histogram showing the number of parcels against the percentage of parcels covered by a bracken control option

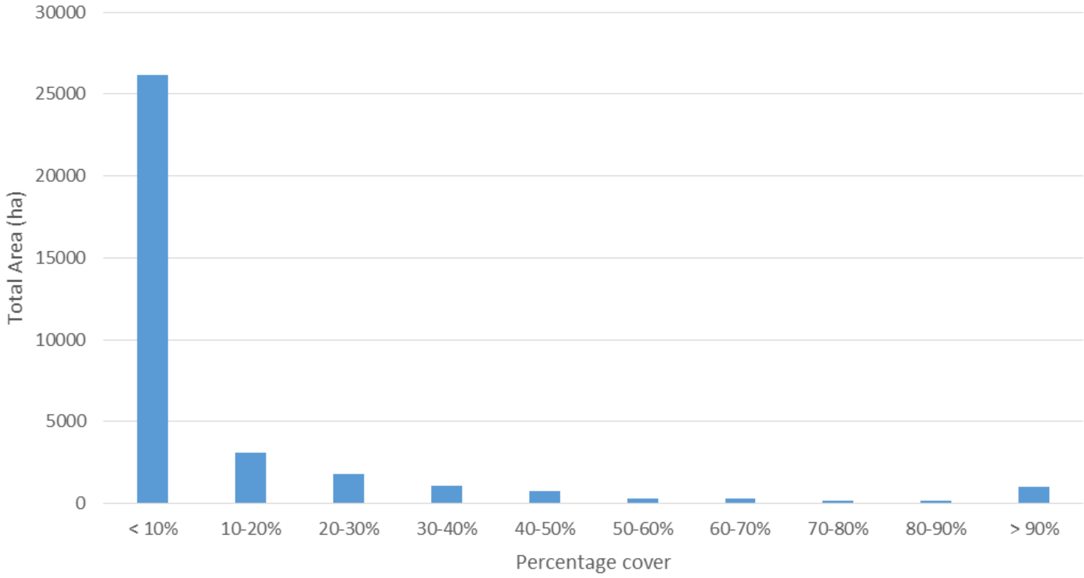

Figure 3-2: Histogram showing the total area of parcels against the percentage of parcels covered by a bracken control option

The extent of the bracken option was not available in the Natural England CS and HLS spreadsheets. For parcels where the bracken control option/capital item only covers a small area of the parcel, it is therefore impossible to distinguish between changes in bracken cover due to option management, versus other changes such as natural expansion elsewhere within the parcel.

Figure 3-3 provides a good example of the challenges presented with part-parcel options. In this case there is a 2-ha option within a 90-ha parcel; while the precise location of the bracken option is not available, we have indicated a 2-ha area in the legend for comparative purposes. The baseline and revisit assessments show that there has been considerable change to the bracken cover, with an overall reduction from 53.5 ha to 41.1 ha. Comparing the bracken cover maps, we can see that some areas of the parcel have been completely cleared of bracken, some show expansion and in others it is stable. Without knowing the exact shape and location of the option we cannot assess its' effectiveness on bracken control as relatively small shifts in the position of the option can introduce significant changes to the bracken change statistics.

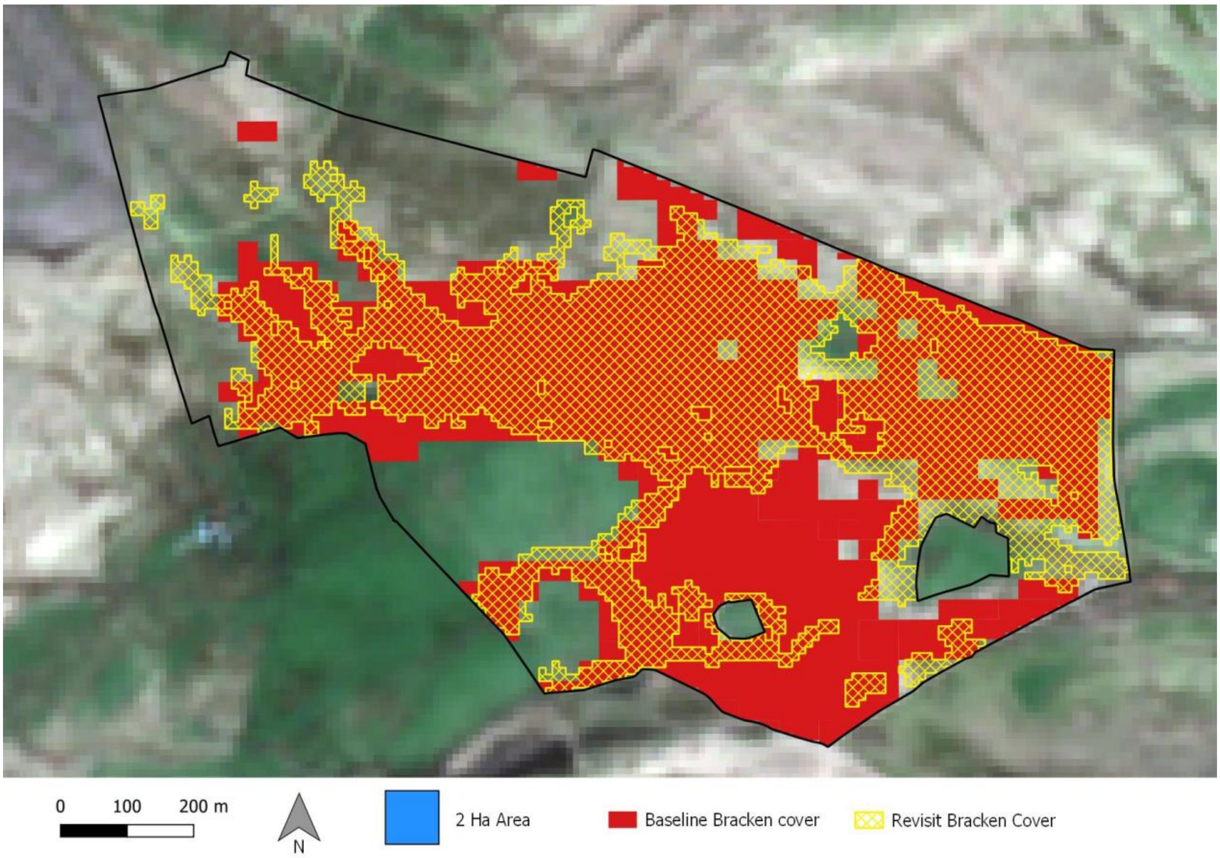

Figure 3-3: Baseline and revisit bracken coverage for an upland parcel. The parcel contains a 2-ha option, and a reference square 2 ha in size is provided in the legend for comparison

In order to accurately evaluate the effect of management upon bracken cover using remote sensing we needed to remove the uncertainty introduced by the lack of option spatial data. Therefore, only parcels where the option covered greater than 90% of the area were selected for further analysis, reducing the sample under consideration substantially from 533 to 141 parcels. Of these 141 parcels, 37 also contained options that were larger than the parcel itself, but as the difference was mostly within 5% of the parcel size these parcels were accepted for analysis. This further underlines the need for accurate extents of bracken options to support spatial analysis of management.

The location of the Whole Parcel options selected for analysis versus the omitted Part Parcel options is shown in Figure 3-4. This map clearly shows that, as expected from Figure 3-2, a number of large upland parcels in the Pennines, Dartmoor and Exmoor have been excluded. Whole Parcel options area also more frequently found on the West side of England, especially Cornwall, and all parcels in East Anglia have been omitted.

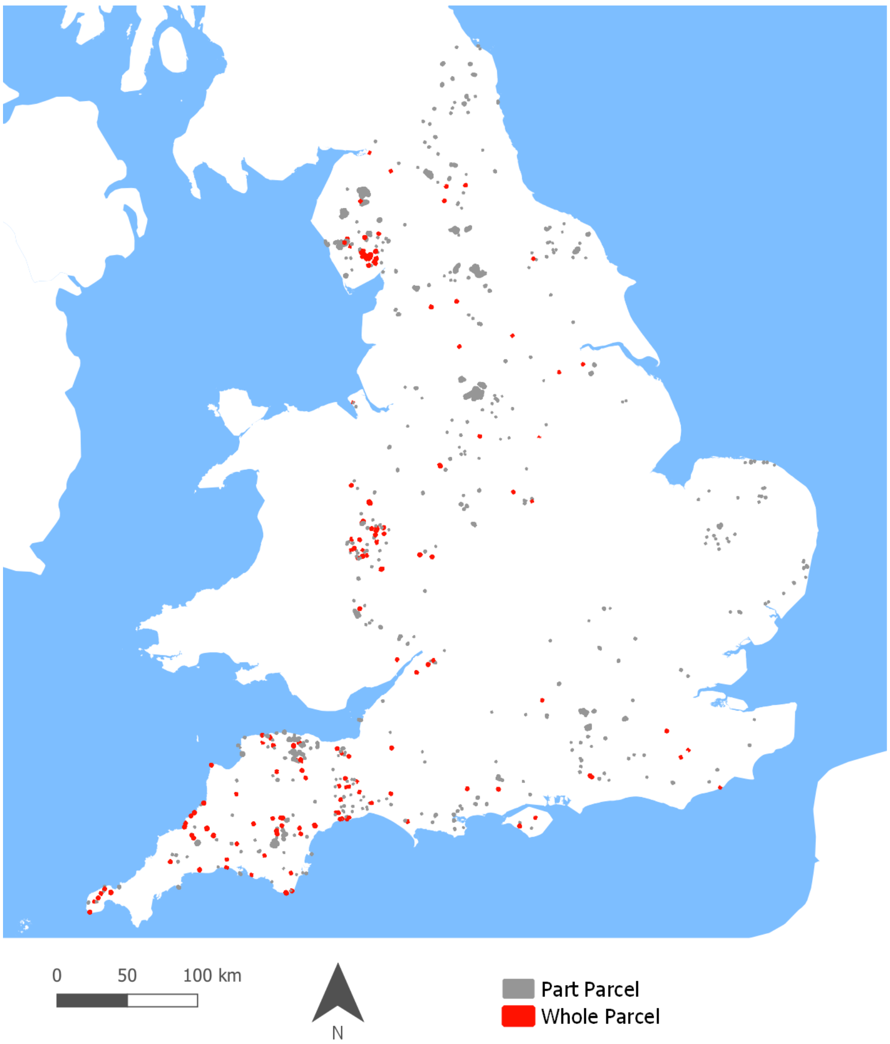

Figure 3-4: Location of bracken options separated into the rejected Part Parcel and analysed Whole Parcel categories

While this filtering has a marked effect on the geographic distribution of parcels, it provides a robust basis for evaluating the effect of management upon bracken cover using remote sensing. It should also be noted that, if the extent of options was available in a spatial data format, for example through digitisation of existing records, it would be possible to expand the analysis to evaluate all 533 parcels.

A final filter was conducted to remove 7 parcels that contained the CS options as these began in 2017 or 2018 meaning that the bracken control work was only being undertaken during the revisit classification. Therefore, any change between baseline (2014-2016) and revisit (2018-2020) could not be attributed to follow up work under option. This created a final sample of 134 parcels submitted for further analysis,

To categorise the bracken cover change, we introduced two metrics assessed at the parcel level; a change and a final condition score:

- The change score compared bracken areas between the two assessments. Bearing in mind the findings about comparing assessment resolutions (section 2.5.6), we introduced a 10% threshold for comparison between baseline and revisit assessments. Thus, if the revisit bracken area was within +/- 10% of the baseline area, no change was identified and a **Stable** score assigned. If the revisit area was more than 10% greater than the baseline, then an **Increased** score was assigned, and if less than 10% than baseline a **Decreased** score was assigned.
- The final cover score evaluates the success of the management option by comparing bracken area against the parcel area for the revisit assessment. If the detected bracken area was greater than 90% of the parcel area, the parcel was scored as **High**. If bracken covered less than 30% of the parcel a **Low** score was assigned. Parcels covered by 30-90% of bracken were scored as **Medium**. Note that the parcel rather than option area was used due to the number parcels with options larger than the RLR itself.

A cross-tabulation of these scoring metrics is provided in Table 3-1. Looking at the final condition score, we can see that the majority of parcels (94) are in the good category, and that within this category, the majority have either remained stable over time (46) or decreased between baseline and revisit assessments (41). Looking at the 9 parcels with a poor final condition, most of these (6) have remained in the stable category.

Table 3-1: Cross tabulation showing the number of parcels in each change and final condition category

Final Cover Score		Change Score: Decreased	Stable	Increased	Total
	Low	46	41	7	**94**
	Medium	11	5	15	**31**
	High		6	3	**9**
	Total	**57**	**52**	**25**	**134**

Figure 3-5 provides a more detailed breakdown of the relationship between bracken cover change and final cover, and clearly illustrates how the vast majority of parcels with low cover have either remained stable, or shown decreased cover. Considering the small number of parcels with high cover, they have either been stable between baseline and revisit or have had substantial increases in cover of greater than 30%.

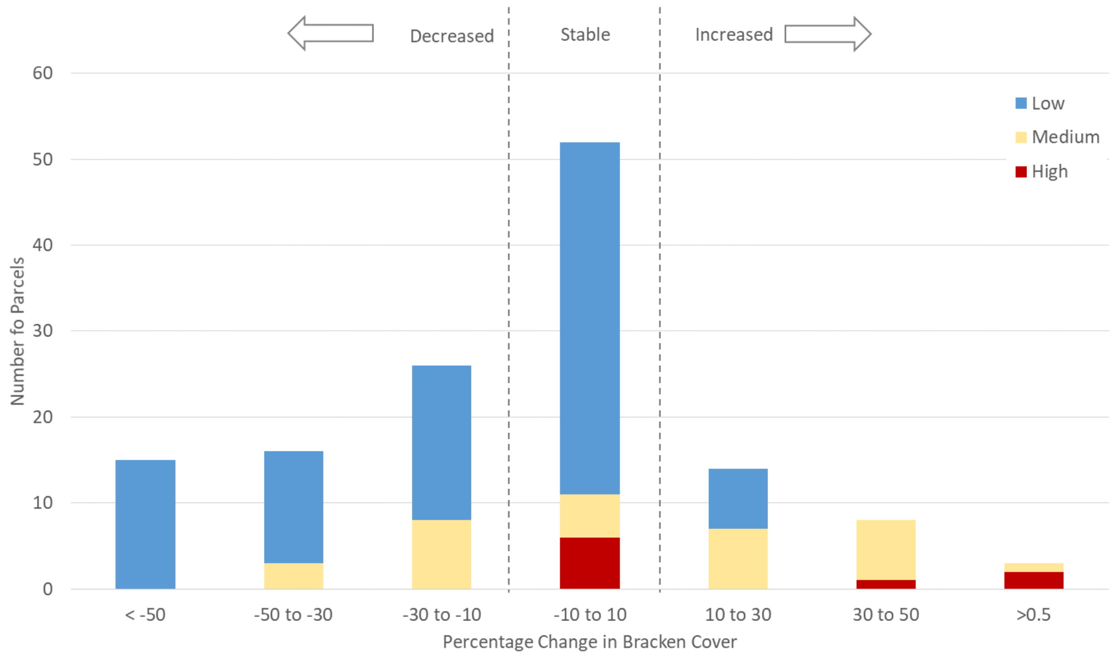

Figure 3-5: Histogram showing percentage bracken change between baseline and revisit assessments against final condition score. The change score categories are also indicated for clarity.

The distribution of parcels according to their bracken change and final cover scores is provided in Figure 3-6, and reveals some interesting patterns. The majority of parcels with decreased cover are found in the south west, and there is a notable cluster of increased parcels in the north west. While final cover map does not show such clear geographic patterns, the majority of parcels with high final cover are found in the south west, and there is a cluster of parcels with medium cover in the north west. However, with only a total of 9 parcels falling into the high final cover class, this may not be a significant result.

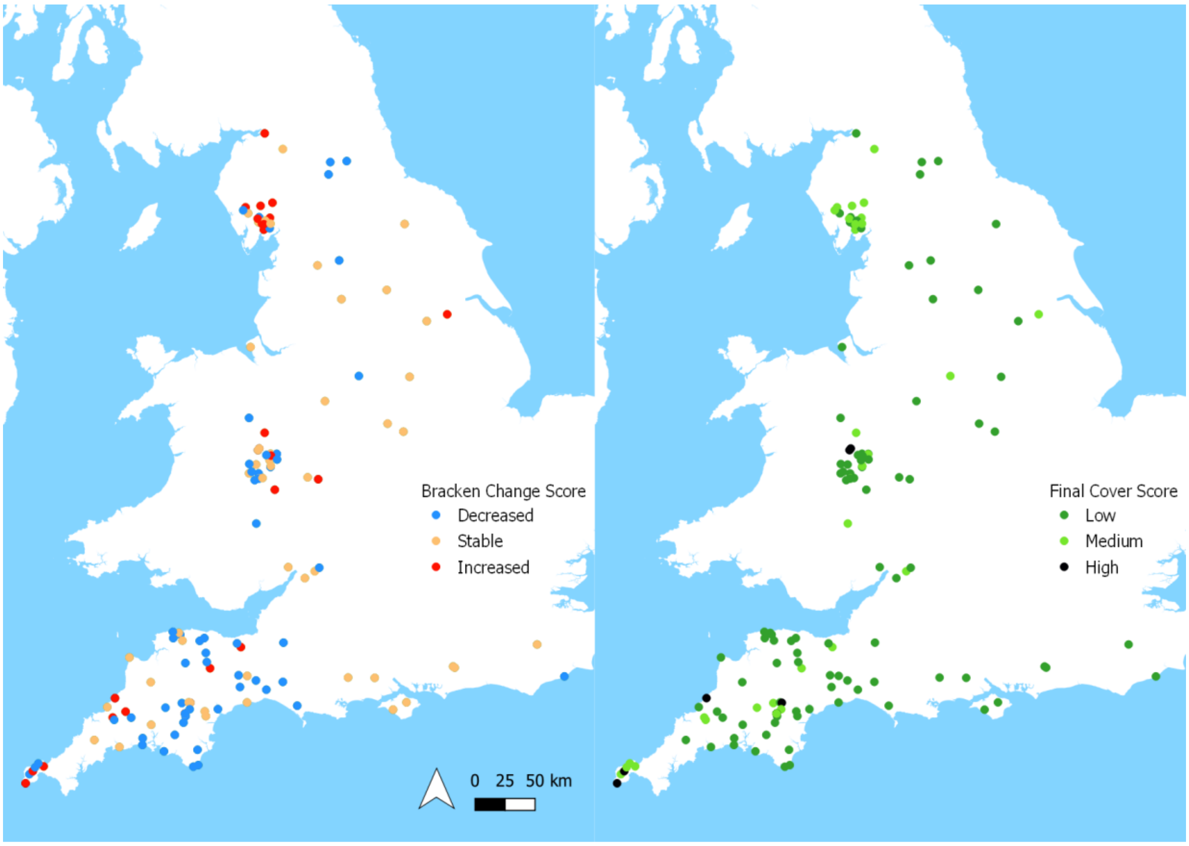

Figure 3-6: Map showing location of parcels and their associated bracken change (left) and final cover (right) scores

Taken as a whole, the data suggest that the bracken follow-up control options are working to either reduce bracken cover, or limit its expansion. The clustering of parcels with increased cover in the north-west of England may also indicate some geographic influence on the effectiveness of management. This will be explored in more detail in section 3.2.

3.2 Analysis of Environmental & Historic Landscape Factors

3.2.1 Analysis of environmental variables

In this section we consider the relationship between environmental variables (such as mean temperature, soil type or elevation) and the scoring metrics introduced in section 3.1. The environmental variables were separated into two categories; continuous and categorical, with separate analysis methods introduced for each.

Continuous variables

A range of statistical tests were considered in order to explore whether there were meaningful differences between the scoring metrics and environmental variables. Looking at the distribution of samples between classes for each scoring metric, it became apparent that a T-Test was the most appropriate measure in each case. For the change score, we were most interested in exploring the differences between the decreased and increased classes, while for the final cover score the high cover class contained too few samples (9) for meaningful analysis, and was thus combined with the medium cover class.

A T-Test evaluates whether there are statistically significant differences between the means of two independent groups for a single dependent variable (Sokal & Rohlf, 1995). The test produces a p-value that measures the evidence against the null hypothesis that there is no difference between the means of each group. A p-value below the nominated significance level indicating that the null hypothesis can be rejected. In this study we used the widely applied significance level of 0.05

Table 3-2: T-Test p- values for environmental variables grouped by change score. Statistically significant scores are highlighted in bold.

	p
Max Air Temperature	0.789
Mean Air Temperature	0.714
Min Air temperature	0.712
Total Rainfall	0.813
Total Days Ground Frost	0.092
Elevation	**0.026**
Slope	0.498

Table 3-3: T-Test p-values for environmental variables grouped by final cover score. Parcels scored as low cover were compared against aggregated medium and high parcels for each variable. Statistically significant scores are highlighted in bold.

	p
Max Air Temperature	**0.0001**
Mean Air Temperature	0.162
Min Air temperature	0.546
Total Rainfall	**0.0006**
Total Days Ground Frost	0.915
Elevation	0.262
Slope	0.986

For the change score (Table 3-2), only elevation was found to have a statistically significant difference between sites where bracken cover had increased and where it had decreased. Total days ground frost had a p-value below the 0.1 significance level, and also bears further investigation. For the final cover of bracken scores, both max air temperature and total rainfall had significant p-values and are also assessed in more detail.

Box and whisker plots[1] were used to further investigate the relationship between environmental variables and the scoring metrics. In most cases, the distributions appeared very similar, supporting the evidence from the T-Tests that there is little variation between classes for most variables. However, for the four variables highlighted above, we did find interesting differences between distributions. Results for each of the remaining variables are also included in appendix A for completeness.

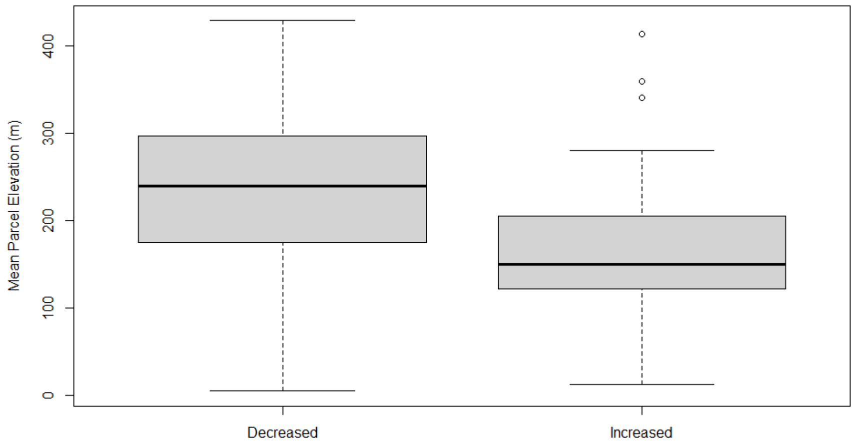

Figure 3-7: Distribution of mean parcel elevation against change score

Comparing the mean parcel elevation against change score (Figure 3-7), we can see that the increased parcels are at typically at lower elevations compared to the decreased parcels. Looking at the spatial distribution of the decreased parcels, many of them are in upland/upland fringe locations in Cornwall, Devon and Shropshire. An increase in bracken overall might be occurring in the low land due to increased vigour of the bracken plants making the management actions less effective, or allowing the bracken to grown back quicker than in the upland fringe.

[1] *In a box and whisker plot, the distribution is shown as a box with top and bottom drawn at the upper and lower quartile to encompass the central 50% of observations, while the box is itself divided at the median. The whiskers are drawn to encompass values within 1.5 interquartile ranges of the top and bottom of the box; values beyond this range are plotted individually (Sokal & Rohlf, 1995). These show at a glance the degree of similarity or difference of distributions between classes.*

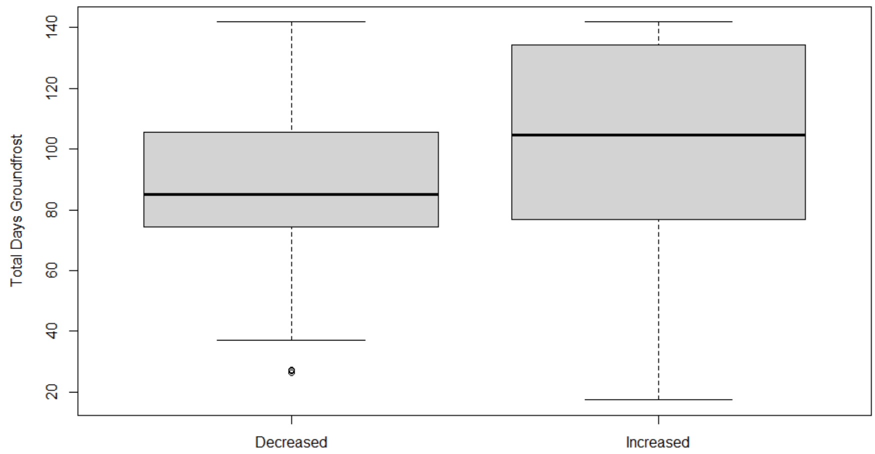

Figure 3-8: Distribution of total days ground frost per year against change score

Comparing ground frost against the change score (Figure 3-8), we can see that the decreased and increased parcels have similar lower ranges, but the increased parcels are also found in locations with more days of ground frost per year. At first glance, this seems to contradict the finding of decreased bracken in higher locations as it may be expected that these are also likely to have more frost. However, this effect appears to reflect the cluster of parcels with increased cover scores in the north west of England. These are all at low elevations, but have more days of ground frost due to their more northerly location. It is therefore likely to be a highly geographically specific site effect.

Turning to the significant final cover score results, Figure 3-9 shows that parcels with a low final cover tend to have higher maximum temperatures than those with medium/high final bracken cover. Similarly, Figure 3-10 shows that parcels with less rainfall are more likely to have lower final bracken cover. Similar to the change score analysis, this appears to be largely a reflection of geographic differences as the north west England cluster of parcels with medium final cover scores have the highest total rainfall and lower max air temperatures.

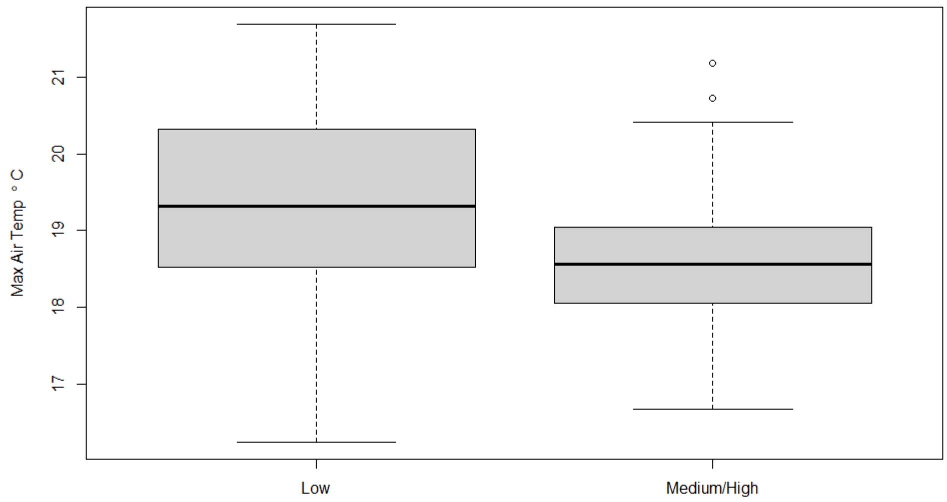

Figure 3-9: Distribution of maximum air temperature against final cover score

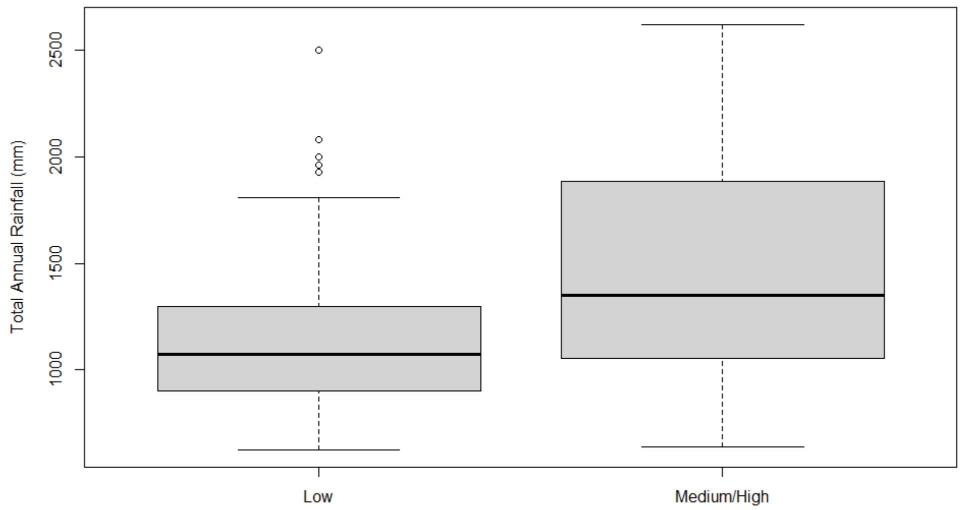

Figure 3-10: Distribution of total annual rainfall against final cover score

Categorical variables

For categorical variables, such as aspect or soil moisture class, the relationship between scoring metrics and environmental variables was explored using grouped bar charts.

Comparing aspect against change score (Figure 3-11) we can see that decreased scores are fairly evenly distributed across slopes with easterly, southerly and westerly aspects. The increased scores are more unevenly distributed, tending towards west and east aspects. For the final cover score, high parcels were mostly on west facing slopes, and good parcels mostly south east. Also, as may be expected, both graphs show that bracken is least commonly found on northerly slopes overall.

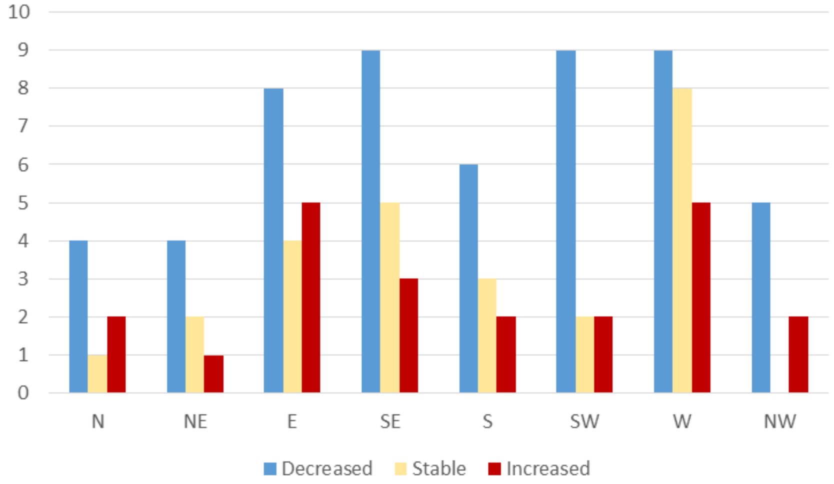

Figure 3-11: Relationship between change score and aspect

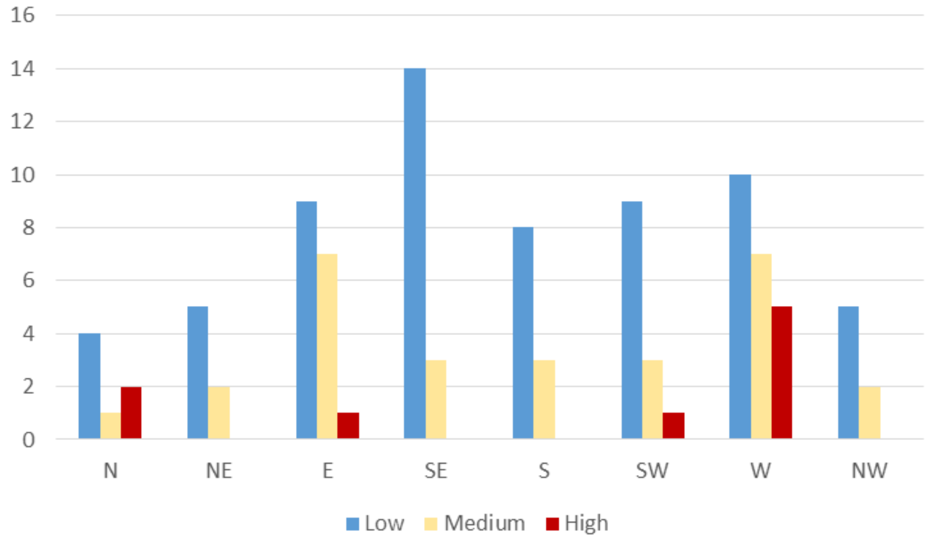

Figure 3-12: Relationship between final score and aspect

Turning to the results for soil wetness, the vast majority of parcels (74/133) are found in the driest wetness class, and parcels are fairly evenly spread across the rest of the wetness classes, with the exception of a second peak in class V. This is somewhat surprising as bracken is noted for preferring more well drained soils. Looking at the map, the parcels in class V are mostly upland parcels in the Lake District, and it appears that the bracken is distributed along the steeper, and hence dryer, parts of these parcels. considering the relationship between change class and soil wetness (Figure 3-13), we find that the increased parcels are most likely to be found in wetness class I, but this is also true for decreased parcels. The final condition score showed little difference between the different wetness classes beyond the underlying distribution.

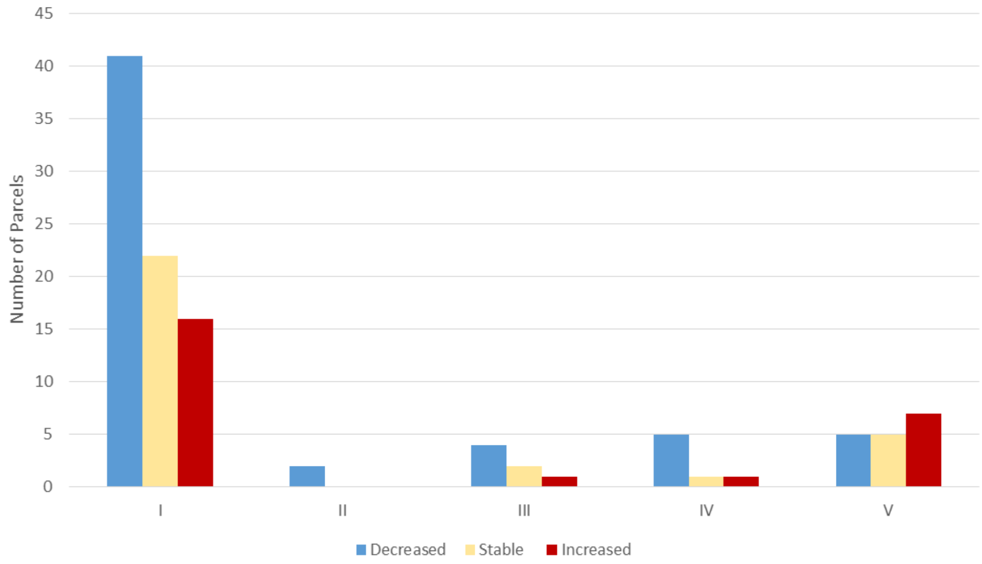

Figure 3-13: Relationship between change score and soil wetness

The final environmental variable we considered was subsoil and topsoil texture class (Figure 3-14). These data showed that the parcels were predominantly linked to loamy soil textures, particularly clay loam and medium sandy loam, reflecting the expected relationship between bracken and well-drained soils. However, there were no clear relationships between either scoring metric and soil type beyond the underlying parcel distribution.

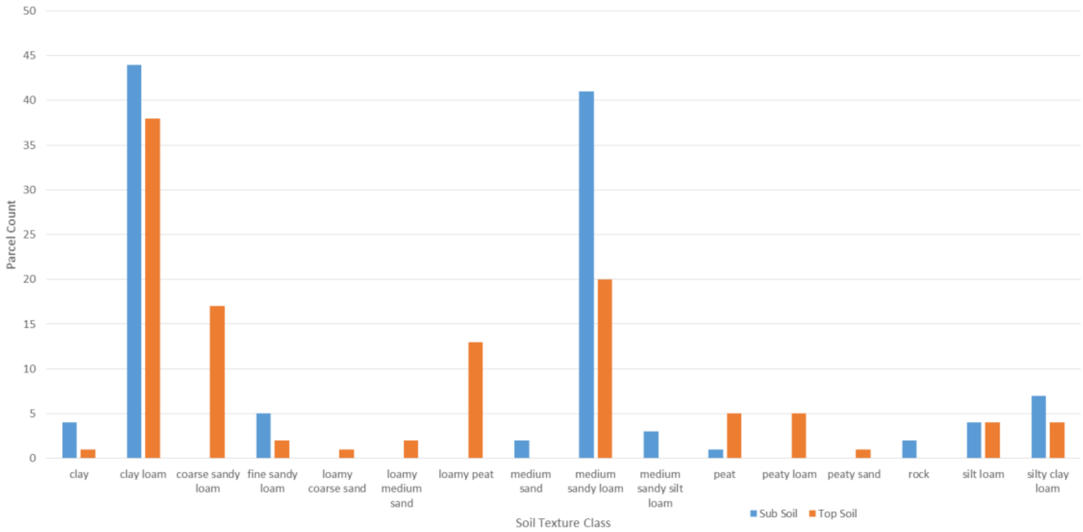

Figure 3-14: Distribution of parcels by soil texture classes

Summary of environmental results

The bracken change and final cover analysis shows geographic clustering, with a concentration of parcels with an increased change score and medium final cover in the North-West of England. This finding may indicate that there are regional management differences that have led to a generally poorer bracken control for these parcels.

The generally lower elevation for these parcels may also have an influence. Studies have shown that bracken in the UK is more abundant in uplands above 200 m (Grime *et al*, 1988; Pakeman *et al*, 2000), which is supported by the distribution of parcel elevations assessed in this study (Figure 3-15). However, bracken is noted as being more vigorous in less exposed situations (Natural England, 2008). In these more favourable environments, bracken could be expected to return more quickly following treatment and would require more vigorous follow-up to keep it under control compared to less favourable environments.

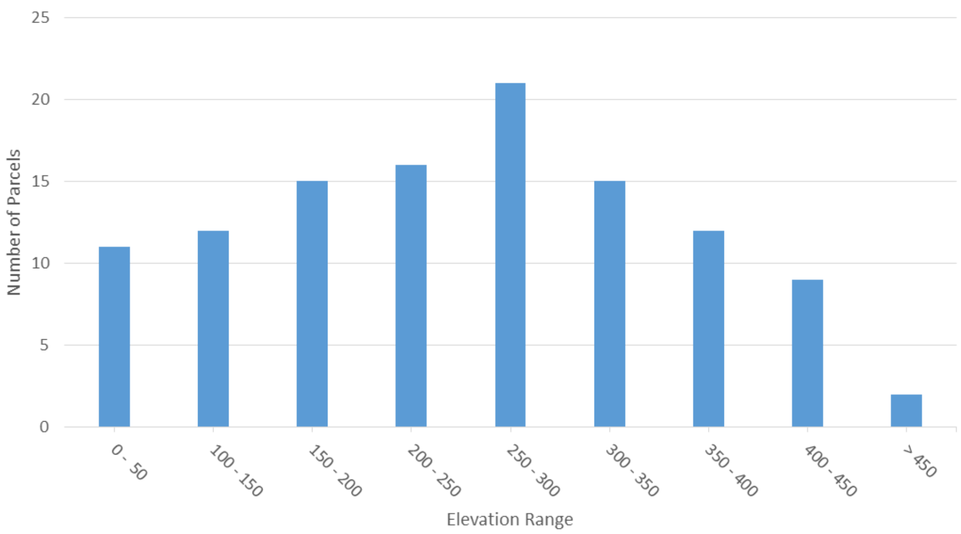

Figure 3-15: Distribution of parcel elevations

Low sample size and fact that we have had to discount the majority of the parcels due to lack of spatial information on option extents within parcels mean that we do not have enough data for a fully statistically robust unpicking of the environmental variables that will overcome the geographic clustering. Furthermore, with the exception of the LIDAR data used to retrieve elevation, slope and aspect data, the environmental data is available at a much coarser spatial resolution than the bracken mapping. While these more national scale datasets were the best available to this study, they are much more generalised than the mapped bracken extents; this difference in scales will also lead to additional error and uncertainty in the analysis. Finally, it should be noted that field calibration of the remotely sensed data may allow for more nuanced measures of bracken canopy, such as vigour and growth, might allow for additional multivariate analyses of environmental factors. A multivariate analysis may also allow for evaluation of relationships between environmental on bracken control, such as latitudinal day-length differences vs temperatures.

3.2.2 Historic Landscape

Looking across the five categories of historic landscape data assessed, very few parcels overlapped with these designations. Out of the total 622 parcels, 124 overlapped with one or more designation, and only 22 of these were whole-parcel options. Furthermore, 10 of these parcels overlapped with a single scheduled monument further reducing the power of this results. Scheduled monuments were the most frequent type of designation encountered, and included a range of field systems, defensive features and earth works. Similar numbers of parcels overlapped with the HAR 2020 and Parks and Gardens designations. Only one of these parcels overlapped with the additional HLS historic features provided by Natural England.

Comparing the historic environment results against the change (Figure 3-16) and final cover (Figure 3-17) scores we can see that, in both cases, increased and high scores respectively are more frequent than were observed with the sample population as a whole. However, given the small sample size, these results are unlikely to be particularly meaningful.

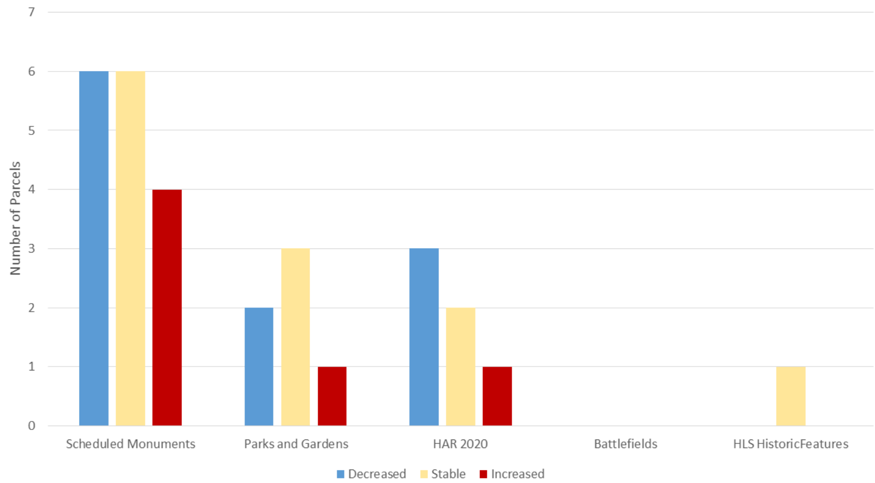

Figure 3-16: Distribution of parcels across each designation category split by change score

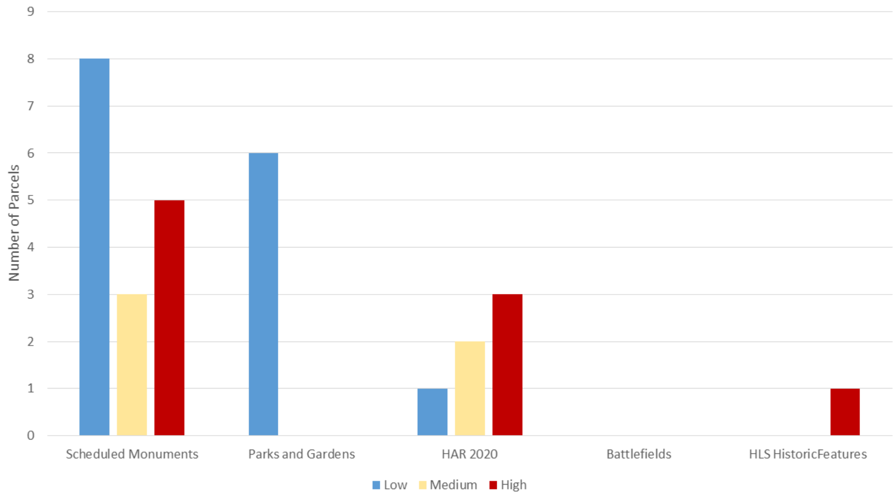

Figure 3-17: Distribution of parcels across each designation category split by final cover score

The overall parcel score does not tell the whole story as we have spatial extents for the designated monuments that can be directly compared against the baseline and revisit bracken classifications to see if the options have had an effect on the features. Figure 3-18 shows a parcel that contains a prehistoric field system that is flagged as heritage at risk, and has a decreased change score and low final cover score. Bracken cover over the field system itself has been substantially reduced, and there has been some expansion to the south west of the monument.

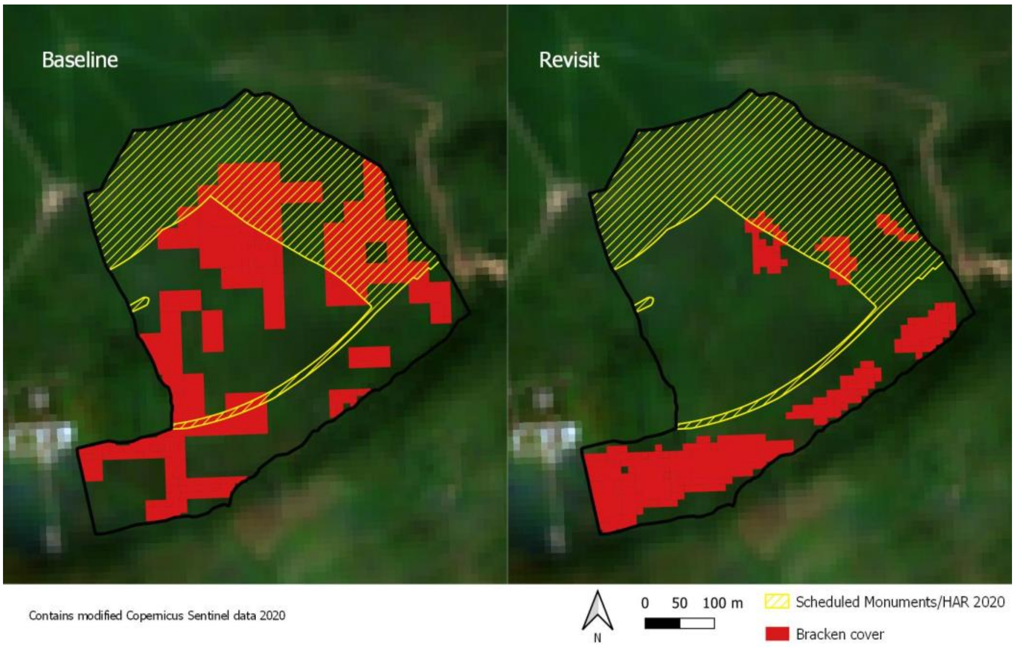

Figure 3-18: Comparison of bracken cover for baseline (left) and revisit (right) assessments against the extent of a Scheduled Monument/Heritage at Risk feature. The background image is a Sentinel-2 scene from summer 2020.

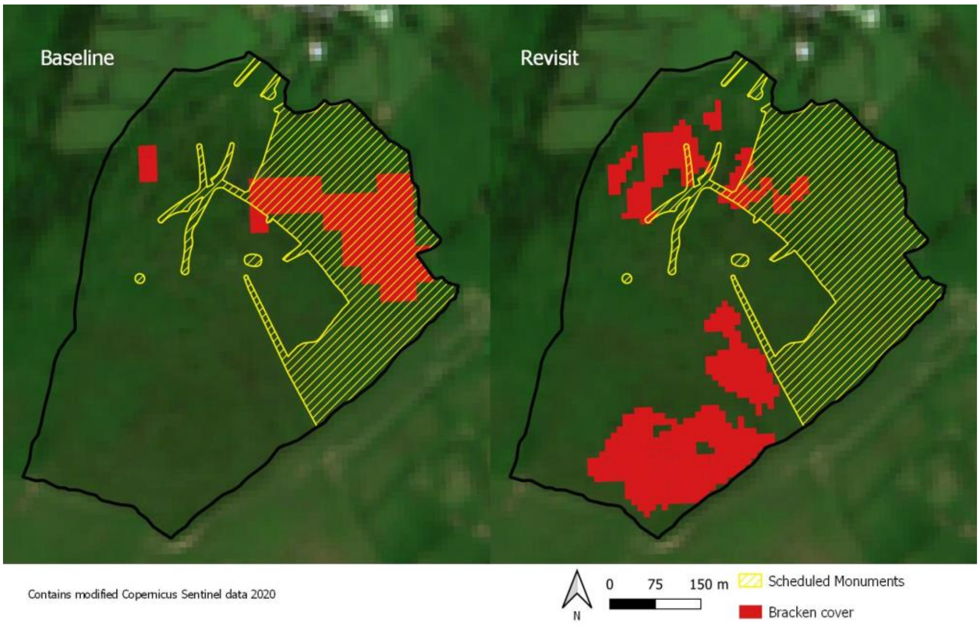

Figure 3-19: Comparison of bracken cover for baseline (left) and revisit (right) assessments against the extent of a Scheduled Monument feature. The background image is a Sentinel-2 scene from summer 2020.

Figure 3-19 shows another field system but has an increased change score and low final cover score. Looking at the location of bracken in this parcel, we can see there has been a dramatic decrease over the monument itself, but again there has been growth of bracken outside the monument area. As bracken options can specify that stands should remain for biodiversity reasons these results may indicate that bracken has successfully been relocated within the option away from the monument.

Figure 3-20: Comparison of bracken cover for baseline (left) and revisit (right) assessments against the extent of a Scheduled Monument feature. The background image is a Sentinel-2 scene from summer 2020.

Figure 3-20 shows a parcel that overlaps with a Parks and Gardens feature where the bracken has been completely removed between baseline and revisit.

Figure 3-21: Comparison of bracken cover for baseline (left) and revisit (right) assessments against the extent of a Scheduled Monument feature. The background image is a Sentinel-2 scene from summer 2020.

Figure 3-21 shows one of the worst parcels assessed from a historic environment perspective. This parcel contains a scheduled castle and also has three additional features identified in the Natural England HLS features layer. Virtually the entire parcel was covered in bracken in the baseline and revisit assessments, and what little variation in extent exists between the assessments appears largely a result of the difference in spatial resolution between assessments. This parcel is also not listed on the HAR 2020 layer which may indicate an oversight as bracken can be a contributing factor to designating a monument as at risk.

These four case studies show that comparing parcel-level bracken cover maps against designated feature boundaries can provide useful additional information on the effectiveness of control. As Figure 3-18 and Figure 3-19 show, the parcel scoring system employed in this study is not entirely suitable for this application as a parcel can have effective control over a designated feature and bracken growth elsewhere in the parcel that cancel each other out in the overall parcel scoring. These results also further underline the importance of sub-parcel spatial data for assessing the impact of bracken options.

3.3 Interviews

3.3.1 Response rate

Of the 494 agreement holders selected for interview, 171 were undertaken, resulting in a response rate of 35%. This was split between 48 CS interviews (39% response rate) and 123 HLS interviews (33% response rate). A breakdown of the responses and reasons for not being interviewed are provided in Table 3-4, Table 3-5 and Table 3-6.

Table 3-4: CS interview responses

Category of Response	Number of Respondents	%
Interview Done/Booked	***48***	***39***
Awaiting Call Back	24	20
Not Applicable	4	3
Number is incorrect	6	5
Strikeout as 3 failed attempts to contact	26	21
Does not wish to participate	7	6
Duplicate record so already interviewed	3	2
No answer/voicemail left:	5	4

Table 3-5: HLS interview responses

Category of Response	Number of Respondents	%
Interview Done/Booked	***123***	***33***
Awaiting Call Back	24	6
Not Applicable	5	1
Number is incorrect	24	6
Strikeout as 3 failed attempts to contact	52	14
Does not wish to participate	58	16
Duplicate record so already interviewed	1	<0.01
No answer/voicemail left:	84	23

Table 3-6: Combined CS & HLS interview responses

Category of Response	Number of Respondents	%
Interview Done/Booked	***171***	***35***
Awaiting Call Back	48	10
Not Applicable	9	2
Number is incorrect	30	6

Strikeout as 3 failed attempts to contact	78	16
Does not wish to participate	65	13
Duplicate record so already interviewed	4	<0.01
No answer/voicemail left:	89	18

3.3.2 Summary of interview responses

Type of Bracken Control

All of the agreement holders were asked about the type of bracken control which they undertook in their AES agreements. The results show that 57 (34%) out of the 169 agreement holders who provided a viable response used chemical controls, 85 (50%) mechanical and 27 (16%) used both chemical and mechanical. This will be a key variable throughout the detailed analysis.

Bracken Control options

Using the data provided by NE for each agreement in the survey the bracken control options could be assessed. A summary break down is shown here with more detailed analysis conducted in Appendix D. Under CS the main options in the 48 agreements were:

Option	N	Average area (ha)	Total area (ha)
SB3 supplement	27	12.55	338.97
SB4 chemical	23	9.85	226.64
SP5 mechanical	10	6.944	69.44

The first things to note is that the SB3 supplement, while in most agreements, was not present in all of them. Of the 48, 23 (48%) had chemical and 10 (21%) mechanical options. Also, the total number of agreements with either mechanical or chemical options is 33, meaning that 15 only had the SP3 option. The areas involved for chemical options was larger than mechanical with 10 of the 23 covering areas of between 10 and 50 ha. There were none over 50 ha. The SB3 supplement covered the largest area and on average was larger.

Looking at the options under 123 ES agreements the options present in the survey were:

Option	N	Average area (ha)	Total area (ha)
HR5 supplement	123	28.20	3,468.9
BMB mechanical base	51	-	-
BMA mechanical area	55	11.64	640.9
BCB chemical base	35	-	-
BCA chemical area	34	29.79	1,042.57
BDS difficult supplement	34	13.15	446.97

The most common bracken control option was HR5 and this was present on all of the 123 ES agreements involved in the survey. There were 55 (45%) agreements with mechanical area payments and 34 (28%) with chemical area payments. The agreements with chemical options had a higher average area (29.70ha) compared to mechanical option agreements (11.64ha). Over two thirds (71%) of the mechanical BMA area options are on for areas less 10 ha compared to the chemical BCA area option which has almost half (46%) that are over 10ha in size, with 3 over 50 ha. In some case the BMA payments are made for repeat applications over the agreements, where this occurs it is for two or three Interventions over the course of the 10-year agreement. A further 34 (28%) had an option covering the management of bracken on difficult sites, which could be either mechanical or chemical. The two base payments for both mechanical and chemical refer to agreements with capital payments linked to bracken control and these closely mirror the area payments.

The agreements holders were independently asked which approach they used on the holding and reassuringly the responses closely mirrored the NE database of agreement options. Of the 85 agreement holders who stated that they used mechanical methods to control bracken, 40 contained BMA in their HLS agreements and 8 SB5 in their CS agreements. This leaves 37 who do not have an area-based mechanical option in their agreement. Of these 37, 26 have HR5 and 10 SP3. This leaves one agreement holder who stated that they used mechanical approaches for bracken control, even though the options in the agreement were for chemical. Looking closely at the responses to this interview it is clear that they had traditionally used mechanical approaches under previous AES agreements but had requested to use chemical as a follow-on treatment in one area.

For the 57 agreement holders who have used chemical methods to control bracken, 22 contained BCA in their HLS agreements and 20 SB4 in their CS agreements. This leaves 15 who do not have an area-based chemical option in their agreement, of which 10 have HR5 and the rest have BCB to cover capital aspects of bracken control. There is one agreement with SB5, a mechanical bracken control option, who stated that they used chemical approaches. Again, looking at the response from this interview, it is clear that in the past they had used both approaches in combination but now view chemical as more effective than mechanical for longer lasting results.

Of the 27 agreements who stated that they used both approaches in combination on the same areas of bracken, 12 have mechanical options and 11 have chemical options. Only 6 have both mechanical and chemical options listed in their agreements. Ten agreements have neither mechanical or chemical options in their agreement, instead having HR5, BDS or SP3 specified. The two agreement holders who did not provide a viable response both had HR5 options in their agreements but no specific mechanical or chemical options.

Holding size
Responses were received from 167 agreement holders, with 51% of the sample farming over 100ha. A quarter (25%) are under 50ha and 24% fall into the 50-< 100ha category. Comparison with Defra statistics shows that the survey is not so representative, with much fewer holdings in the smaller categories compared with the 40% under 20ha (Defra 2019). However, this is misleading and other surveys of AES agreements holders have found a much more comparable proportion of those under 50ha, such as 24% (Short et al 2017) or 30% (Boatman et al 2014). Since this survey is concerned with bracken control, these options are often associated with the uplands and therefore larger holdings are likely to be involved, although not all by any means. The split between the CS and ES samples is quite similar with even sized groups in the larger categories.

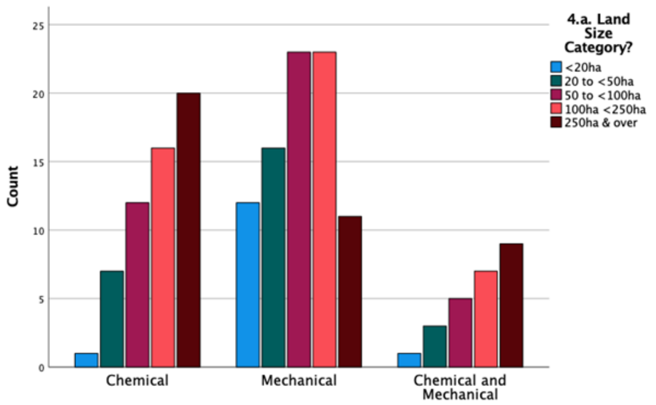

Figure 3-22: Type of bracken control by holding size

Looking at the impact of holding size on the type of bracken control undertaken (Figure 3-22), mechanical control was more likely on holdings under 250ha and chemical control more common on holdings of over 250ha.

Presence of Livestock
Nearly all (93%) of the agreement holders indicated that they had livestock on the holding, with only 10 of the 171 stating that they did not have access to livestock of any sort. There Is no variation according to schemes and for the type of bracken control. The question also asked about the type of livestock, with the following results:

- 56% Beef Suckler herd
- 28% Beef store cattle
- 3% Dairy cattle
- 73% Sheep flock
- 22% Other (including ponies, goats, donkeys, pigs and poultry)

There were small variations according to scheme in terms of the livestock on the holding, for example sheep are more likely on holdings with CS agreements (82%

compared to 69% for ES) but beef store cattle are more likely on holdings with ES agreements (31% compared to 18% for CS). However, some caution is required as the number of CS holdings is quite small (45). In terms of bracken control approach, those using mechanical approaches were slightly more likely to have beef store cattle than those using chemical but the numbers are too small to deduce anything.

The question also included asking about who the livestock belonged to. In over half the case (58%) the livestock belonged to the agreement holder. In a further 45 cases (28%) the livestock on the holding belonged to someone else and in a few cases (13%) they were a mixture of the agreement holder's livestock and someone else's. Later analysis will determine the link between the livestock on the holding and the management of bracken.

Previous AES experience

Of the 171 agreement holders; 125 (73%) had been in a previous AES scheme. Therefore for 46 agreement holders (27% of the total sample) the current ES or CS scheme was their first AES agreement. Of the 125:

- 60 in 'classic' Countryside Stewardship agreement (15 now in CS;45 in ES).
- 37 in previous ES agreement (22 now in CS; 15 in follow-on ES agreement).
- 28 in an Environmentally Sensitive Area (ESA) agreement (1 now in CS; 27 in ES).
- 27 in 'other' schemes, such as the Wildlife Enhancement Scheme or national park programmes (8 now in CS; 19 In ES).

This demonstrates a wide range of AES experience amongst those with bracken options in their current agreement. However, not all previous AES agreements included bracken control options. Where agreement holders were present on the holding and able to recall the options in these agreements, bracken control was an element in less than half (43%) of the 'classic' CS agreements, over half (57%) of the ES agreements and a half (48%) the ESA and other (57%) agreements. The numbers are small but there is no clear variation between chemical and mechanical controls.

Before going on to discuss the current agreement all of the respondents were asked about previous management of bracken on the holding. This will be helpful in understanding the knowledge of the agreement holder and perhaps the reason for including bracken control options in the AES agreement. The question was an open one and the text responses coded after all the surveys had been completed.

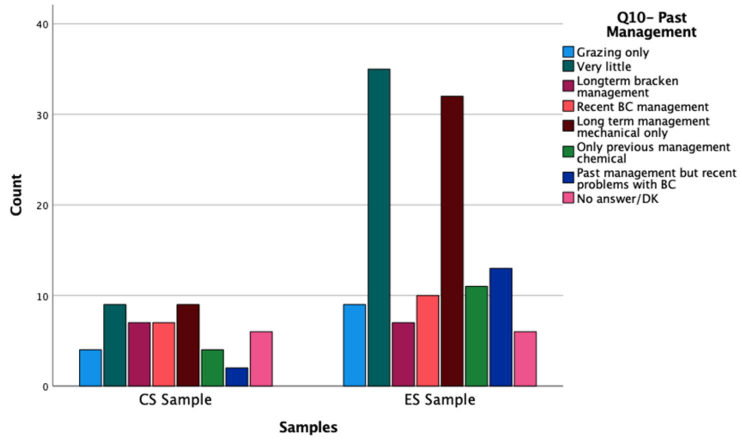

Figure 3-23: Past management of bracken by type of agreement

The largest single response was for the category 'very little' (44, 26%) followed by 'long term management, mechanical only' (41, 24%). The other responses were quite even and under 10% of the overall responses. By condensing some of the categories, we can deduce that 41% of the sample suggested that there has been long term management of the bracken but for some of these (9%) there had been recent problems in controlling the spread of bracken. Looking at the split between the two schemes it seems that two aspects stand out. The ES sample contains a higher proportion of those who had undertaken little bracken control previously and those who had been using mechanical approaches for long term management of bracken.

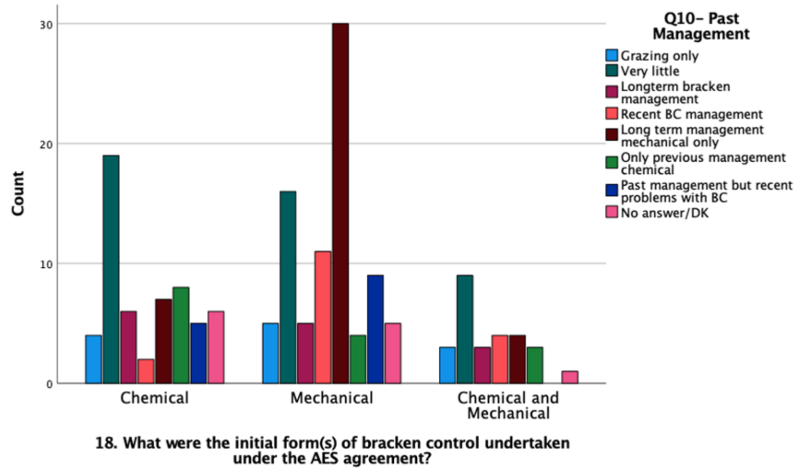

Figure 3-24: Past management of bracken by type of bracken control

The graph showing the response matched against the bracken control treatments used by the sample reveals that most those using mechanical methods have retained that approach. Those who have undertaken little or no management of bracken are the largest group In the chemical and combined treatment groups.

Agreement holders view on the Impact of bracken

All of the participants were asked to comment on a series of 8 statements concerning the impacts of bracken, responding on a 4-point scale from Strongly Agree to Strongly Disagree. The full responses are shown in

Table 3-7. These results show that the perceived most likely impact of bracken was the loss of biodiversity and habitat (90% either strongly agree or agree). The least likely was bracken causing a wider environmental issue (37%). The statement concerning historic features received fewer responses as they were not present on these sites. Of those who responded, two thirds (66%) agreed with the statement that bracken was encroaching on a historic feature. There was a perceived impact on productivity in two thirds (89%) of cases suggesting that the loss of grazing land was important to agreement holders. This will be investigated further later in the analysis. In addition, bracken was also viewed to be encroaching on grazing land, both enclosed (84% agreement) and unenclosed (76% agreement).

Table 3-7: Impact of bracken on holdings

Statement	Strongly Agree	Agree	Disagree	Strongly Disagree	Not applicable	Total
Bracken has encroached on enclosed grazing land	53 (36%)	72 (48%)	22 (15%)	2 (1%)	20	169 (100%)
Bracken has encroached on unenclosed grazing land	32 (30%)	50 (46%)	20 (19%)	6 (5%)	58	166 (100%)
Bracken caused concern for grazing animals' welfare	29 (19%)	69 (46%)	49 (32%)	5 (3%)	16	168 (100%)
Bracken was impacting productivity	31 (21%)	72 (48%)	41 (27%)	6 (4%)	18	168 (100%)
Bracken was decreasing farm biodiversity/habitat quality	79 (48%)	68 (42%)	16 (10%)	0 -	4	167 (100%)
Bracken was causing wider environmental issues	6 (5%)	42 (32%)	81 (60%)	4 (3%)	27	160 (100%)
Bracken was encroaching on a historic feature	26 (27%)	37 (39%)	31 (33%)	1 (1%)	72	167 (100%)
Bracken was encroaching on a 'Heritage at risk' site	9 (18%)	11 (22%)	29 (58%)	1 (2%)	115	165 (100%)

Considering the differences between those with CS and ES agreements for these questions, both groups show a similar profile of agreement with the statement ‘Bracken was decreasing farm biodiversity/habitat quality’. For the statement that bracken encroaches on enclosed grazing land (Figure 3-25) the CS sample has a stronger base of 'strongly agree' than the ES sample. The same is true of the unenclosed grazing land statement, although the 'not applicable' category is high in both samples. The differences between bracken control methods showed no variation suggesting this was not a factor.

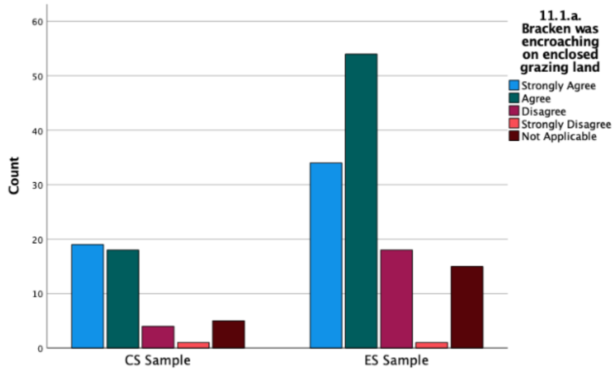

Figure 3-25: Comparison of CS and HLS responses for encroachment of bracken on enclosed grazing land

Understanding and implementing an AES agreement

All the agreement holders were asked two questions about the bracken control option in their agreement. The same questions have been asked in other AES evaluations. The first asked 'how complex did they feel the bracken control options were to understand' when they were considering including them in their AES agreement. The second asked 'how complex the options were to implement' once the AES agreement had started. The responses are shown in Figure 3-26 and 3-25 divided between bracken control management type. The first graph shows that the majority of agreement holders in the three groups and overall (81%) find the options very manageable in terms of understanding with very little difference between the three groups. The same is true of the two AES groups.

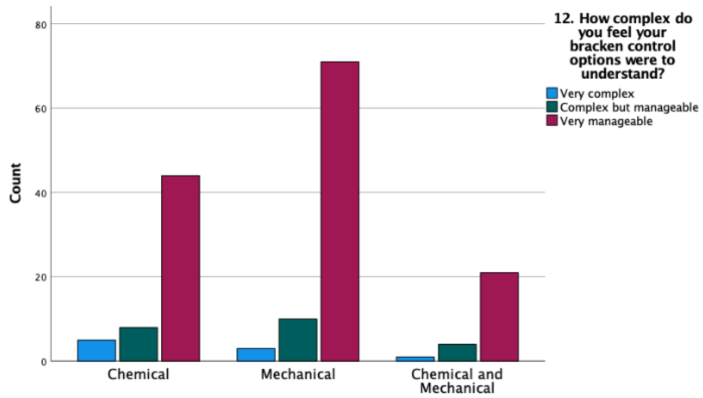

Figure 3-26: Complexity of understanding bracken control options by control method

The second question regarding the issue of implementing the bracken control options showed a difference between the CS and ES agreement holders (Figure 3-27). The graph shows that those with ES agreements are slightly likely to say that Implementing the bracken control options is 'very manageable' (56%) compared to those with CS agreements (48%). However, a fifth (19%) of the ES group said the options were 'very complex' to implement, compared to 11% of the CS sample.

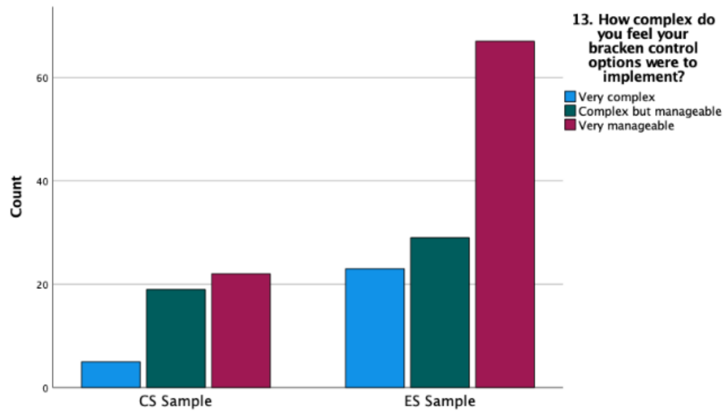

Figure 3-27: Complexity of implementing bracken control options by scheme

The findings suggest that there is a spread of views concerning the implementation of the bracken control options, with a significant number in both samples and across treatments finding the option complex to implement. However, the majority of them find the options very manageable. Interestingly there was virtually no difference in the type of bracken control management suggesting that it was not the selected approach but the overall nature of bracken control that some agreement holders found complex.

Advice received

All of the agreement holders were asked if they received advice when they were considering and securing the bracken control option for their AES agreement. Of the 171 agreement holders 60% (103) said that they did, 31% (53) did not and 15 (9%) didn't know. The response was very similar between schemes and bracken control methods.

All of the 103 who received advice were asked where the advice came from. The responses were as follows:

- 73% NE officer
- 17% conservation NGO advisor
- 10% own agricultural advisor
- 3% other farmer
- 2% HEFER or Historic England
- 22% other (included own knowledge, specialist, national park and Forestry Commission)

Again, there appears to be little difference between the two schemes or management approaches. The only slight difference appears to be for mechanical control where agreement holders were more likely to receive advice from a conservation NGO officer. For those who implemented chemical control; they were more likely to talk to their own agricultural advisor. What is clear is that advice plays an important part in the consideration of bracken control options regardless of the scheme and the type of management.

When asked what the advice referred to, the following responses were received:

- 69 (67%) assistance with option selection
- 80 (78%) advice on control methods
- 57 (55%) advice on long term management
- 10 (10%) other advice (e.g., on a specific species or wider landscape issues)

This suggests that the range of issues covered in the advice received were comprehensive and wide ranging. This would warrant further Investigation in any follow-on and more detailed analysis of bracken control approaches.

What would have happened in the absence of an AES agreement?
When asked if bracken management would have been undertaken in absence of the AES options 62% of agreement holders indicated that some bracken management would have been undertaken. A third (32%) suggested that none would have taken place with 6% saying that they didn't know. There was little if any difference between the two schemes (ES and CS), but for the management approach there is a clear difference as Figure 3-28 shows.

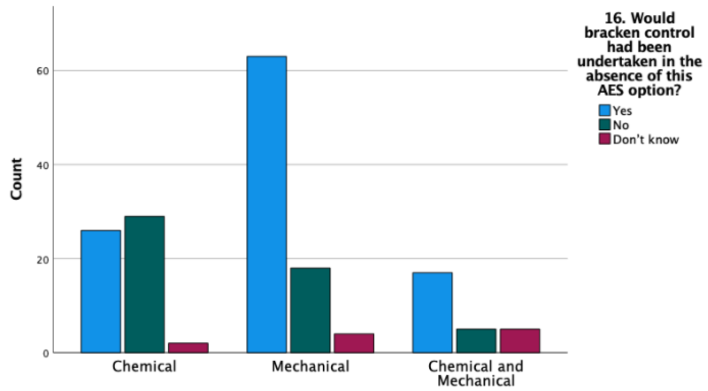

Figure 3-28: Comparison of control method versus likelihood of implementation without AES

This graph shows that those with chemical options were more likely to say that there would have been no management (51%) of bracken without the AES options, compared to mechanical (21%) of a combination of both approaches (19%). Those with only mechanical and those with both options were more likely to say that there would be some management, 74% and 63% respectively.

There was the opportunity to add a text response, focusing mainly on the method that they would have controlled the bracken. Overall, there was a move away from chemical approaches in favour of mechanical. Of the 94 responses, eight (9%) were for both approaches, 21 (22%) chemical and 65 (69%) mechanical. Among those 65 agreement holders were 12 who actually used chemical or a combination of approaches, but in the absence of the AES agreement indicated that they would only use mechanical treatments. Likewise, there were six agreement holders who would use chemical methods rather than the combination indicated in the agreement. The other most frequent comment was that the work would be undertaken at a smaller scale. This would support the perceptions that mechanical management of bracken is seen by agreement holders as a simpler task.

Views of effectiveness of bracken control options

Three questions enquired how effective the bracken control options were in terms of:

- meeting the scheme objectives
- providing long term control of bracken spread
- fitting with the farming system
- similar questions were asked of other options so some comparison is possible.

Overall, between 156 and 166 agreement holders provided an answer, with responses summarised in Table 3-8.

Table 3-8: breakdown of responses on effectiveness of bracken control

Statement	Very ineffective	Somewhat ineffective	Neither	Somewhat effective	Very effective	Total
How effective at meeting the AES option?	6 4%	12 7%	52 32%	65 40%	29 17%	164 100%
How effective at reducing bracken spread?	12 7%	22 13%	41 25%	68 41%	23 14%	166 100%
How effective at fitting with the farming system?	18 12%	9 6%	31 20%	66 42%	32 21%	156 100%

The overall figures suggest that agreement holders' perception of the bracken control AES options are broadly effective, but not convincingly so. In terms of their impact on reducing the spread of bracken, 55% indicating that they are effective but 25% are not convinced and 20% feel they are ineffective. A similar proportion of agreement holders (57%) feel that the options have met the scheme objectives, with a third (32%) say neither and 11% they are ineffective. A higher proportion of agreement holders (63%) feel that it fits with the farming system on the holding.

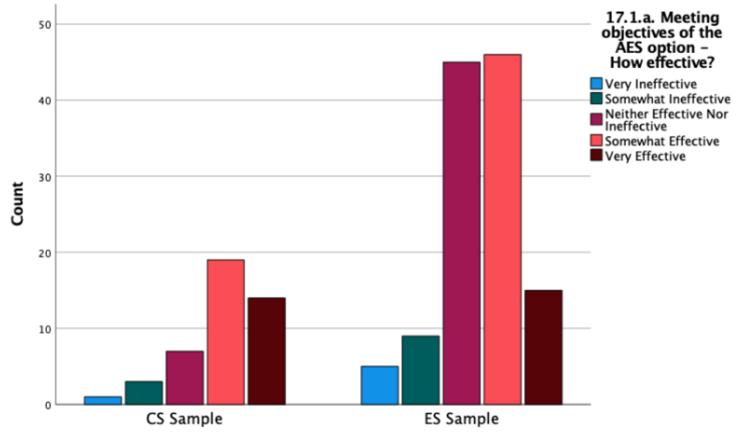

Figure 3-29: Effectiveness of meeting AES objectives by scheme

Breaking these results down by scheme, in the case of effectiveness in meeting the option objectives (Figure 3-29), it seems that CS is more positive than ES, although it is worth noting that the ES agreements are older. The ES responders seem to feel that the options have reduced the spread of bracken 'somewhat' with CS agreement holders feeling they have been very effective (Figure 3-30).

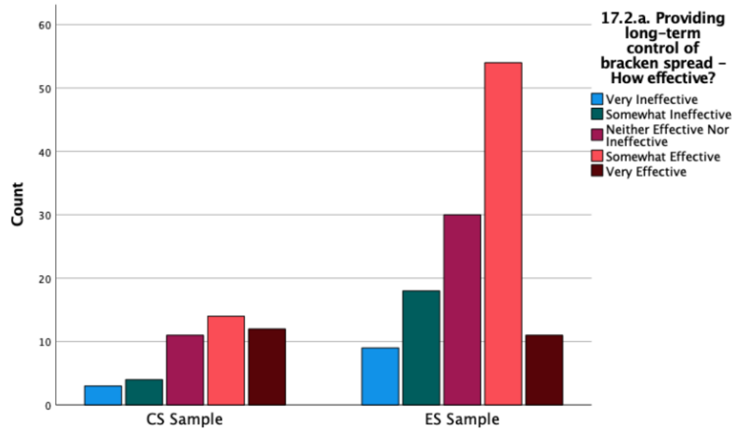

Figure 3-30: Effectiveness of long-term control of bracken spread by scheme

The responses in terms of the effectiveness of the AES option by control method suggest that those using chemical treatments are evenly split between very effective, somewhat effective and ineffective, but the mechanical group largest group is for 'somewhat effective' (**Error! Reference source not found.**). In terms of the l ong-term control of bracken spread the responses are broadly similar with the very effective responses for those using chemical treatments slightly higher (Figure 3-31).

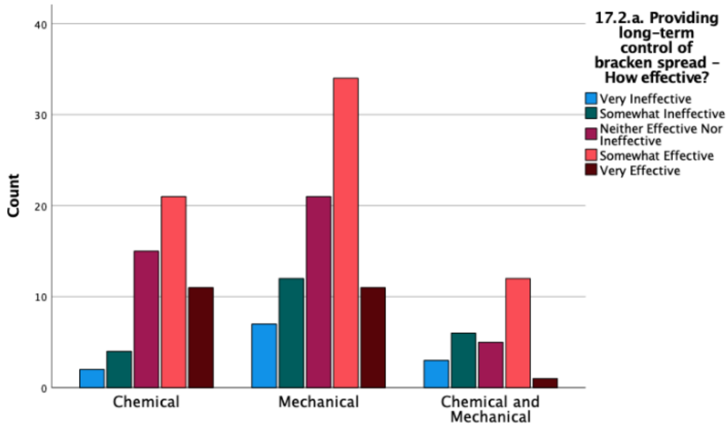

Figure 3-31: Effectiveness of long-term control of bracken spread by control method

Type of bracken control and who undertakes the bracken control work

There were a series of questions for all agreement holders enquiring about the type of bracken control undertaken. The first asked them to indicate which methods they had used in their AES agreement, mechanical, chemical or a combination of both. Overall, 57 (34%) agreement holders used chemical treatments, 85 (50%) used mechanical and 27 (16%) used a combination of both in the first year.

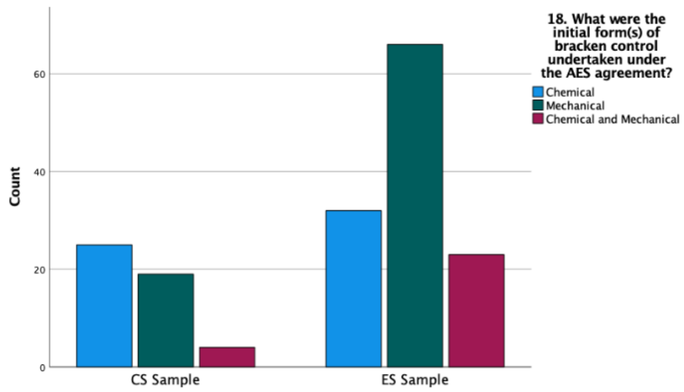

Figure 3-32: Initial control method in AES agreement by scheme

Considering the initial form of bracken control in the first years of the AES agreement (Figure 3-32), of the 48 in the CS sample just over half (25) are using chemical treatments, 19 mechanical and 4 both. This compared with 32 (26%) of the ES with chemical treatments, 66 (54%) mechanical and 23 (19%). This indicates that chemical treatments are more likely under CS than ES.

Looking more closely at those using chemical treatments in their first year, all but a few (seven) of the agreement holders used Asulam/Asulox. of the remainder Glyphosate (five) was the most popular alternative or another broadleaved treatment. The method of application among the 84 using chemicals treatments was by knapsack spraying in 33% of cases (28) or quad bike or 'Gator' (19, 23%). There were fewer using larger machinery, such as aerial applications (11) or tractor mounted sprayers (11). For the Initial mechanical treatments, all but 6 of the 112 agreement holders who used this approach were either cutting (68, 61%) or crushing or bruising (38, 34%). Very few managed it by livestock treading (3) or burning (2) or a combination of cutting and livestock treading (1) as an initial treatment.

All the agreement holders were asked when the Initial treatment took place during the year. For those undertaking chemical treatments, these almost exclusively took place in the summer between June and August, with a rare exception in April, May or September, October. For mechanical treatments there was the same emphasis on early summer, with the majority who offered a month or season stating June, July or August with some opting for two cuts in June and August or September or a single treatment in May or October. There were several comments suggesting that later summer months avoided the period of ground nesting birds.

Finally in this section, agreement holders were asked who physically undertakes the work relating to bracken control. Most (46%) of the work is undertaken by the agreement holder or their own staff. A third (33%) use contractors and 12% a combination of both. Also 9% use another option, for example volunteers.

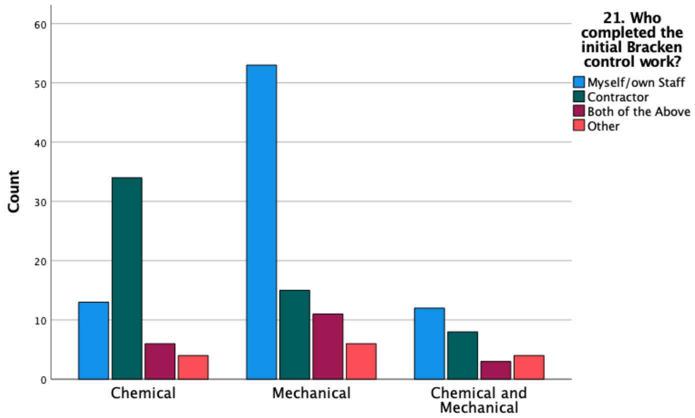

Figure 3-33: Who delivered initial bracken work by control method

The type of management option has a direct impact who undertakes the work as Figure 3-33 shows. For those with chemical options, a contractor is the most likely choice, but for mechanical management is the agreement holder or their own staff. This is perhaps not surprising as the chemicals needs specialist equipment and can be applied over large areas. It is more likely that the machinery needed for mechanical management will be owned by the agreement holder.

Effectiveness of initial bracken control treatment

All agreement holders were asked how effective the first year of control work was in tackling the bracken. This variable was included in some more detailed analysis shown at the end of this chapter. However, the initial findings show that overall, of the 166 who offered an answer, 24 (15%) said it was 'not at all effective', 83 (50%) 'somewhat effective' and 46 (28%) 'very effective' with 13 (8%) who didn't know. The responses by AES are shown in Figure 3-. Note Most of those responding 'don't know' were respondents who were not on the holding in the first year.

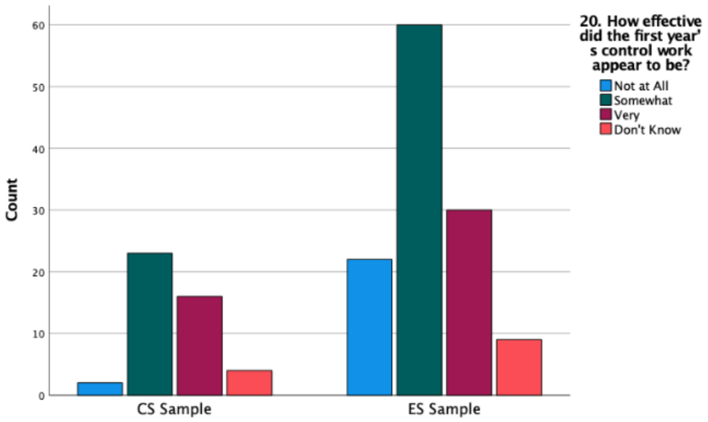

Figure 3-33: Effectiveness of first year's bracken control by scheme

The response suggest that the CS treatments were most effective in the first year of the application with few responding 'not at all' and a higher proportion of 'very' responses. This links to the higher presence of chemical treatment in the CS sample, as shown In Figure 3-34.

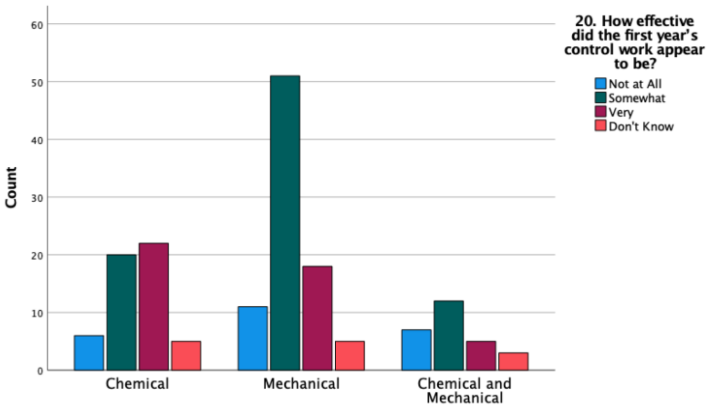

Figure 3-34: Effectiveness of first year's control by method

Figure 3-34 shows that those with chemical options for bracken control are more likely to say that the actions in the first year are very effective than the mechanical options or those with both. This is perhaps not surprising as the chemical is likely to have a higher initial impact and mechanical options tend to build up over time.

As a result, all agreement holders were asked if there were subsequent repeat treatments of bracken control after the first year. Overall, 49% (81) said there were in all areas, 44% (72) in some areas and only 7% (12) that there was no follow-on treatment.

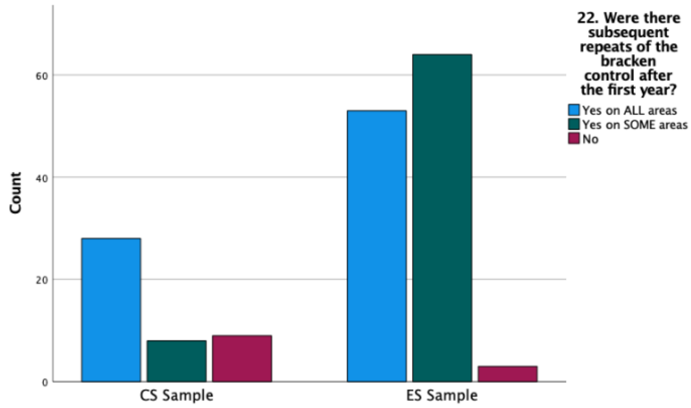

Figure 3-35: Degree of follow-on control after first year by scheme

Splitting results by scheme sample (Figure 3-35) shows that those in the CS sample were more likely to reapply treatment to all areas compared to the ES sample which offered something on some areas. There was also a variation by management type.

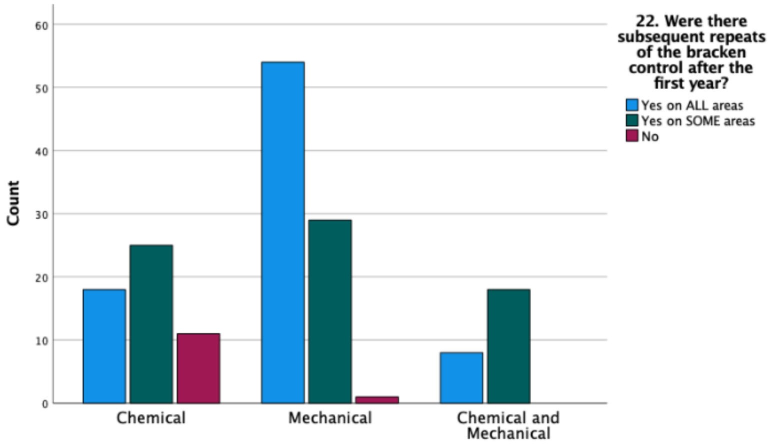

Figure 3-36: Degree of follow-on control after first year by control method

Considering follow on by control method (Figure 3-36), those with chemical options are less likely to re-treat all areas and most likely to say that they did not re-treat. Those with mechanical options are much more likely to re-treat all areas. There was not reliable data of the frequency of repeat treatments but it Is clear from some of the replies that mechanical treatments are undertaken every year whether the AES agreement paid for this or not. The analysis of the NE data showed that the most options were repeated was 3 times in a 10-year agreement suggesting that much bracken control was undertaken in additional to the agreement. Chemical applications were only paid for once in most cases.

Management plans

In most case (56%) the bracken management was undertaken as part of a specific bracken control plan. This was not the case in 36% of case, with 8% not knowing if this was the case. This was the same in CS and ES agreements and there was no difference by management type either.

All agreement holders were asked if the bracken control options formed part of a wider site management plan (Figure 3-37), with all but 5 providing a useable reply. In 52% of cases the options were part of a wider plan, in 36% they were not and 12% didn't know. There is little difference between the two schemes, but clearer difference emerges between the management options, as the graph below shows.

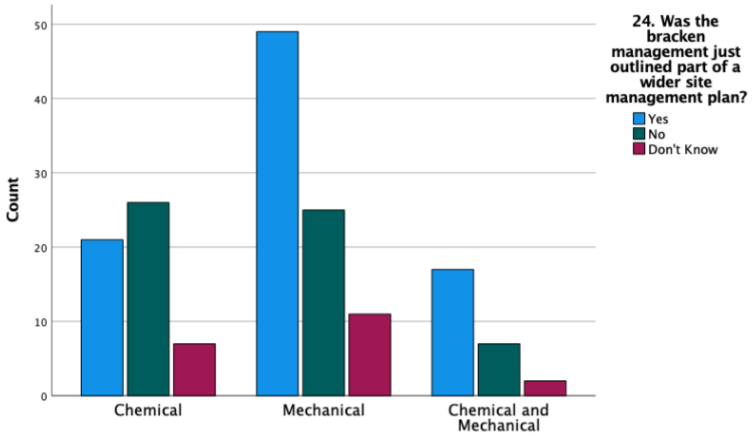

Figure 3-37: Relationship between bracken management and site management plan by control method

The graph shows that for those with mechanical management options are much more likely to be part of a wider site management plan. The same is true of those with both mechanical and chemical. Those with chemical are more likely to be specifically about bracken control.

Agreement holders were asked if they have a clear idea what the bracken management is intended to achieve. The overwhelming response was that they do (89%) and only a few respondents (5%) saying that they did not or they did not know (6%). The response is the same across the two schemes.

Grazing as part of bracken control

A key part of this project was attempting to understand the relationship between grazing and bracken control. As a result, the survey included a series of questions around this aspect. Grazing is undertaken in most (87%) of the areas in which bracken management occurs among the 166 agreement holders who provided a response. In three quarters of cases (75%) this is as agreed in the AES agreement and in a further 13% of cases the area is used for grazing but not as part of an AES agreement. There is a slight difference between the two schemes, with those in ES (77%) slightly more likely to include grazing as part of the agreement than those in CS (68%). Under the management approaches there was little difference, although numbers of those who grazed outside of the agreement were more likely to be using chemical approaches than mechanical.

The effectiveness of grazing was assessed using a 3-point scale with responses quite evenly split overall. Of the 145 who used grazing as an option, 40 (28%) said it was 'very' effective; 50 (41%) said it was somewhat effective and 34 (23%) not at all effective. A further 12 (8%) didn't know. Figure 3-38 shows this response for the two schemes and this suggests that those in the ES sample are more inclined to say that gazing is partially effective, whereas for CS the response is more even. The same split is also seen in the management approach, as Figure 3-39 shows.

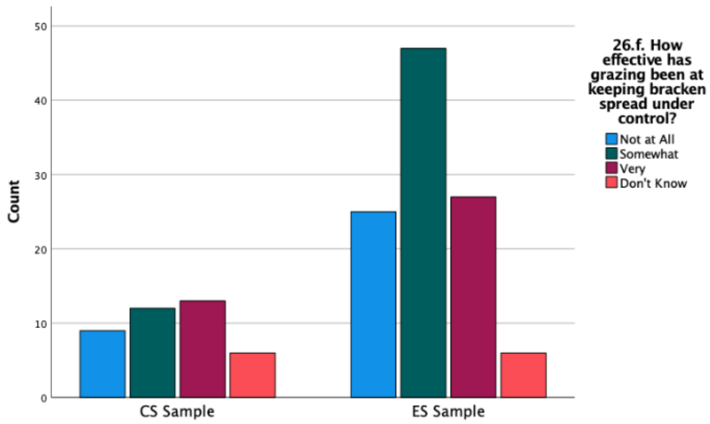

Figure 3-38: Effectiveness of grazing on bracken control by scheme

Those with mechanical options are more likely to say that grazing is 'somewhat' effective, compared to those with chemical options who offer an even response with 'not at all' slightly higher.

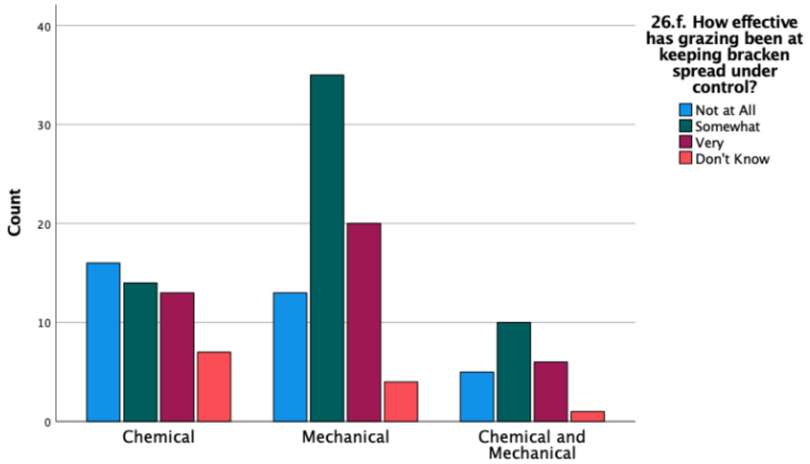

Figure 3-39: Effectiveness of grazing on bracken control by control method

A series of follow-on questions asked agreement holders to detail the time of year that the grazing took place to the month of season and the type of livestock. These were text responses and were placed into categories once the surveys were completed. Of the 135 responses received that specified the timing of grazing, 41 (30%) said that grazing was "all year round", 36 (27%) in "spring & summer (May-Oct)", 20 (15%) "summer". There was no variation by scheme or treatment.

Slightly more (145) provided details of the type of grazing with 50 (35%) having beef cattle, 43 (30%) sheep, 30 (21%) cattle and sheep in combination with other responses less than 10 response. Comparing the two schemes, there Is a slight preference for cattle in ES (38% to 25%) but those in CS were more likely to have cattle and sheep in combination (30% compared to 17% in ES). Looking at treatment there is no clear theme and the numbers are small.

A series of five statements were presented to all agreement holders which covered a range of Issues concerning the issue of grazing. For each statement they were asked to respond on a five-point scale. Not all agreement holders offered an answer as they were only asked to offer where they had an opinion. The summary of results is shown in

Table 3-9. It shows that there is a positive response regarding the importance of the timing of grazing (58% saying it is at least important); stocking density (59%) and type of livestock (63%). For the later almost half (46%) say that this is "important" and very few (4%) say it is "very unimportant". The notion of the importance of soil moisture is supported by 49% of participants but soil temperature is not with only 21% saying this is at least important. Notably the numbers responding also drops for both of these statements suggesting that these are more specialist areas that might vary with geology or climate factors.

Table 3-9: Responses to questions regarding impact of grazing on bracken control

Statement	Very unimportant	Un-important	Neither	Important	Very important	Total
Timing of grazing is important in bracken control	14 (11%)	17 (13%)	23 (18%0	43 (33%0	32 (25%)	129 (100%)
Stocking intensity is important in bracken control	12 (9%)	15 (12%)	27 (21%)	47 (36%)	30 (23%)	131 (100%)
Type of livestock is important in bracken control	5 (4%)	12 (10%)	30 (24%)	57 (46%)	21 (17%)	125 (100%)
Soil moisture is important in bracken control	12 (14%)	10 (12%)	21 (25%)	33 (39%)	8 (10%)	84 (100%)
Soil temperature is important in bracken control	19 (27%)	8 (11%)	29 (41%)	10 (14%)	5 (7%)	71 (100%)

In terms of the responses across the two schemes, there are some variations:

- responses between the two schemes for the timing of grazing, stocking density and the type of livestock are almost identical at between 58-64% saying they are 'important';
- those in CS agreements seem to be evenly spread across ‘neither’ and the two important categories for all three of these statements
- the responses across both the management approaches are evenly distributed and the numbers are small in each category.

The final question in this section asked the agreement holders if ‘additional bracken control measures were required alongside grazing’. There were 156 responses, and 135 (87%) said that yes, additional measures were needed, 9% said no and 4% didn’t know. There was no difference between the two agreement types or the type of bracken management. All this suggests that grazing is an integral part in the management of bracken for both chemical mechanical treatments.

The impact of weather was assessed by asking ‘do you feel that the weather has an impact on bracken control needs?’ Overall, of the 167 who responded, 29 (17%)

said ‘no’; 74 (44%) yes and 64 (38%) didn’t know. The large proportion of ‘don’t knows’ suggests a lack of knowledge on this issue in order to make an informed decision. There was no difference between the two schemes, but the number saying ‘don’t know’ was the largest category among those using mechanical approaches to control the bracken.

As a final question in the interview, all the respondents were asked to say, based their experiences, if they would change or improve anything regarding their bracken control options in the AES agreement. This was an open question that yielded a text response, which was analysed after the interviews were complete. Of the 161 who offered some text, 50 (31%) Indicated that they were content and would not change anything, 25 (16%) that the financial aspects needed to be increased, 24 (15%) had a negative view of the BC options in their AES agreement; 24 (15%) that they preferred chemical treatments and these needed to be retained, 13 (8%) preferred mechanical treatments, 12 (8%) suggested an improvement and 10 (6%) wanted better information about what worked.

From an overall perspective almost a third (31%) who were content and did not require any changes is quite encouraging. The number indicating the payments are too low (16%) or are negative about the AES option (15%) might be considered low as well. The proportion who are content is the same in both ES and CS. However, those saying the payments are too low are mostly from ES (21) compared to CS (4), but the numbers are small. In terms of the type of treatment those with mechanical options are most likely to say they are content (32, 42%), compared to chemical (11 ,20%) and both treatments (6, 22%). The response for the finance being too low are very similar.

Characterising those who consider current approach effective and Ineffective
Clearly the agreement holders feel that grazing is important, so the analysis attempted to locate a connection between grazing and the effectiveness of the treatment in reducing bracken spread in the first year or over the longer term. One approach looked at the presence or absence of cattle, creating two groups. There were 89 (63%) with cattle and 53 (37%) without cattle. However. there was no difference in the response according to effectiveness both in terms of the first year of treatment and the long-term impact of the bracken control options. Indeed, the responses are almost identical.

Similarly, the past management categories were condensed into two groups representing 'long-term past management' (82, 49%) and 'little or no past management' (84, 51%) in order to see if this was an influence on perceptions of initial or longer term effectiveness. In the event the responses were inconclusive with a slight Increase in those in the long term management saying current management was effective in the long term (52% to 46%) but this is not statistically robust. There was no link with the presence or absence of cattle and long-term management of bracken. Nor in the effectiveness of the initial year of management with the AES options impacted by the duration of past management, indicating that those who had undertaken little or no past management were as pleased with the first years' control as those with a longer history of managing bracken.

Some further analysis was undertaken using the Machine Learning methodology in Orange Data Mining to explore connections between different variables within the data. This might better understand the variations between different groups within the study. Across the whole there were 171 participants, of which 166 presented information on ‘How effective did the first year’s control work appear to be?’. We categorised the responses for this question to two groups, Group 1 those responded, ‘very effective or somewhat’ (n=129) and Group 2 those responded, ‘Not at all or don’t know’ (n=37).

We used the Machine Learning methodology in Orange Data Mining to better understand on what the specifications of these two groups are in our study. We used high accuracy (more than 90%) and letting the algorithm to split the groups to small numbers of participants (5) in classification process. To do the analysis, we used the participants responses (n=166) to the following three questions:

- Q10.History of the Bracken Management (1= Little Know past management; 2= Long term past management)
- 17.2.a. Long-term control of bracken spread (1= Effective; 2= Ineffective)
- 26.a. Two Categories (1= With cattle; 2= Without cattle)

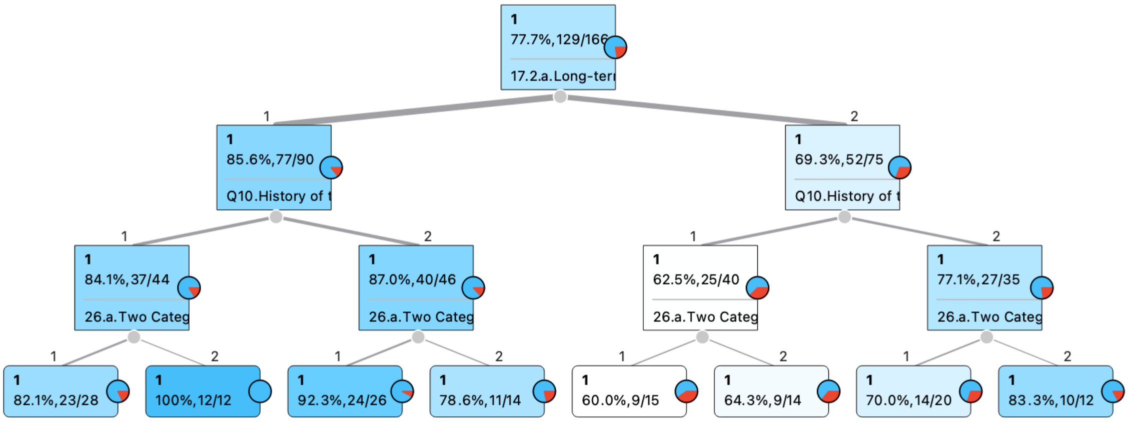

Figure 3-38: Tree decision in Orange Data Mining

This allowed the production of the following table.

Table 3-10: Output of Orange Data Mining

Respondents	Rules	%	Number of Respondents	Long-term management 1= Effective 2= Ineffective	Past management of bracken 1= Little or No past management 2= Long term past management	Livestock grazing bracken 1= With cattle 2= Without cattle
'Very effective' or 'somewhat effective'	1	17.83%	23/28	1	1	1
	2	9.30%	12/12			2
	3	18.60%	24/26		2	1
	4	8.53%	11/14			2
	5	7.75%	10/12	2	2	2
	6	10.85%	14/20			1
Total=129		**72.87%**	**Total of 112 participants satisfy these rules, where 94 are those responded 'very effective' or 'somewhat' effective in first year control of bracken**			

The classification successfully classified 72.87% of the first group of participants (selected 'Very effective' or 'somewhat effective' in Q20) based on their responses to the three questions of 'Q17.2.a', 'Q10' and 'Q26.a'.

The tree classification did not categorise the responses of the second group (responded 'Not at all' or 'don't know') based on their provided responses to these three questions.

Applying this methodology, we gain a picture of the sample which reveals that there is a core of agreement holders who are largely content with the bracken control measures, fairly knowledgeable and well-practiced in undertaking the management required but keen to receive advice. Some of this group also feel that the treatments are effective but have concerns that the spread of bracken will impact the productivity of the land and in particular the grazing. In group 2, which was not categorised, those who are not convinced about the effectiveness of the treatments, the largest group are those who feel the bracken Is impacting on the productivity of the grazing land. What Is clear is that the relationship is complex with a number of factors influencing how the agreements holders feel about bracken control options within AES.

3.4 Case Studies

3.4.1 Case study 1

This case study looks at the effectiveness of HR5 bracken control for a series of 10 contiguous upland parcels managed under a single HLS agreement. These parcels also formed part of a Historic England bracken control research project, under which a variety of control methods were tested between 2016-2019 (Oatway, 2020). The parcel areas, results of our remote sensing classification and control methods from the study are shown in Table 3-11.

Table 3-11: Summary of parcels with bracken cover in 2014 and 2020

Parcel	Parcel Area (Ha)	% covered by option	% Bracken Cover 2014	% Bracken Cover 2020	Bracken control method(s)
A	0.10	100%	6%	1%	N/A
B	0.98	100%	96%	47%	Chemical
C	0.55	100%	98%	35%	Lime
D	0.35	100%	99%	80%	N/A
E	4.19	100%	98%	59%	Single Bash, Lime
F	0.13	100%	100%	5%	N/A
G	0.90	100%	98%	1%	Double Bash
H	0.78	100%	98%	1%	Cut, Double Bash
I	1.17	100%	98%	32%	Chemical
J	0.46	100%	100%	1%	Single Bash

Overview of agreement

- Agreement dates ran from 2010 - 2020
- Management prescription was to be by mechanical means, followed up by grazing.
- All parcels were covered by G05 Lowland dry acid grassland
- The parcels were covered by a series of medieval strip fields, tinworks and prehistoric that were designated as a Scheduled Monument flagged by the HAR 2020 dataset as being under risk from plant growth (Figure 3-39)
- Indicators for success of the agreement (from 2017) identified that by year 10, cover of bracken on historic features identified in the FEP should be between 0% and 20%, and less than 5% in areas of species rich grassland

Effectiveness of control

- As Table 3-11 shows, the bracken control agreement for these parcels appears to be having an effect on bracken coverage. 6 parcels have a Decreased change score, with two of these parcels resulting in a Good final condition (bracken < 50% of option area), and the other 4 showing a Moderate final condition (bracken 50-90% of option area).

- Comparison of 2014 against 2020 coverage maps (Figure 3-40) shows that substantial areas have been cleared of bracken for most parcels, but some large stands still remain.
- Looking at the individual bracken classifications over the parcels for years without cloud cover (2014, 2017-2020), the majority of these areas have been cleared since 2018-2020 (Figure 3-41).
- Considering the indicators of success, 50% of the parcels have met the year 10 requirement of bracken area between 0-20% of parcel area, and it appear that the work has mostly taken place towards the end of the agreement.
- The reductions in bracken area seen in our classification are largely in line with the UAV and ground assessments of bracken cover from the Historic England study (Oatway, 2020). This provides further evidence for the suitability of satellite remote sensing for sub-parcel bracken monitoring
- Regarding control methods, Historic England found that the double bash method provided the most effective method for reducing bracken cover, while the chemical controls also had a significant effect on reducing bracken vigour (Oatway, 2020)

Figure 3-39: Relationship between parcels and HAR 2020 / Scheduled monument feature

Figure 3-40: Change in bracken cover between 2014 (left) and 2020 (right) assessments

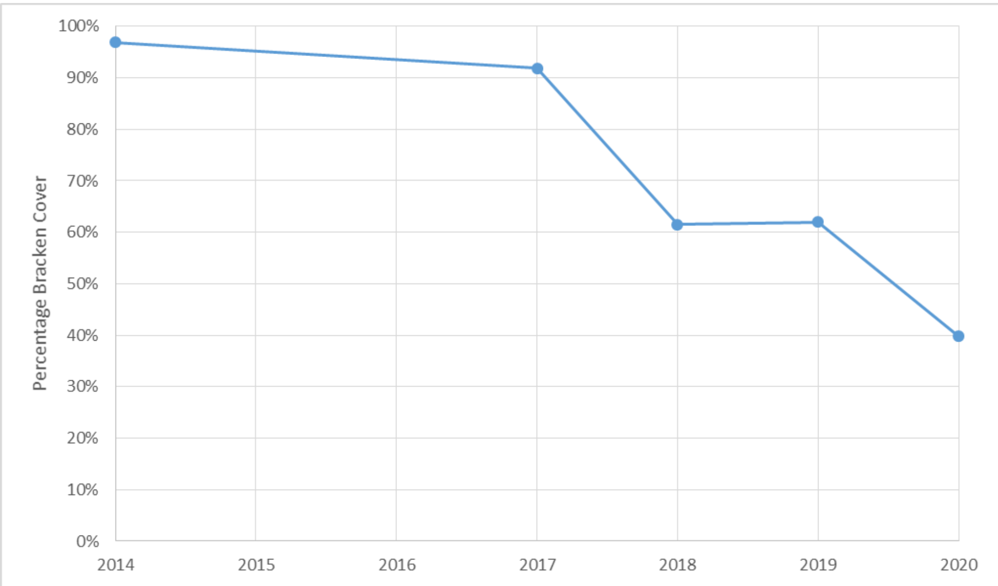

Figure 3-41: Year on year change in bracken cover across all parcels in agreement

3.4.2 Case study 2

This case study looks at the effectiveness of HR5 bracken control for single upland parcel managed under an HLS agreement.

Table 3-12: Summary of parcel

Parcel Area (Ha)	% covered by option	% Bracken Cover 2014	% Bracken Cover 2020
8.65	95%	12%	0%

Overview of agreement

- Agreement dates run from 2014 - 2024
- Management prescription was to be via mechanical means, either cutting and/or bruising
- Parcel was covered by a mixture of M02 Fragmented heath and SP01 Juniper
- A single historic feature was noted for the parcel, but there is no record of this is in any of the historic landscape datasets evaluated
- This option is aimed at controlling the spread, or removing existing stands, of bracken where it is desirable to do so.
- In addition to HR5, the parcel is also covered by HK16 (Restoration of Grassland for Target Features) which aims to create a mosaic of bracken structures with dense litter beds, grassy open bracken stands supporting populations of dog violets and grassy rides to aid livestock grazing. Bracken should not be completely eradicated.
- Indicators of success were that by year 5 the bracken cover should be between 50-60% of the area mapped on the FEP. By this date there should be a mosaic of bracken structures with dense litter beds, grassy open bracken stands supporting populations of dog violets, and grassy rides to aid livestock grazing.

Effectiveness of control

- As Table 3-12 and Figure 3-42 both show, the bracken control measures have been having a strong effect, with all the bracken appearing to have been removed by 2020.
- The year-on-year change graph (Figure 3-43) shows that there was a slight increase in bracken coverage 2014-2015, and then a clear downwards trend 2018-2020. 2016 & 2017 were omitted due to cloud cover.
- Turning to the indicators of success, wholesale removal of bracken was not the objective; instead, the desired result was a mosaic of bracken stands and other vegetation.
- Looking in detail at the Sentinel-2 imagery for 2019-2020, and a VHR satellite image from May 2020 in Google Earth, it is apparent that there is still bracken in this parcel. However, the stands are well interspersed with other vegetation

and smaller than the 900m² minimum mapping unit used in the classification so appear to have been missed

- In summary, this option appears to have had the desired impact of breaking up the large bracken beds into a mosaic of smaller stands. However, given the limitations of the satellite remote sensing it is impossible to quantify whether the target of bracken covering 50-60% of the original area has been met.

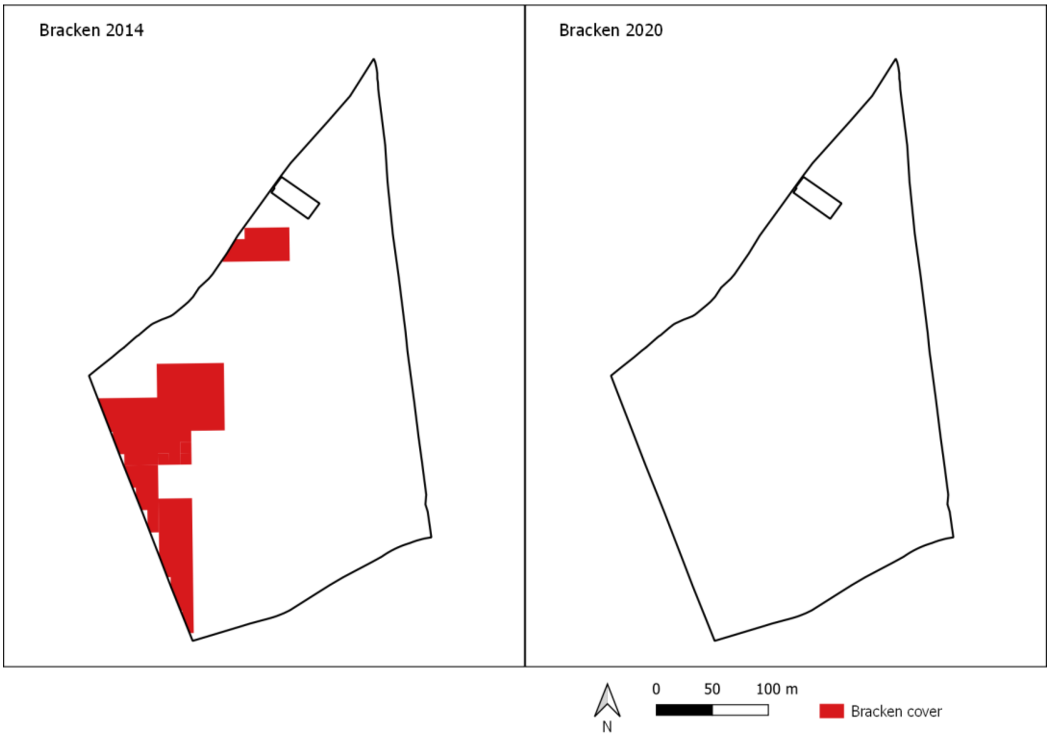

Figure 3-42: Change in bracken cover between 2014 (left) and 2020 (right) assessments

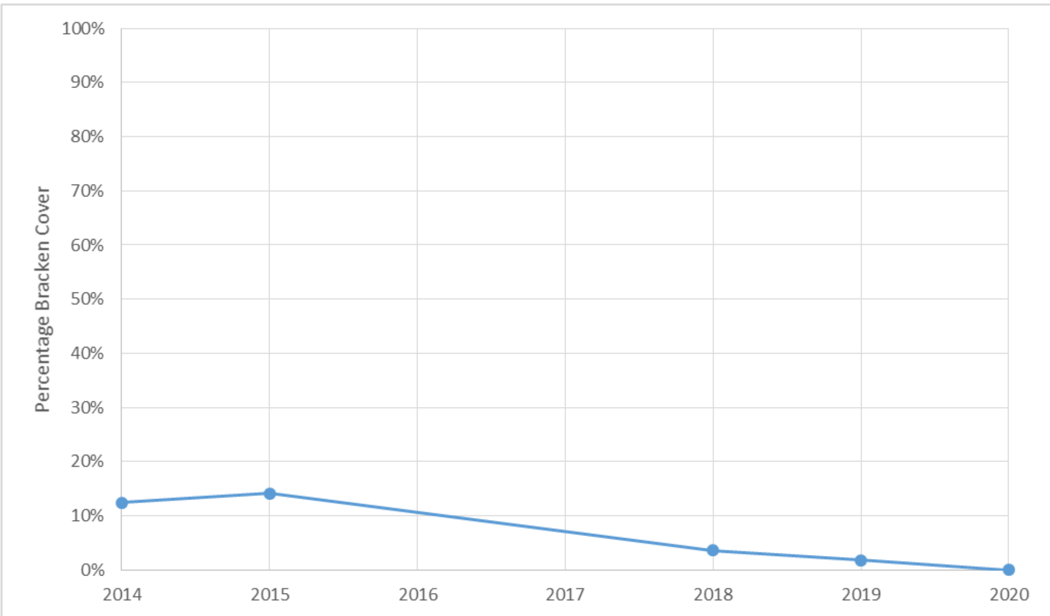

Figure 3-43: Year on year change in bracken cover for parcel

3.4.3 Case study 3

This case study looks at the effectiveness of SP3 bracken control supplement for a single lowland parcel managed under a CS agreement.

Table 3-13: Summary of parcel

Parcel Area (Ha)	% covered by option	% Bracken Cover 2017	% Bracken Cover 2020
3.88	41%	16%	23%

Overview of agreement

- Agreement dates run from 2017 - 2021
- Control method was not indicated in SP3 management description, but an SB5 mechanical control option was shown on the options map
- The parcel contains woodland around its edge, and an open area in the middle covered by MO3 Lowland Heath. The MO3 habitat is mosaic of heathland, acid grassland and rotationally managed bracken. The management prescriptions for the parcel were focussed on conservation of small pearl-bordered fritillary.
- The parcel is also covered by a SSSI, the location of which is shown in Figure 3-44.
- The option area covered 1.6 ha of the parcel, and its exact extent was not recorded on the option map. However, it is noted as overlapping both the lowland heath and SSSI.
- No historic features were found for the parcel
- This option was aimed at controlling re-infestation during the term of the agreement, and it was expected that by year 5 overall bracken cover should be the same or less than at the start of the agreement, but it should cover no more than 60% of the SSSI and have reduced density and vigour.

Effectiveness of control

- Figure 3-45 shows that the bracken cover in the open part of the parcel evaluated has had an overall increase between 2017 and 2020. The bracken has also moved in the parcel, with a decrease in the NW and increase in the SE. However, without knowing the exact location of the option we cannot evaluate whether this is due to the control work undertaken
- Looking at the year on year change (Figure 3-46), we can see that there was an expansion of bracken between 2017 and 2018, but bracken cover from 2018 to 2020 has largely stayed steady
- Considering the indicators of success, it is noted that the overall cover was expected to stay largely stable, but the with decreased vigour and density. As this approach has been designed to monitor presence/absence not density or vigour it is entirely possible that the option is having the desired effect. To further evaluate changes to vigour and density would require monitoring from higher resolution imagery such as drones.

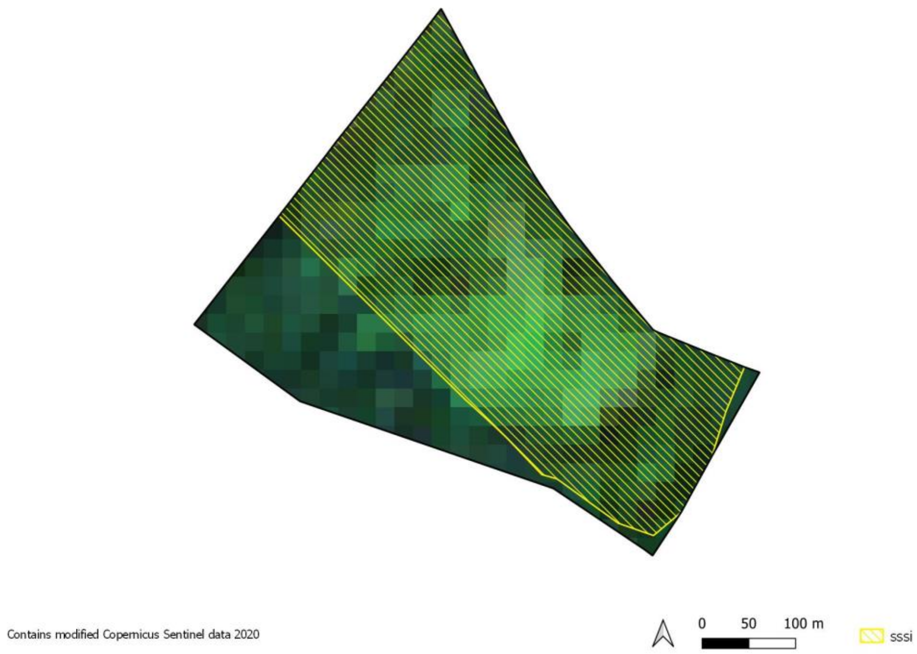

Figure 3-44: Location of SSSI within parcel

Figure 3-45: Change in bracken cover between 2014 (left) and 2020 (right) assessments

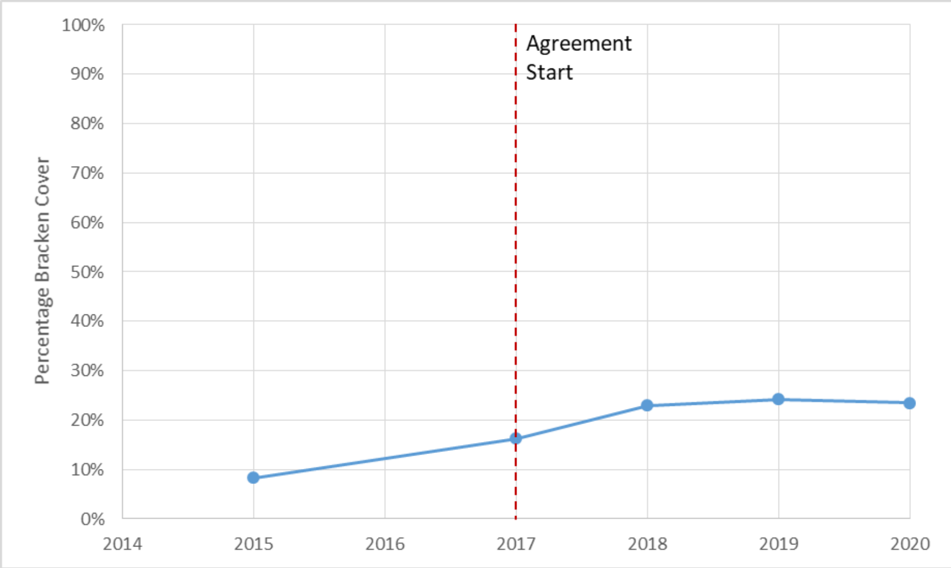

Figure 3-46: Year on year change in bracken cover for parcel. The agreement start date is also indicated.

3.4.4 Case study 4

This case study looks at the effectiveness of HR5 bracken control for single upland parcel managed under an HLS agreement.

Table 3-14: Summary of parcels

Parcel Area (Ha)	% covered by option	% Bracken Cover 2014	% Bracken Cover 2020
1.97	99%	55%	0%

Overview of agreement

- Agreement dates run from 2009 - 2021
- Management prescription was to be via mechanical means, either cutting and/or bruising
- Parcel was covered by unimproved grassland with small stands of semi-natural woodland (T08)
- This option is aimed at controlling the spread, or removing existing stands, of bracken where it is desirable to do so.
- In addition to HR5, the parcel was also covered by HK7 (Restoration of species-rich, semi-natural grassland) and HR1 (Supplement for cattle grazing).
- Indicators of success were that by year 5 the bracken cover should be between 0 and 5%

Effectiveness of control

- Figure 3-47 shows that the bracken control measures have had a strong effect, with all the bracken appearing to have been removed by 2020.
- The year-on-year change graph (Figure 3-48) shows that bracken in 2014 covered 55% over the parcel, and in fact expanded in 2015 to cover 80%. however, by 2018 bracken had been completely removed by 2018, and remained absent in 2019-2020. 2016 and 2017 were obscured by cloud cover.
- Turning to the indicators of success, the target of 0-5% bracken cover has been achieved. However, it appears to have taken longer than the target of 5 years (i.e., 2014-2015) to deliver this impact.

Figure 3-47: Change in bracken cover between 2014 (left) and 2020 (right) assessments

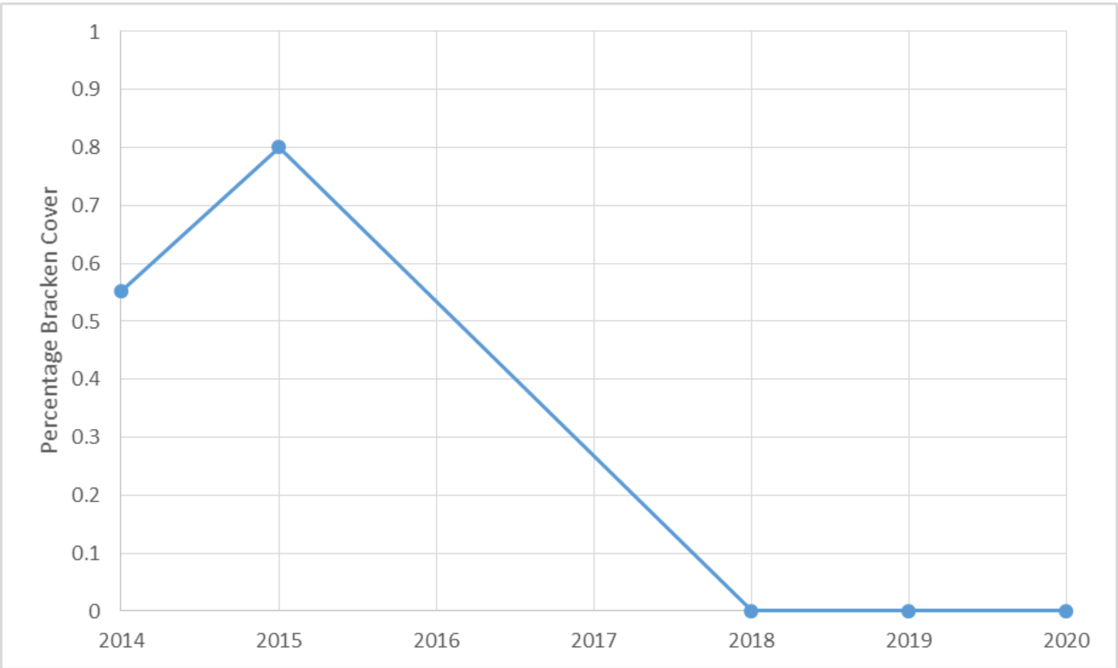

Figure 3-48: Year on year change in bracken cover for parcel

4 Main Findings and Conclusions

4.1 Main Findings

4.1.1 Bracken classification methodology

- The analysis of winter and summer NDVI differences appears capable of detecting the presence and absence of bracken within parcels, but further field work is required to assess the accuracy of the classification. The approach is scalable and automated, and may provide a viable method for monitoring sub-parcel changes to bracken cover.
- Over the 7 years evaluated, cloud cover proved a significant challenge. This was especially true prior to 2017 as only Landsat-8 imagery with a 16-day revisit time was available.
- The effect of cloud cover was mitigated by combining results into two time windows; baseline (2014-2016) and revisit (2018-2020), allowing for comparison of bracken cover over the assessed time period.
- The spatial 10-30m resolution of the satellite imagery used means that stands of bracken smaller than the minimum mapping unit of 900m^2 cannot be identified.
- The approach was designed to deliver a presence/absence assessment rather than a bracken density assessment. As Case Study 2 shows, bracken can still be present in a parcel, but at lower levels than this approach can detect as a result of management breaking up bracken patches.
- The lack of spatial extents for bracken options within parcels was a significant limitation. Sixty percent of parcels contained options that covered less than half of the parcel. In the case of such sub-parcel options, it is impossible to determine whether changes in bracken cover are due to management or other effects.

4.1.2 Bracken cover findings

- The bracken cover analysis was restricted to parcels containing options that covered >90% of the parcel area in order to mitigate against the lack of spatial information on option location within the parcel. This provided a final sample of 134 parcels for evaluation from remote sensing.
- The remote sensing analysis was used to generate two scores for each parcel:
    - Bracken change score that compared the cover at baseline (2014-2016) and revisit (2018-2020) windows and assigned a decreased, stable or increased cover score based on percentage change thresholds
    - Final bracken cover score that evaluated the proportion of the parcel covered by bracken during the revisit assessment and assigned a low, medium and high score.
- Looking at the change score, a narrow majority of parcels (57) had decreased bracken cover, a similar number (52) had remained stable and a small number (25) had increased cover.
- For the final cover score, a clear majority (94) had a low final cover, 31 had medium final cover and only 9 had high final cover.
- Overall, these results suggest that the bracken control work is having a positive effect on reducing bracken canopy cover for the parcels evaluated.
- Looking at the spatial distribution of the bracken change and final cover scores, there was a clear geographic cluster of parcels with increased bracken cover and medium final bracken cover scores in the NW of England.
- The environmental data provided some indication that rate of bracken growth may be affecting outcomes, with areas likely to support faster bracken growth more strongly correlated with increase in bracken cover between baseline and revisit assessments.
- The historic landscape case studies (section 3.2.2) showed that satellite remote sensing is capable of monitoring bracken cover over scheduled monuments and parks and gardens, and provided some evidence that bracken control is reducing cover over features.
- In three of the agreement case studies (section 3.4), it took multiple years after work began for bracken cover to significantly reduce. This is somewhat at odds with literature that suggests bracken control has an immediate impact on cover that fades over time. However, it does provide a good case for the need to continue bracken management beyond the first two years of an agreement.

4.1.3 Interview findings

Importance of AES and previous experience

- A significant proportion of the agreement holders had been managing bracken both within and outside AES agreement for a long time.
- There is a sense that bracken management is more challenging now.
- A quarter of the sample were in their first AES agreement and had selected bracken control option because they were not managing it effectively and need advice.
- The impacts of bracken are wide ranging but centre on the impact on biodiversity and a loss of grazing land.
- Agreement holders perceive the bracken control options to be well understood and are 'manageable' to implement.

Importance of advice and effectiveness of AES options

- The receipt of advice is important to agreement holders and most likely to be provided by NE, but those using chemical treatments are keen to use their own adviser.
- Management of bracken would have been undertaken without the AES scheme but with a greater focus on mechanical options and often on a smaller scale, especially if the agreement was for chemical options
- Agreement holders are not entirely convinced of the effectiveness of the AES options in terms of the first year with many undertaking treatments throughout their agreement. Mechanical options are often undertaken annually, even though the AES agreement only pays for 2 or 3 years within a 10-year agreement.
- The first year's work was most likely to be 'very' effective in the chemical group. With most mechanical treatment agreement holders saying it has been 'somewhat' effective and repeated activity each year.
- Mechanical approaches were most likely to require repeated management on all areas but this is often repeating a traditional pattern of management.

Management plans and the role of grazing

- Management plans were most likely in the ES sample with bracken control seen as part of a larger landscape approach.
- The role of grazing is important and warrants further investigation to understand the trends. It seems likely that cattle are the preferred option in many situations, with grazing happening all year or most intensively in the summer.
- However, there appears to be no clear approach amongst agreement holders about how to manage bracken. A more detailed face-to-face survey would be able to collect data on stocking density, timing and the connection between treatments and grazing.
- Knowledge about managing bracken seems to vary among the agreement holders with some concerned about the impact on productivity while others linked management of bracken to concerns about nesting birds and the spring flush of flora.

4.2 Conclusions

- Optical satellite imagery is capable of mapping bracken within parcels, but cloud cover limits the capability of such data to evaluate changes to cover. Looking from 2017 onwards, the 5-day revisit frequency of Sentinel-2 greatly increases the volume of seasonal cloud-free imagery available. Optical satellite remote sensing provides clear capacity for monitoring the effectiveness of bracken control work into the future.
- Given the limitations of cloud, Sentinel-1 radar imagery should be evaluated to see whether it is capable of detecting bracken cover as this would provide an all-weather, year-round monitoring capability.
- The 10-30m spatial resolution of the sensors evaluated in this study missed smaller, scattered patches of bracken that may be still an indicator of successful control. High resolution aerial photography clearly shows the presence of small bracken patches and can also be used to infer bracken stand density. Manual interpretation of high-resolution aerial and UAV imagery and could form part of an integrated approach to assess the effectiveness of bracken control without the need for field visits. Whether such an approach would prove cost effective requires additional consideration.
- The lack of spatial extents for options within parcels, combined with generally small areas of bracken under option, was a key limitation for assessing the effectiveness of control from remote sensing. If these data were available, the method could be readily rolled out across all parcels and provide a more complete assessment of the effectiveness of control upon bracken cover.
- Related to the above point, field or UAV mapped extents of bracken canopy collected throughout the lifetime of agreements could provide useful evidence to assess the performance of control methods and better calibrate monitoring through remote sensing.
- The omission of small treatment options may also be biasing results towards only short-term canopy reduction, as these are more likely to be patches of continuous bracken surrounded by dense canopy. The type of small bracken stands that might be more easily controlled and eliminated, because they are not backed up by nearby canopy outside of the area of control, have been filtered out in this study but could be evaluated in future studies (Alan Brown, Pers. Comm.).
- The results from the wider analyses and case studies indicate that environmental management under the agri-environment schemes is proving beneficial for reducing the impact of bracken on grasslands. The rewilding agenda, coupled with the likely increased vigour of bracken due to climate change and nitrogen deposition are factors that are likely to make bracken more of a problem. Schemes that help land managers control it are therefore likely to be more valuable in the future
- The interviews with agreement holders revealed a possible link between grazing and bracken control but the shortcomings of telephone interviews were such that this could not be explored in sufficient detail. The analysis did

not suggest that those with cattle find their approach to bracken control more effective, even though there is a body of thinking that suggest that heavy footed livestock are able to break up dense bracken areas. This should be tested more robustly in order to assess the effectiveness of approaches like high stocking rates for short periods (sometimes called mob grazing) also need testing alongside other aspects such as timing as well as the type of livestock.

- Given the inability to find a clear theme linking effectiveness of control and agreement holder characteristics the issue of bracken control is clearly complex and it could be impacted by local factors, such as altitude or geology, as the other sections suggest.
- What is clear is that farmers and other agreements holders are innovative in their attempts to reduce the spread of bracken. Given the high presence of local knowledge it would make sense to assist the development of knowledge exchange by developing local hubs and demonstrations so different approaches to bracken control can be shared and the outcomes tested. Such approaches have worked well in relation to other environmental issues such as water quality with Catchment Sensitive Farming.
- From examining the NE data it is clear that the areas of bracken control under AES options are typically quite small, even where the bracken areas are larger. The options are rarely, if ever, funded for management every year, but it is clear that management occurs regularly through the agreement through mechanical and, to a lesser extent, chemical control. A thorough examination of the cost of different approaches might help the management options to be more realistic in terms of time and resources. This is particularly relevant in when considering the potential for long distance translocation of carbohydrates through bracken rhizomes, which may allow small stands of treated bracken to draw nutrients from nearby untreated stands and recover rapidly.

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Appendix A: Complete Results of Environmental Variable Analysis

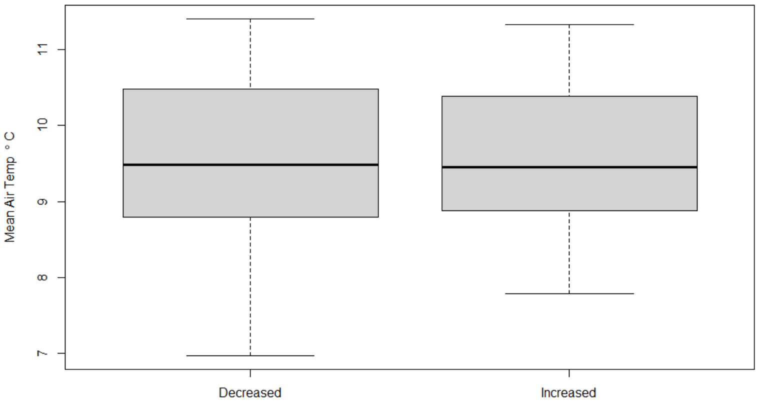

Figure A-1: Distribution of mean parcel temperature against change score

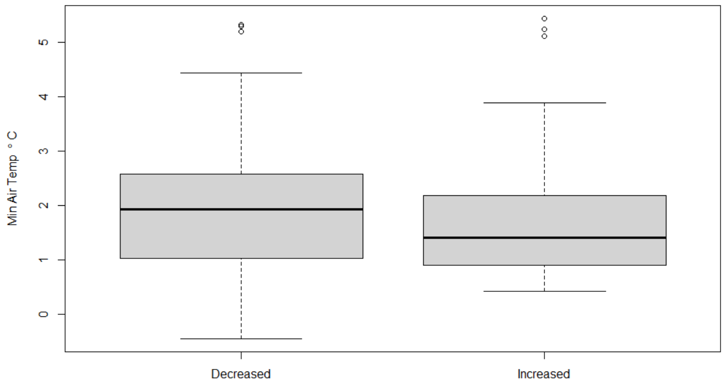

Figure A-2: Distribution of minimum parcel temperature against change score

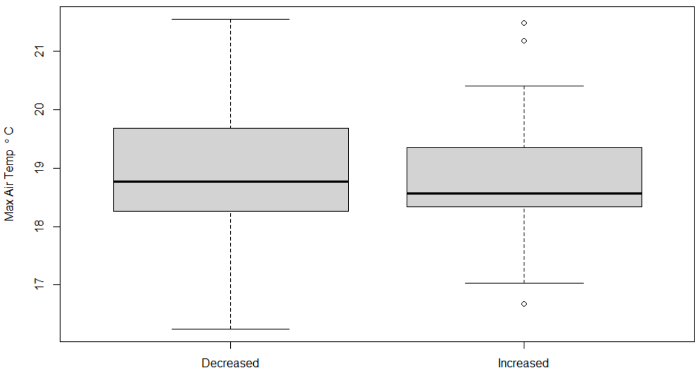

Figure A-3: Distribution of maximum parcel temperatures against change score

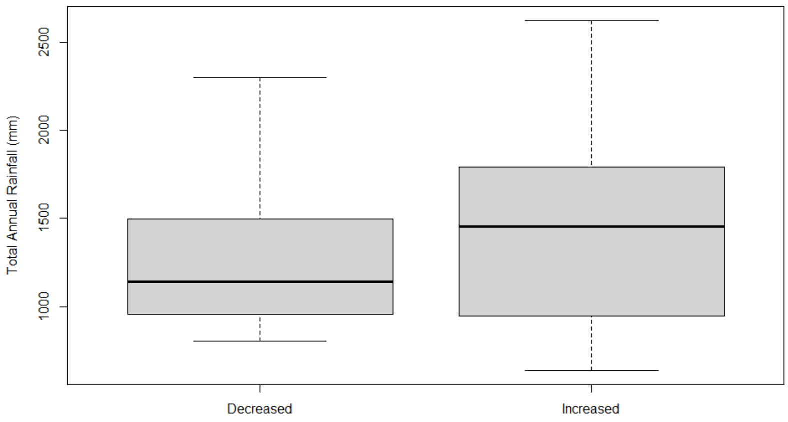

Figure A-4: Distribution of total parcel precipitation against change score

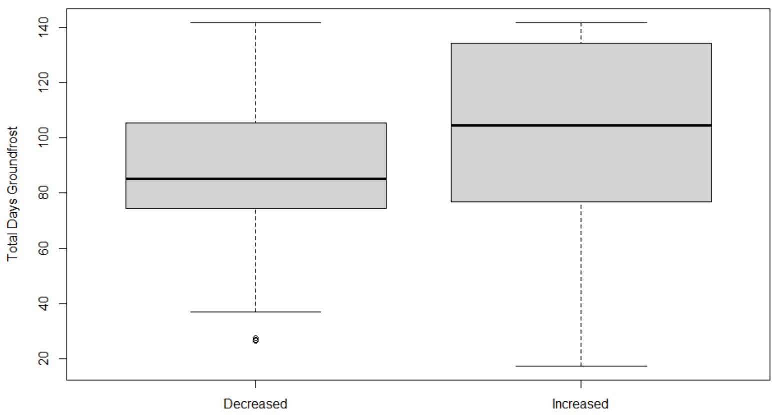

Figure A-5: Distribution of total days of ground frost against change score

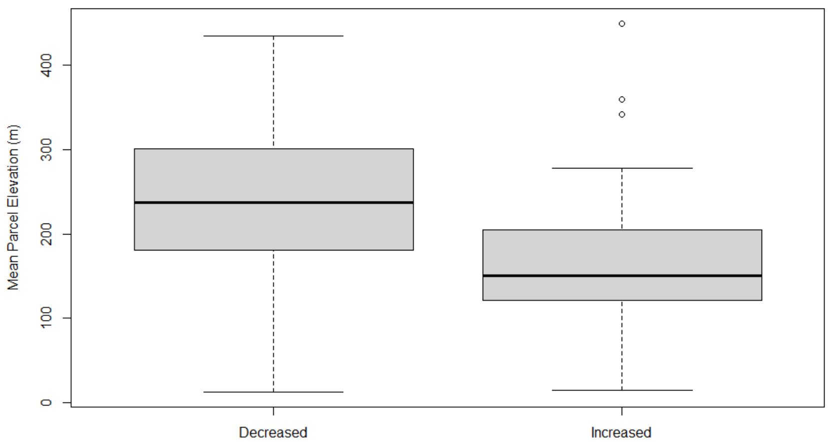

Figure A-6: Distribution of mean parcel elevation against change score

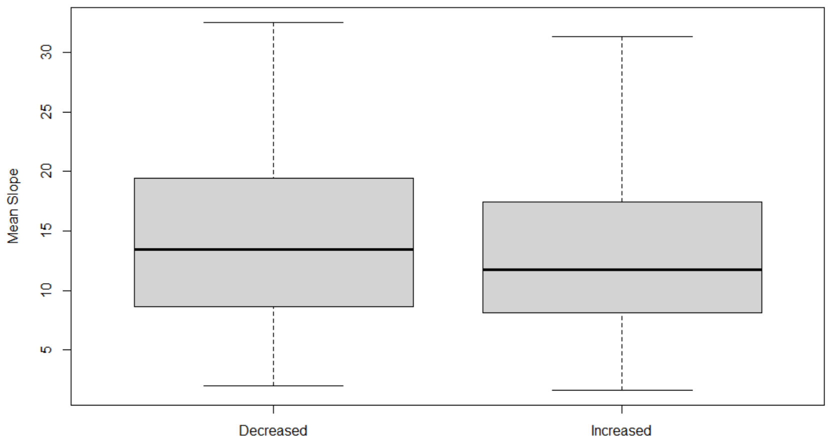

Figure A-7: Distribution of mean parcel slope against change score

Final Condition Score

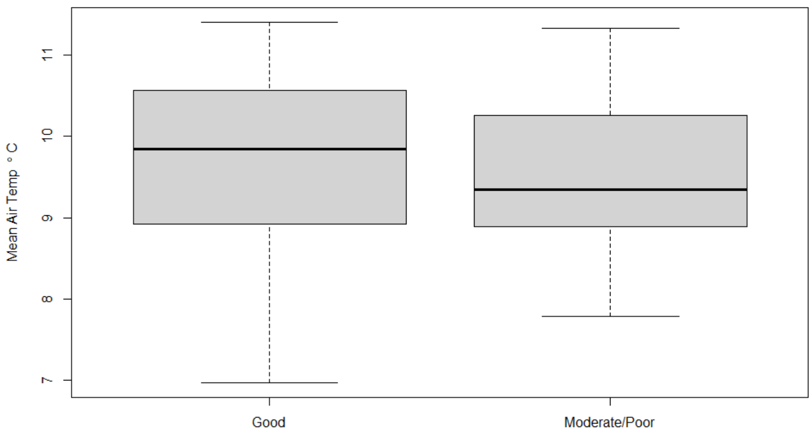

Figure A-8: Distribution of mean parcel temperature against final condition score

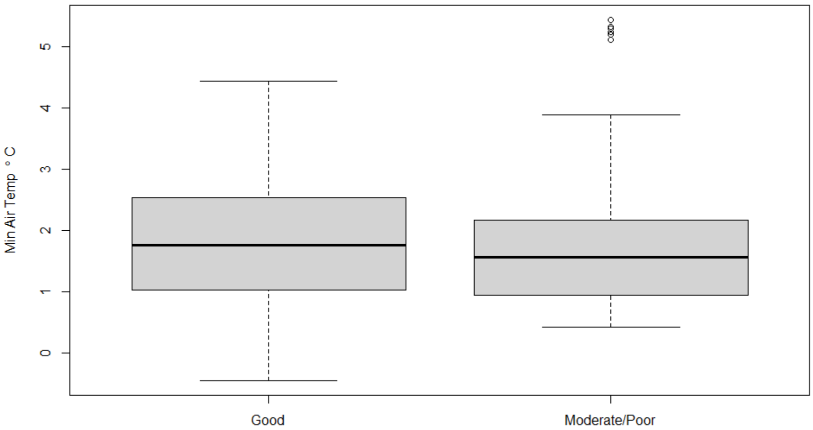

Figure A-9: Distribution of minimum parcel temperature against final condition score

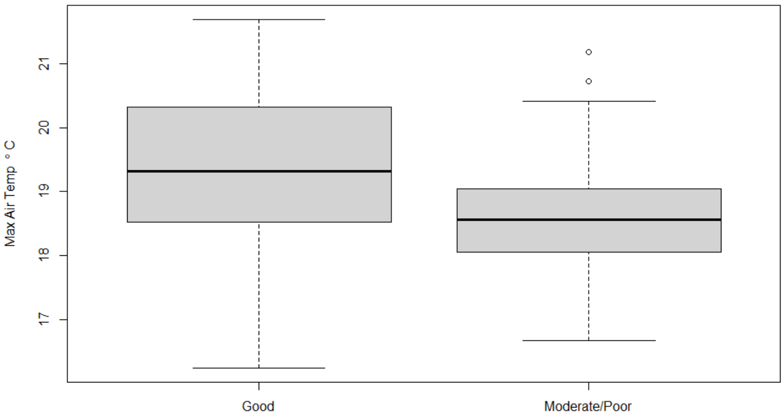

Figure A-10: Distribution of maximum parcel temperature against final condition score

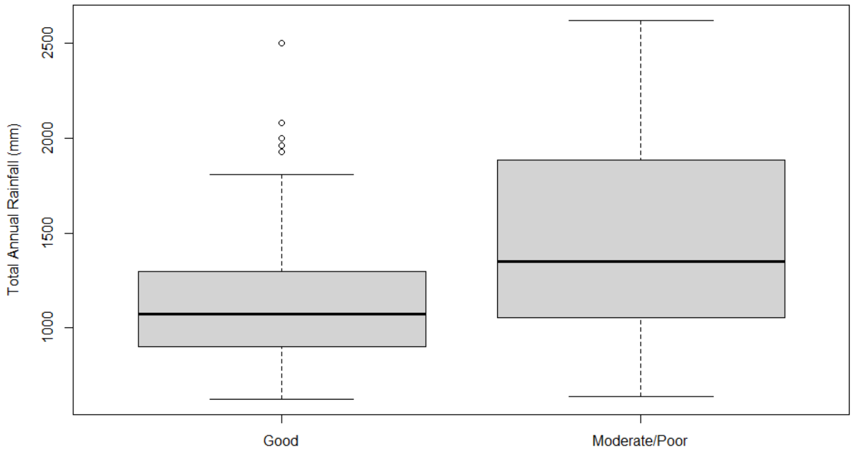

Figure A-11: Distribution of total parcel precipitation against final condition score

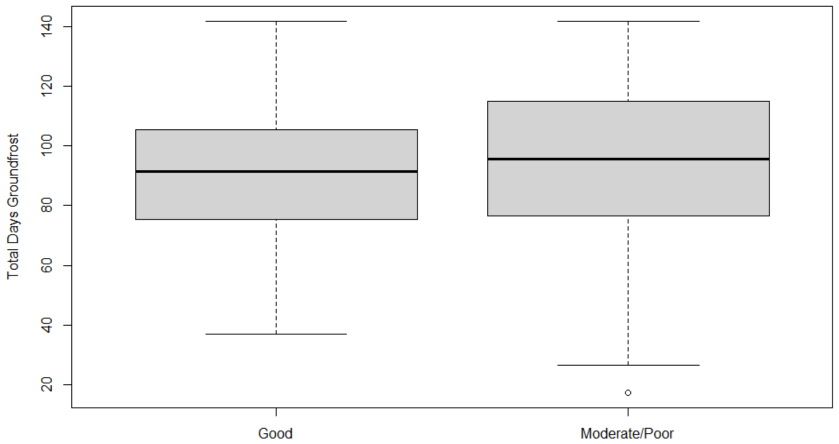

Figure A-12: Distribution of total days of ground frost per parcel against final condition score

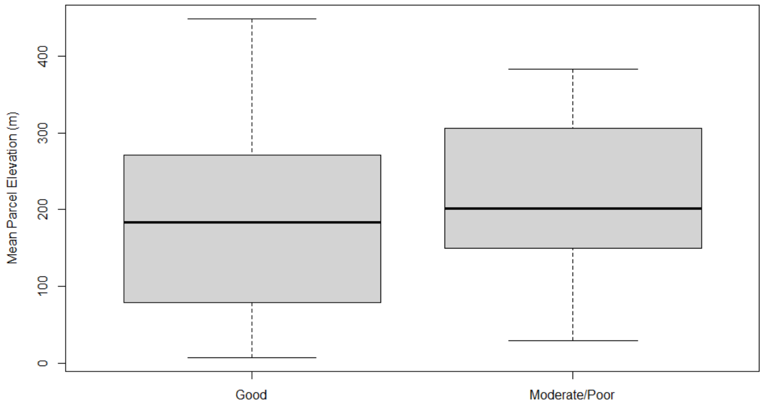

Figure A-13: Distribution of mean parcel elevation against final condition score

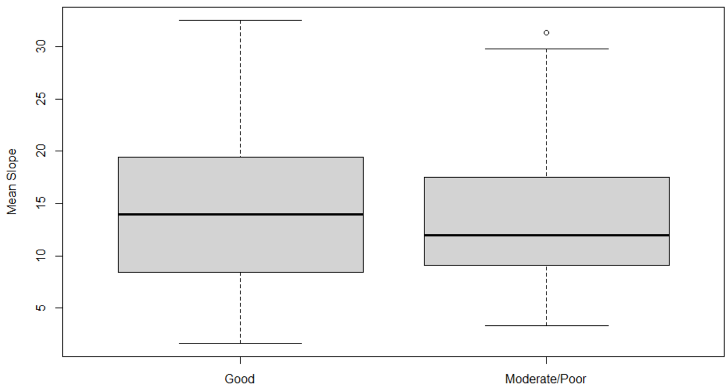

Figure A-14: Distribution of mean parcel slope against final condition score

Appendix B: Invitation to Interview Letter

Date

Dear

Invitation to participate in a survey assessing the long-term effectiveness of Agri-Environment Scheme options for bracken control

Natural England carries out a programme of monitoring to assess the impact and effectiveness of Agri-Environment schemes and does this on behalf of the Rural Development Programme for England. Natural England is conducting a project to gain a better understanding on the effectiveness of different bracken control management options under HLS and CS options. The outcome of the survey will enable more effective options to be prioritised in current and future schemes

For this project, Natural England has appointed Countryside and Community Research Institute at the University of Gloucestershire to conduct a survey of former agreement holders.

Your name has been selected as you have bracken control options in either an Environmental Stewardship or Countryside Stewardship agreement. For this project the relevant bracken control options are:

HLS	
HR5	*Bracken Control Supplement*
BMB	*Mechanical bracken control – base payment*
BMA	*Mechanical bracken control – area payment*
BCB	*Chemical bracken control – base payment*
BCA	*Chemical bracken control – area payment*
BDS	*Difficult site supplement for bracken and scrub control*
CS	
SB4	*Chemical Bracken Control*
SB5	*Mechanical Bracken Control*
SP3	*Bracken Control Supplement*

In the next few days a researcher from the Countryside and Community Research Institute at the University of Gloucestershire will contact you and invite you to help this study by taking part in a phone survey. The survey will take around 20 minutes to complete. Your verbal agreement to participate will be requested.

Your participation in the survey is voluntary and the information you provide is covered by current data protection legislation. The project report will not identify anyone taking part in the research. When reporting on the research findings, we will not reveal your name, your businesses name, nor will any information be provided which might lead to you being identified. By taking a few minutes to complete the questionnaire and sharing your experiences as an agreement holder, you will help to inform and enhance the results of the project.

Even if you initially decide to take part, you are still free to withdraw from the research without giving any reason. You can withdraw up to 30 days after completing your survey by contacting Chris Short on any of the details below - these details are provided again upon completion.

Whilst we cannot promise that this study will provide you with a direct benefit, we hope that by publishing our findings these will contribute to DEFRA’s policy and programmes that aim to provide agri-environment options that enhance the natural environment on holdings like yours.

The main disadvantage to take part in the study is that you will be donating your time to take part. We do not envisage any risk to you in participating in this research. At no time will you be obliged to discuss anything you are uncomfortable discussing nor to disclose anything that you don’t wish to. As such, any information you give us is completely under your control.

The study has been approved in accordance with the research ethics procedures of both the University of Gloucestershire and DEFRA.

If you have any questions or comments about this study, please feel free to contact me on XXXX-XXXX or XXXX.

Thank you very much in advance for helping with this important study.

Yours sincerely,

Mr Chris Short
Project Lead CCRI

Appendix C: Interview Questions

Long term effectiveness of AES funded bracken control
Telephone Questionnaire

Sample No (UID):	Interviewer Name:
Interviewee Name:	
Interviewee Position with respect of AES agreement:	

Introduction

Interviewer: When you phone the interviewee check that they have received a letter outlining the research, assessing the link between AES bracken options and effective management of bracken. Early in the call clarify that the purpose of this questionnaire is to establish what bracken management has been undertaken and the link to the AES options. Ask them:

Can I confirm if you had bracken control options as part of your AES agreement? There is a list of the options in the letter/email.

- *If NO or not sure – end the call.*
- *If YES, explain the reason for the research.*

Give a brief reminder that:

- The research is aimed at gaining a better understanding of the effectiveness of bracken control funded by AES agreements.
- The interview is in 4 parts: - First, details of the farm business and the interviewee's recent experience with ES; second looks at decision to take up bracken control options; third checks on advice; fourth and largest part looks at activities and outcomes
- Indicate to the agreement holder that you would like to record the interview for the purposes of providing a clear record for use of quotes and partial transcribing. Reassure them that it helps make sure that important points that come up during the interview are not missed but is not used in any other way. Ask them if they are happy for the interview to be recorded.
- The interviews usually take about 20 mins to complete. Suggested timings are given for each section.

Privacy statement: to be read out before start of the interview

- *The survey is confidential, and no details will be released to third parties.*
- *The project complies with Data Protection Legislation. Data will be stored in a database on the University of Gloucestershire's secure computer network and will only be available in its original form to the research team for purposes relating to this project.*
- *Data that we collect is anonymised and will not be reported at an individual level. You can read a full statement http://www.ccri.ac.uk/data-protection/*
- *REFER TO THE LETTER OR EMAIL THE FULL PRIVACY STATEMENT AND ASSOCIATED POINTS*

<u>Consent statement – Obtaining and recording</u>

Indicate to the agreement holder that in the survey is voluntary and the project report will not identify anyone taking part in the research. Say: 'Even if you initially decide to take part, you are still free to withdraw from the research without giving any reason. You can withdraw up to 30 days after completing your survey by contacting Chris Short on any of the details in the letter'. REMIND THEM OF THE PRIVACY AND CONSENT STATEMENTS ON THE LETTER OR EMAIL. Ask them '*Are you happy to proceed on this basis*'. Record Yes or No.

Section 1 You and your farm (4 mins)

- Background aspects to the holding like tenure and structure
- Factors influencing decision making in the future

Land tenure and Enterprises

4. What is the total area of the holding/farm? (WHOLE numbers only)

   Is this acres or hectares? (select)

5. Is the land that you farm...(Select ONE only)

- Wholly owned
- Mix of owned & rented
- Wholly rented
- Contract farm
- Other, please state................

6. Do you have any livestock on the holding?

- No
- Yes (belonging to the farm)
- Yes (belonging to someone else)
- Yes (belonging to the farm AND someone else)
- Don't know

   If **yes**, please provide details (record those that apply and approx. number)

   Beef Suckler herd
   Beef store cattle
   Dairy herd
   Sheep flocks
   Other (please specify) ....

7. Approximately how much of your business income derives from the agricultural enterprises (including AES payments) on the farm?

   (If business income not known 'unknown', for holdings with non-business focus (e.g. Wildlife Trust) enter 'Not Applicable')

   All of it / most of it / about half / less than half / very little / none
   Unknown / Not applicable

8. According to NE records you had the following bracken control options: …………………..

   Pre-populate table with information held on NE database

HLS		***NE Data (ha)***	***Interviewee (ha)***
HR5	*Bracken Control Supplement*		
BMB	*Mechanical bracken control – base payment*		
BMA	*Mechanical bracken control – area payment*		
BCB	*Chemical bracken control – base payment*		
BCA	*Chemical bracken control – area payment*		
BDS	*Difficult site supplement for bracken and scrub control*		
CS			
SB4	*Chemical Bracken Control*		
SB5	*Mechanical Bracken Control*		
SP3	*Bracken Control Supplement*		

9. Which of the following AES schemes have you been involved in? Please provide the year in which you entered each scheme:

Scheme	***Year started***	***Was Bracken control an option? (Y/N)***
OLD Countryside Stewardship		
Env Stewardship		
ESA		
Other……		

10. Please describe the history of bracken management on your holding before you entered any AES agreements.

Section 2 Background to bracken control options (3 mins)

- Background to selecting these options
- How well they operated during the agreement

11. Please indicate how much you agree or disagree with each of the following 8 statements. They concern your reason for taking up AES options for bracken control. For each I need to record one of four options (*state options)*.
    - Strongly Agree / Agree / Disagree / Strongly Disagree / Not Applicable

Bracken was encroaching on enclosed grazing land	S A / A / D / S D / N A
Bracken was encroaching on unenclosed grazing land	S A / A / D / S D / N A
Bracken caused concern for grazing animals' welfare	S A / A / D / S D / N A
Bracken was impacting productivity	S A / A / D / S D / N A
Bracken was decreasing farm biodiversity / habitat quality	S A / A / D / S D / N A
Bracken was causing wider environmental issues e.g. having an impact on water quality	S A / A / D / S D / N A
Bracken was encroaching on a Historic Feature	S A / A / D / S D / N A
Bracken was encroaching on a 'Heritage at Risk' site	S A / A / D / S D / N A

12. How complex do you feel your bracken control options were to **understand**?
    - (Very complex, Complex but manageable, Very manageable)?
13. How complex do you feel your bracken control options were to **implement**?
    - (Very complex, Complex but manageable, Very manageable)?

14. Would you be willing to share records of bracken controls (if available)? (Your responses to this question will not be identifiable and there will be no repercussions should there have been any lapses). i.e. what was done and when, in relation to current and previous AES bracken control options, including grazing records

Section 3 Advice and support received (3 mins)

15. Did you receive advice whilst considering and securing your bracken control AES options?

    Yes … No … Don't know …

    If **Yes**, who gave you advice? (*select any sources from which advice received*)

    - NE officer (including Catchment Sensitive Farming officer)
    - Conservation NGO advisor,
    - Own agricultural advisor,
    - Other farmers,
    - HEFER or Historic England.
    - Other source (please specify) ……………………………

    If **Yes**, what was the advice about? (*select all that apply*)

    - Assist with option selection
    - Advice on control methods
    - Advice on long-term management
    - Other, please state………

16. Would bracken control had been undertaken in the absence of this AES option?

    Yes … No … Don't know …

    - If **Yes** – by what method would you have controlled Bracken?

17. How effective do you feel the bracken control option was concerning:

(Select a number between 1-5: Where 1=very ineffective ~ 5=very effective)

	1	***2***	***3***	***4***	***5***
Meeting objectives of the AES option					
Providing long-term control of bracken spread					
Fitting with the farming system					

Section 4 Details and outcomes of bracken control activities (10 mins)

18. What was the initial form of bracken control undertaken under the AES agreement? (select all that apply).

- **Chemical ☐**
  - Which chemical(s) were used?
    - Asulam (Asulox)
    - Glyphosate
    - Other
  - How was the chemical applied? (Select **one** - Main method of application)
    - Tractor mounted sprayer
    - Quad bike / 'Gator' mini off-rd vehicle sprayer
    - Aerial application
    - Knapsack spraying
    - Low volume drift spraying
    - Weed wipers
    - Spot treatment
- **Mechanical ☐**
  - Which method was used? (Select **one** - Main method)
    - Cutting
    - Crushing/Bruising
    - Livestock treading
    - Burning

19. When did the INITIAL Bracken control measures take place?
*(Note **YEAR** and **MONTH**, if possible - This will inform how long after agreement signed measures were implemented)*

20. How effective did the first year's control work appear to be?
    - Not at all
    - Somewhat
    - Very
    - Don't know

➢ Provide some details if possible: Note if this was true of ALL areas with bracken options

21. Who completed the initial Bracken control work?
    - Myself/own staff
    - Contractor
    - Both of the above
    - Other

22. Were there subsequent repeats of the bracken control after the first year?

- Yes on ALL areas
- Yes on SOME areas
- No **(go to Q23)**

➢ **If YES** (All or some), when did this take place (Year and Month if possible)

- What were the subsequent form(s) of Bracken control under the AES agreement?

- **Chemical ☐**
  - Which chemical(s) were used?
    - Asulam (Asulox)
    - Glyphosate
    - Other……
  - How was the chemical applied? (Select **one** - Main method of application)
    - Tractor mounted sprayer
    - Quad bike / 'Gator' mini off-road vehicle sprayer
    - Aerial application
    - Knapsack spraying
    - Low volume drift spraying
    - Weed wipers
    - Spot treatment
- **Mechanical ☐**
  - Which method was used? (Select **one** - Main method)
    - Cutting
    - Crushing/Bruising
    - Livestock treading
    - Burning

- How effective were your chosen follow up method(s) in keeping bracken under control?

➢ Not at all

➢ Somewhat

➢ Very

➢ Don't know

23. Was the bracken management just outlined carried out as part of a written/specific bracken control plan?
    - Yes
    - No (goto Q24)
    - Don't know (goto Q24)

If YES, was this plan drawn up as part of the AES agreement?

- Yes
- No
- Don't know

24. Was the bracken management just outlined part of a wider site management plan?
    - Yes
    - No (goto Q25)
    - Don't know (goto Q25)

If YES, please can you briefly describe the wider site management plan (e.g. habitat and area)

25. Do you have a clear idea on what the bracken management in your AES agreement was for?
    - Yes
    - No (goto Q26)
    - Don't know

If YES or DON'T KNOW, what was the MAIN reason the plan was for?

- Enhance/protect a threatened habitat
- Protect a threatened historical feature
- Enhance/protect a threatened species
- Other……

26. What grazing is undertaken on the areas in which bracken management occurs?

- Grazed as agreed in AES agreement
- Grazed but not in AES agreement,
- Not grazed

  - ➢ Please provide details of livestock species / breed
  - ➢ Please provide details of livestock density
  - ➢ Please provide details of timing
  - ➢ Please provide details of approach (eg mob grazing)
  - ➢ Please provide details reasons for this approach

➢ How effective has grazing been at keeping bracken spread under control?

- Not at all
- Somewhat
- Very
- Don't know

➢ Please rate how important the following details are when using grazing to keep bracken under control. *(1 is very unimportant and 5 is very important).*

	1	*2*	*3*	*4*	*5*
Timing of the grazing & bracken growth stage					
Stocking intensity					
Type of livestock used					
Link with soil moisture					
Link with soil temperature					

27. Do you feel that additional bracken control measures are required alongside the grazing?

- Yes
- No
- Sometimes

➢ If YES or SOMETIMES what are they?

28. Do you feel that the weather has an impact on bracken control needs? *(e.g. does a wet spring or dry summer etc appear to affect bracken spread?)*

    Yes .... No .... Don't know ...

    ➢ If YES can you explain the impact?

29. Do you feel that the weather influences your choice of bracken control approach?

    - Yes
    - No
    - Don't know

    ➢ If YES can you explain why this might be the case?

Section 5 Final Closing Questions

30. Based on your experiences, if you could change and or improve anything about the bracken control AES options you had, what would it be?

31. Do you have any other comments you would like to make about your bracken control options and the AES scheme and related processes?

32. Any other final comments you feel would be relevant?

Thank you very much for taking part in this survey. Your contribution has been very helpful and should help towards improving the scheme over the next few years. Your assistance is therefore much appreciated.

Appendix D: AES bracken control options among 171 survey respondents

Mechanical Bracken Control AES options

	HLS BMB Mechanical bracken control – base payment NE Data (Ha)	*HLS BMA Mechanical bracken control – area payment NE Data (Ha)*	*CS SB5 Mechanical Bracken Control NE Data (Ha)*
Total number using this option	*51 (0)**	*55*	*10*
Total area in hectares	*0*	*640.49*	*69.44*
Average	*0*	*11.64527273*	*6.944*
*** All 51 are zeros*			

	HLS BMA Mechanical bracken control – area payment NE Data (Ha)	*CS SB5 Mechanical Bracken Control NE Data (Ha)*	*Total*
	N (Total area in ha)	*N (Total area in ha)*	*N (Total area in ha)*
under 2ha	*17 (16.78)*	*4 (4.71)*	*72 (21.49)*
2-less than 10ha	*22 (132.06)*	*4 (13.09)*	*26 (145.15)*
10-less than 50	*14 (336.23)*	*2 (51.64)*	*16 (387.87)*
more than 50 ha	*2 (155.42)*	*0*	*2 (155.42)*

Chemical Bracken Control AES options

	HLS BCB Chemical bracken control – base payment NE Data (Ha)	*HLS BCA Chemical bracken control – area payment NE Data (Ha)*	*CS SB4 Chemical Bracken Control NE Data (Ha)*
Total number using this option	*34 (0)**	*35*	*23*
Total area in hectares	*0*	*1042.57*	*226.64*
Average	*0*	*29.78771429*	*9.853913043*
** All 34 are zeros*			

	HLS BCA Chemical bracken control – area payment NE Data (Ha)	*CS SB4 Chemical Bracken Control NE Data (Ha)*	*Total*
	N (Total area in ha)	*N (Total area in ha)*	*N (Total area in ha)*
under 2ha	*4 (4.24)*	*6 (6.4)*	*10 (10.64)*
2-less than 10ha	*15 (73.72)*	*7 (27.5)*	*22 (101.22)*
10-less than 50	*13 (307.11)*	*10 (192.74)*	*23 (499.85)*
more than 50 ha	*3 (657.5)*	*0*	*3 (657.5)*

Non-specific treatment Bracken Control AES options

	HLS HR5 Bracken Control Supplement NE Data (Ha)	*HLS BDS Difficult site supplement for bracken and scrub control NE Data (Ha)*	*CS SP3 Bracken Control Supplement - NE data (Ha)*
Total number using this option	*123*	*34*	*27*
Total area in hectares	*3468.9*	*446.97*	*338.97*
Average	*28.20243902*	*13.14617647*	*12.5544444*

	HLS HR5 Bracken Control Supplement NE Data (Ha)	*HLS BDS Difficult site supplement for bracken and scrub control NE Data (Ha)*	*CS SP3 Bracken Control Supplement NE data (Ha)*	*Total*
	N (Total area in ha)	*N (Total area in ha)*	*N (Total area in ha)*	*N (Total area in ha)*
under 2ha	*25 (27.47)*	*8 (8.77)*	*7 (6.26)*	*40 (42.5)*
2-less than 10ha	*42 (194.8)*	*13 (64.52)*	*10 (35.16)*	*65 (294.48)*
10-less than 50	*42 (1085.43)*	*12 (299.38)*	*9 (182.84)*	*63 (1567.65)*
more than 50 ha	*14 (2161.2)*	*1 (74.3)*	*1 (114.71)*	*16 (2350.21)*