Dartmoor evidence review

Rapid evidence assessment on the condition of Dartmoor and management options for improving condition

Evidence report: v1.0

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Foreword

Natural England (NE) has a statutory duty to act for the benefit of SSSIs, including those on Dartmoor, and to take reasonable steps to further the conservation and enhancement of the SSSIs (Wildlife and Countryside Act 1981 and subsequent amending legislation).

Natural England is evidence-led and uses evidence to inform decisions concerning the management of SSSIs. To do this, Natural England – and all stakeholders involved in land management – need access to the best available evidence to inform their decision making.

This review aimed to summarise the information in Natural England's databases about the condition of Dartmoor SSSI, as well as the available published and grey literature on the methods for managing SSSIs on North, South, and East Dartmoor and comparable sites. The review sets out the evidence that can inform the effective management of Dartmoor's SSSIs, but it does not prescribe management regimes, nor does it make policy recommendations.

This review was carried out between July and October 2023 to feed into the Government's Independent review of Dartmoor (Fursdon Review). This full report was commissioned later to support stakeholders who have a role in managing Dartmoor, including the Land-Use Management Group established after the Fursdon Review.

Executive summary

Context and objectives

25,167 ha of moorland on Dartmoor is notified as Sites of Special Scientific Interest (SSSI), with an extensive area also designated as a Special Area of Conservation (SAC); 22,785 ha are included in the three large moorland SSSIs of interest for this review: North Dartmoor, South Dartmoor, and East Dartmoor.

Most of the site units in Dartmoor’s SSSIs, which underpin the SAC, are in unfavourable condition. Achieving favourable condition is key to achieving the Government’s environmental targets, with the Environmental Improvement Plan (2023) committing England to restore 75% of protected sites to favourable condition by 2042. There are also interim targets for 50% of SSSIs to have actions on track to achieve favourable condition by 31 January 2028.

Land management on Dartmoor has been supported by agri-environment schemes since the introduction of the Dartmoor Environmentally Sensitive Area (ESA) in 1994 and continued with the current Higher Level Stewardship (HLS) and Countryside Stewardship (CS) agreements. Most of Dartmoor’s commons are managed under HLS agreements, which aim to achieve favourable condition of SSSIs and deliver wider environmental objectives. However, it is Natural England’s assessment that most current agreements on Dartmoor have not delivered appropriate management to achieve favourable condition.

The current review aimed to provide stakeholders on Dartmoor, including Natural England and landowners, with evidence to inform the effective management of Dartmoor’s SSSIs.

Research topics

This review focused on three research topics:

- Current and historic condition of Dartmoor
- Causes of changing condition on Dartmoor
- Management options for improving condition on Dartmoor

Methods and scope

We conducted a rapid evidence assessment of the literature. This included a systematic search of two academic databases (Scopus and CAB Direct) for peer-reviewed academic literature, as well as a supplementary search of the grey literature (i.e., unpublished literature), reference lists of relevant studies, conference proceedings, Conservation Evidence, and Google Scholar. We also extracted and analysed relevant data from Conservation Management System international (CMSi) and TRIM, the Natural England internal databases used by advisors to record SSSI condition assessments and notes.

The focus of the review was Dartmoor (particularly North, South, and East Dartmoor SSSIs, but data on the management of comparable areas was also considered. The comparable areas included Bodmin Moor, Exmoor, Quantocks, East Devon Commons, West Penwith, Goss Moor, Long Mynd, moorland in south- and mid-Wales (Cambrian Mountains, Black Mountains, and Brecon Beacons), and the Lake District National Park. The review did not consider evidence from other upland areas; broader evidence is available in prior uplands reviews (see Section on Prior uplands reviews).

This review focused on key habitat and species features on Dartmoor, including:

- Blanket and valley bog
- Transition mire, ladder fen and quaking bog (upland)
- Acidic fen
- Wet and dry heath (including subalpine dwarf shrub heath)
- Grassland (any)
- Assemblages of breeding birds
- Fritillary butterflies
- Small red damselfly

This review summarised the condition of relevant habitat and species features, based on condition assessments carried out from 1999 to 2022. The review also used condition assessments and grazing assessments to look at the reported reasons for changes in the recorded condition (e.g. management interventions, disease, etc). Finally, the review considered data from published and grey literature on common management and restoration options (e.g., grazing, cutting, burning, etc) used to achieve favourable condition of habitat and species features on Dartmoor and comparable areas.

Process

The search of academic databases yielded 4,453 citations: 2,932 from Scopus and 1,521 from CAB Direct. After removal of 486 duplicates, 3,967 citations were screened. The titles and abstracts of the citations were interrogated first, and 3,798 studies were excluded at this stage. The remaining 169 studies were sought for retrieval, but 13 studies were not available. Of the 156 full publications that were available for screening, 129 studies were excluded. In total, 27 articles were included from the academic database search. An additional 53 publications were identified from the supplementary searches, giving a total of 80 eligible publications.

Results

Condition of Dartmoor SSSIs

I. Most units on North and South Dartmoor are in unfavourable condition (94% and 86% respectively); half of the units on East Dartmoor are in favourable condition.
II. Most habitat features are in unfavourable condition on the three SSSIs (13 out of 14).
III. Species features, including assemblages of breeding birds and lichen assemblages, are generally in favourable condition.

Causes of changing habitat condition

I. Assessors reported unfavourable condition to be caused by multiple factors, including overgrazing, undergrazing of key livestock (e.g., early summer hardy cattle), overburning (e.g., ≥20% of unit burnt, burning on sensitive habitats, or burning too frequently), peat cutting and drainage, and heather beetle.
II. Nitrogen deposition and climate change may also contribute to unfavourable condition, but the precise effect of these factors on Dartmoor is not well evidenced and current condition assessment methods are not designed to detect these factors.
III. The condition was recorded as recovering when appropriate grazing and burning regimes, facilitated by agri-environment agreements, was expected to lead or had led to recovery of characteristic vegetation for the habitat, the presence of a diverse vegetation structure, and no visible damage.

Management options

There are various management options for improving SSSI condition, including managing livestock (i.e., different stocking regimes), rewetting peatland, targeted burning, and cutting and/or chemical control of undesirable species.

Management of livestock

I. Observational evidence from Dartmoor:
    - Consecutive agri-environment agreements, which include measures to reduce maximum monthly stocking levels at sites on Dartmoor, have so far been unable to achieve favourable condition or cause a meaningful improvement in condition at most sites, although dwarf shrub cover has improved in some areas.
    - Despite the historic reductions in stocking levels, grazing pressure has generally remained high at sites on Dartmoor, as shown by the condition of the vegetation.
II. Observational evidence from Exmoor, Bodmin Moor, and the Lake District:
    - Lowering summer stocking rates (<0.32 LU/ha) and preventing winter stocking of sheep and cattle reduces grazing intensity and improves vegetation condition.

III. Experimental evidence from Dartmoor, Exmoor, and Pwllpeiran[1]:

- Effect of soil disturbance, grazing, and seeding on species composition of *Molinia/Nardus*-dominated grassland:
  - The balance of evidence suggests that soil disturbance caused by trampling or rotavating can create regeneration niches for *Calluna*, and possibly other desirable species, but it also provides opportunity for non-target species, such as *Juncus effusus*, to establish.
  - There was conflicting evidence on the effect of cattle versus sheep grazing on the establishment of *Calluna*; however, the best available evidence suggests that *Calluna* establishes better on land grazed by cattle in the summer than on land grazed by sheep year-round.
  - *Calluna* morphology – including height, weight, and number of shoots – and total cover was optimal when land was either ungrazed or grazed by cattle during summer at low stocking rates.
  - Evidence on the effect of grazing on cover of *Molinia* and *Nardus* was inconclusive. However, evidence suggests that livestock can be used to managed *Molinia* leaf litter.
  - Seeding enhances recovery of *Calluna*, particularly in areas where it is limited or absent from the seed bank but also where it was present.
- Managing the distribution of grazing animals:
  - While large livestock and ponies play a role in conservation of moorland, moving and keeping animals in areas dominated by *Molinia* or uniform short swards may prove difficult on unenclosed commons.
  - Salt blocks can be used to guide ponies (and possibly cattle) to *Molinia*-dominated areas where they will trample and graze on sward in the vicinity of the salt block.
- Effect of grazing on marsh fritillary *Euphydryas aurinia*:
  - Evidence suggests that stocking at 'intermediate' levels[2] can optimise sward height and density of the host plant Devil's-bit scabious, *Succisa pratensis*, which supports the recovery of *E. aurinia* populations.

Rewetting peatland

I. Blocking drainage channels on peatland on Dartmoor raises the water table of the surrounding area.

II. There was mixed evidence on the effect of blocking drainage channels on plant communities. Large-scale studies conducted on Dartmoor and Exmoor indicate a recovery of native mire species and a decrease in the prevalence of *Molinia* – sometimes an indicator of degraded peatland habitat when present at high cover – following the blocking of drainage channels. However, these studies lacked a control comparison and cannot conclusively demonstrate that the observed effects were due to the altered drainage. Controlled studies on Dartmoor and Exmoor have

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[1] Most experimental evidence identified by the review examined the relationship between grazing management and cover of *Molinia caerulea* (purple moor grass), *Nardus stricta* (matgrass), and dwarf shrubs. There were limited data on the influence of different grazing regimens on other features (assemblages of breeding birds, etc).

[2] This result was based on a proxy measure for stocking intensity (evidence of stock at transect points). It was unclear how the study's measure for stocking intensity equated to stocking levels in LU/ha.

found no effects of drainage blocking on plant communities even after a seven-year period.
III. Initial evidence from Exmoor showed no increase in bog asphodel following the rewetting of peatland.

Controlled burning

I. There was limited evidence on the effects of burning on Dartmoor, and the findings are largely inconclusive.
II. Burning can reduce leaf litter depth at sites dominated by *Molinia*, which may provide suitable conditions for new growth of grass or dwarf shrubs, but there was no evidence that burning affected cover of *Molinia* in the short term; the long-term effects of burning on *Molinia* cover were not clear.
III. There was mixed evidence on the effect of burning on fritillary butterflies. There was initial evidence that burning can facilitate recovery of heath fritillary *Melitaea athalia.* However, there was no evidence of a relationship between burning and the marsh fritillary *Euphydryas aurinia* larval web abundance. Due to the paucity of strong evidence on the topic, the review did not reach any clear conclusions.
IV. Overburning (too much/too intense/too frequent) can reduce biodiversity and worsen habitat condition by making the vegetation more uniform or damaging sensitive habitat.
V. The review didn’t identify enough academic or grey literature to determine the effect of burning on different habitats, but data from condition assessments suggest that burning on sensitive areas, including wet and dry heathland and mire/bog, has a detrimental effect on condition.

Cutting or chemical control of bracken

I. Twice-yearly cutting (mechanical control), herbicides (e.g., asulam; chemical control), or a combination of both can reduce bracken biomass and density in subsequent years compared with taking no action.
II. As the emergency authorisation of asulam was not renewed for 2024, mechanical control is currently the only practical solution for bracken management.
III. Initial evidence indicates that controlling bracken in areas previously occupied by *M. athalia* encouraged the growth of the host plant common cow-wheat, creating appropriate conditions for recovery of the heath fritillary butterfly.

Further UK upland evidence

This review complements other reviews published by Natural England regarding the effect of management and other impacts on the UK uplands. The current review offers the best available evidence on Dartmoor and comparable areas, but our other reviews summarise the wider evidence base relevant to the UK. When considered together, these reviews provide comprehensive evidence on the likely effects of upland management and other impacts on Dartmoor’s habitat mosaic. Visit Access to Evidence to view our catalogue of reviews on upland evidence.

Conclusions

This review finds that most units of the relevant SSSIs on Dartmoor (North, South and East Dartmoor) are in unfavourable condition. The reported causes of unfavourable condition are multifaceted, with overgrazing, undergrazing of key livestock (e.g., early summer hardy cattle), overburning or burning on sensitive habitats, peat cutting, and drainage each contributing to the issue. The role of external factors such as nitrogen deposition and climate change are not well evidenced for Dartmoor. However, their potential impact should not be ignored when making management decisions.

Centuries-old practices have shaped Dartmoor's landscape and habitats. We can address some issues about the current condition of designated features by adjusting management practices, such as adjusting grazing and burning regimens, to operate at sustainable levels. This could enhance the resilience of the designated features. In some situations, we will need to intervene further to restore habitats, such as reversing drainage in wet habitats or reducing dominant vegetation through cutting or other means. Further study is needed to understand the effects of nitrogen deposition and climate change on Dartmoor, and these issues must be addressed at a local, national and international scale.

The findings should be interpreted while considering the limitations of the review and the identified studies. Even so, the review presents the best available evidence on the management interventions that are most likely to improve SSSI condition. This review may, therefore, support Natural England and stakeholders with ongoing conversations and decisions around the management of SSSIs on Dartmoor.

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Background and context

25,167 ha of moorland on Dartmoor is notified as Sites of Special Scientific Interest (SSSI), with an extensive area designated as a Special Area of Conservation (SAC); 22,785 ha are included in the three SSSIs of interest for this review: North Dartmoor, South Dartmoor, and East Dartmoor.

Most units on Dartmoor's SSSIs are in unfavourable condition (1). Achieving favourable condition is key to achieving the Government's environmental targets, with the Environmental Improvement Plan (2023) committing to restore 75% of protected sites in England to favourable condition by 2042 (2). There are also interim targets for 50% of SSSIs to have actions in place to achieve favourable condition by 31 January 2028 (2). Favourable condition is also key to achieving 30x30 (30% of global land and 30% of global ocean to be protected by 2030) – a global target, with backing from the UK Government. This will ensure that our most important places at the core of nature's recovery, including Dartmoor, have the long-term, effective management needed for biodiversity to thrive (2, 3).

Land management on Dartmoor has been supported by agri-environment schemes, including the Environmentally Sensitive Areas (ESA), Higher Level Stewardship (HLS), and Countryside Stewardship (CS) agreements. ESA agreements were introduced by the government in 1987 to incentivise farmers to restore and maintain nature in priority habitats (4), with the first ESA agreements introduced on Dartmoor in 1994 (5). These agreements have since developed and now most of Dartmoor's commons are managed under HLS agreements. The HLS agreements aim to achieve favourable condition and to deliver wider environmental objectives. However, it is Natural England's assessment that current agreements on Dartmoor have not delivered appropriate management to achieve favourable condition (1).

Natural England has a statutory duty to act for the benefit of SSSIs, including those on Dartmoor, and to take reasonable steps to further the conservation and enhancement of the SSSIs. During March 2023, Natural England set out the principles for the extensions to the current HLS agreements. Controversy over the extension of HLS agreements led to Ministers commissioning an Independent Review of Protected Site Management on Dartmoor, which reported in December 2023 (5, 6). Natural England and other stakeholders involved in land management are now tasked with implementing the recommendations made by the Independent Review.

This review aimed to provide stakeholders on Dartmoor, including Natural England and landowners, with evidence that can inform the effective management of Dartmoor's SSSIs. The review does not prescribe management regimes, nor does it make policy recommendations.

Research questions

The evidence review addressed the following research questions[3]:

1) What is the current and historic condition of SSSIs on Dartmoor, and how has condition changed?

2) What are the factors causing changing condition (both declining and improving) or static unfavourable condition of SSSIs on Dartmoor?
   a) Which factors contribute the most toward unfavourable condition on Dartmoor SSSIs?
   b) How do these factors affect different features of SSSIs on Dartmoor?
   c) Which causes of unfavourable condition on Dartmoor SSSIs can be addressed through agri-environment schemes?

3) Which management options are most likely to be effective at improving condition or restoring favourable condition of SSSIs on Dartmoor and comparable sites?
   a) On which features and sites can management options be effective at restoring favourable condition of SSSIs on Dartmoor and comparable sites?
   b) Which factors are and are not effective at supporting land managers to deliver conservation management on SSSIs on Dartmoor?

[3] The focus of the review is the three main questions; however, sub questions (2a, 2b, etc) were addressed if there were sufficient data to do so.

Methods

Data sources

We conducted a rapid evidence assessment of the literature[4]. This included a systematic search of two academic databases (Scopus and CAB Direct) for peer-reviewed academic literature, as well as a supplementary search of the grey literature, reference lists of relevant studies, and conference proceedings. A summary of the data sources is provided below, and a summary of the search strategy is provided in Appendix A.

- Electronic academic databases
  - Scopus, 1823 to present
  - CAB Direct, 1973 to present
- Reference lists of relevant primary articles and systematic reviews
- Conference proceedings:
  - Dartmoor society conference
  - UK National Parks' conference
  - Managing *Molinia* conference
- Grey literature sources
  - Natural England grazing assessments
  - Natural England survey data
  - Natural England Access to Evidence
  - Unpublished Natural England reports
  - Dartmoor National Park Authority (DNPA) and Devon Biodiversity Records Centre (DBRC) websites
  - Royal Society for the Protection of Birds (RSPB) website
  - National Trust website
  - Botanical records from Environmental Monitoring Database for Department for Environment food and Rural Affairs (Defra)/Ministry of Agriculture, Fisheries, and Food (MAFF) funded research and development reports (available at: Science Search (defra.gov.uk))
  - Condition Assessments from Conservation Management System international (CMSi) and TRIM (internal NE records databases)
- Other supplementary sources
  - Google Scholar
  - Conservation Evidence

[4] The methods used in this review were designed by Natural England's evidence review experts and were informed by discussion with the project's sounding board. Due to the unique circumstances surrounding this project (principally the commitment to submit evidence to the Independent Evidence Review), the review methods were not aligned with any one set of guidelines.

Eligibility criteria

The eligibility criteria for the review are summarised in Table 1.

Table 1: Summary of eligibility criteria

<table>
<tr><th>Criteria</th><th>Inclusion criteria</th></tr>
<tr><td>Population/ location/ features</td><td>Q1, Q2: SSSIs on Dartmoor (North, East, and South Dartmoor SSSIs)

Q3: Dartmoor and comparable sites

Comparable areas:
Bodmin Moor
Exmoor
Quantocks
East Devon Commons
West Penwith
Goss Moor
Long Mynd
Moorland in south- and mid-Wales, including:
Cambrian Mountains
Black Mountains
Brecon Beacons
Lake District National Park
Features:
Blanket and valley bog
Transition mire, ladder fen and quaking bog (upland)
Acidic fen
Wet and dry heath; subalpine dwarf shrub heath
Grassland (any)
Assemblages of breeding birds
Fritillary butterflies
Small red damselfly</td></tr>
<tr><td>Intervention</td><td>Q3: Any management option aimed at restoring favourable condition, including but not limited to:
Stocking rates and regimens
Burning / swaling
Mowing, rotovating and sod cutting
Scrub and bracken management
Peatland restoration (e.g., rewetting)</td></tr>
</table>

<table>
<tr><th>Criteria</th><th>Inclusion criteria</th></tr>
<tr><td>Comparator</td><td>Q3: Any of the following:
• Any management option aimed at restoring favourable condition
• Observation / no intervention</td></tr>
<tr><td>Outcome/ research objectives</td><td>Q1: Current and historic condition of SSSIs on Dartmoor
• Latest condition assessments
• Historic condition assessments

Q2: Any of the following:
• Factors contributing to unfavourable condition reported in condition assessments
• Factors contributing to unfavourable condition reported by academic or grey literature
• Impact of factors contributing to unfavourable condition on different features
• Relative contribution of causes of changing condition to condition status
• Factors that can be addressed by agri-environment schemes; factors of interest include but are not limited to:
    o Grazing
    o Nitrogen deposition
    o Climate change
    o Heather beetle
    o Burning / swaling

Q3: Effect of interventions on condition of features or on stakeholders’ willingness to engage with conservation management, including but not limited to:
• Prevalence of Molinia grass
• Prevalence of dwarf shrubs, including heather and bilberry
• Health of peatlands: water retention on bogs and mires
• Adherence to agri-environment schemes
• Factors influencing stakeholders to deliver conservation management
• Surveys of stakeholders’ satisfaction with support</td></tr>
<tr><td>Study design</td><td>Any primary study</td></tr>
<tr><td>Date of publication</td><td>No restriction</td></tr>
</table>

Criteria	Inclusion criteria
Language	Reports published in English

Abbreviations: SSSI, Site of Special Scientific Interest.

Screening and data extraction

We searched Scopus and CAB Direct on 2 August 2023. Citations were deduplicated in EndNote and exported to Microsoft Excel®. The citations were then screened in two stages: 1) title and abstract and 2) full publication. Studies excluded at the full publication stage were given one of the following reasons for exclusion:

- Non-relevant research objective
- Non-relevant intervention
- Non-relevant location
- Non-relevant study design
- Non-relevant review
- Publication superseded (e.g., conference abstracts that were superseded by a full publication)

Eligible studies were extracted into an Excel®-based data extraction table (DET; Appendix B). The data extraction table was designed to be filterable for easy data retrieval.

We took a rapid approach for the review, with one reviewer conducting screening and data extraction of the identified publications.

Critical appraisal of strength of evidence

As the review had to be completed in a short timeframe, determined by the Independent Review timetable, we did not use a critical appraisal tool to assess the strength of evidence. Instead, we reported individual study limitations and their effect on the strength of evidence in the syntheses.

Report

The qualitative report was developed in accordance with Synthesis Without Meta-Analysis (SWiM) guidelines (7).

We analysed data in groups, with the following hierarchy: management intervention > study design.

We provided a narrative summary of the included studies. These summaries included key data alongside study characteristics, such as study design and sample size, which may affect interpretation of the data. Data tables and figures were used to support the study summaries. Where possible, we have reported effect estimates or test statistics, with associated 95% confidence intervals (CIs) and p values, but continuous and discrete data have also been summarised.

Results

Summary of screening process

The search of academic databases yielded 4,453 citations: 2,932 from Scopus and 1,521 from CAB Direct. After removal of 486 duplicates, 3,967 citations were screened. The titles and abstracts of the citations were interrogated first, and 3,798 studies were excluded at this stage. The remaining 169 studies were sought for retrieval, but 13 studies were not available. Of the 156 full publications that were available for screening, 129 studies were excluded. The reasons for exclusion were as follows:

- Non-relevant research objective: 94
- Non-relevant intervention: 14
- Non-relevant location: 13
- Non-relevant study design: 6
- Non-relevant review: 1
- Publication superseded: 1

In total, 27 articles were included from the academic database search. An additional 53 publications were identified from the supplementary searches, giving a total of 80 eligible publications (Figure 1) (8-87).

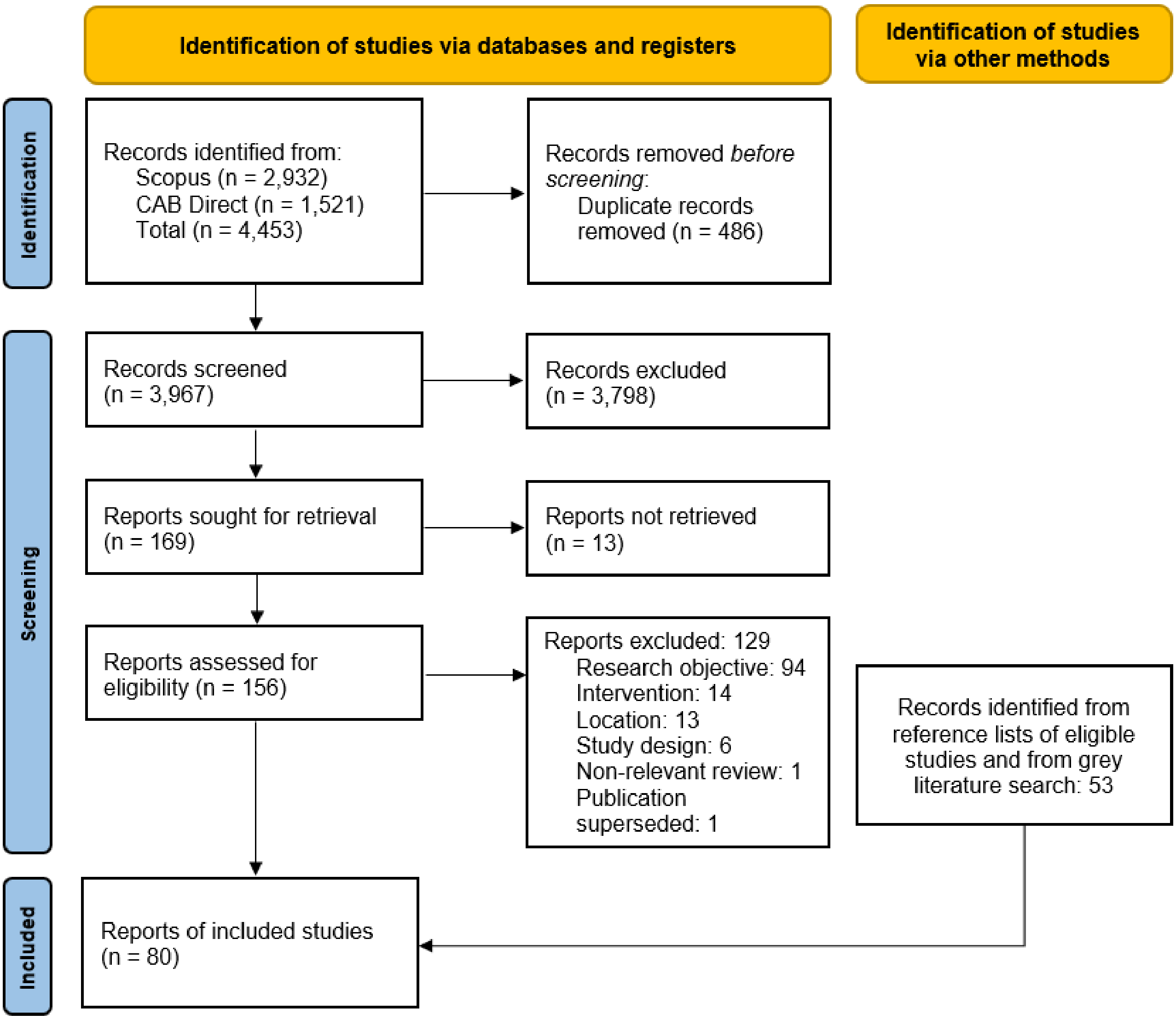

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram showing the process for identifying and screening potentially relevant studies.

Condition of Dartmoor

Section summary

- Standardised Condition Assessments did not take place in SSSIs in the UK until the late 1990s–early 2000s, once the guidance was agreed by the statutory conservation agencies
- The condition of the Dartmoor SSSIs at designation is not known, except for file notes
- Most units on North and South Dartmoor are in unfavourable condition (17 out of 18 and 12 out of 14 units, respectively); half of the units on East Dartmoor are in favourable condition (11 units)
- Most habitat features are in unfavourable condition on the three SSSIs (4 of 4 in East Dartmoor; 4 of 5 in South Dartmoor and 5 of 5 in North Dartmoor)
- Species features, including assemblages of breeding birds and lichen assemblages, are generally in favourable condition

The narrative for this section has been summarised from Condition Assessments (CMSi +TRIM, the internal Natural England databases), which provide the best information on the condition of units on Dartmoor's SSSIs. The condition assessments used for this review were carried out from 1999 to 2022. Supplementary data is available from monitoring surveys and academic literature (8-23, 30, 32-34, 37, 40, 42, 43, 45, 47, 48, 58, 59, 62-64, 66, 74, 75).

As with all SSSIs, Dartmoor was designated based on the importance of habitat and species features (designated features). Sites of Special Scientific Interest Site Units are divisions of SSSIs based on habitat, tenure, and management, and, until recently, they were the basis for recording all information on SSSI Condition and management. This has now changed, and the condition of sites is determined based on the assessment of the designated features across all units. At the time of writing this review, only the historic condition by units was available.

It is worth highlighting this file note from the time the sites were designated: "The heaths and blanket-bog are generally badly damaged by burning and grazing, though the wettest soligenous mires and valley mires are relatively untouched. There are slightly better valley mires on Bodmin – where those have been fenced off from stock. Similarly damaged vegetation would not be considered of SSSI status elsewhere in Britain, where there is a wide choice of comparable sites. However, Dartmoor has no comparable site and, with Bodmin, shows a strong contrast with every other English site despite its poor condition."

Natural England's expectation would have been for the condition to improve following designation, not maintain it in the same degraded state. Achieving and maintaining favourable condition has also been the aim of various government targets, in national legislation, or as a signatory of international conventions (88). For example, the recent Environmental Improvement Plan (2023) commits to restoring 75% of protected sites to favourable condition by 2042 (2). The Dartmoor SSSIs were designated in the late 1980s, and the condition of the units was initially assessed by experienced field ecologists, but there wasn't a standardised assessment method until the late 1990s–early 2000s. The method, sponsored by JNCC (Joint Nature Conservation Committee) and used across all nature conservation agencies in the UK (English Nature/Natural England, Scottish Natural Heritage/NatureScot, Countryside Council for Wales/Natural Resources Wales and Department of Environment Northern Ireland) for all designated features, is called Common Standard for Monitoring (CSM, all guidance is found here). In summary, a feature (habitat, species or geological) is in favourable condition if it meets a series of criteria defined in the Conservation Objectives for each site. For habitats, these Conservation Objectives will describe e.g. the species that contribute to better condition, by being present or absent, or by showing a height or cover that benefits other species depending on it. In general, the higher structural vegetation diversity, the more opportunities for many species to thrive. Dominance of one species will result on declines of others that need more variety. Favourable condition also reflects the absence of disturbance or damaging impacts.

Most categories are self-explanatory, but the interpretation of 'Unfavourable Recovering' has changed over the years. JNCC states that "an interest feature can be recorded as recovering after damage if it has begun to show, or is continuing to show, a trend towards favourable condition." (A Statement on Common Standards for Monitoring Protected Sites (2022) [version 2.1] p4) (89). However, internal guidance in 2003 described this condition as also applying to units where "the management of the unit is known to be enough (on our best judgement) to get the unit back into favourability". In later assessments, it was found that this expectation hadn't always been met. The definition of all the condition categories was revised in June 2024 (Technical Information Note 216 - TIN216 Edition 2 Environment Act Interim Target for protected sites - TIN216; annex 3). At some points 'Site checks', rather than full condition assessments were carried out. Site checks are intended to gather key information relating to site management; possible threats; the condition of the site; and the relationship between the Favourable Condition Tables, Citation, and Common Standards Monitoring. There have also been many grazing assessments, which followed a standardised method of measuring whether an area showed signs of overgrazing (8-20, 22, 23, 33, 34, 36, 43, 45, 58, 59). These assessments sometimes, but not always, fed into the condition assessments of the SSSI units.

Prior to 2011, Natural England aimed to assess SSSIs on a six-year cycle though this was not always achieved. Since 2011 Natural England has adopted a risk-based approach to better match resources to requirements for assessment.

The recorded condition of units in three Dartmoor SSSI (East Dartmoor, South Dartmoor, and North Dartmoor), as of October 2023, is summarised in Figure 2. In terms of area in each condition, only 40% is Favourable in East Dartmoor (855 ha), 4.5% in South Dartmoor (319 ha), and 0.2% in North Dartmoor (30 ha).

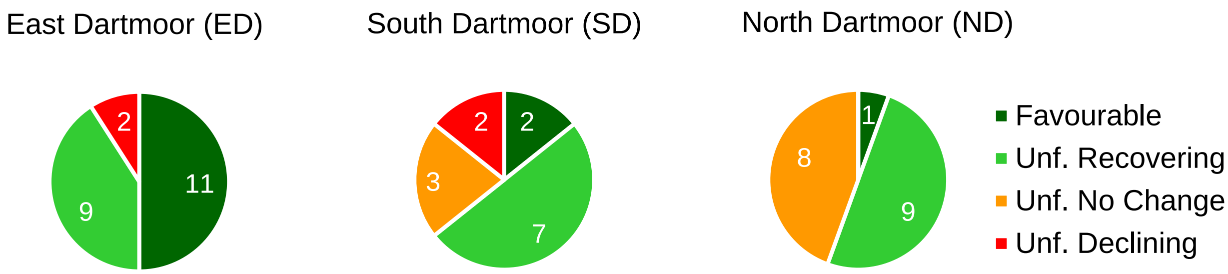

Figure 2: Number of units in each condition in each Dartmoor SSSI. Total number of units: ED = 22; SD = 14; ND = 18.
Abbreviations: Unf., unfavourable.

The type and number of designated features in each unit of each SSSI in Dartmoor are summarised in Figure 3, Figure 4, and Figure 5. Note, if features are in different condition in a unit, the “Condition” (colour) column indicates the least favourable condition. For some units, the condition was determined by features other than those considered in the review. Since April 2023, NE and Defra have used the proportion of whole features in different condition categories for reporting and statistics, but since the evidence below refers to historic assessments, we refer to units.

Most units in North and South Dartmoor and half of East Dartmoor are in unfavourable condition. Most habitats on Dartmoor are in unfavourable condition, including bog, fen, heath, and grassland. Species features, including assemblages of breeding birds and lichen assemblages, are generally in favourable condition.

East Dartmoor SSSI

Feature	Condition	1	2	3	5	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Assemblages of breeding birds - Submontane grasslands and heaths	UD	F	UR	F	F	F	UD	UD	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Blanket bog and valley bog (upland)	UR		UR		F								F							UR			
Short sedge acidic fen (upland)	UR		UR																				
Subalpine dwarf-shrub heath	UD	UR		UR		F	UD	UD	F		F	F				F	UR	F	UR		UR		UR
Transition mire, ladder fen and quaking bog (upland)	UR		UR																				

Figure 3: Current condition of designated features at units on East Dartmoor SSSI (from NE's Designated Sites View system).
■ Favourable; ■ unfavourable recovering; ■ unfavourable no change; ■ unfavourable declining; blank: not present.

South Dartmoor SSSI

Feature	Condition	3	8	9	10	21	57	58	59	60	61	62	63	65	67
Acid grassland (upland)	UR						UR		UR		UR	UR			UR
Blanket bog and valley bog (upland)	UD	?			UD	F	UR	UN	UN	UN	UR	UR	UR		UR
Short sedge acidic fen (upland)	F	F													
Subalpine dwarf-shrub heath	UR		UR	UR			UR							UR	UR
Wet heath (upland)	?						UR				UR	?	UR	UR	UR

Figure 4: Current condition of designated features at units on South Dartmoor SSSI (from NE's Designated Sites View system).
■ Favourable; ■ unfavourable recovering; ■ unfavourable no change; ■ unfavourable declining; blank: not present.

North Dartmoor SSSI

Feature	Condition	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
Acid grassland (upland)	UR		UR	UR	UR		UR							UR					
Assemblages of breeding birds - Upland moorland and grassland without water bodies	F																		F
Blanket bog and valley bog (upland)	UN		UR		UR			UR			UN	UN	UN	UN	UN	UN	UN	UN	
Lichen assemblage	F																		F
Nationally rare and scarce dragonfly species - *Coenagrion mercuriale*, Southern Damselfly	?									?									
Short sedge acidic fen (upland)	UR							UR		UR									
Subalpine dwarf-shrub heath	UN		UR	UR	UR	UR	UR	UR	UR	UN	UN					UN	UN	UN	
Wet heath (upland)	UN	UR	UR	UR	UR	UR		UR	UR	UR	UN	UN	UN			UN	UN	UN	

Figure 5: Current condition of designated features at units on North Dartmoor SSSI (from NE's Designated Sites View system).
■ Favourable; ■ unfavourable recovering; ■ unfavourable no change; ■ unfavourable declining; blank: not present.

Causes of changing habitat condition

Section summary

- Reasons given for the improvement of habitat condition in assessments are presence of characteristic species, diverse vegetation structure, or no sign of damage. Notes from monitoring assessment reports suggest that this was usually achieved by appropriate grazing and burning regimes and/or entering into agri-environment agreements
- Reasons given for the worsening of the habitat condition are lack of diverse vegetation composition or structure, signs of habitat damage (drains, burns), overgrazed heather or overabundant *Molinia*. Assessment notes suggest that this was usually associated with overgrazing or inappropriate burning

As with the previous section, the narrative for this section has been summarised from Condition Assessments (CMSi +TRIM, the internal Natural England databases) carried out from 1999 to 2022, with supplementary information from the academic and grey literature (8-20, 22, 23, 31, 33, 34, 36, 43, 45, 49, 58, 59, 65, 67).

There are two components in condition assessments:

- Biological and geological data to make an assessment against the attributes set out in the monitoring specifications (which are based on UK common standards monitoring (CSM) guidance).
- Information on the pressures acting on the feature (internal and external to the SSSI).

The biological/geological data provides information on overall condition (favourable or unfavourable). Pressure data is required to understand the interventions required to bring about positive condition change. They are both needed to assess trends (recovering, declining, no change). The interventions include agri-environment agreements, partnership working, and land use planning. However, in the past, condition may have been classed as recovering when land was entered into an agri-environment scheme, which was intended to improve condition prior to having evidence of any change in condition.

The main factors that led advisors to change the previous condition category of a unit, are provided in Table 2.

Table 2, section A, lists the attributes that met or failed to meet targets for Common Standards Monitoring assessments. For each designated feature, the assessor checks whether a series of attributes are within the threshold range set. There are different attributes and thresholds for each designated feature, but typically for habitats, they include a combination of:

- Vegetation composition: presence or absence of species, both characteristic species of the habitat (positive indicators) or problematic or invasive species (negative indicators, or rather indicators of negative conditions, as some of them are native species).

- Vegetation structure: presence of dwarf shrubs in all stages of growth; presence of small amounts of bare ground and for open habitats, low presence of scrub, or trees.
- Signs of damage: drainage, erosion, pollution, trampling, etc.

Table 2, section B, shows the type of interventions mentioned by advisors which are expected to lead to the habitat features improving (left column) or where there is evidence that condition is deteriorating (right column).

Table 2 also shows in square brackets the designated features to which the attributes (Section A) or the interventions (Section B) refer to. They are mostly acid grassland, heathland (wet and dry), and mires or bogs.

Reasons given for the improvement of condition in assessments are presence of characteristic species, diverse vegetation structure, or no sign of damage. This was usually achieved by appropriate grazing and burning regimes and entering into agri-environment agreements. Conversely, reasons given for the worsening of the condition are lack of diverse vegetation composition or structure, signs of habitat damage (drains, burns), overgrazed heather, or overabundant *Molinia*, usually resulting from overgrazing or inappropriate burning. These findings are generally supported by monitoring reports and the academic literature, with publications implicating excessive grazing or grazing with inappropriate livestock (8-12, 14-16, 18-20, 22, 23, 33, 34, 36, 43, 45, 58, 59), burning (15), heather beetle (15, 20), peatland drainage (31), drought (49), climate change (65, 67), and nitrogen pollution (65) as potential pressures on Dartmoor's landscape. Of note, there were limited data on the potential effect of climate change and nitrogen pollution on condition of Dartmoor's SSSI, other than the two publications mentioned prior (65, 67).

Table 2: Extract of factors mentioned by NE advisors as reasons to change the recorded condition of the units (from DET & CMSi). Note, some cells have been left blank.

To improving condition	To worsening condition
A. Related to CSM attributes and targets	
Presence of positive indicator species [Mire/Bog, Dry Heathland]	Lack of botanical diversity, heathers or forbs [Heathland, Acid grassland]
	High litter cover [Acid grassland]
Extensive *Sphagnum* moss cover [Mire/Bog]	Low *Sphagnum* moss cover, or *Sphagnum* damaged

To improving condition	To worsening condition
	[Mire/Bog]
No/little sign of poaching, small scrub encroachment [Mire/Bog]	No bare ground [Heathland]
	Heather beetle [Heathland]
Reduced gorse cover [Heathland]	Lack of dwarf shrub regeneration [Heathland]
Increased vegetation structural diversity [Heathland]	Low structural diversity in vegetation (i.e., heather in all growth stages) [Heathland]
	Presence of negative indicator species: e.g., high percentage of rushes, *Molinia*, bracken, scrub… [Heathland]
	Presence of drainage and/or erosion [Mire/Bog]
	High cover of grasses [Mire/Bog]
B. Related to CSM changes in management or unit boundaries	
Light to moderate grazing /reduced grazing pressure / reduced poaching / changes from sheep to cattle grazing [Heathland, Mire/Bog]	Heavy grazing / overgrazing / insufficient reduction of grazing levels (not implemented, strays, or insufficient) / high winter grazing pressure [Heathland, Mire/Bog]
Enter into ESA Tier 2B /HLS agreement [Heathland, Mire/Bog]	HLS agreement no longer in place [unit 61 South Dartmoor; Acid Grassland, Heathland, Mire/Bog]
Management being implemented: cutting and grazing [Heathland]	
Low incidence of burning / recovery from burning / good burning regime	Overburning (e.g., >20% of unit burnt), sometimes followed by heavy grazing

To improving condition	To worsening condition
[Heathland]	[Heathland]
Scrub/tree management [Heathland]	
Changing the SSSI units (excluding worse patches or separating features), e.g., Unit 20 East Dartmoor (cell I84) or different habitat (e.g., cell I104)	
Re-wetting/Peatland restoration measures [Mire/Bog]	
Over-grazed heather hard to find [Heathland]	Evidence of >33% heather stems grazed (topiary) or broken; Failure to meet grazing survey thresholds; High levels of dung [Wet and dry Heathland, Mire/Bog]

Abbreviations: CSM, Common Standard for Monitoring; ESA, Environmentally Sensitive Area; HLS, Higher Level Stewardship.

Management options

This section reports the evidence identified on the management options that are likely to be effective at restoring favourable condition on Dartmoor and comparable areas. The narrative for this section has been summarised from all relevant academic literature and grey literature (e.g., unpublished grazing reports) identified by the review.

Management of livestock

The following sections are arranged by type of study: experimental studies, observational studies, or mixed method (both experimental and observational). In experimental studies, an intervention (treatment, procedure, or programme) is intentionally introduced by researchers, who then observe the results. In observational studies, researchers observe the effect of an intervention or exposure – without trying to change who or what is exposed.

Experimental evidence

Experimental studies offer the strongest evidence of the effect of livestock management on landscape condition. There are limited experimental data from Dartmoor (51); however, the review identified eleven publications on eight experimental studies from comparable areas, including Pwllpeiran, Wales, and Exmoor and Bodmin Moor, southwest England (46, 55, 61, 68, 77, 80-83, 85, 87).

The experimental studies reported in this section cover the following topics:

- The effect of grazing and soil disturbance on species composition (55, 68, 77, 80-83, 87).
- The effect of grazing on distribution of vegetation communities (46, 61).
- The effect of grazing on the abundance of the marsh fritillary *Euphydryas aurinia* (85).
- The effect of salt blocks on grazing behaviour of Dartmoor ponies on *Molinia*-dominated grassland (51).

Effect of grazing and soil disturbance on species composition

Section summary

- The following evidence focuses on suppression of swards and recovery of *Calluna* on *Molinia/Nardus*-dominated grasslands:
    - The balance of evidence suggests that soil disturbance through trampling or rotavating can provide regeneration niches for *Calluna*, although it also provided opportunity for non-target species, such as *Juncus effusus*, to establish
    - There was conflicting evidence on the effect of cattle vs sheep grazing on the establishment of *Calluna*, but the best available evidence suggests that *Calluna* establishes better on land grazed by cattle in the summer compared with land grazed by sheep year-round*
    - *Calluna* morphology (height, weight, number of shoots, etc) and total cover was best when land was ungrazed or grazed during by cattle summer at low stocking rates
    - Evidence on the effect of grazing on cover of *Molinia* and *Nardus* was inconclusive
    - However, evidence suggests that year-round stocking of sheep, cattle, and ponies at agreed rates under ESA reduces *Molinia* leaf litter more than summer only grazing or no grazing
    - Seeding enhances recovery of *Calluna*, especially in areas where *Calluna* was limited or absent from the seed bank but also in areas where it was present

*See 'Observational evidence' section for additional information on winter exclusion of cattle and sheep.

Trampling of sward by large grazing animals may help to reduce the dominance of *Molinia*, which in turn helps to establish dwarf shrub species. Mitchell and others (2008) examined the effect of soil disturbance, grazing or livestock exclusion, and seeding on recovery of *Calluna* at a *Nardus*-dominated site in Pwllpeiran, Wales, and a *Molinia*-dominated site in Redesdale, northern England (the latter site did not meet the inclusion criteria for the review, but key methods and results will be reported) (55). The *Nardus* was formerly dwarf-shrub heath that had been degraded by heavy grazing. The site was ungrazed from 1990 to 1994 and then grazed at a low stocking density (1.0–1.5 ewes/ha) until 2002.

The *Nardus* site was divided into three blocks of land, each with three fields of 5–7 ha (Figure 6). In each block, the three fields were randomly assigned to one of three grazing regimes: cattle only, mixed (sheep and cattle), or sheep only. The study used the following grazing rates at the *Nardus* site:

- Cattle only: 0.5 cows/ha in July and August
- Mixed: 1.0 ewe/ha all year and 0.5 cows/ha in July and August
- Sheep only: 1.5 ewes/ha all year

The *Molinia* site consisted of three fields (21–29 ha), each of which was assigned a single grazing regimen:

- Sheep only: 1.5 ewes/ha all year
- Mixed low: 0.66 ewes/ha all year and 0.75 cows/ha in July and August
- Mixed high: 1.5 ewes/ha all year and 0.75 cows/ha in July and August

The *Nardus* site had a depleted *Calluna* seed bank, deemed by the authors to be absent. The *Molinia* site had good presence of *Calluna* in the seed bank, with 606 seed/m^2 in the mixed high fields, 2,590 seeds/m^2 in the mixed low fields, and 3,780 seeds/m^2 in the sheep only fields.

At the *Nardus* site, six plots were established per field, and at the *Molinia* site, 18 plots were established per field. The plots were randomly assigned to one of three disturbance treatments (undisturbed, rotavated, and trampled [using five Welsh Black Bull heifers for 25–45 minutes per plot at the *Nardus* site and one pony ridden for ~40 minutes at each plot on the *Molinia* site]) carried out in September 2002. From March 2003 to Autumn 2006, *Calluna* seed was mixed with silver sand and hand-sown at a rate of 0.8 g/m^2 seed on half of each plot. A ‘no-grazing’ treatment was applied by fencing half of each plot perpendicular to the seeding treatment, thus creating a 2x2 factorial structure: (a) grazed, not seeded, (b) not grazed, not seeded, (c) not grazed, seeded and (d) grazed and seeded.

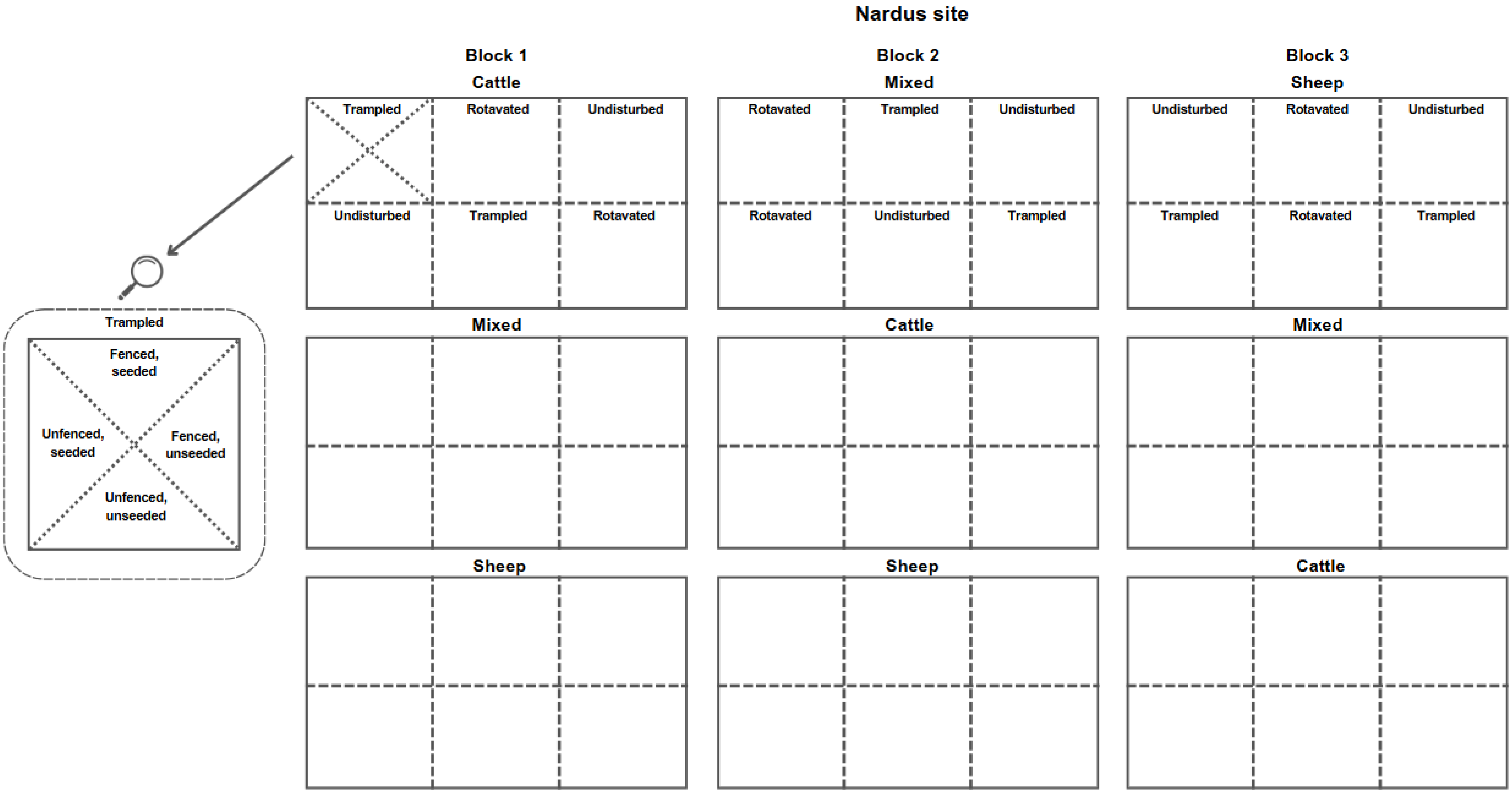

Figure 6: Visual representation of the design of the Mitchell and others (2008) study; adapted from Mitchell and others (2008).

Effect of disturbance and seeding (Mitchell 2008)

At the *Nardus* site, plots that were rotavated and trampled had more bare ground cover compared with undisturbed plots ($F_{2,43}$=150; p<0.001), which may provide suitable conditions for the germination of *Calluna* and other desirable species. Accordingly, after four growing seasons (3.5 years), presence of *Calluna* was higher in disturbed plots compared with undisturbed plots ($F_{2.46}$=25.1; p<0.001). The researchers conducted a second analysis of *Calluna* cover using bare ground cover as an explanatory variable. After adjusting for cover of bare ground, presence of *Calluna* was still higher at disturbed plots compared with undisturbed plots ($F_{1,30}$=7.5; p<0.01), which suggests that bare ground cover was not the only factor contributing to *Calluna* recovery at disturbed sites.

Calluna had a limited seed bank at the Nardus site. Accordingly, seeding enhanced *Calluna* establishment, with higher cover in plots that were seeded than not seeded ($F_{1,203}$=432; p<0.001). *Calluna* cover was also higher in plots that were disturbed and seeded compared with plots that were only seeded ($F_{2,250}$=5.5; p<0.01).

Similar results were reported at the *Molinia* site, although researchers noted that *Molinia* was difficult to break down compared with *Nardus* sward. *Molinia* also produced a greater volume of litter than *Nardus*, increasing the amount of litter on bare ground compared with *Nardus* sward. At sites dominated by *Molinia*, more intense disturbance may be required compared with sites dominated by *Nardus*. Seeding enhanced recovery of *Calluna*, even in the fields with the largest natural seed banks.

Effect of grazing and fencing (Mitchell 2008)

At the *Nardus* site, grazing exclusion had a non-significant effect on *Calluna* presence compared with the grazing regimens; however, *Calluna* cover was highest at sites grazed by cattle, followed closely by ungrazed sites, and lowest at sites grazed by sheep. There was also a significant interaction between grazing, disturbance, and seeding, with greater *Calluna* presence at ungrazed-disturbed-seeded plots compared with grazed-disturbed-seeded plots ($F_{1,38}$=12.0; p<0.001).

At the Nardus site, grazing affected *Calluna* morphology. *Calluna* was taller ($F_{1,33}$=165; p<0.001), weighed more ($F_{1,34}$=61.4; p<0.001), and had more shoots ($F_{1,37}$=20.6; p<0.001) at ungrazed plots compared with grazed plots. There was a significant interaction between grazing and fencing for *Calluna* height ($F_{2,32}$=12.1; p<0.0001) and for dry weight ($F_{2,34}$=9.8; p<0.001). Plants were taller and heavier at plots grazed by cattle compared with plots grazed by sheep or a mix of cattle and sheep.

Contrasting results were reported at the *Molinia* site, with a greater presence of *Calluna* at grazed compared with ungrazed sites ($F_{1,215}$=7.7; <0.001). This effect persisted in the trampled subplots ($F_{2,243}$=5.7; p<0.01), but, at the rotavated and control plots, there was no significant difference in cover of *Calluna* between the ungrazed and grazed plots.

The results indicate that soil disturbance and, in some cases, grazing with cattle can help reduce the dominance of *Nardus* and *Molinia*, producing good conditions for *Calluna* to establish. Once established, *Calluna* grew best when it was ungrazed. The authors noted that cattle trampling as a one-off restoration treatment on grass-dominated moorlands has not been tried previously. However, rotavating or trampling *Nardus*- or *Molinia*-dominated grassland followed by a reduction in stocking levels and seeding may facilitate good conditions for establishment and subsequent growth of *Calluna*.

Mitchell and others (2009) reported additional results from the Mitchell and others (2008) study that were not covered in the original publication (80). Only results for the *Nardus* site will be reported here, but the Mitchell and others (2009) publication reports results for the *Molinia* site, too. Notably, this publication partially reports data for some outcomes, focusing on significant results. However, this did not substantially hinder the interpretation of the results.

Disturbance affected the cover of dwarf shrubs, with significantly lower cover in trampled plots than undisturbed plots ($F_{2,43}$=40.3; $p<0.001$). Dwarf shrub cover improved over time ($F_{2,413}$=90.7; $p<0.001$), but after three years, mean cover was still lower in trampled plots (6%) than undisturbed plots (20%). The observed effect was driven by changes to the cover of *Vaccinium*, which declined significantly one year and four years after trampling compared with undisturbed plots ($F_{2,43}$=6.9; $p<0.01$; and $F_{2,43}$=12.0; $p<0.001$, respectively). The seeding and grazing treatments did not affect dwarf shrub cover after three years (data not shown).

Disturbance initially affected the total cover of grasses, with lower cover in May 2003 at disturbed plots compared with undisturbed plots ($p<0.001$); however, by May 2005 there was no significant difference (data not shown). The seeding and grazing treatments did not affect total grass cover. However, grazing treatment affected the cover of *Agrostis* ($F_{2,43}$=7.8; $p<0.01$) and *Festuca* ($F_{2,43}$=4.4; $p<0.05$). *Agrostis* increased when grazed by sheep, decreased in the mixed regimen, and did not change when grazed by cattle. *Festuca* cover decreased when grazed by sheep but did not change under the other regimens.

Disturbance affected the occurrence of the competitive rush *Juncus effusus* ($F_{2,42}$=9.1; $p<0.001$), with higher frequency in trampled plots than undisturbed plots. *J. effusus* was also more frequent in grazed than ungrazed plots ($F_{1,266}$=6.6; $p<0.001$) and increased throughout the study ($F_{2,439}$=37.7; $p<0.001$). The type of grazing regimen (sheep vs cattle vs mixed) and seeding did not affect the occurrence of *J. effusus* (data not shown).

Results from the *Molinia* site largely echo those of the *Nardus* site. Notably, however, *Molinia* increased when ungrazed or when grazed by sheep, but decreased for both mixed grazing regimens.

Critchley and others (2013) performed an eight-year follow-up of the Mitchell and others (2008 and 2009) study (77). The follow-up assessment reported results for the Nardus-dominated site in Pwllpeiran, Wales.

Effect of disturbance and seeding (Critchley 2013)

Both disturbance and seeding affected the establishment of *Calluna*. Plots that were disturbed by trampling or rotavating had significantly higher cover of *Calluna* than plots that were undisturbed ($F_{2,43}$=14.2; p<0.0001). Seeded plots had significantly higher cover of *Calluna* compared with unseeded plots ($F_{1,135}$=193.4; p<0.0001).

Disturbance may provide an opportunity for non-target species with a seed bank to establish. Indeed, disturbance significantly increased the occurrence of the rush *J. effusus* ($F_{2,47}$=4.6; p<0.05), with higher rates in trampled plots compared with undisturbed plots (p<0.1). However, seeding plots with heather seeds reduced the occurrence of *J. effusus* compared with unseeded plots ($F_{1,189}$=29.3; p<0.0001).

Effect of grazing and fencing (Critchley 2013)

Grazing regimen and fencing affected the establishment of *Calluna.* Plots that were grazed by cattle had significantly higher cover of *Calluna* than plots that were grazed by sheep or a mix of sheep and cattle ($F_{2,43}$=13.7; p<0.0001). Fenced (i.e., ungrazed) plots had significantly higher cover of *Calluna* compared with unfenced (i.e., grazed) plots ($F_{1,135}$=44.8; p<0.0001).

Grazing regimen and fencing also influenced *Calluna* morphology. *Calluna* in plots grazed by cattle was significantly taller (p<0.05), had more shoots (p value not reported), and weighed more (p value not reported) compared with *Calluna* in plots grazed by sheep or a mix of sheep and cattle. *Calluna* in fenced (ungrazed) plots was taller ($F_{1,42}$= 99.7; p<0.0001), had more shoots ($F_{1,33}$= 42.4; p<0.0001), and weighed more ($F_{1,42}$= 42.0; p<0.0001) compared with grazed plots. However, there was no statistical difference in *Calluna* morphology between ungrazed plots and plots grazed by cattle.

Grazing regimen and fencing affected the vegetation height. Plots grazed by cattle had taller vegetation than plots grazed by sheep (p<0.01) and plots grazed by a mix of sheep and cattle (p<0.1), although the latter comparison was non-significant. Unfenced plots had taller vegetation than fenced plots ($F_{1,147}$=436; p<0.0001).

Disturbance x seeding x fencing x grazing interactions (Critchley 2013)

The study found significant interactions that affected the establishment of *Calluna.* There was a significant interaction between disturbance and fencing ($F_{2,135}$=6.3; p<0.01), with more *Calluna* at disturbed, fenced plots compared with undisturbed, fenced/unfenced plots. There was also a significant interaction between disturbance and seeding ($F_{2,135}$=15.4; p<0.0001), with more Calluna at disturbed, seeded plots compared with undisturbed, seeded/unseeded plots. Finally, fenced, seeded plots had more *Calluna* than unfenced, seeded plots ($F_{2,135}$=10.3; p<0.01).

Critchley and others (2013b) performed an eight-year study that examined the effect of different grazing regimens on *Nardus*-dominated grassland in Pwllpeiran, Wales (the same *Nardus* site but different plots was used by Mitchell and others [2008]) (82). The grassland site was formerly dwarf-shrub heath, but it had been degraded by heavy grazing (2.2–2.7 ewes/ha; dates of heavy grazing not specified). The site was ungrazed from 1990 to 1994 and then grazed at a low stocking density (1.0–1.5 ewes/ha) until 2002.

The study site was divided into three blocks, each containing four paddocks, resulting in a total of 12 paddocks. From spring 2003 to autumn 2010, researchers implemented four different grazing regimens:

1. Low sheep (1.0 ewes/ha, Welsh Mountain)
2. High sheep (1.5 ewes/ha, Welsh Mountain)
3. Cattle only (0.5 heifers/ha, 2-year-old Welsh Black)
4. Sheep and cattle (1.0 ewes/ha, Welsh Mountain, plus 0.5 heifers/ha, 2-year-old Welsh Black)

Treatments were randomly assigned to one paddock in each block. Sheep were grazed for 10 months each year and lambed from May to August. Cattle were grazed in July and August. Data were collected from pre-treatment in 2002 to end of treatment in 2010.

Vegetation frequency and cover and grazing index[5] were examined between 2002 and 2010; results for vegetation cover were not fully reported in the publication. The type of grazing regimen had a significant effect on the mean grazing index for *Molinia* and *Calluna*. For *Molinia*, the mean grazing index was 30.8 (standard error [SE]: 16.48) for the low sheep regimen, 11.9 (SE: 6.74) for high sheep, 63.1 (SE: 10.2) for sheep and cattle, and 54.4 (SE: 13.9) for cattle only ($F_{3,6}$=64.12; $p<0.01$). For *Calluna*, the mean grazing index was 5.0 (SE: 6.18) for the high sheep regimen, 11.1 (SE: 14.91) for sheep and cattle, and 13.8 (SE: 8.94) for cattle only ($F_{3,6}$=6.85; $p<0.05$); while the difference is statistically significant, the grazing intensity was low in all cases; results for low sheep were not reported. The type of grazing regimen did not significantly affect the grazing index for *Nardus* or *Vaccinium* (both $p>0.05$). There were also no significant treatment effects on the mean frequency of *Calluna*, *Molinia*, *Nardus*, or *Vaccinium* (all $p>0.05$) or mean vegetation height ($p>0.05$).

Notably, the authors reported that *Calluna* was sparse at baseline and fragmented within the sward, which may have contributed to its higher utilisation by cattle than sheep. Furthermore, the authors suggest that the lack of *Calluna* regeneration was partly due to the paucity of a seed bank. This is consistent with the results of Mitchell and others (2008) and Critchley and others (2013) who demonstrated the importance of seeding (used as a supplement for the natural seed bank) to the regeneration of *Calluna*.

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[5] An estimate of grazing pressure, which measures the proportion of the previous year's shoots that have been grazed.

Critchley and others (2014) performed a 10-year follow-up of the Critchley and others (2013b) study (81). The treatments were the same as the original study; however, the researchers ceased grazing in 2011 and 2012 on all plots to examine the effect of a 'pulsed' grazing system, in which areas are left ungrazed for a set time between periods of grazing. Grazing resumed in 2013. Notably, the study did not use an active control, so there was no basis for comparison between the 'pulsed' regimen and continuous grazing.

Mean vegetation height increased across all plots after cessation of grazing, but only by 2 cm (p=0.06). *Nardus* frequency reduced after cessation of grazing, from 37.6% in 2010 to 30.8% in 2012, although the change was not statistically significant (p=0.06). This continued a long-term trend in declining *Nardus* frequency, which was 51.4% in 2003 (mean across all plots). However, *Molinia* frequency significantly increased after cessation of grazing from 4.4% in 2010 to 6.7% in 2012 ($F_{1,6}$=11.5; p<0.05). There was no change in the frequency of *Calluna* or *Vaccinium*.

The authors suggested that 'pulsed' grazing regimens may have a small effect on *Nardus* dominance, but a greater effect may require more time or higher stocking levels.

Fraser and others (2011) conducted a study that examined the effect of livestock grazing on vegetation composition at a site dominated by *Molinia* in Pwllpeiran, Wales (83). Notably, in the 1960s and '70s, the site was considered over-grazed and dominated by *Nardus*, *Festuca*, and *Vaccinium*; however, after cessation of grazing in the 1980s, the site became dominated by *Molinia*. Three grazing regimens were implemented in 2001 to reduce the dominance of *Molinia*. The treatments were:

1. Grazing with cattle (2 cows/ha or 0.30 LU/ha, yearling Welsh Black heifers)
2. Grazing with sheep (8 ewes/ha or approx. 0.30 LU/ha, Welsh Mountain hoggets)
3. No grazing

There were only two, 2 ha replicates for each treatment. Grazing commenced in June/July and ceased when utilisation of *Molinia* reached 50%, usually in September. Data were collected between 2001 and 2008.

The study reported a significant treatment effect on the average change in *Molinia* cover between the beginning and end of the grazing seasons (June/July to September), with reduced cover in cattle plots and increased cover in sheep and ungrazed plots (p<0.05). However, *Molinia* cover increased in all plots between 2001 and 2008 (p<0.001). The type of management had a significant effect on the average cover of *Molinia* (p<0.05), but, crucially, it had non-significant effect on change in *Molinia* cover over the eight-year study period (treatment x year interaction: p>0.05). The type of management also had a non-significant effect on the cover of other grasses (broad/fine-leaved grasses, *Nardus*), rushes/sedges, dwarf shrubs, forbs, and mosses over the study period (all p>0.05).

Stewart (2002) reported a PhD thesis that examined grazing management and the plant composition of Bodmin Moor (87). The thesis was formed of several studies that examined the effects of grazing on Bodmin Moor. Briefly, the studies cover:

- The distribution of plant communities on Bodmin Moor and the relationship between plant community composition and environmental factors, including grazing management (Chapter 5)
- Soil seed bank composition on Bodmin Moor (Chapter 6)
- The effect of Countryside Stewardship schemes on plant communities / individual species on Bodmin Moor (Chapter 7)
- The effect of defoliation on the growth of *Molinia* (Chapter 8)
- A summary of the effects of grazing management on plant community composition on Bodmin Moor (Chapter 9)

The synthesis below is based mainly on the methods and results of Chapters 7 and 8, as well as key findings summarised in Chapter 9.

In Chapter 7, Stewart (2002) conducted an observational study monitoring the response of vegetation to Countryside Stewardship stocking rates at Ivey and Hawkstor farms (87). The farms were formerly heavily grazed but changed to light, summer-only grazing after entering a Countryside Stewardship agreement in 1995. The semi-natural vegetation on the farm was grazed at 0.5 LU/ha (April–September), while semi-improved vegetation was grazed at 1.5 LU/ha (April–August). Both regimens used a mix of sheep and cattle. Twelve exclosures were erected on plots with six vegetation types (semi-improved grassland; fine, unimproved grassland; coarse-grained *Molinia* with *Calluna*; fine-grained *Molinia* mire; *Molinia* grassland with gorse; and mixed valley mire). Plant species inside and outside of each exclosure were monitored between June and August 1997–2001.

Results of the 5-year study suggest that the Countryside Stewardship stocking rates of 0.5 LU/ha did not significantly change the biomass of *Molinia* or dwarf shrubs (all $p>0.05$). The author suggests that stocking rates were not high enough to lower *Molinia* abundance and not low enough to promote recovery of dwarf shrubs. As a result, Countryside Stewardship objectives for the area were not met. Similar results were reported for the control (no grazing) exclosures, with no significant changes in the biomass of *Molinia* or dwarf shrubs over time (all $p>0.05$). The author suggests that the lack of recovery of dwarf shrubs may have been attributed to competition with other species, such as *Molinia*. Changes in biomass on individual species were not reported for semi-improved land (1.5 LU/ha).

In Chapter 8, Stewart (2002) conducted a defoliation experiment at Hawkstor Farm, Bodmin Moor to examine the effect of grazing and soil moisture on *Molinia* growth (87). The experiment used a 53 m x 12 m exclosure set on a *Molinia*-dominated slope, with drier land at the top and wetter land at the bottom. The exclosure was divided into 10 m x 10 cm plots, with one of five treatments randomised to each plot; this resulted in 60 replicates for each treatment. The treatments consisted of a control (no grazing) and four 'grazing' treatments, where a proportion of *Molinia* lamina material was cut to simulate grazing:

- Spring grazing (50% of lamina cut in May 2000)

- Summer grazing (50% of lamina cut in July 2000)
- Spring and summer grazing (50% of lamina cut in May and July 2000)
- Heavy summer grazing (80% of lamina cut in July 2000)

In addition to these experimental groups, the study examined the effect of stocking at Countryside Stewardship levels outside the exclosure. *Molinia* growth was monitored between May 2000 and September 2000.

The study showed that treatment and soil moisture had a significant effect on *Molinia* height, tiller number, and lamina length (all $p<0.05$). The effect of treatment and soil moisture is summarised visually in Figures 8.5–8.7 of the publication. To summarise, grazing at Countryside Stewardship levels decreased *Molinia* height, tiller number, and lamina length compared with control. This result is at odds with the former long-term Countryside Stewardship monitoring study which showed that grazing at Stewardship levels did not control *Molinia*. The author suggests that reductions in tiller number, lamina extension, and *Molinia* height may not result in a reduction in *Molinia* biomass. Grazing early in the spring did not inhibit *Molinia* growth in dry conditions and promoted growth in wet conditions. Heavy grazing in the summer reduced the height of *Molinia*, but not tiller number or lamina length, compared with control. The author also suggests that heavy summer grazing may impact the cover of dwarf shrubs, although this was not measured in the experiment.

There were notable limitations to the Chapter 8 study, described by the author. The study used cutting as a proxy for grazing pressure; however, some effects of grazing livestock, such as trampling, were not accurately simulated by cutting. Additionally, as the study used a proxy for grazing, each cutting plot will have been affected by a cessation of grazing, which was formerly at Countryside Stewardship levels. These issues limit the inferences that can be made regarding management on other sites.

Todd and others (2000) examined whether *Molinia* could be reduced on moorland using three targeted treatments (grazing, burning, and herbicide) at three locations: Exmoor, the North Peak, and the Yorkshire Dales (the latter two sites did not meet the inclusion criteria for the review) (68). The study was conducted at two sites on Exmoor: a ‘white’ moorland site dominated by *Molinia* and a ‘grey’ moorland site with a mixture of *Molinia*, *Calluna*, and *Vaccinium*. Treatments were assigned to the white and grey sites using a randomised split-block design, with burning as the main treatment, grazing as the first sub-treatment, and herbicide use as the second sub-treatment. The grazing regimens were as follows:

- Existing regimen: Free access by sheep, cattle, and ponies, with stocking rates based on ESA prescriptions:
    - White site stocking density: 0.02 LU/ha (1 January–30 April); 0.11 LU/ha (1 May–31 August); 0.07 LU/ha (1 September–31 December)
    - Grey site stocking density: 0.2 LU/ha (1 April–31 December)

- Summer only: entry to a fenced paddock (30 m x 20 m and gated at both ends) allowed between 15 April and 15 October; rates same as above (0.11 LU/ha in April, 0.11 LU/ha in May and August, and 0.07 LU/ha in September and October)
- Ungrazed

Treatment began in 1995, and follow-up measurements were taken in 1996 and 1997. Todd and others (2000) reported that litter depth was lower with the existing regimen compared with the summer grazing regimen and the no grazing regimen (white site: $F=14.8$; $p<0.01$; grey site: $F=16.2$; $p<0.01$)[6]. Similar results were reported for dry matter yields (all vegetation), with lower dry matter at the grey site under ESA stocking rates compared with the summer grazing regimen and the no grazing regimen ($F=12.5$; $p<0.01$; results not reported for the white site). Notably, there was a significant interaction between grazing and burning, with the highest annual dry matter yields at ungrazed, unburned plots on the Exmoor grey site ($F=35.12$; $p<0.05$). Vegetation was tallest on Exmoor where grazing was excluded. *Calluna* cover was highest at the ungrazed plots in 1995, but it was unclear whether this effect persisted in later years.

This publication sporadically reported the effects of the different grazing regimens, seemingly focusing on significant results. As much of the data on the effects of grazing was unreported, it was difficult to interpret the results with any certainty. Furthermore, the ESA and summer stocking rates were relatively low, which may explain why there were few reported differences between the three regimens.

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[6] Degrees of freedom not reported.

Effect of grazing on distribution of vegetation communities

Section summary

- The evidence on the effect of grazing on distribution of vegetation communities was inconclusive

The prior studies begin to show how different stocking regimens can influence the composition of plant species. Studies further examined the effect of grazing on the distribution of vegetation communities (46, 61).

Rushton and others (1996) conducted a quasi-experimental study to examine the effect of stocking rates on the distribution of four vegetation communities: *Agrostis-Festuca* grassland, *Nardus-Galium* grassland, *Vaccinum-Deschampsia* heath, and *Calluna-Vaccinium* heath (61). The study was conducted between 1989 and 1990 at Pwllpeiran, Wales, and Redesdale, England, the latter of which did not meet the inclusion criteria for the review. Studies at Pwllpeiran consisted of a small plot experiment at Tye Emrys Hill (2 ha) and field experiments at Garn Hill (20 ha). In the small plot experiment, researchers implemented three grazing interventions: ESA, 1.25 ewes/ha (April–October), ESA 30%, 0.83 ewes/ha (April–October), and no grazing. In the field experiment, researchers implemented only the ESA and ESA 30% regimens at the rates described above. At both sites, fixed 1 m x 1 m quadrats were set up (N=15 at the small plot experiment and N=30 at the field experiment for each treatment). The sites were surveyed in 1990 for baseline measurements and again in 1992 and 1994. The change in vegetation between 1990 and 1992 was used to predict changes in 1994 and 2000 using a Markov model.

The small plot experiment showed that between 1990 and 1994 the proportion of quadrats dominated by *Calluna-Vaccinium* heath decreased in the ESA plot (13% vs. 7%) and increased in the ESA 30% (33% vs. 40%) and zero grazing plots (6% vs. 7%; Table 3). The proportion of quadrats dominated by *Vaccinum-Deschampsia* heath decreased to 0% in 1994 in all three plots, while the proportion of *Nardus-Galium* grassland increased in all plots. *Agrostis-Festuca* grassland showed inconsistent trends. There was poor agreement between observed and predicted frequencies in 1994 (Table 3). As the Markov model poorly predicted the 1994 frequencies (just two years after the 1992 survey), it is unlikely that the model will be accurate for the year 2000. It’s also notable that the baseline distribution of vegetation communities was different for the three plots. This may have affected the changes in frequencies between 1990 and 1994, limiting the certainty of comparisons between plots.

Table 3: Change in vegetation communities (percentage of quadrats) at the small plot experiment based on surveys in 1990 and 1994 and Markov predictive models in 1994 and 2000.

	ESA				ESA 30%				No grazing			
	1990	1994	1994 pred.	2000 pred.	1990	1994	1994 pred.	2000 pred.	1990	1994	1994 pred.	2000 pred.
***Agrostis-Festuca*, %**	0	7	0	0	6	0	0	0	20	20	20	20
***Nardus-Galium*, %**	74	87	22	3	27	60	3	0	54	73	53	43
Vaccinum-*Deschampsia*, %	13	0	66	84	34	0	75	90	20	0	13	9
***Calluna-Vaccinium*, %**	13	7	13	13	33	40	21	10	6	7	13	28
Absolute deviation, %	147				147				40			

Abbreviations: ESA, Environmentally Sensitive Area; pred., predicted.

The distribution of vegetation communities in the field-scale experiments was broadly similar between the intervention groups at baseline. Between 1990 and 1994, the proportion of quadrats dominated by *Calluna*-*Vaccinium* remained the same in the ESA plot and increased in the ESA 30% plot, whereas *Vaccinum*-*Deschampsia* decreased to 0% in both plots (Table 4). Total grassland increased in both plots, although the proportion of quadrats dominated by *Agrostis*-*Festuca* grassland decreased. As with the small plot experiment, the Markov model was inaccurate for the field scale experiment, with absolute differences between observed and predicted values in 1994 of 70% for the ESA plot and 30% for the ESA 30% plot (Table 4).

The study provides some evidence that reducing summer stocking rates from 1.25 ewes/ha to 0.83 or 0 ewes/ha may increase the prevalence of *Calluna*-*Vaccinium* heath, although this increase was accompanied by a decrease in the prevalence of *Vaccinum*-*Deschampsia* heath and an increase in grassland. However, the study had notable limitations: the sample size was low for each experiment (N=1 for each intervention), and the baseline distribution of vegetation communities at the small plot experiment differed for each grazing intervention.

Table 4: Change in vegetation communities at the field-scale experiment based on surveys in 1990 and 1994 and Markov predictive models in 1994 and 2000

	ESA				ESA 30%			
	1990	1994	1994 pred.	2000 pred.	1990	1994	1994 pred.	2000 pred.
***Agrostis-Festuca*, %**	13	3	19	22	13	0	3	7
***Nardus-Galium*, %**	20	37	9	3	20	40	25	20
***Vaccinium-Deschampsia*, %**	7	0	19	31	27	0	12	7
***Calluna-Vaccinium*, %**	60	60	53	44	40	60	60	66
Absolute deviation, %	70				30			

Abbreviations: ESA, Environmentally Sensitive Area; pred, predicted.

Hetherington and others (2002) conducted a second quasi-experimental study in Pwllpeiran, Wales, that examined the effect of stocking prescriptions on the distribution of vegetation communities (46). In the study, two farmlets comprising approximately equal areas of improved land and semi-natural land were selected in 1989/1990. Semi-natural land consisted of four plant communities: *Calluna*-*Nardus*, *Nardus*-*Vaccinium*, *Festuca*-*Agrostis*, and *Calluna*-*Eriophorum*. The larger farmlet (153 ha) was prescribed Tier 1A rates, with 1.5 ewes/ha on semi-natural plant communities and an overall stocking rate of 1.94 ewes/ha (semi-natural plus improved land). The smaller farmlet (148 ha) was prescribed tier 2A rates, with 1.0 ewes/ha on semi-natural plant communities and an overall stocking rate of 1.81 ewes/ha.

Hetherington and others (2002) reported that at the Tier 1A farmlet, the composition of *Calluna-Nardus* communities significantly changed between 1990 and 1997 ($F_{4,68}$=4.009; $p<0.01$); there was no significant change in cover of *Calluna* or *Nardus*, but *Vaccinium* declined from 1990 to 1997 ($F_{4,68}$=2.83; $p<0.04$). At the Tier 2A farmlet, there was no significant change in *Calluna-Nardus* communities between 1990 and 1997 (data not shown). The authors did not report significant changes in other vegetation communities. Notably, however, data on changes in vegetation communities were not fully reported.

The studies by Rushton and others (1996) and Hetherington and others (2002) provide initial evidence that vegetation communities change as a result of lower stocking rates, but there was limited evidence to suggest that lower stocking rates improved total dwarf shrub heath cover. *Vaccinium* declined in both studies, but this effect seemed independent of changes in stocking regimens. It was not clear what caused the decline in *Vaccinium*. Due to methodological weaknesses of the studies (e.g., the absence of matched control groups and incomplete reporting of data), it was difficult to attribute changes in the vegetation communities to changes in stocking rates. It is possible that confounding variables played some role in the changing cover of grassland and heath.

Effect of grazing on marsh fritillary *Euphydryas aurinia*

Section summary

- Stocking at 'intermediate' levels can optimise sward height and density of Devil's-bit scabious, *Succisa pratensis (*a host plant), which supports the recovery of *E. aurinia* populations

Smee and others (2011) conducted a study that examined factors associated with the prevalence of the marsh fritillary *E. aurinia* (85). The study examined larval web abundance and adult butterfly abundance at nine sites across the mid-Cornwall moors (including Goss Moor) between 2004 and 2008. Each year, researchers conducted two surveys at the sites: one in spring (late May and June) to survey adult butterflies and one in autumn (late August and September) to survey larval webs. The authors conducted two investigations. The first examined the relationship between habitat variables, including stocking intensity (measured using the percentage of transect points with evidence of stock), and the density of larval webs and adult butterflies. The second examined the effect of management on habitat variables and web and adult butterfly densities. The management measures analysed were:

1) the year grazing started;
2) the number of times a transect area was burnt during the 5 years project; and
3) the number of years since the most recent burning of a transect area.

The first investigation found a significant relationship between stocking intensity and larval web density (single regression: coefficient, 0.0290; x^2_1=3.91; p<0.048), with the greatest abundance of larval webs present under 'intermediate' stocking levels; too high and too low stocking levels were each detrimental to larval web abundance (single regression with quadratic term: coefficient, -0.0004; x^2_1=6.02; p=0.014[7]). The relationship was non-significant in multiple regression (x^2_1=1.60; p<0.21); the authors suggest that stocking at intermediate levels had an indirect effect on larval web abundance by optimising sward height and Devil's-bit scabious, *Succisa pratensis* (host plant), density. The study did not detect a significant relationship between stocking intensity and the density of adult butterflies.

The second investigation found that the only management measure to affect the density of *S. pratensis* (x^2_1=15.29; p=0.033) was grazing; *S. pratensis* density was lowest in areas that hadn't been grazed or had begun grazing recently and greatest in areas that had been grazed for longer. Despite management at the nine surveyed sites, *S. pratensis* density did not significantly increase over the study period (x^2_1=2.83; p=0.09). Additionally, there was a significant decline in both the number of larval webs (coefficient, -0.32; x^2_1=15.42; p<0.001) and adult butterflies (coefficient, -0.19; x^2_1=7.83; p=0.005).

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[7] Quadratic intensity of stock grazing.

Effect of salt blocks on the distribution of grazing animals

Section summary

- There is initial evidence that salt blocks can attract ponies to *Molinia*-dominated areas
- Ponies congregate around salt blocks, reducing sward height, *Molinia* height, and *Molinia* cover and increasing bare ground cover
- This may facilitate good conditions for establishment of more diverse vegetation

Mitchell and others (2008) demonstrated that short-term stocking of large grazing animals can reduce *Nardus* and *Molinia* dominance (55). However, moving grazing livestock deep into areas dominated by *Nardus* or *Molinia* may prove a barrier to successful restoration (52-54).

Lunt and others (2021) conducted a randomised controlled study based in Dartmoor that examined whether Dartmoor ponies could be attracted to *Molinia*-dominated areas using salt blocks attached to a post (N=5) compared with posts without salt blocks (N=5) or control areas without posts or salt blocks (N=3) (51). Sites were randomised to the salt post group or no-salt post group in 2017, and, in 2019, the researchers assigned three control areas. In 2018, an amendment was made to the salt post group due to excessive trampling around the posts. A salt block was randomised to one of the five posts assigned to the salt post group. Every three weeks between March and September, a replacement salt block was randomly assigned to one of the five posts.

The study showed that ponies preferentially grazed around salt posts, significantly increasing bare ground cover ($H_{2,621}$=119; p<0.001) and reducing *Molinia* cover ($H_{2,621}$=67.16; p<0.001), *Molinia* height $F_{2,879}$=25.89 (p<0.001), and sward height ($F_{2,933}$=73.71; p<0.001) compared with no-salt posts and control plots. Sward height was lower at salt-post plots than control plots up to 12 m from the centre of the plot, although sward height was not tested further than 12 m. Ponies tended to graze near posts, and sward height was lower closer to the centre of posts at salt post plots (r_s=0.495; p<0.001) and no-salt post plots (r_s=0.392; p<0.001). The number of *Calluna* seedlings was higher at salt posts compared with no-salt posts and control ($H_{2,10}$=7.91; p≤0.01), but pairwise comparisons were only significant between salt posts and control (p<0.05). Mature *Calluna* plants were significantly healthier[8] at salt posts compared with no-salt posts (t_8=2.4; p=0.042; the study did not compare salt posts with control). Interestingly, bare ground was significantly higher and sward height and *Molinia* cover were significantly lower at no-salt posts compared with control (all p<0.001), indicating that ponies roamed to posts regardless of whether a salt block was present.

[8] Heather plants were categorised as healthy if they had green leaves or in poor condition if >50% of branches were senescent with sparse or discoloured leaves.

Overall, the study provides initial evidence that salt blocks attached to wooden posts can attract ponies to *Molinia*-dominated areas. However, the study had a small sample size and included only 88 ha of moorland. Further experiments on Dartmoor are required to confirm whether ponies preferentially graze at salt posts within *Molinia*-dominated areas when ponies have a wider choice of grassland to graze.

Mixed-method studies (experimental and observational)

The review identified one mixed-method study that reported on the management of livestock (57). The study examined the effect of grazing on woodland habitat condition.

Exclusion fencing

Section summary

- There is some evidence that livestock exclusion can improve establishment of woodland

Exclusion of livestock from areas of new woodland may influence the development of saplings. Murphy and others (2022) tested this hypothesis in a two-phase study: 1) a quasi-experimental phase and 2) an observational phase (57). In the experimental phase of the study, Murphy and others (2022) examined the effect of exclusion fencing on the growth of oak saplings at Dendles Waste, Dartmoor. At the site, trees were planted in groups of eight (a total of 18 groups), with half of the groups protected by fencing. The remaining trees were open to grazing by sheep, ponies, and deer (0.080 LU/ha). The researchers reported that grazing pressure was lower in fenced areas compared with open areas ($p<0.001$). After seven months, survival of saplings was higher in the fenced area by 55%. Saplings in the fenced areas also had significantly greater root ($p<0.001$), shoot ($p<0.001$), and leaf growth ($p<0.001$) compared with open areas.

Murphy and others (2022) collected observational data at locations with extensive grazing (Dartmeet), enclosed grazed pasture (Merivale), and a former ungrazed pasture with four replicate fenced enclosures (Piles Copse). Livestock density was as follows:

- Dartmeet: 0.400 LU/ha summer and 0.170 LU/ha winter by sheep, cattle, and ponies.
- Merrivale: sheep and cattle (LU/ha not reported).
- Piles Copse: 0 inside fenced areas; 0.201 LU/ha summer, 0.012 LU/ha winter in open areas.

Sapling height, adjusted for age, was higher at fenced sites where livestock were excluded compared with enclosed or extensive pasture ($p<0.001$ vs. enclosed and extensive). Saplings at fenced sites also sustained lower browsing damage with age compared with enclosed or extensive pasture ($p<0.001$ vs. enclosed and $p=0.017$ vs. extensive). At Piles Copse, oak density was higher inside fenced areas compared with outside fenced areas ($p=0.028$), particularly for older trees aged 4–7 years or 8–12 years. Notably, the observational study only examined one site for each type of management, making direct comparisons of the regimens difficult.

Overall, the data suggest that livestock exclusion can improve the establishment of woodland.

Observational evidence

While there were limited experimental data on the effect of different stocking rates on habitat condition, there's a wealth of observational data; this section covers data from 25 studies.

The observational studies reported in this section cover the following topics:

- Correlation between stocking rates an dwarf shrub cover (63).
- Effectiveness of ESA Tier 1E and Tier 2B agreements (30, 48, 64).
- Effect stocking rates on habitat condition on Dartmoor (10-12, 14, 16, 18, 19, 22, 23, 33, 34, 36, 45, 58, 59).
- Effect of stocking rates on habitat condition in comparable areas (Exmoor, Bodmin Moor, Lake District) (24-26, 28, 35, 76).

Stocking rates for restoration of condition on Dartmoor

Section summary

- There is some evidence to suggest a correlation between lower stocking rates and higher dwarf shrub cover at heathland sites in south-west England
- However, in many areas of Dartmoor where ESA/HLS agreements have been implemented to reduce maximum monthly stocking levels, grazing pressure on *Calluna* has remained high
- Overall, there has been little success in restoring or achieving meaningful improvements towards favourable condition

Some observational studies have suggested a correlation between stocking rates and dwarf shrub cover. Smallshire and others (1996) examined sustainable grazing practices on moorland in southwest England (63). As part of the study, the researchers reported the relationship between mean monthly stocking levels on dwarf shrub cover at five *Calluna* sites in Dartmoor and four *Calluna* sites in Exmoor. They reported a significant negative correlation between dwarf shrub cover and stocking levels (r^2=71%; p=0.004). This relationship persisted when the researchers examined winter stocking rates (r^2=52%; p<0.029) and summer stocking rates (r^2=51%; p=0.032). There was also a significant correlation between dwarf shrub cover and maximum monthly winter cattle stocking rates (r^2=48%; p=0.041) but not for mean monthly winter cattle stocking rates or mean or maximum monthly summer sheep stocking rates. Smallshire and others (1996) also examined the correlation between dwarf shrub cover and stocking rates on southwestern heath and grassland areas, but the correlations were all non-significant. The study also reported that sites with >50% heather cover were associated with overall stocking levels of >0.3 LU/ha, with >0.13 LU/ha of winter cattle. Authors further stated that stocking rates at 18 sites dominated by dwarf shrubs was 0.29 LU/ha (0.34 LU/ha summer and 0.24 LU/ha winter). As well as examining the correlation between dwarf shrub cover and stocking levels, the study summarised the use of different livestock types on moorland. The researchers present anecdotal evidence that hardy cattle were becoming less frequent on southwest moorland and suggest this may lead to inadequate utilisation of *Molinia*. While the results of this study are largely predictive and should be interpreted with caution, the study provides initial evidence that low dwarf shrub cover at southwest moorland sites correlated with higher stocking rates.

A series of studies on 64 moorland monitoring sites and eight sites in the Forest of Dartmoor conducted between 1994 and 2003 examined the effectiveness of ESA Tier 1E and Tier 2B agreements (30, 48, 64)[9]. The studies reported that overall grazing pressure on *Calluna* increased (grazing index: 42.3% in 1994 and 50.0% in 2003; $p<0.05$) and *Calluna* cover decreased (10.3% in 1994 and 7.7% in 2003; $p<0.05$) over the survey period. Grazing index increased between 1994 and 2003 at Tier 1E sites (41.6% vs. 50.9%) but decreased between 1994 and 2003 at Tier 2B sites (8.7% vs. 2.6%) and non-agreement sites (60.8% vs. 57.6%), although the grazing pressure at non-agreement sites was still high in 2003. All sites saw a reduction in *Calluna* cover between 1994 and 2003, with a greater decrease at the Tier 1E site (13.0% vs. 9.7%) compared with Tier 2B sites (6.6% vs. 6.0%) and the non-agreement sites (1.1% vs. 0.4%). The frequency of other dwarf shrub species did not significantly change. There was little evidence of a difference in *Calluna* recovery between ESA management tiers 1E and 2B, despite – or perhaps because of – initial lower abundance at heath sites that entered the enhancement Tier 2B compared with heaths in maintenance Tier 1E. There was also no significant effect of winter grazing supplements (winter removal of cattle or winter removal of cattle and early imposition of winter stocking levels), although the exclusion of sheep from the sites at the same time as cattle was not trialled. Overall, the study concluded that ESA objectives had been met for most performance indicators, except grazing pressure[10]. The authors noted, however, that most of the performance indicators related to maintenance of condition from what was a degraded baseline – and there was little evidence of enhancement of condition between 1994 and 2003.

There are several landscape-monitoring surveys, including long-term follow-up surveys on Okehampton Common and Ugborough and Harford Moors, that examined the effect of lowering stocking rates on the condition of Dartmoor. Due to their uncontrolled before-and-after design, these studies are not ideal for linking changes in habitat conditions directly to grazing regimens. However, by examining the effects of ESA/HLS schemes across multiple sites, it may be possible to identify broad trends in changes to habitat conditions in response to the implementation of new grazing regimens.

Okehampton Common, Dartmoor

Longitudinal grazing survey reports have been produced on Okehampton Common since 2004 (22, 45, 58, 59). The latest follow-up on Okehampton Common was reported in

[9] Note that ESAs have multiple entry tiers. Landowners receive higher payments for meeting stricter management conditions of the higher tiers.
[10] Performance indicator: ‘grazing pressure is reduced to a level such that the condition and extent of *Calluna* does not decline as a result of suppression’.

2017, using survey data from 2–3 April 2014 (22). The surveys examined whether changes in stocking rates between 2000 and 2012 (Table 5) affected vegetation growth and cover.

Table 5: Stocking rates at Okehampton Common

Period	Average annual stocking rate (LU/ha)	Maximum monthly stocking rate (LU/ha)	Average summer stocking rate (LU/ha)	Average winter stocking rate (LU/ha)
Pre-2000	0.91	1.15 (September)	0.96	0.90
2000–2002 (ECC restrictions)	0.33	0.37 (16 April–30 October)	0.37	0.28
After 2002 (ESA agreement)	0.17	0.28 (16 April–30 October)	0.22	0.11
After 2004 (SWES agreement)	0.13	0.22 (June–July)	0.19	0.08
After 2012 (HLS agreement)	0.11	NR	0.16*	0.07*

Abbreviations: ECC, Environmental Cross Compliance; ESA, Environmentally Sensitive Area; HLS, Higher Level Stewardship; SWES, Sheep Wildlife Enhancement Scheme. *Maximum of 0.08 LU/ha cattle and sheep in summer, 0.05 LU/ha sheep and 0.07 LU/ha cattle in autumn, and 0.05 LU/ha sheep and no cattle in winter.

Despite average stocking rates decreasing, albeit marginally, between 2004 to 2014 (Table 5), the *Calluna* grazing index significantly increased over this time period, from 43.4% in 2004 to 63.2% in 2014 ($F_{3,204}$=4.85; p<0.01) (Table 6). Accordingly, dwarf shrub cover significantly decreased between 2004 and 2014 (9.8% vs. 4.2%; $F_{3,225}$=10.5; p<0.001). This was driven by a decrease in the cover of *Calluna* from 8.5% in 2004 to 2.5% in 2014 ($F_{3,225}$=9.8; p<0.001), whereas bilberry cover increased from 0.2% in 2004 to 4.5% in 2014 ($F_{3,225}$=22.4; p<0.001). *Calluna* height decreased between 2004 and 2014 (11.9 cm vs. 8.2 cm; $F_{3,225}$=22.5; p<0.001), but there was no significant difference in the height of graminoids.

The 2017 publication compared data from 2004 to 2014. However, there are data available from as far back as 1999, which are reported by Nisbet (2004) (58). Nisbet (2004) demonstrated a decrease in *Calluna* grazing index from 64% in 1999 to 43% in 2004, with a significant change between 2002 and 2004 (61% vs. 43%; p=0.05). There was also an increase in mean *Calluna* height, from 9.2 cm in 1999 to 11.9 cm in 2004, which was again significant between 2002 and 2004 (8.0 cm vs. 11.9 cm; p=0.05). Dwarf shrub cover, including *Calluna* cover, did not change significantly between 1999 and 2004.

Overall, the authors concluded that changes to stocking densities required under the agri-environment schemes had not reduced grazing intensity on *Calluna* or promoted *Calluna* growth on the common. Notably, the stock reductions specified by the HLS scheme may not have had time to cause an effect since they were implemented.

Table 6: Data on vegetation height and cover, and *Calluna* grazing index at Okehampton Common reported in the 2014 survey; data are presented as mean (standard deviation [SD])

Outcome	2004	2006	2008	2014	$F_{3,225}$
Dwarf shrub cover, %	9.8 (16.30)	8.2 (16.06)	3.8 (13.09)	4.2 (10.92)	10.5 (p<0.001)
Bilberry cover, %	0.2 (0.46)	0.2 (0.55)	0.5 (1.15)	4.5 (9.73)	22.4 (p<0.001)
***Calluna* cover, %**	8.5 (15.88)	7.3 (14.99)	1.6 (6.63)	2.5 (7.26)	9.8 (p<0.001)
Bilberry height, cm	NR	7.5 (4.98)	NR	8.8 (5.01)	22.5 (p<0.001)
***Calluna* height, cm**	11.9 (9.06)	11.1 (4.99)	6.4 (6.54)	8.2 (4.08)	22.5 (p<0.001)
Graminoid height, cm	8.0 (4.00)	7.7 (4.44)	6.8 (3.71)	6.0 (3.33)	2.2 (non-significant)
Mean *Calluna* grazing index	43.3 (28.98)	47.3 (29.32)	64.0 (31.51)	63.2 (36.17)	4.85 (p<0.01)

Ugborough and Harford Moors, Dartmoor

Longitudinal grazing survey reports have also been produced on Ugborough and Harford Moors since 2004 (10, 23, 33, 34). The latest follow-up on the Ugborough and Harford Moors was reported in 2017, using survey data from 31 March–1 April 2014 (23). Like the 2017 Okehampton report, the Ugborough and Harford Moors study examined whether changes in stocking rates from before 1998 to 2010 (Table 7) affected vegetation growth and cover.

Table 7: Stocking rates at Ugborough and Harford Moors

Period	Average summer stocking rate (LU/ha)	Average winter stocking rate (LU/ha)
Pre-1998	0.490	0.439
1999/2000 (ESA agreement)	0.258	0.143
2001 (ESA agreement)	0.258	0.158
After 2010 (HLS agreement)	0.3	0.17

Grazing intensity on *Calluna* significantly increased between surveys, with a grazing index of 44.1% in 2004 and 77.9% in 2014 ($F_{2,86}=7.17$; $p<0.01$) (Table 8). There was a non-significant decline in the cover of *Calluna* between 2004 and 2014 (1.4% vs. 0.8%; $F_{286}=0.7$). Despite this, dwarf shrub cover had a net increase from 3.5% in 2004 to 11.4% in 2014 ($F_{2,86}=5.0$; $p<0.01$), which was driven by a significant increase in the cover of bilberry (0.6% vs. 5.3%; $F_{2,86}=9.6$; $p<0.001$). *Calluna* height increased from 11.6 cm in 2004 to 15.8 cm in 2007, but it declined to 13.7 cm in 2014 ($F_{2,86}=3.1$; $p<0.001$). Graminoid height decreased between 2004 and 2014 ($F_{2,86}=6.2$; $p<0.01$).

The 2002 survey of the Ugborough and Harford Moors showed that dwarf shrub condition declined between 1999 and 2002, despite a reduction in stocking levels in the same period (33). *Calluna* grazing index reduced between 1998 and 2002 but remained high at 61% in 2002 (down from 75% in 1998). Dwarf shrub cover decreased from 14.2% in 1998 to 4.6% in 2002 (6.1% at the points sampled in both 1998 and 2002). Similarly, *Calluna* cover decreased from 7.4% to 1.4% (2.0% at points sampled in 1998 and 2002) between 1998 and 2002.

The authors concluded that consecutive agri-environment scheme agreements caused limited improvement in the condition of the vegetation, with grazing pressure remaining high after reductions in stocking rates. The authors noted that grazing intensity on *Calluna* may have been higher in 2014 due to increases in stocking rates, but it is also possible that the distribution of *Calluna*, which was fragmented among patches of palatable grass, may have had a role. The authors also suggested that even under optimum grazing intensity, full recovery of the vegetation is only likely in the long term, due to the degraded condition of the heath and bog in part reflecting historically high stocking levels.

Table 8: Data on vegetation height and cover, and *Calluna* grazing index at the Ugborough and Harford Moors reported in the 2014 survey; data are presented as mean (SD)

Outcome	2004	2007	2014	$F_{2,86}$
Dwarf shrub cover, %	3.5 (10.15)	4.9 (15.67)	11.4 (22.51)	5.0 ($p<0.01$)
Bilberry cover, %	0.6 (1.75)	2.4 (9.26)	5.3 (11.61)	9.6 ($p<0.001$)
***Calluna* cover, %**	1.4 (6.16)	0.9 (4.91)	0.8 (2.67)	0.7 (non-significant)
***Calluna* height, cm**	11.6 (6.21)	15.8 (8.20)	13.7 (7.42)	3.1 ($p<0.05$)
Graminoid height, cm	9.0 (4.04)	9.8 (6.01)	7.0 (6.09)	6.3 ($p<0.01$)
Mean *Calluna* grazing index	44.1 (25.34)	56.4 (29.62)	77.9 (29.24)	7.17 ($p<0.01$)

Data from other sites on Dartmoor

Studies on Chagford Common, Mary Tavy Common, Peter Tavy Great Common, Whitchurch Common, Wigford Down had similar results; reductions in stocking rates in the early 2000s resulted in lower – but still high – *Calluna* grazing intensity and limited improvement or decline in dwarf shrub and *Calluna* cover after consecutive agri-environment agreements (11, 12, 14, 16, 18, 19, 36). These sites had a poor starting condition, with low cover of dwarf shrubs, which may have contributed to the weak recovery.

Stocking rates for restoration of condition at comparable areas

Section summary

- Lowering summer stocking rates (<0.32 LU/ha) and eliminating winter stocking of sheep and cattle reduced grazing intensity and improved vegetation condition at several sites on Exmoor, Bodmin Moor, and the Lake District
- Given that reducing summer stocking rates to <0.32 LU/ha in Dartmoor had limited effect, improvements in condition at comparable areas may be attributed to a combination of reducing summer grazing and reducing or eliminating winter grazing

Note: these findings are based on uncontrolled observational studies with a before-and-after design, and uncontrolled covariates may have influenced the results

While efforts to reduce grazing pressure and improve dwarf shrub cover have had limited success on Dartmoor, there are several cases from other regions in southwest England where reducing stocking improved the condition of vegetation. Note that case studies discussed in this section use the same study design as the landscape-monitoring surveys discussed in the prior section and are subject to the same limitations.

Winsford Allotment, Exmoor

Agri-environment schemes have contributed to habitat recovery on the Winsford Allotment, Exmoor (28, 35). After the introduction of Environmentally Sensitive Area (ESA) agreements in 1993, summer stocking rates on the Winsford Allotment reduced considerably and winter stocking was eliminated (Table 9) (35).

Table 9: Stocking rates at Winsford Allotment

Period	Average summer stocking rate (LU/ha)			Average winter stocking rate (LU/ha)		
	Cattle	Sheep	Total	Cattle	Sheep	Total
1992/1993 (pre-ESA)	0.027	0.305	0.332	0.362	0.316	0.678
1995/1996 (ESA)	0.000	0.105	0.105	0.000	0.000	0.000
2002/2003 (ESA)	0.000	0.105	0.105	0.000	0.000	0.000
2010 (HLS)	NR	NR	0.09–0.15*	0.000	0.000	0.000

*Both sheep and cattle.

One publication reported on vegetation condition after a survey in April 2003 (35). Mean *Calluna* grazing index reduced from 88.2% in 1993 to 14.2% in 1996 and 10.0% in 2003, and *Calluna* cover improved from 5.0% in 1993 to 8.4% in 1996 and 29.4% in 2003. Mean dwarf shrub height also improved between 1993 and 2003 (5.0 cm–23.1 cm) (Table 10) (35). Over the same period, the vegetation type on the Winsford Allotment changed from grassland-dominated (rough acid grassland, 73%; bent-fescue grassland, 16%; *Calluna*/wet heath, 8%) to a wet heath-dominated (rough acid grassland, 18%; bent-fescue grassland, 21%; *Calluna*/wet heath, 50%).

The authors concluded that heath restoration was achieved under an Exmoor ESA Tier 2 agreement and that the Tier 2 moorland performance indicators had been met on the Winsford Allotment. However, they cautioned that even with good early regeneration, heath recovery at the site takes time (43% *Calluna* cover after 10 years) and some agri-environment schemes at the time were over-ambitious with their goals (e.g. 40–50% cover after 5 years).

Table 10: Data on vegetation height and cover, and *Calluna* grazing index at the Winsford Allotment reported in the 2003 survey

Outcome	1993	1996	2003
Dwarf shrub cover, %	NR	NR	31.2
Dwarf shrub height, cm	5.0	8.0	23.1
***Calluna* cover, %**	5.0	8.4	29.4
***Calluna*/wet heath, %**	8	NR	50
Bent-fescue grassland, %	16	NR	21
Rough acid grassland, %	73	NR	18
Bracken, %	1	NR	7
Western heath, %	1	NR	2
Other (scrub), %	1	NR	2
Mean *Calluna* grazing index	88.2	14.2	10.0

Abbreviations: NR, not reported.

A follow-up survey of the Winsford Allotment was conducted on 8–9 April 2014. However, the 2014 survey used a different sampling regimen to the earlier surveys, making a direct analysis of change difficult (28). That said, the study drew some general comparisons. The grazing index was 23.2% overall, 14.0% in *Calluna* heath, and 17.4% in fragmented heath, which was higher than the 2003 value of 10%. *Calluna* cover was 35% in *Calluna* heath and fragmented heath in 2014, and mean dwarf shrub height was 24 cm in fragmented heath and 48 cm in *Calluna* heath. Mean bracken cover was 27% in 2014, which compared with 7% in 2003. Notably, the mean proportion of land classed as bent-fescue grassland or rough acid grassland decreased from 2003 to 2014 (39% vs. 14%).

The authors concluded that the initial improvement in the condition and extent of *Calluna* caused by initiation of the ESA agreements in 1993 had been maintained during the transition to HLS agreements in 2010, although there was not a notable increase in *Calluna* since 2003 and restoration to the full complement of dry heath indicator species across the site is likely to take much longer. Adaptive management of moorland may have been suitable in this case (e.g., introducing bracken cutting when cover started to rise beyond desirable levels).

Dozmary Downs, Bodmin Moor

Vegetation condition on Dozmary Downs in Bodmin Moor also improved after stocking rates were reduced between 2003 and 2011 (Table 11) (24).

Table 11: Stocking rates at Dozmary Downs

Period	Average summer stocking rate (LU/ha)	Average winter stocking rate (LU/ha)
2003	0.7 (16 April–July)	0.3 (December–15 April)*
2005	0.7 (16 April–31 August) and 0.5 (September–October)	0.3 (1 November–15 April)
2011 (HLS agreement)	0.32 (February–September)	0.00 (unless permitted by Natural England)

*Stocking rates unclear from August to November.

The latest follow-up on the Dozmary Downs was reported in 2017, using survey data from 25–26 March 2014 (24). *Calluna* grazing index reduced from 31.4% to 11.2% in 2014 (Table 12); the number of heavily grazed features also decreased (x^2=106.8; p<0.001). This was accompanied by a significant improvement in dwarf shrub cover between 2004 and 2014 (2.7% vs. 7.5%; $F_{3,161}$=12.0; p<0.001), driven by an uplift in *Calluna* cover from 2.3% in 2004 to 5.8% in 2014 ($F_{3,161}$=12.3; p<0.001). Bilberry cover did not improve, but this is likely because the existing seed bank was insufficient (0% bilberry cover in both surveys). *Calluna* height increased from 9.0 cm in 2004 to 10.3 cm in 2014 ($F_{3,161}$=14.7; p<0.001), as did graminoid height ($F_{3,161}$=8.1; p<0.001).

The authors concluded that reductions in stocking levels had been successful in improving dwarf shrub height and cover. However, they noted that the dry heath is still predominantly fragmented, and much longer timescales will be needed to allow recovery of indicator species and *Calluna* heath vegetation type.

Notably, while summer stocking rates reduced from 2003 levels, the rate in 2011 was still relatively high and was comparable to summer rates at Ugborough and Harford Common, which saw a decline in dwarf shrub cover between 2004 and 2014. While this may be explained by site-specific variables, it is also possible that the success at Dozmary Downs was partially attributable to exclusion of livestock between October and February. During this time, vegetation growth is slow, palatability of grasses decreases, and sheep selectively graze on heather (29). Reducing stocking rates in winter may have allowed *Calluna* to recover while it was most vulnerable to grazing.

Table 12: Data on vegetation height and cover, and *Calluna* grazing index at Dozmary Downs reported in the 2014 survey; data are presented as mean (SD)

Outcome	2004	2005	2006	2014	$F_{3,161}$
Dwarf shrub cover, %	2.7 (5.35)	2.8 (5.00)	2.4 (4.9)	7.5 (11.16)	12.0 ($p<0.001$)
Bilberry cover, %	0.0 (0.00)	0.0 (0.16)	0.0 (0.07)	0.0 (0.31)	1.7 (non-significant)
***Calluna* cover, %**	2.3 (4.38)	1.3 (2.14)	2.1 (4.65)	5.8 (8.81)	12.3 ($p<0.001$)
***Calluna* height, cm**	9.0 (16.90)	8.0 (15.27)	5.0 (2.95)	10.3 (3.64)	14.7 ($p<0.001$)
Graminoid height, cm	5.6 (2.20)	5.3 (1.79)	4.5 (1.81)	6.8 (2.75)	8.1 ($p<0.001$)
Number of heavily-grazed features, n/N	31/35 (1.88)	34/36 (1.37)	33/36 (1.66)	6/58 (2.32)	X^2=106.8 ($p<0.001$)
Mean *Calluna* grazing index	31.4 (32.58)	38.2 (24.44)	NR	11.2 (14.62)	17.77 ($p<0.001$)

Birkbeck Commons, Lake District

The results of the Dozmary Downs surveys were echoed at Birkbeck Common in the Lake District (25). Stocking rates reduced at Birkbeck Common in 2001 and again in 2010 (Table 13).

Table 13: Stocking levels at Birkbeck Commons

Period	Average annual stocking rate	Average summer stocking rate	Average winter stocking rate
1998	3.2 sheep/ha, 0.17 cattle/ha, 0.05 equines/ha	NR	NR

Period	Average annual stocking rate	Average summer stocking rate	Average winter stocking rate
2001 (ESA agreement)*	NR**	1.5 sheep/ha (0.225 LU/ha) plus followers	25% reduction compared with summer rates
2010 (HLS agreement)	NR**	1.3 sheep/ha or 0.104 LU/ha; up to 7 ponies from May to October	No sheep grazing from November to March; up to 25 ponies from November to April

*12 of 15 commoners agreed to the 2001 ESA

**Cattle stocking rates were not reported from 2001 onwards

The latest survey on Birkbeck Common was carried out on 18–27 February 2015 (25). The reduction in stocking rates resulted in a lower *Calluna* grazing index from 2004 to 2015 (48.1 vs. 19.4; $F_{4,194}$=5.79; p<0.001), as well as fewer heavily grazed features (X^2=27.0; p<0.001) (Table 14). *Calluna* cover significantly increased from 9.0% in 2004 to 13.7% in 2014 ($F_{4,194}$=5.8; p<0.001). *Calluna* height also significantly increased between 2004 and 2015 (17.3 cm vs. 24.9 cm; $F_{4,194}$=5.5; p<0.001), as did graminoid height ($F_{4,194}$=8.4; p<0.001). Dwarf shrub cover increased between 2004 and 2015, but not significantly (12.2% vs. 16.8%; $F_{4,194}$=1.8).

Notably, all vegetation growth and cover metrics improved between 2009 and 2015, after the HLS agreements excluded winter grazing, with *Calluna* cover improving from 10.7% in 2009 to 13.7% in 2015 and *Calluna* height increasing from 19.1 cm in 2009 to 24.9 cm in 2015. However, it was unclear whether exclusion of winter grazing was the main factor driving growth from 2009 to 2015, as summer stocking rates also decreased as part of the HLS agreement.

The authors concluded that the reduction in stocking levels under the ESA and subsequent HLS agreements, along with cessation of winter grazing under HLS, reduced the grazing intensity on *Calluna* and other vegetation and contributed to heathland recovery.

Table 14: Data on vegetation height and cover, and *Calluna* grazing index at Birkbeck Commons reported in the 2015 survey; data are presented as mean (SD)

Outcome	2004	2005	2006	2009	2015	$F_{4,159}$
Dwarf shrub cover, %	12.2 (24.75)	12.0 (22.31)	15.7 (25.48)	16.0 (24.71)	16.8 (27.15)	1.8 (non-significant)
Bilberry cover, %	0.6 (0.62)	0.6 (0.68)	0.9 (0.54)	0.1 (0.79)	0.9 (0.39)	0.4 (non-significant)

Outcome	2004	2005	2006	2009	2015	$F_{4,159}$
***Calluna* cover, %**	9.0 (22.87)	6.0 (17.75)	10.7 (23.58)	10.7 (22.93)	13.7 (26.69)	5.8 ($p<0.001$)
***Calluna* height, cm**	17.3 (9.28)	14.1 (8.77)	15.0 (9.96)	19.1 (11.27)	24.9 (11.10)	5.5 ($p<0.001$)
Graminoid height, cm	11.0 (5.35)	12.3 (8.03)	8.3 (4.29)	11.9 (10.92)	14.2 (5.87)	8.4 ($p<0.001$)
Number of heavily-grazed features, n/N	20/24 (1.83)	NR	26/48 (3.45)	23/46 (3.39)	5/33 (2.06)	$x^2=27.0$ ($p<0.001$)
Mean *Calluna* grazing index*	48.1 (34.68)	39.4 (27.02)	28.6 (35.53)	20.3 (27.19)	19.4 (13.94)	5.79 ($p<0.001$)

*Grazing index was 38% between 1995 and 1999 and 64% in 2000

Manor & Trehudreth Common, Bodmin Moor

At Manor & Trehudreth Common in Bodmin Moor, stocking rates reduced between 2000 and 2003, but rates raised again in 2010 after entry into a HLS scheme (Table 15) (26).

Table 15: Stocking rates at Manor & Trehudreth Common

Period	Average summer stocking rate (LU/ha)	Average winter stocking rate (LU/ha)
2000	0.42 (16 April–15 July) and 0.23 (16 July–30 September)*	0.17 (1 October–15 April)**
2003	0.17 (excluding ponies; 16 April–31 August)*	0 (1 September–15 April)
2005/6 (amendment to 2003 levels)	No change	0.17 cattle in September
2010	0.05 sheep, 0.2 cattle, 0.06 ponies	0.03 sheep, 0.1 cattle, 0.06 ponies

*Cattle and sheep
**Rates frequently exceeded.

The latest survey on Manor & Trehudreth Common was conducted on 27 and 28 March 2014. Mean *Calluna* grazing index reduced between 2005 and 2007, but grazing index increased again in 2014, possibly in response to higher stocking rates in 2010 (33.5 vs.

29.1 vs. 54.9; $F_{2,124}$=6.79; p<0.01) (Table 6). *Calluna* height increased from 9.2 cm in 2005 to 11.9 cm in 2007 and then reduced to 9.9 cm in 2014 ($F_{2,124}$=6.2; p<0.01), which is consistent with the changes in grazing pressure. However, graminoid height reduced consistently between the three survey periods ($F_{2,124}$=26.3; p<0.001), while dwarf shrub cover ($F_{2,124}$=12.3; p<0.001) and *Calluna* cover ($F_{2,124}$=5.9; p<0.01) increase between surveys. The increase in dwarf shrub cover was driven by an increase in western gorse, which had coverage of <0.5% in 2005, 0.8% in 2007, and 9.2% in 2014.

The data suggest that there has been some improvement in condition since 2005, but it remains to be seen whether the increase in *Calluna* grazing index after introduction of the 2010 HLS regimen will affect condition.

Table 16: Data on vegetation height and cover, and *Calluna* grazing index at Manor & Trehudreth Common reported in the 2014 survey; data are presented as mean (SD)

Outcome	2005	2007	2014	$F_{2,124}$
Dwarf shrub cover, %	2.1 (3.39)	3.2 (5.40)	11.7 (20.75)	12.3 (p<0.001)
Bilberry cover, %	0.1 (0.33)	0.1 (0.23)	0.0 (0.14)	0.8 (non-significant)
***Calluna* cover, %**	1.0 (1.79)	2.0 (4.09)	2.4 (6.07)	5.9 (p<0.01)
Western gorse cover, %	<0.5	0.8	9.2	NR
Bare ground cover, %	0.7 (3.79)	0.1 (1.06)	0.9 (3.89)	2.0 (non-significant)
***Calluna* height, cm**	9.2 (5.13)	11.9 (4.92)	9.9 (10.39)	6.2 (p<0.01)
Graminoid height, cm	9.1 (5.68)	8.9 (4.41)	5.7 (3.49)	26.3 (p<0.001)
Number of heavily-grazed features, n/N	27/48 (3.44)	17/41 (3.15)	29/39 (2.73)	8.8 (p<0.05)
Mean *Calluna* grazing index	33.5 (31.63)	29.1 (27.20)	54.9 (32.32)	6.79 (p<0.01)

Abbreviations: NR, not reported.

Armboth Fell, Lake District

Young and others (2014) conducted a cross-sectional analysis of Armboth Fell in 2001 and examined whether stocking rates affected habitat condition (76). Armboth fell is a 'plateau-like' area in the Lake District, with blanket bog on flatter areas, shallow peat on gentle slopes, and stony loam on valley sides. The study identified four land units on Armboth fell, which were designated G1–G4. The authors state that stocking rates were lowest at G1 and highest at G4 but then reported that stocking rates were 0.74 ewes/ha for G1, 0.66 ewes/ha for G2 and G3, and 1.04 ewes/ha for G4; given the contradiction, it's probable that one or more of these values is incorrect.

The cover of dwarf shrub heath was significantly higher in G1 (72%) than in G2 (44.3%), G3 (20.2%), or G4 (15.2%; χ^2_{df3}= 12.22; p<0.01). Meanwhile, cover of grassland or degraded wet heath was lowest in G1 (24.78%) followed by G2 (53.69%), G3 (76.2%), and G4 (81.17%). The authors conclude that areas with low grazing pressure had higher cover of dwarf shrub heath compared with areas with high grazing pressure. It should be noted, however, that these conclusions were based on a cross-sectional analysis of the study area. Longitudinal data would have provided a better understanding of the relationship between stocking levels and dwarf shrub condition.

Other data

Longitudinal surveys were conducted on Molland Moor between 1993 and 2014; however, the surveys used different sampling methods, which made it difficult to detect changes over time (27).

Most of the data covered in this section were derived from grey literature databases. These databases had limited search functions, which made it difficult to systematically search for relevant data. It is possible that there is relevant grey literature on comparable sites that wasn't included in the review.

Rewetting peatland

Section summary

- Evidence from Dartmoor and Exmoor suggests that blocking drainage channels raises the water table of the surrounding peatland
- Results on the effect of blocking drainage channels were inconclusive:
    - Large-scale studies on Dartmoor and Exmoor show recovery of native mire species and lower prevalence of *Molinia* (sometimes an indicator of degraded peatland habitat when present with high cover) after blocking drainage channels, but these studies had no control comparison, and cannot demonstrate the effect was due to the altered drainage
    - Controlled studies on Dartmoor and Exmoor found no effects of drainage blocking on plant communities after seven years
- Initial evidence from Exmoor showed no increase in bog asphodel after rewetting peatland

This review identified five studies that reported the effect of rewetting on the condition of peatland on Dartmoor and comparable areas. The studies reported in this section cover the following topics:

- Effect of blocking drainage channels on water levels, recovery of key indicator species, and cover of *Molinia* (31, 39, 41, 79).
- Effect of raised water levels on the prevalence of bog asphodel (31, 44).

Studies without a control group

In 2019, Carless and others estimated that 2900 ha (9.2%) of peat on Dartmoor was significantly damaged or degraded by peat cutting or formation of drainage ditches, erosional gullies, or bare peat (31, 90). Most of the remaining peat was functionally degraded, and Luscombe and others (2017) estimated that only 3.6 km^2 (0.8%) of blanket bog was functionally intact (31, 91). Several research groups have blocked drainage channels in an attempt to restore the hydrological condition of peatland (31, 39, 41).

The main aim of blocking drainage channels is to prevent drainage and raise the water table of the surrounding peatland. On Dartmoor, Brazier and others (2020) have blocked drainage channels as part of the Mires on the Moors project since 2010. The project used blocks made from peat, wood, stone, or bales to fill in dendritic erosional features, erosional gullies, and ditches over an area of 180 ha (31). Before and after data from the project showed that restoration increased average water table depths by 2.45 cm and maximum water table drawdown by 7.3 cm. The project also blocked drainage channels on Exmoor (i.e., 2,603 ha of shallow peat). Water tables were statistically similar before and after restoration, although the researchers note that rainfall was lower post-intervention.

A key objective of raising water levels on Dartmoor's peatland is to restore native mire species and reduce prevalence of *Molinia*. Researchers from the Mires On The Moors project observed an increase in mire species, including cottongrass *Eriophorum* spp and

Sphagnum, three years after restoration on Dartmoor (data not shown) (31). The researchers also observed an increase in snipe and dunlin following restoration. There were limited data on change in *Molinia* cover on Dartmoor. However, on Exmoor, the cover of *Molinia* did not decline until 11 years after restoration.

While raising water levels may have a positive effect on the prevalence of some desirable species, there is concern among some stakeholders that the prevalence of bog asphodel *Narthecium ossifragum*, which is toxic to lambs and calves, may increase following restoration of peatland (31). Evidence from the Mires on the Moors project showed that on Exmoor, bog asphodel did not spread following restoration (31). Furthermore, Hand and others (2022) examined 43 sites on Exmoor 2–11 years after restoration of drainage ditches and showed that frequency and cover of bog asphodel were similar before and after restoration (44).

Studies with a control group

Most data from the Mires on the Moors project and Hand and others (2022) are based on an uncontrolled, before-and-after study design. The results may have been affected by covariates and there is low certainty that blocking drainage channels directly caused the benefits reported by the studies. However, the review identified three studies based at Dartmoor and Exmoor that compared restored sites with unrestored sites (39, 41, 79).

Gatis and others (2020) conducted a quasi-experimental study that compared four matched pairs of sites (N=8) at Aclands and Spooners, Exmoor (41). In each pair, one site was blocked with peat dams and one site remained unrestored. The researchers reported that restoration caused a small but significant increase in the water table depth compared with control ($F_{2.12}$=5.927; p=0.009). Despite the increase in water table depth, the change in Ellenberg's moisture indicator value between 2012 and 2018 did not significantly differ between the two interventions (p=0.812; Table 17). Similarly, change in *Molinia* cover (p=0.546), cover of non-*Molinia* species (p=0.580), species richness (p=0.350), and annual net primary productivity (p=0.901) between 2012 and 2018 did not significantly differ between the two interventions. The cover of non-*Molinia* species increased between 2012 and 2018, but the effect was consistent between the two groups. The authors of the study suggest that the results raise doubt over the ability of ditch blocking to disrupt *Molinia* dominance and improve species richness on degraded land – at least in the short-to-medium term.

Table 17: Change in condition of restored and control sites between 2012 and 2018

Outcome	2012		2018		P value*
	Control	Restored	Control	Restored	
Ellenberg's moisture indicator value	8.0	7.9	7.9	7.7	0.812
***Molinia* coverage, %**	85	72	85	75	0.546

Outcome	2012		2018		P value*
	Control	Restored	Control	Restored	
Cover of non-*Molinia* species, %	7	6	33	24	0.580
Species richness	2.9	2.4	3.2	3.8	0.350
Annual net primary productivity, g/m^2	290	338	515	586	0.901

*P value for repeated measures ANOVA or paired Wilcoxon signed rank test for Ellenberg's moisture indicator value

Fitz-Gerald (2020) provides further evidence in a retrospective analysis of peatland restoration on Blackabrook Down, Dartmoor (79). Researchers examined a site restored by blocking ditches and gullies with timber or peat dams. This was compared with a control site located directly next to the blocked site. Of note, due to the proximity of the sites, it is possible that ditch blocking had some effect on the control site, as well as the experimental site. Vegetation records for both sites were analysed from 2009 to 2016.

The restored site had more standing water than the unrestored site throughout the study. Cover of desirable species, such as *Calluna* and the bryophytes *Hypnum cupressiforme* and *Sphagnum papillosum*, increased on both sites between 2009 and 2016 (Table 18). Notably, *S.* papillosum increased by 101% on the restored site and 7% on the unrestored site. However, the bryophytes *Dicranium scoparium* and *Sphagnum capillifolium ssp. rubellum* decreased on both sites.

Table 18: Number of quadrants (1/4 of a quadrat) in which a species/variable is present (total number of quadrats/quadrants was unclear)

Species / variable	Restored		Unrestored	
	2009	2016	2009	2016
Standing water	45	16	1	1
Calluna vulgaris	19	233	3	281
Erica tetralix	298	307	306	340
Molinia caerulea	357	380	355	384
Trichophorum (Scirpus) cespitosum	298	293	342	363
Juncus squarrosus	129	112	210	173

Species / variable	Restored		Unrestored	
	2009	2016	2009	2016
Eriophorum angustifolium	321	335	365	271
Dicranium scoparium	110	49	76	20
Hypnum cupressiforme	178	187	233	290
Sphagnum capillifolium ssp. rubellum	129	97	184	140
Sphagnum papillosum	89	179	125	134

The findings reported by Gatis and others (2020) and Fitz-Gerald (2020) were corroborated by Freeman (2017) who conducted a survey of blocked and unblocked sites at Aclands and Spooners, Exmoor, between Autumn 2012 and Autumn 2015 (39). The survey showed no significant differences in sward quality between restored and unrestored sites (data not shown).

Targeted burning

Section summary

- There was limited evidence on the effects of burning, and the findings are largely inconclusive
- Studies examined whether burning could provide a suitable breeding habitat for fritillary butterflies
    - There was initial evidence that burning can facilitate recovery of *Melitaea athalia*
    - There was no evidence of a relationship between burning and *Euphydryas aurinia* larval web abundance
    - Both findings were based on weak evidence
- There was some evidence to suggest that targeted burning can reduce litter depth and dry matter yield at sites dominated by *Molinia*, but there was no evidence that burning affected cover of *Molinia* in the short term (up to two years); the long-term effects of burning on *Molinia* cover were not clear
- The review didn't identify enough academic or grey literature to determine the effect of burning on different habitats

The review identified five studies that reported benefits and disbenefits of burning on Dartmoor and comparable areas. The studies reported in this section cover the effect of burning on the following:

- Populations of Heath Fritillary *Melitaea athalia* (69).
- Abundance of Marsh Fritillary *Euphydryas aurinia* larval webs (50).
- Cover of *Molinia*, litter depth, and dry matter yield (68).
- Habitat condition (25, 27).

Land managers carry out swaling (targeted burning) in heathland and grass-moorland on Dartmoor to manage vegetation structure by removing mature plants (e.g., *Calluna,* gorse, or *Molinia*) (92, 93). This management aims to open the ground for seed germination; encourage growth of young, productive vegetation; and prevent wildfires (92, 93).

Burning may also create suitable breeding grounds for fritillary butterflies. As part of a survey study on the population of Heath Fritillary *M. athalia*, Warren and others (1991) retrospectively examined the effect of controlled burning on butterfly populations at three sites in Exmoor (69). The researchers reported that burning one full breeding habitat in March 1982 resulted in the immediate extinction of *M. athalia* at that site. However, butterflies returned to the habitat the year after burning and were more prevalent in 1989 (5,500 butterflies at peak flight), seven years after burning, compared with the 1980 baseline (280 butterflies at peak flight). The researchers also reported that a partial burn of two breeding sites in March or April 1988 did not adversely affect *M. athalia* numbers, with butterflies returning to the burnt area from nearby unburnt areas soon after (data not shown). Long-term follow-up data were not available for the partially burnt sites. This study provides initial evidence that limited burning can provide a suitable breeding habitat for *M. athalia.* However, as the study did not include matched control groups, it is difficult to confirm a causal link between burning and rising butterfly numbers. Indeed, the population of butterflies at the partial-burn sites increased in the years before burning (approx. 1985–1988), indicating that uncontrolled variables may have played a role in *M. athalia* population growth.

In a second study, Lewis and others (1997) examined the effect of management (including burning, grazing, cutting/mowing, and no management) on Marsh Fritillary *E. aurinia* larval web abundance at 34 sites in Glamorgan, South Wales (50). Surveys were carried out to identify management regimens on each site and the abundance of larval webs. Researchers found eight sites that had been burned across 50% of the area (the remaining sites were either unmanaged, grazed, or cut). However, they did not find a significant relationship between management and population size ($F_{3,26}=1.65$; $p=0.202$).

Burning may play a role in managing *Molinia* leaf litter. Todd and others (2000) examined whether *Molinia* could be controlled on moorland at three locations: Exmoor, the North Peak, and the Yorkshire Dales (the latter two sites did not meet the inclusion criteria for the review) (68). The study was conducted at two sites on Exmoor: a ‘white’ moorland site dominated by *Molinia* and a ‘grey’ moorland site with a mixture of *Molinia*, *Calluna*, and *Vaccinium*. Treatments were assigned to the white and grey sites using a randomised split-block design, with burning as the main treatment, grazing the first sub-treatment, and herbicide use as the second sub-treatment. Burning was carried out in March 1995 and was contrasted with an adjacent unburned area at each site. Burning reduced litter depth on the Exmoor white site in August 1997 compared with unburned areas ($F=213.6$; $p<0.05$), but there was no significant effect at the grey site or at other times. Burning reduced annual dry matter yield at the Exmoor white site, but there was no effect on the Exmoor grey site (data not shown). There was, however, a significant interaction between burning and grazing at the grey site ($F=35.12$; $p<0.05$), with the highest dry matter yields at plots that were unburned and ungrazed. Burning did not have a significant effect on *Molinia* cover in 1997 at either of the Exmoor sites. Todd and others (2000) sporadically reported the effects of burning, focusing on significant results. As much of the data on the effects of burning were unreported, it was difficult to interpret the results with any certainty. However, burning once in 1995 appeared to have a limited effect on *Molinia* cover in 1997. Notably, as burning was only conducted once in this study, it’s not possible to determine the long-term effects of repeated burns on *Molinia* cover.

The two remaining studies were moorland habitat monitoring studies that examined burning restrictions alongside grazing interventions (reduced stocking rates). As the studies were uncontrolled, it was impossible to distinguish the effect of burning from the effect of stocking rate reductions and other confounding variables (25, 27). However, on Molland Moor, Exmoor, and Birkbeck Commons, Lake District, researchers reported that controlled burning of small, non-sensitive areas of moorland did not appear to have a significant impact on habitat condition.

Cutting or chemical control of bracken

Section summary

- There was strong evidence that twice-yearly cutting, chemical control, or a combination of both can reduce bracken biomass and density in subsequent years compared with taking no action
- Asulam was consistently reported to be effective at reducing bracken biomass
- Initial evidence suggests that bracken control on areas formerly occupied by *M. athalia* promoted the growth of the host plant cow-wheat, creating appropriate conditions for recovery of the fritillary butterfly

The review identified six publications on five studies that reported on cutting or chemical control of bracken (60, 70, 71, 78, 84, 86). The studies examined the effect of bracken control on the following:

- Bracken growth, biomass, density, etc (60, 70, 71, 78, 84).
- Recovery of heath fritillary butterflies (78, 84, 86).

Bracken is a competitive plant that can become dominant if left unchecked (60). In areas where bracken is outcompeting key species (e.g., dwarf shrubs on heathland or cow-wheat, *Melampyrum pratense,* on land hosting colonies of fritillary butterflies), bracken management may be desirable.

Paterson and others (1997) conducted a randomised controlled trial that examined the effect of cutting and chemical control on the growth of bracken in the UK (60). The study covered six locations, but only Devon and the Lake District met the inclusion criteria for the review; data were not extracted for Mull, Scottish Borders, Clwyd, and Breckland.

The study included six interventions:

- Untreated (control)
- Cut once yearly, starting 1993
- Cut twice yearly, starting 1993
- Single application of asulam in 1993
- One cut and single application of asulam in 1993
- Single application of asulam in 1993 followed by cut in 1994

Researchers conducted a follow-up assessment of bracken biomass, density, and height during 1994 and 1995. The follow-up data reported for Devon and the Lake District are summarised in Table 19 and Table 20. Overall, asulam was the most effective treatment for reducing frond biomass and frond density during the follow-up period. Cutting was the least effective intervention for reducing frond biomass and frond density. However, it was the most effective intervention for reducing rhizome biomass. Cutting twice yearly was consistently more effective than cutting once yearly. These results were confirmed at the national level, and there was little difference between sites. These results are important since the emergency authorisation of the use of asulam has not been renewed for 2024. It is therefore illegal to use this herbicide for bracken control and only mechanical control is now practical.

Table 19: Outcomes of bracken control in 1994 and 1995 in Devon; data are presented as mean (SE)

Treatment	Frond biomass, g/m^2		Frond density, n/m^2		Frond height, cm		Rhizome biomass 1995, g/m^2
	1994	1995	1994	1995	1994	1995	
Untreated	282.1 (5.61)	362.1 (5.83)	14.7 (3.93)	16.0 (4.09)	115.3 (4.75)	110.7 (4.71)	1,789.1 (7.48)
Cut once yearly	139.2 (4.66)	227.9 (5.40)	12.7 (3.63)	18.0 (4.35)	78.3 (4.34)	78.0 (4.37)	1,221.1 (7.10)
Cut twice yearly	82.3 (3.81)	46.8 (3.57)	12.0 (3.45)	10.0 (3.29)	58.5 (4.04)	37.7 (3.62)	1,192.5 (7.08)
Single application of asulam in 1993	8.8 (2.18)	35.2 (1.90)	0.9 (1.38)	2.7 (1.90)	76.2 (4.34)	72.2 (4.24)	1,589.2 (7.36)
One cut plus asulam in 1993	56.2 (4.03)	92.1 (4.34)	8.0 (2.87)	8.0 (2.96)	78.9 (4.38)	61.3 (4.12)	NR
Asulam in 1993 followed by cut in 1994	15.5 (2.80)	28.4 (1.73)	1.1 (1.43)	2.0 (1.73)	93.9 (4.52)	71.7 (4.27)	NR

Abbreviations: NR, not reported.

Table 20: Outcomes of bracken control in 1994 and 1995 in the Lake district; data are presented as mean (SE)

Treatment	Frond biomass, g/m²		Frond density, n/m²		Frond height, cm		Rhizome biomass 1995, g/m²
	1994	1995	1994	1995	1994	1995	
Untreated	282.6 (5.64)	408.7 (6.01)	28.7 (5.43)	36.0 (6.04)	72.3 (4.30)	70.8 (4.27)	1,409.9 (7.25)
Cut once yearly	218.4 (5.38)	190.3 (5.13)	32.0 (5.74)	30.0 (5.50)	57.4 (4.07)	42.6 (3.76)	1,286.4 (7.16)
Cut twice yearly	138.2 (4.81)	118.6 (4.74)	30.7 (5.60)	26.0 (5.09)	42.1 (3.75)	37.2 (3.64)	1,026.6 (6.92)
Single application of asulam in 1993	3.6 (1.53)	44.9 (3.59)	2.3 (1.82)	10.7 (3.36)	30.1 (3.44)	32.9 (3.51)	1,481.1 (7.28)
One cut plus asulam in 1993	42.5 (3.68)	141.6 (4.73)	7.3 (2.88)	23.3 (4.88)	47.4 (3.86)	40.1 (3.70)	NR
Asulam in 1993 followed by cut in 1994	4.1 (1.62)	22.3 (2.92)	2.3 (1.83)	8.7 (3.05)	29.1 (3.39)	27.0 (3.33)	NR

Abbreviations: NR, not reported.

West (1991) conducted a quasi-experimental field study (there was no mention of randomisation), which assessed the activity of sulfonylurea herbicides against bracken in Dartmoor and the Brecon Beacons (70). The study was split into two experiments. The first experiment was conducted in 1988 and used herbicides on a) fronds 50% grown, b) full frond expansion, and c) onset of frond senescence to determine dose responses and best application timing. The second experiment was conducted in 1989 and used herbicides at stages a) and b) to compare the effects of two sulfonylureas applied alone or in a mixture. Herbicide formulations used were:

- asulam 400g a.i./l SL;
- chlorsulfuron 20% a.i. EG;
- metsulfuron-methyl 20% a.i. WG;
- DPX-L5300 75% a.i. WG;
- DPX-M6316 75% a.i. WG.

The first experiment showed that asulam and chlorsulfuron + metsulfuron-methyl were effective at both Dartmoor and the Brecon Beacons when sprayed at full frond expansion. However, DPX-L5300 caused only moderate suppression and DPX-M6316 was ineffective at the Brecon Beacons. Asulam and chlorsulfuron + metsulfuron-methyl reduced frond regrowth when applied at 50% frond growth and caused substantial reductions in regrowth when applied at senescence. Early or senescence treatment of DPX-L5300 and DPX-M6316 had no significant effect on frond regrowth. The second experiment demonstrated that after the application of herbicides at full frond expansion, asulam prevented regrowth at Dartmoor and reduced growth by 81% at the Brecon Beacons. DPX-L5300 and DPX-M6316 were both ineffective at reducing regrowth when used alone, but when used together bracken regrowth was reduced by 86% at Dartmoor and 73% at the Brecon Beacons.

West and others (1995) conducted a randomised study to assess the activity of sulfonylurea herbicides against bracken in Dartmoor and the Quantock Hills (71). The study examined five interventions at Dartmoor, each used at full frond expansion:

- asulam,
- tribenuron-methyl (60 g AI/ha),
- tribenuron-methyl (90 g AI/ha),
- metsulfuron-methyl+metsulfuron-methyl (60+5 g AI/ha),
- observation (no treatment).

The study also examined eight interventions at Quantock Hills, again used at full frond expansion:

- asulam (4400 g AI/ha),
- tribenuron-methyl (45 g AI/ha),
- tribenuron-methyl (90 g AI/ha),

- metsulfuron-methyl (5 g AI/ha),
- metsulfuron-methyl+metsulfuron-methyl (45+5 g AI/ha),
- amidosulfuron (45 g AI/ha),
- amidosulfuron (90 g AI/ha),
- observation (no treatment).

All four active treatments used at Dartmoor reduced frond count one year after treatment. Similarly, all seven active treatments used at Quantock Hills reduced frond count one year after treatment. However, after two years of treatment, only asulam and amidosulfuron (both doses) maintained bracken at <5 fronds/m^2. Similar results were found for other growth metrics, with the asulam and amidosulfuron showing the greatest sustained reduction in average frond weight and height after two years compared with other treatments. The active treatments used at both sites did not affect the understorey compared with observation.

Brook and others (2007) conducted a randomised study that examined the effect of post-burn bracken control on the recovery of heath fritillary butterfly *M. athalia* (78, 84) [11]. The study was conducted at a site in Halse Combe, Exmoor, that became dominated by scrub and bracken after changes in grazing, resulting in the loss of *M. athalia.* To produce a suitable habitat for *M. athalia*, land managers burnt 10 ha in March 2002. The burnt land was then divided into 18 plots, which were randomly assigned one of three treatments aimed at controlling bracken. Six plots were assigned as a control (i.e., no management post-burn), six plots were treated with Asulox (9.6 L/ha) in May 2002, and six plots received mechanical treatment (bracken bashing) once annually between May 2002 and May 2005. Follow-up assessments were conducted between 2003 and 2007. Note that most of the study data are visualised in figures. Raw data were not fully provided in the text or a table.

Asulox reduced bracken dominance in 2003, at which point the frequency of bracken was much lower than the other two treatments. Bracken started to recover in 2004, and between 2005 and 2007, bracken frequency was similar in Asulox and control plots. European gorse, *Ulex Europaeus,* was present in low frequencies at the beginning of the study. After five years, gorse as more established in plots sprayed with Asulox than in control plots. Despite this, spraying with Asulox appeared to provide an opportunity for recovery of cow-wheat, *Melampyrum pratense*; the frequency of cow-wheat was higher in sprayed plots than in control plots from 2003 onwards. The authors also reported that *Vaccinium* density was highest in plots sprayed with Asulox, although data to support this finding were not available.

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[11] The original publication, McCraken and others (2005), was superseded by the Brook and others (2007) publication; only the latter publication was reported.

Mechanical treatment failed to sufficiently reduce bracken dominance or encourage growth of cow-wheat or *Vaccinium* compared with control. In 2005 land managers ceased mechanical control as they judged that it wasn't benefiting *M. athalia*. From 2005 to 2007, no management was conducted on the six plots assigned to mechanical treatment.

M. athalia recolonised the burned site in 2003, and the maximum estimated population size varied between 65 and 967 between 2003 and 2007. The study did not draw a direct relationship between the different interventions (burning, Asulox, mechanical treatment) and the return of *M. athalia.* However, the recovery of cow-wheat on sprayed plots likely played a role in their return.

Camp and others (2006) conducted an uncontrolled experimental study that examined the effect of swiping, burning, and chemical control of bracken on the recovery of *M. athalia* at Bin Combe, Holnicote Estate, Exmoor (86). The site at Bin Combe was divided into four experimental sections. The application and timing of interventions varied between the experimental Sections:

- Sections 1 and 2 (5 ha)
  - Burning, March 2003
  - Application of Asulox to densest areas of bracken, July 2003
- Section 3 (1 ha)
  - Burning, March 2000
  - Application of Asulox to areas of live bracken, August 2000
  - Respray with Asulox of 50% of the burnt area, August 2004
- Section 4 (3 ha)
  - 'Swiping' (mechanical control) an area heavily covered by gorse, January 2003 and 2004
  - Burning, January/February 2005
  - Cutting by chainsaw of 1.5 ha of burnt gorse, February 2005

Information on vegetation change and butterfly numbers was reported for 1999–2005. Data were not fully reported in this publication and baseline data were not reported for most of the outcome variables. No statistical analyses were conducted. The following summary of the results is, therefore, based on the study's key findings – although it was difficult to verify the findings due to the paucity of reported data.

The study reported an increase in cow-wheat after burning and spraying in Section 3. This section also saw an increase in *M. athalia*, from an average count of 4.33 in 1999 to 46.75 in 2005. Notably, red deer had been active in Section 3 during winter, which may have contributed to the reported effects. Cow-wheat recovered in some parts of Sections 1 and 2, but not in Section 4. *M. athalia* did not recolonise Sections 1, 2, or 4 to a meaningful extent.

Support for stakeholders

A secondary aim of the review was to identify factors influencing stakeholder engagement with agri-environment schemes on Dartmoor. A summary of the data identified by the review is available in the DET (See Appendix B). However, the review failed to identify sufficient evidence to yield any meaningful findings on the subject (72, 73). It is possible that our inclusion criteria or search terms were too restrictive to identify useful evidence. Future reviews on this topic would benefit from a broader approach (e.g., removing the geographical restriction and using broader search terms).

Discussion

Caveats and considerations

The following considerations are key to the interpretation of the evidence reported in this review.

This review summarises the best available evidence on Dartmoor and comparable areas. While there is additional evidence on upland management for other areas, it has not been considered in the findings of this review. Natural England and others have published broader reviews regarding the effect of management and other impacts on upland habitats and/or species condition (92, 94-98). For more detail on upland evidence that did not meet the criteria for inclusion, see the section on Prior uplands reviews and Access to Evidence.

This review showed there is a small body of peer-reviewed and published evidence, alongside a larger body of grey literature, on the condition and management options for Dartmoor's SSSIs. Stakeholders, in Natural England and other interested parties, have accumulated a wealth of experience over the years. The rigorous and systematic approach of an evidence review (in this case a rapid evidence assessment) is not designed to capture that type of evidence. Instead, this review provides an objective summary of the published and grey literature, which may be used alongside expert knowledge to aid future conversations and decisions around the management of Dartmoor.

Dartmoor, like most of our national parks, features a varied landscape, characterised by a complex mosaic of habitats. In contrast, studies on habitat restoration typically focus on a specific site or sites with similar characteristics (e.g., *Molinia*-dominated grassland, sites with drainage channels, etc). While the insights gained from these focused studies will be transferable to comparable sites on Dartmoor, they may not be generalisable to all parts of Dartmoor. This has been considered in the following synthesis.

Unfavourable condition of Dartmoor's SSSIs

Most units on Dartmoor's SSSIs are in unfavourable condition, particularly on North Dartmoor and South Dartmoor (Figure 2). The last condition assessments reported here are from 2020 to 2022, but they don't include all units. There were further condition assessments in 2024, which will be reported shortly. Most habitat features are in unfavourable condition on North, South, and East Dartmoor SSSIs, but assemblages of breeding birds are favourable at most units on North and East Dartmoor (Figure 3, Figure 4, Figure 5). Only Short sedge acidic fen (upland); breeding birds and lichens were in favourable condition.

The causes of unfavourable condition are complex and possibly interlinked, with over-grazing, undergrazing of key livestock (e.g., early summer hardy cattle), excessive burning (e.g., ≥20% of unit burnt, burning on sensitive habitats, or burning too frequently), peat cutting and drainage, heather beetle, and possibly nitrogen deposition and climate change each considered to contribute to the result. However, there is no strong empirical evidence for most of these causal effects related to management, as it is hard to measure. There is even less research on the potential impacts of atmospheric nitrogen deposition and climate change on the condition of Dartmoor. Although there is little direct evidence from Dartmoor and comparable sites, our understanding of the causes of the unfavourable condition is informed by evidence showing how the moorlands can be induced to recover by changing management actions such as grazing levels, drainage, and burning.

Management of unfavourable condition

Many of the issues contributing to unfavourable condition have proven difficult to address. However, by providing the best available evidence on effective management practices, the review may help stakeholders to decide on management regimes that counteract the negative effects of overgrazing, undergrazing, burning, peat cutting, and drainage.

This review examined all management options for improving the condition of SSSIs on Dartmoor. Most of the evidence related to livestock management, but the review also identified data on rewetting, burning, and cutting or chemical control of bracken.

Managing livestock

Effect of livestock management on recovery of *Molinia*- or *Nardus*-dominated land

Overgrazing can damage woody vegetation and cause replacement of heathland habitat with grass-dominated vegetation (30, 48, 64). Where species such as *Calluna* and *Vaccinium* survive, recovery of heathland from existing plants or seed banks may be possible although slow; where the heathland species are lost, recovery will depend on colonisation of new plants from seed (55). This is more difficult in an established and dense grass sward and may require action to introduce seed or create conditions for plants to establish from seed in a seedbank, such as removing leaf litter and creating bare ground (55).

Soil disturbance on moorland sites dominated by *Molinia or Nardus* can create conditions that allow desirable moorland plants to establish. There is strong evidence that cattle and ponies trample leaf litter and graze on the sward, leaving areas of bare ground (i.e., regeneration niches) (51, 55, 77, 80). Over time, these niches are recolonised by species from the local area or the seed bank; on current or former heathland, this often includes *Calluna* (51, 55, 77, 80, 87). Experimental studies demonstrate that soil disturbance and the creation of bare ground facilitates *Calluna* regeneration over time (51, 55, 77, 80). Using this approach requires caution, as some evidence indicates that trampling can damage desirable species, such as *Vaccinium*, as well as the dominant grasses (80). Opening regeneration niches also allows non-target species, such as *J. effusus*, to establish (77, 80), and *Nardus* and *Molinia* can (re)colonise the regeneration niches over time (80). Overall, while soil disturbance has its downsides, it provides an opportunity for recovery of desirable species and an improvement to the species composition on *Molinia* *or Nardus*-dominated moorland. This conclusion is supported by a review of grazing management in the Lake District (29). The review reported that heavier cattle broke up uniform short swards at sites in the Lake District, allowing regeneration of flowers, trees, and dwarf shrubs. Light pony grazing had similar effects.

The impact of different livestock on the condition of *Molinia or Nardus*-dominated grassland varies. Evidence generally shows that cattle graze *Molinia* more intensively than sheep (82, 83). This suggests that cattle may be more effective at reducing *Molinia* dominance; however, few studies reported the effect of different grazing regimens on *Molinia* cover, thus the findings on this subject are inconclusive (80, 83). Both cattle and sheep graze *Nardus* at low intensity (82). But, as with *Molinia*, there was insufficient evidence to determine the effect of different grazing regimens on *Nardus* cover (80-82). There is conflicting evidence regarding the effect of grazing different species on *Calluna* (55, 77, 82, 83); however, the best available evidence suggests that *Calluna* establishes better on land grazed by cattle in the summer only compared with land grazed by sheep year-round (55, 77)[12].

While livestock grazing and soil disturbance can encourage the establishment of desirable species on *Molinia/Nardus*-dominated land, prolonged high-intensity stocking or using unsuitable livestock may adversely affect the morphology and overall cover of growing *Calluna;* it may grow better when ungrazed. Accordingly, evidence suggests that high stocking rates exert heavy grazing pressure, which inhibits the growth of *Calluna* (22, 33, 55)(77). This effect is most pronounced when grazing sheep year-round, and less pronounced when grazing cattle in the summer (the comparative effect of summer-only sheep grazing was not examined) (28, 35, 77, 80). There is strong evidence that *Calluna* morphology (height, weight, number of shoots, etc) is superior when ungrazed or grazed by cattle in the summer than when grazed by sheep year-round (55, 77)[12]. Consequently, overall cover of *Calluna* is higher on land that is either ungrazed or only grazed by cattle (55, 77). However, both options have downsides. Livestock exclusion results in the growth of taller vegetation that may outcompete the *Calluna* and other dwarf shrubs or necessitate further intervention to clear taller vegetation over the long term, although this was not shown during eight-year experimental studies (77). Grazing, either by cattle or sheep, provides an opportunity for competitive species, such as *J. effusus*, to establish, which again could outcompete the *Calluna* and other dwarf shrubs (80). All things considered, to achieve favourable condition, *Calluna* is likely to grow best when grazing is excluded for some time or when cattle graze at low intensity during the summer. Year-round stocking of sheep does not appear to support optimal growth conditions for *Calluna* nor restoration to favourable condition of the habitat features.

While large livestock and ponies may play a role in moorland conservation, moving and keeping animals on areas dominated by *Molinia* or uniform short swards may prove difficult in an open landscape. Salt blocks can be used to encourage ponies (and possibly

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[12] The studies these findings are based on use stocking rates of 0.5 heifers/ha for two months in summer and 1.5 ewes/ha for 10 months a year.

livestock) on to *Molinia*-dominated areas where they will trample and graze on sward around salt blocks (51, 99). Interestingly, if salt blocks are attached to a wooden post, ponies appeared to form an association between the post and the salt blocks, leading ponies to migrate between wooden posts, regardless of whether salt blocks were present. It may, therefore, be possible to guide ponies to *Molinia*-dominated areas using a mix of posts with salt blocks and empty posts, reducing the cost of implementing this management intervention. Notably, these findings are based on a small-scale study, and further experiments on Dartmoor are required to confirm whether ponies and livestock preferentially graze at salt posts within *Molinia*-dominated areas when ponies have a wider choice of moorland to graze.

Seeding enhances the recovery of *Calluna*. There is strong evidence to show that seeding with *Calluna* improves its cover over time, particularly when combined with one-off soil disturbance, through either trampling or rotavating (55, 77, 80). Seeding is especially important in areas where *Calluna* was limited or absent from the seed bank, but it also enhances recovery in areas where *Calluna* seed is present in relatively high quantities (55, 77, 80).

In summary, the balance of evidence suggests that soil disturbance through trampling or grazing can create regeneration niches for *Calluna*, and possibly other dwarf shrubs, to establish. Once established, high stocking rates cause heavy grazing pressure, inhibiting the growth of *Calluna.* This produces tension between achieving enough grazing to knock back the *Molinia* or *Nardus* without the stock also grazing out desirable species. It may be possible to implement short-term heavy stocking of large grazing animals to reduce *Molinia* dominance, followed by lower summer stocking rates and exclusion of grazing animals in the winter to allow desirable species, including dwarf shrubs, to establish and grow. If land managers struggle to confine livestock to areas that require grazing (e.g., areas dominated by *Molinia*), they can use salt blocks to attract animals to these areas. Regardless of which soil disturbance or stocking regimen is used, supplementary seeding enhances the recovery of *Calluna*.

Notably, the narrative above was mainly informed by experimental studies, which offer the best insight into the effect of grazing. These studies largely focus on the effect of grazing on suppressing *Molinia* or *Nardus* or on the recovery of *Calluna*. There was a paucity of experimental studies that reported on the effect of grazing on other features, such as woodland or different species of dwarf shrubs. However, observational studies (so-called ‘real-world’ studies) provided more data on the effect of grazing on other features, albeit the evidence was generally less certain.

Broader effects of livestock management on condition of habitats

There is evidence of a correlation between lower stocking rates and higher dwarf shrub cover at heathland sites in south-west England and the Lake District (29, 63). However, in many areas of Dartmoor where ESA/HLS agreements have been implemented to reduce maximum monthly stocking levels, grazing pressure on *Calluna* has remained high (10-12, 14, 16, 18, 19, 22, 23, 33, 34, 36, 45, 58, 59). There has also been little success in restoring or achieving meaningful improvements towards favourable condition on Dartmoor (10-12, 14, 16, 18, 19, 22, 23, 30, 33, 34, 36, 45, 48, 58, 59, 64). The ongoing high grazing pressure on *Calluna*, coupled with poor recovery of heathland sites, suggests that grazing was still too intensive at the times the sites were surveyed.

Several real-world studies have trialled lowering summer stocking rates and removing grazing animals in winter in areas comparable to Dartmoor (24-26, 35). These studies aimed to reduce the grazing pressure on desirable species, including dwarf shrubs, particularly in winter when sheep actively and selectively graze dwarf shrubs, as other forage (e.g., grasses) decline in nutritional value (29, 30). This approach proved successful at several sites, including the Winsford Allotment, Exmoor; Dozmary Downs and Manor & Trehudreth Common, Bodmin Moor; and Birkbeck Common, Lake District (24-26, 35). At these sites, reducing summer stocking rates to <0.32 LU/ha and excluding winter grazing lowered grazing pressure on dwarf shrubs, which led to increases in height and cover of dwarf shrubs over several years. These findings were based on uncontrolled studies, which may have been influenced by confounding factors, but the results were consistent across the studies, and they provide initial evidence that reducing summer stocking rates and excluding winter grazing can improve condition.

The findings are also supported by the review of nature recovery in the Lake District (29). The review reported that favourable condition of SSSI units in the Lake District was more likely to be achieved with a stocking rate of ≤0.4 ewes/ha compared with ≥0.5 ewes/ha. In addition, most agreements that achieved environmental objectives in the Lake District included off-wintering of sheep, which preferentially grazed on dwarf shrubs during the winter months due to the absence of other nutritive forage. The review also reported that cattle have relatively unselective grazing habits, which meant that cattle had a less seasonal grazing impact.

There is an ambition to expand woodland on Dartmoor. Grazing livestock can inhibit the growth of seedlings, but experimental and observational evidence suggests that exclusion of livestock from areas of new woodland improves the survival and growth of seedlings and saplings (57). Studies showed that density of older oak trees (up to 12 years) is higher inside fenced areas compared with outside, indicating that long-term fencing can improve woodland establishment (57). While grazing appears to reduce growth and survival of seedlings and saplings, livestock may play a role in clearing land of competitive vegetation in areas earmarked for new woodland (55, 57).

Grazing at the correct levels could help with the recovery of the marsh fritillary butterfly *E. aurinia* on moorland sites. There is initial evidence that suggests stocking at ‘intermediate’ levels can optimise sward height and density of Devil’s-bit scabious *Succisa pratensis* (their main host plant), which supports the recovery of *E. aurinia* populations (85). Stocking at too high or too low levels are each detrimental to larval web abundance (85). Notably, there is limited evidence on this subject, which contributes to uncertainty in the findings. Further evidence would help to define the relationship between stocking densities and recovery of *E. aurinia.*

There were limited data on the effectiveness of grazing management options for different habitats (e.g., blanket bog, wet/dry heath, acid grassland, etc). This is pertinent to Dartmoor, which is characterised by a mosaic of landscape features. Further studies are required to address this data gap.

Other management options

Rewetting peatland

There is strong interest in rewetting peatland on Dartmoor (31). Drainage channels and gullies, which contribute to drying of Dartmoor's peatland, can be plugged with blocks made from peat, wood, stone, or bales (31). On Dartmoor, this has been shown to raise the water table depth in surrounding peatland. There is also evidence from Dartmoor and Exmoor that rewetting can restore native mire species, including cottongrass and *Sphagnum*, and reduce prevalence of *Molinia* (31). However, these findings are based on studies without a control comparison and cannot demonstrate with certainty that the effect was due to the altered drainage and not an uncontrolled covariate (31). Stronger evidence from controlled studies on Dartmoor and Exmoor suggests that blocking drainage channels improves the water table depth but, restoration does not reduce the prevalence of *Molinia* or increase the cover of non-*Molinia* species in the short-to-medium term (up to seven years) (41, 79). These findings suggest that blocking drainage channels may contribute to peatland restoration (e.g., raising water tables), but restoring key indicator species may require further intervention or more time with current interventions. Owing to the variation in results, it would be beneficial to conduct further studies, ideally large-scale controlled studies, on the effects of rewetting on Dartmoor and comparable sites.

There is concern among some stakeholders that the prevalence of bog asphodel *Narthecium ossifragum*, which is toxic to lambs and calves, may increase following restoration of peatland (31). However, initial evidence from Exmoor showed no increase in bog asphodel after rewetting peatland (31).

Burning and bracken control

There was limited evidence on the effect of targeted burning on habitat or species condition on Dartmoor and the findings are largely inconclusive. However, there was initial, albeit weak, evidence suggesting that controlled burning at select sites may provide suitable breeding ground for the heath fritillary butterfly *M. athalia* (69, 78, 84, 86). Based on this evidence, burning a full breeding habitat causes extinction of fritillary butterflies in that area, but, if nearby colonies exist, the butterflies soon recolonise the burnt area and the population will recover in time (69). In contrast to these findings, the review also identified weak evidence that suggested there was no relationship between burning and *E. aurinia* larval web abundance (50). Given the paucity of strong evidence on the effects of burning on fritillary butterflies on Dartmoor or comparable areas, further research in this area could prove beneficial.

Burning may also be a useful tool for clearing *Molinia* litter. Evidence suggests that burning can reduce litter depth and dry matter yield at sites dominated by *Molinia*, which may provide suitable conditions for new growth of species present in the local seedbank (ideally dwarf shrubs on heathland) (68). If used with trampling (e.g., grazing with heavy livestock) or rotavating grassland, targeted burns may be useful for clearing patches of land, allowing desirable species to establish (55, 68). Excessive burning, however, has been linked with drying peatland and shifts towards *Molinia* dominance (31, 68). Data from condition assessments also suggest that burning on sensitive areas, including wet and dry heathland and mire/bog, although not frequently reported, is detrimental to habitat condition.

Bracken control may be required to restore favourable condition in some areas (66). A previous review indicated that ponies may have a role in mechanical control of bracken (100). The review suggested that pony behaviours such as resting, rolling, trampling, and grazing may open the bracken canopy and reduce the cover of bracken litter. However, most of the data identified by the review were from the lowlands, and further data are required on pony behaviour in the uplands. Primary evidence identified by this review suggests that a combination of twice-yearly cutting, chemical control, or a combination of both can reduce bracken biomass and density in subsequent years. Several chemical herbicides were trialled. Asulam consistently reduced bracken biomass; however, emergency authorisation of asulam was not renewed for 2024. This leaves mechanical control as the only practical solution for bracken management. The review also identified initial evidence suggesting that bracken control via burning and/or chemical treatment on areas formerly occupied by *M. athalia* promoted the growth of the host plant cow-wheat, creating appropriate conditions for recovery of the fritillary butterfly (78, 84, 86).

Leveraging findings in the short and long term

The stated aim of the review was to provide stakeholders on Dartmoor, including Natural England and landowners, with evidence that can inform the effective management of Dartmoor's SSSIs. It is not the place of the review to prescribe management regimes or to make policy recommendations. Therefore, in the short term, the experience of local experts, alongside the Land Use Management Group and other stakeholders, will be invaluable in using the evidence from this review, and evidence from broader upland reviews (see Prior uplands reviews), to tailor management options to Dartmoor's complex ecological mosaics.

The review provides a good evidence base that can be used by stakeholders; however, there is scope to extend the evidence base, as well as the real-world application of the evidence, over the long-term. Further research will help refine approaches to improve the condition of Dartmoor's features in a changing climate. Long-term success will also depend on regularly monitoring and reviewing the interventions implemented locally, as well as evaluating how these interventions perform within Dartmoor's habitat mosaic.

Monitoring of the condition of SSSI features will indicate whether there is progress towards favourable condition. Together, these measures will ensure that the management of Dartmoor's SSSIs continues to be supported by the best available evidence.

Limitations of included studies

Study-specific limitations have been discussed in the results section; however, there are some limitations that were observed across multiple studies.

Some of the temporal studies identified by the review had relatively short follow-up periods. Landscape change happens over multiple years or decades, and it is likely that some effects of management options will only present themselves after monitoring for several years. Long-term monitoring studies would help to track the longitudinal changes in habitat condition. In addition, experimental studies with follow-up periods of years or decades will help to establish the immediate and long-term effects of management approaches.

Much of the identified evidence is based on uncontrolled studies, which are often conducted on a single site or sites with similar characteristics. While these studies offer initial insights on the effect of management interventions, the results can be influenced by covariates, reducing certainty that changes in condition were caused by the intervention and not a confounding factor. It would be beneficial to conduct more randomised, controlled studies comparing different management approaches, both on targeted sites (e.g., *Molinia*-dominated grassland) and on different habitats or across habitat mosaics. This will not only help to establish the relative success of different management approaches, but it will also help determine their success or failure under different conditions and on different habitats.

Survey studies often failed to take measurements immediately before implementation of new management interventions (i.e., baseline measurements), which made it difficult to demonstrate a direction of effect. Future survey studies would benefit from taking baseline measurements, both at the beginning of the study and any point when management changes, as well as regular follow-up measurements.

The review identified several controlled studies, some of which were randomised. These were generally better at linking intervention with outcome, but they still had limitations. Some of the controlled studies did not match baseline variables between the intervention groups; mismatching of key variables at baseline may have influenced the follow-up results. In future studies, matching baseline characteristics between studies groups, as best as possible, will ensure that any observed effect is caused by the intervention and not site-specific variables. Other controlled studies did not fully report their findings – at times focusing only on significant results – which made it difficult to interpret the studies. If studies cannot provide all their data in the published paper, it should be provided as a supplement instead.

Several studies, both observational and experimental, had a small sample size, with some studies using an intervention and control on a single plot/field/land unit (i.e., N=1). Using replicates would have improved our confidence in the results.

The methodological weaknesses discussed above introduced potential sources of bias, reducing confidence in the results. However, the synthesis (i.e., discussion and conclusions) considered the impact of study-specific limitations on the findings.

Limitations of the review

This rapid evidence review has limitations, and the findings should be interpreted with these in mind.

Formal critical appraisal of the strength of evidence would have made it easier to interpret the results of studies, with due consideration of their limitations. However, the report discussed key study limitations in each section, and study quality has been considered in the analysis.

Screening and data extraction were carried out by a single reviewer. Including a second reviewer in the screening process may have yielded additional relevant studies. However, supplementary searches of the literature mitigated this issue, making it more likely the review captured the key studies.

Most of the grey literature databases searched by reviewers did not have an adequate search function, which made it impossible to systematically search for relevant data. It is possible that there is relevant grey literature that wasn't included in the review.

Our review was limited to Dartmoor and selected comparable areas. Comparable areas were chosen for their similarity to Dartmoor. However, it is likely that there are relevant management data from areas the review did not include.

Prior uplands reviews

There are several prior uplands reviews that provide a broader summary of the effect of management on upland habitat and/or species condition (92, 94-98). These were not included in this review as they did not focus on Dartmoor or comparable areas, but they are worth mentioning. The reviews covered the following topics:

- Impact of moorland grazing and stocking rates (96).
- Effect of targeted burning on peatland (92, 95, 101, 102).
- Management of heather beetle (94).
- Restoration of degraded blanket bog (98).
- Effect of chemical control or cutting vegetation on peatland and heathland (97, 103).

Note that this is not a comprehensive list, but rather key reviews identified during the screening process. Many of these reviews can be accessed via Access to Evidence.

This review provides the data most relevant to Dartmoor, but the reviews listed above may be useful as an additional source of data, filling in data gaps identified by this review (e.g., the effect of burning on peatland).

Conclusions

This review finds that most SSSIs on Dartmoor are in unfavourable condition. The causes of unfavourable condition are multifaceted, with overgrazing, undergrazing of key livestock (e.g., early summer hardy cattle), excessive burning, peat cutting, and drainage each contributing to the issue. The role of external factors such as nitrogen deposition and climate change are not well evidenced for Dartmoor. However, their potential impact should not be ignored when making management decisions.

Centuries-old practices have shaped Dartmoor's landscape and habitats. We can address some issues by adjusting management practices, such as changing grazing and burning regimens, to operate at sustainable levels. This could enhance the resilience of the designated features. In some situations, we will need to intervene further to restore habitats, such as reversing drainage in wet habitats or reducing dominant vegetation through cutting or other means. Further study is required to understand the management implications of nitrogen deposition and climate change on Dartmoor, and these issues must be addressed at a national and international scale.

The findings should be interpreted while considering the limitations of the review and the identified studies. Even so, the review presents the best available evidence on the management interventions that are most likely to improve SSSI condition. This review may, therefore, support Natural England and stakeholders with ongoing conversations and decisions around the management of SSSIs on Dartmoor.

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Appendices

Appendix A: Search strategy

Scopus and CAB Direct were searched on 02/08/2023 (Table 21).

Table 21: Search strategy for Scopus and CAB Direct (02/08/2023)

Search	Terms	
Search 1	Scopus	TITLE-ABS-KEY (Dartmoor)
	CAB Direct	Dartmoor
Search 2	Scopus	TITLE-ABS-KEY (("Bodmin Moor" OR Exmoor OR Quantock* OR "East Devon Common*" OR "West Penwith" OR "Goss Moor" OR "Cambrian Mountains" OR "Black Mountains" OR "Brecon Beacons" OR "South Wales" OR "Lake District" OR “Long Mynd”) AND (bog* OR mire* OR fen* OR heath* OR upland OR grass* OR moor OR butterfl* OR damselfl* OR soakaway OR sump OR bird* OR curlew* OR Numenius OR snipe* OR Gallinago OR dunlin* OR "Calidris alpina" OR "red-backed sandpiper" OR "red backed sandpiper" OR lapwing* OR "Vanellus vanellus" OR "golden plover*" OR "Pluvialis apricaria" OR "ring ouzel*" OR "Turdus torquatus" OR whinchat* OR "Saxicola rubetra" OR cuckoo* OR Cuculidae OR wheatear* OR Oenanthe OR linnet* OR "Linaria cannabina" OR yellowhammer* OR "Emberiza citrinella" OR "tree pipit*" OR "Anthus trivialis" OR "dartford warbler*" OR "Sylvia undata" OR "willow warbler*" OR "Phylloscopus trochilus" OR "hen harrier*" OR "Circus cyaneus" OR "short-eared owl*" OR "short eared owl*" OR "Asio flammeus" OR "lesser-

Search	Terms	
		spotted woodpecker*" OR "lesser spotted woodpecker*" OR "Dryobates minor" OR "wood warbler*" OR "Phylloscopus sibilatrix" OR "pied flycatcher*" OR "Ficedula hypoleuca" OR "marsh tit*" OR "Poecile palustris" OR "willow tit*" OR "Poecile montanus" OR sward* OR *Molinia* OR shrub OR scrub OR *Calluna* OR bracken OR Pteridium OR bilberry OR "*Vaccinium* myrtillus" OR ling OR gorse OR ulex* OR peat* OR "Lochmaea suturalis" OR hydrolog* OR "water retent*" OR stock* OR graz* OR (nitrogen w/5 depos*) OR "N depos*" OR "climate change" OR swaling OR burning OR mow* OR rotovat* or "sod cutting" OR "peat cutting" OR re-wet* OR rewet* OR manag* OR steward* OR observation OR "no intervention*" OR control* OR "agri-environment" OR "agri environment" OR HLS OR "condition assessment") AND NOT Australia AND NOT "New South Wales")
	CAB Direct	(("Bodmin Moor" OR Exmoor OR Quantock* OR "East Devon Common*" OR "West Penwith" OR "Goss Moor" OR "Cambrian Mountains" OR "Black Mountains" OR "Brecon Beacons" OR "South Wales" OR "Lake District" OR “Long Mynd”) AND (bog* OR mire* OR fen* OR heath* OR upland OR grass* OR moor OR butterfl* OR damselfl* OR soakaway OR sump OR bird* OR curlew* OR Numenius OR snipe* OR Gallinago OR dunlin* OR "Calidris alpina" OR "red-backed sandpiper" OR "red backed sandpiper" OR lapwing* OR "Vanellus vanellus" OR "golden plover*" OR "Pluvialis apricaria" OR "ring ouzel*" OR "Turdus torquatus" OR whinchat* OR "Saxicola rubetra" OR cuckoo* OR Cuculidae OR wheatear* OR Oenanthe OR linnet* OR "Linaria cannabina" OR yellowhammer* OR "Emberiza citrinella" OR "tree pipit*" OR "Anthus trivialis" OR "dartford warbler*" OR "Sylvia undata" OR "willow warbler*" OR "Phylloscopus trochilus" OR "hen harrier*" OR "Circus cyaneus" OR "short-eared owl*" OR "short eared owl*" OR "Asio flammeus" OR "lesser-

Search	Terms	
		spotted woodpecker*" OR "lesser spotted woodpecker*" OR "Dryobates minor" OR "wood warbler*" OR "Phylloscopus sibilatrix" OR "pied flycatcher*" OR "Ficedula hypoleuca" OR "marsh tit*" OR "Poecile palustris" OR "willow tit*" OR "Poecile montanus" OR sward* OR *Molinia* OR shrub OR scrub OR *Calluna* OR bracken OR Pteridium OR bilberry OR "*Vaccinium* myrtillus" OR ling OR gorse OR ulex* OR peat* OR "Lochmaea suturalis" OR hydrolog* OR "water retent*" OR stock* OR graz* OR (nitrogen w/5 depos*) OR "N depos*" OR "climate change" OR swaling OR burning OR mow* OR rotovat* or "sod cutting" OR "peat cutting" OR re-wet* OR rewet* OR manag* OR steward* OR observation OR "no intervention*" OR control* OR "agri-environment" OR "agri environment" OR HLS OR "condition assessment") AND NOT Australia AND NOT "New South Wales")

Appendix B: Data extraction table

Available on request.

Appendix C: Abbreviations

Table 22: List of abbreviations

Term	
CI	Confidence Interval
CMSi	Conservation Management System international
CSM	Common Standards for Monitoring
DBRC	Devon Biodiversity Records Centre
DEFRA	Department for Environment, Food, and Rural Affairs
DET	Data extraction table
DNPA	Dartmoor National Park Authority
ECC	Environmental Cross Compliance
ED	East Dartmoor (SSSI)
ESA	Environmentally Sensitive Areas
HLS	Higher Level Stewardship
JNCC	Joint Nature Conservation Committee
LU	Livestock units
MAFF	Ministry of Agriculture, Fisheries, and Food
ND	North Dartmoor (SSSI)
NE	Natural England
NESAC	Natural England Science and Advisory Committee
NR	Not reported
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SD	South Dartmoor (SSSI)
SE	Standard error
SSSI	Site of Special Scientific interest
SWES	Sheep Wildlife Enhancement Scheme
SWiM	Synthesis Without Meta-Analysis
Unf.	Unfavourable

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