Shrubland and heathland Conservation

Global evidence for the effect of interventions

Philip A. Martin, Ricardo Rocha,
Rebecca K. Smith & William J. Sutherland

SYNOPSES OF CONSERVATION EVIDENCE SERIES

This should be cited as: Martin P.A., Rocha R., Smith R.K., & Sutherland W.J. (2017) *Shrubland and heathland conservation: Global Evidence for the Effects of Interventions*. Synopses of Conservation Evidence Series. University of Cambridge, Cambridge, UK.

This document was updated on 12/04/18

Digital material and resources associated with this synopsis are available at
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Advisory Board

We thank the following people for advising on the scope and content of this synopsis:

Professor Andrew Bennet, La Trobe University, Australia

Professor Brian van Wilgen, Stellenbosch University, South Africa

Professor Rob Marrs, University of Liverpool, UK

Chris Diek, Royal Society for the Protection of Birds, UK

Dr G. Matt Davies, Ohio State University, USA

Dr David Le Maitre, CSIR, UK

Dr Giles Groome, Consultant Ecologist, UK

Dr Isabel Barrio, University of Iceland, Iceland

James Adler, Surrey Wildlife Trust, UK

Professor Jon Keeley, US Geological Survey, Western Ecological Research Center and Department of Ecology and Evolutionary Biology, University of California, USA

Dr Jonty Denton, Consultant Ecologist, UK

Penny Anderson, Penny Anderson Associates Limited, UK

About the authors

Philip A Martin is a postdoctoral researcher in the Department of Zoology, University of Cambridge, UK.

Ricardo Rocha is a postdoctoral researcher in the Department of Zoology, University of Cambridge, UK.

Rebecca K. Smith is a Senior Research Associate in the Department of Zoology, University of Cambridge, UK.

William J. Sutherland is the Miriam Rothschild Professor of Conservation Biology at the University of Cambridge.

Acknowledgements

This synopsis was funded by the MAVA foundation.

We would like to thank Nancy Ockendon, Silviu Petrovan, Rebecca Robertson, Gorm Shackleford, and Nigel Taylor for advice and assistance.

1. About this book

The purpose of Conservation Evidence synopses

Conservation Evidence synopses **do**	Conservation Evidence synopses **do not**
• Bring together scientific evidence captured by the Conservation Evidence project (over 5,000 studies so far) on the effects of interventions to conserve biodiversity	• Include evidence on the basic ecology of species or habitats, or threats to them
• List all realistic interventions for the species group or habitat in question, regardless of how much evidence for their effects is available	• Make any attempt to weight or prioritize interventions according to their importance or the size of their effects
• Describe each piece of evidence, including methods, as clearly as possible, allowing readers to assess the quality of evidence	• Weight or numerically evaluate the evidence according to its quality
• Work in partnership with conservation practitioners, policymakers and scientists to develop the list of interventions and ensure we have covered the most important literature	• Provide recommendations for conservation problems, but instead provide scientific information to help with decision-making

Who is this synopsis for?

If you are reading this, we hope you are someone who has to make decisions about how best to support or conserve biodiversity. You might be a land manager, a conservationist in the public or private sector, a farmer, a campaigner, an advisor or consultant, a policymaker, a researcher or someone taking action to protect your own local wildlife. Our synopses summarize scientific evidence relevant to your conservation objectives and the actions you could take to achieve them.

We do not aim to make your decisions for you, but to support your decision-making by telling you what evidence there is (or isn't) about the effects that your planned actions could have.

When decisions have to be made with particularly important consequences, we recommend carrying out a systematic review, as the latter is likely to be more comprehensive than the summary of evidence presented here. Guidance on how to carry out systematic reviews can be found from the Centre for Evidence-Based Conservation at the University of Bangor (www.cebc.bangor.ac.uk).

The Conservation Evidence project

The Conservation Evidence project has four parts:

1) An online, **open access journal** *Conservation Evidence* that publishes new pieces of research on the effects of conservation management interventions. All our papers are written by, or in conjunction with, those who carried out the conservation work and include some monitoring of its effects.
2) An ever-expanding **database of summaries** of previously published scientific papers, reports, reviews or systematic reviews that document the effects of interventions.
3) **Synopses** of the evidence captured in parts one and two on particular species groups or habitats. Synopses bring together the evidence for each possible intervention. They are freely available online and available to purchase in printed .book form.
4) ***What Works in Conservation*** is an assessment of the effectiveness of interventions by expert panels, based on the collated evidence for each intervention for each species group or habitat covered by our synopses.

These resources currently comprise over 5,000 pieces of evidence, all available in a searchable database on the website www.conservationevidence.com.
Alongside this project, the Centre for Evidence-Based Conservation (www.cebc.bangor.ac.uk) and the Collaboration for Environmental Evidence (www.environmentalevidence.org) carry out and compile systematic reviews of evidence on the effectiveness of particular conservation interventions. These systematic reviews are included on the Conservation Evidence database.

Of the 112 shrubland conservation interventions identified in this synopsis, three have been the subject of a specific systematic reviews.

Scope of the Shrubland and Heathland synopsis

This synopsis covers evidence for the effects of conservation interventions for shrublands. Shrublands are plant communities dominated by shrubs, which themselves are woody plants, that are smaller than trees and have several stems close to the ground. This includes all shrublands as defined by the International Union for the Conservation of Nature (IUCN) habitat classification scheme (IUCN 2017): subarctic shrubland, subantarctic shrubland, temperate shrubland, heathland, moorland, subtropical/tropical dry shrubland, subtropical/tropical moist shrubland, subtropical/tropical high altitude shrubland, Mediterranean shrubland, and tundra. In addition we included any shrublands described as cedar scrub, chaparral, fynbos, garrigue, karoo, kwongan, mallee, matorral, maquis, macchia, restinga, or strandveld as these represent local names for specific types of shrubland.

This synopsis includes some information about shrub-dominated peatlands, but for more information on interventions in peatland habitats see the peatland synopsis (Taylor *et al.* 2017). We excluded information relating to forests from this synopsis as this is already covered in the forest synopsis (Agra *et al.* 2016) and from grasslands as this is the topic of an upcoming synopsis.

Evidence from all around the world is included. Any apparent bias towards evidence from some regions reflects the current biases in published research papers available to Conservation Evidence.

This synopsis reports the effects of interventions on wild shrubland vegetation, but not on animals. For information on the effects of conservation interventions on animals please refer to the appropriate section of our website – www.conservationevidence.com.

The table below summarises the key metrics we included in this synopsis. Metrics quantify the overall composition (which species are present, and what is their abundance or cover) or physical structure (e.g. vegetation height or density) of the shrubland vegetation. Information about the responses of some focal plant groups that are characteristic of shrublands is also reported. Information on other plant groups is reported on an ad hoc basis when it is an important result of a study.

Importantly, <u>this synopsis does not include the effects of interventions for rare plants</u> (in few locations or not abundant where they do occur). The synopsis also does not include interventions that do not directly relate to wild habitats (e.g. cultivation of plants in greenhouses or seed storage, without introduction to the wild).

Key Metrics for the Shrublands and Heathland Synopsis

Plant Community	• Species richness • Diversity • Overall community composition (usually a mixture of which species are present and their relative abundances/cover). • Richness of shrubland-characteristic plant species (as defined in each study). • Richness of native/non-native plant species (usually included in studies of habitats threatened by non-native species).
Vegetation Cover[1]	• Total vegetation cover • Cover/abundance/presence of shrubs • Cover/abundance/presence of herbaceous plants (including forbs and grasses which may also be listed separately). • Cover/abundance/presence of trees • Cover/abundance/presence of specific shrubland taxa • Cover/abundance/presence of invasive/problematic plant species
Physical Structure	• Vegetation biomass (always aboveground, usually dry mass) • Vegetation height • Vegetation density
Individual Plants[2]	• Survival • Cover/abundance • Growth
Education/Awareness	• Effect on any of the above metrics • Change in behaviour • Change in knowledge or attitude

[1]Cover may exceed 100%, because studies may measure overlapping layers of vegetation (e.g. the leaves of a tree might grow over grasses).
[2] Typically reported when particular plant species are being introduced (Chapters 13 and 14) or controlled (Chapters 8 and 9).

How we decided which conservation interventions to include

A list of interventions was developed and agreed in partnership with an advisory board made up of international conservationists and academics with expertise in shrubland conservation. We have tried to include all actions that have been carried out or advised to benefit shrubland vegetation.

The list of interventions was organized into categories based on the International Union for the Conservation of Nature (IUCN) classifications of direct threats and conservation actions.

How we reviewed the literature

We have searched the following sources for evidence relating to shrubland vegetation:

- The database of evidence captured by the Conservation Evidence project, which has searched 30 general conservation journals and over 180 specialist journals for tests of any conservation intervention, generally from their first publication to the end of 2016.
- The following seventeen specialist journals that cover topics relevant to shrublands, from the first publication that was available to the end of 2016: *African Journal of Ecology*, *Applied Vegetation Science, Austral Ecology*, *Ecological Management and Restoration*, *Fire Ecology*, *iForests, International Journal of Arid Environments, International Journal of the Commons, International Journal of Wildland Fire, Journal of Mountain Science, Journal of Range Management, Land Degradation and Development, Northwest Science, Rangeland ecology and Management*, *South African Journal of Botany, The Rangeland Journal, Western North American Naturalist*.
- Additional studies published in 2016 or earlier were added if recommended by the advisory board or identified within the literature during the summarizing process.

For reviews identified through our searches, we summarised quantitative results directly from the review, unless those results related to only one study not already identified – in which case we summarised that individual study. Evidence published in other languages was included when it was identified.

The criteria for inclusion of studies were as follows:

- There must have been an intervention carried out that conservationists would do.
- The effects of the intervention must have been monitored quantitatively.

These criteria exclude studies examining the effects of specific interventions without actually doing them. For example, predictive modelling studies and studies looking at species distributions in areas with long-standing management histories (correlative studies) were excluded. Such studies can suggest that an intervention could be effective, but do not provide direct evidence of a causal relationship between the intervention and the observed biodiversity pattern. We have made an effort to give details of such studies in the background sections that relate to particular interventions.

Altogether 141 studies were allocated to interventions they tested.

How the evidence is summarized

Conservation interventions are grouped primarily according to the relevant direct threats, as defined in the IUCN Unified Classification of Direct Threats (http://www.iucnredlist.org/technical-documents/classification-schemes/threats-classification-scheme). In most cases, it is clear which main threat a particular intervention is meant to alleviate or counteract.

Not all IUCN threat types are included, only those that threaten shrublands, and for which realistic conservation interventions have been suggested.

Some important interventions can be used in response to many different threats, and it would not make sense to split studies up depending on the specific threat they were studying. We have therefore separated out these interventions following the IUCN's Classification of Conservation Actions (http://www.iucnredlist.org/technical-documents/classification-schemes/conservation-actions-classification-scheme-ver2). Accordingly, we have separate chapters for: 'Habitat protection', 'Habitat restoration and creation' and 'Education and awareness'. These respectively match the following IUCN categories: 'Land/water protection', 'Land/water management – Habitat and natural process restoration' and 'Education and awareness'.

Normally, no intervention or piece of evidence is listed in more than one place, and when there is ambiguity about where a particular intervention should fall there is clear cross-referencing. Some studies describe the effects of multiple interventions. Where a study has not separated out the effects of different interventions, the study is included in the section on each intervention, but the fact that several interventions were used is made clear.

In the text of each section, studies are presented in chronological order, so the most recent evidence is presented at the end. The summary text at the start of each section groups studies according to their findings.

At the start of each chapter, a series of **key messages** provides a rapid overview of the evidence. These messages are condensed from the summary text for each intervention.

Background information is provided where we feel recent knowledge is required to interpret the evidence. This is presented separately and relevant references included in the reference list at the end of each background section.

The information in this synopsis is available in two ways:

- As a pdf to download from www.conservationevidence.com
- As text for individual interventions on the searchable database at www.conservationevidence.com.

Terminology used to describe evidence

Unlike systematic reviews of particular conservation questions, we do not quantitatively assess the evidence or weight it according to quality within synopses. However, to allow you to interpret evidence, we make the size and design of each trial we report clear. The table below defines the terms that we have used to do this.
The strongest evidence comes from randomized, replicated, controlled trials with paired-sites and before and after monitoring.

Term	Meaning
Site comparison	A study that considers the effects of interventions by comparing sites that have historically had different interventions or levels of intervention.
Replicated	The intervention was repeated on more than one individual or site. In conservation and ecology, the number of replicates is much smaller than it would be for medical trials (when thousands of individuals are often tested). If the replicates are sites, pragmatism dictates that between five and ten replicates is a reasonable amount of replication, although more would be preferable. We provide the number of replicates wherever possible, In the case of planting or vegetation introduction, replicates should be sites, not individuals.
Controlled	Individuals or sites treated with the intervention are compared with designated control individuals or sites not treated with the intervention.
Paired sites	Sites are considered in pairs, when one was treated with the intervention and the other was not. Pairs of sites are selected with similar environmental conditions, such as soil type or surrounding landscape. This approach aims to reduce environmental variation and make it easier to detect a true effect of the intervention.
Randomized	The intervention was allocated randomly to individuals or sites. This means that the initial condition of those given the intervention is less likely to bias the outcome.
Before-and-after	Monitoring of effects was carried out before and after the intervention was imposed.
Review	A conventional review of literature. Generally, these have not used an agreed search protocol or quantitative assessments of the evidence.
Systematic review	A systematic review follows an agreed set of methods for identifying studies and carrying out a formal 'meta-analysis'. It will weight or evaluate studies according to the strength of evidence they offer, based on the size of each study and the rigour of its design. Many environmental systematic reviews are available at: www.environmentalevidence.org/index.htm

Study	If none of the above apply, for example a study that has measured change in only one site and only after an intervention.

Taxonomy

Taxonomy has not been updated but has followed that used in the original paper. Where possible, common names and Latin names are both given the first time each species is mentioned within each synopsis.

Significant results

Throughout the synopsis we have quoted results from papers. Unless specifically stated, these results reflect statistical tests presented in articles. Examples of when results do not reflect statistical tests include (a) studies that are not replicated and so cannot perform statistical tests, (b) graphical analyses of community composition, and (c) data presented with error bars from which statistically significant differences can be estimated (Cumming et al. 2007).

Multiple interventions

Some studies investigated several interventions at once. When the effects of different interventions are separated, then the results are discussed separately in the relevant sections. However, often the effects of multiple interventions cannot be separated. When this is the case, the study is included in the section on each intervention, but the fact that several interventions were used is made clear.

How you can help to change conservation practice

If you know of evidence relating to shrubland and heathland conservation that is not included in this synopsis, we invite you to contact us, via our website www.conservationevidence.com. If you have new, unpublished evidence, you can submit a paper to the *Conservation Evidence* journal. We particularly welcome papers submitted by conservation practitioners.

References

Agra H., Carmel Y., Smith R.K., Ne'eman G. (2016) Forest conservation: global evidence for the effects of interventions. Synopses of Conservation Evidence Series. University of Cambridge, Cambridge, UK.

Cumming G., Fidler F. & Vaux D.L. (2007) Error bars in experimental biology. The Journal of Cell Biology, 177, 7–11.

IUCN (2017) Habitats Classification Scheme (Version 3.1). Available at http://www.iucnredlist.org/technical-documents/classification-schemes/habitats-classification-scheme-ver3. Accessed 14 September 2017.

Taylor N et al. (2017) Peatlands: Global Evidence for the Effects of Interventions. Synopses of Conservation Evidence Series. University of Cambridge, Cambridge, UK.

2. Threat: Residential & commercial development

Background

This chapter addresses threats from developments such as urban areas, industrial facilities, tourist sites and recreational areas. These developments may destroy or degrade shrublands. For example, in the United States expansion of suburban areas has resulted in conversion of shrubland in some areas (Radeloff *et al.* 2005) and in South Africa, some strandveld shrublands have been converted to golf courses (Fox *et al*. 2005).

Related threats: Roads, railways, and utility lines (Chapter 5); pollution (Chapter 10).
Related interventions: Habitat restoration (Chapters 13 & 14).

Fox, S.-J.C. & Hockey, P.A.R. (2007) Impacts of a South African coastal golf estate on shrubland bird communities. South African Journal of Science, 103, 27-34.

Radeloff, V.C., Hammer, R.B., Stewart, S.I., Fried, J.S., Holcomb, S.S. & McKeefry, J.F. (2005) The Wildland–urban Interface in the United States. Ecological Applications, 15, 799-805.

Key messages

2.1 Remove residential or commercial development

We captured no evidence for the effects on shrublands of removing residential or commercial development.

2.2 Maintain/create habitat corridors in developed areas

We captured no evidence for the effects on shrublands of maintaining or creating habitat corridors in developed areas.

Interventions

2.1 Remove residential or commercial development

We captured no evidence for the effects on shrublands of removing residential or commercial development.

Background

Removing residential and commercial developments that have been built on or nearby to shrublands may allow vegetation to recover.

Related interventions: Habitat restoration and creation (Chapter 13) and actions to benefit introduced vegetation (Chapter 14).

2.2 Maintain/create habitat corridors in developed areas

We captured no evidence for the effects on shrublands of maintaining or creating habitat corridors in developed areas

Background

Maintaining habitat corridors in areas with widespread human land use has been suggested as a method to retain connectivity between sites (Beier and Noss, 1998). This connectivity may help to maintain interactions between plant and animals such as pollination and seed dispersal, which can aid survival of plant populations and maintain species diversity.

Related interventions: Habitat restoration and creation (Chapter 13) and actions to benefit introduced vegetation (Chapter 14).

Beier, P., & Noss, R. F. (1998). Do habitat corridors provide connectivity? *Conservation Biology*, 12(6), 1241-1252.

3. Threat: Agriculture & Aquaculture

Background

Many serious threats to shrublands and the biodiversity these habitats harbour are the result of agriculture. These threats include habitat conversion, fragmentation, and overgrazing. For example, in Western European countries conversion to cropland has contributed to a 60-95% decline in heathland shrubland area over the past 200 years (Alonso 2004, Newton *et al.* 2009) and in South Africa fynbos habitats have also seen similar levels of habitat conversion to cropland (Rouget *et al.* 2003).

In many parts of the world shrublands have traditionally been used to graze livestock. However, high livestock density can alter the vegetation structure and species composition of shrublands (Alkemade *et al*. 2013). These changes may result in a loss of shrubs and dominance of grass species (Pakeman & Nolan 2009).

Related threats: cessation of traditional grazing management (Chapter 7); invasive and other problematic species, which may spread as a result of changes in grazing management (Chapter 8).

Related interventions: habitat restoration (Chapters 13 and 14).

Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J. & Jeuken, M. (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. Proceedings of the National Academy of Sciences, 110, 20900-20905.

Alonso, I. (2004) La conservación de los brezales en Inglaterra. *Revista Ecosistemas*, 13.

Newton, A.C., Stewart, G.B., Myers, G., Diaz, A., Lake, S., Bullock, J.M. & Pullin, A.S. (2009) Impacts of grazing on lowland heathland in north-west Europe. *Biological Conservation*, 142, 935-947.

Pakeman, R.J. & Nolan, A.J. (2009) Setting sustainable grazing levels for heather moorland: a multi-site analysis. Journal of Applied Ecology, 46, 363-368

Rouget, M., Richardson, D.M., Cowling, R.M., Lloyd, J.W. & Lombard, A.T. (2003) Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. *Biological Conservation*, 112, 63-85.

Key messages

Livestock farming and ranching

3.1 Use fences to exclude livestock from shrublands

- Two replicated, controlled, randomized studies (one of which was also a before-and-after trial) and one controlled before-and-after trial in the UK found that using fences to exclude livestock increased shrub cover or abundance. Two replicated, controlled, randomized studies in Germany and the UK found that using fences increased shrub biomass or the biomass and height of individual heather plants. Two controlled studies (one of which was a before-and-after study) in Denmark and the UK found that heather presence or cover was higher in fenced areas that in areas that were not fenced. However, one site comparison study in the USA found that using fences led to decreased cover of woody plants. Three replicated, controlled studies (one of which was a before and after study) in the USA and the UK found that fencing either had a mixed effect on shrub cover or did not alter shrub cover.
- One randomized, replicated, controlled, paired study in the UK found that using fences to exclude livestock did not alter the number of plant species, but did increase vegetation

height and biomass. One controlled, before-and-after study in the UK found that fenced areas had lower species richness than unfenced areas.

- One randomized, replicated, controlled, before-and-after trial in the UK and one site comparison study in the USA found that using fences to exclude livestock led to a decline in grass cover. However, four controlled studies (one of which a before-and-after trial) in the USA, the UK, and Finland found that using fences did not alter cover of grass species. One site comparison study in the USA and one replicated, controlled study in the UK recorded an increase in grass cover.
- One controlled study in Finland found that using fences to exclude livestock did not alter the abundance of herb species and one site comparison in the USA found no difference in forb cover between fenced and unfenced areas. One replicated, controlled study in the USA found fencing had a mixed effect on herb cover.

3.2 Reduce number of livestock

- Two before-and-after trials in the UK and South Africa,one replicated, , controlled study in the UK found that the reducing or stopping grazing increased the abundance or cover of shrubs. Two site comparison studies in the UK found that cover of common heather declined in sites with high livestock density, but increased in sites with low livestock density. One site comparison study in the Netherlands found that dwarf shrub cover was higher in ungrazed sites. One replicated, randomized, before-and-after study in Spain found that reducing grazing increased the cover of western gorse. One randomized, controlled trial and one before-and-after trial in the USA found that stopping grazing did not increase shrub abundance. One site comparison study in France found that ungrazed sites had a higher cover of ericaceous shrubs, but a lower cover of non-ericaceous shrubs than grazed sites.
- One replicated, randomized, controlled study in the UK found that reducing grazing increased vegetation height. However, one replicated, controlled, paired site, site comparison study in the UK found that reducing grazing led to a reduction in the height of heather plants.
- Two site comparison studies in France and the Netherlands found that ungrazed sites had a lower number of plant species than grazed sites. One replicated, controlled, paired, site comparison study in Namibia and South Africa found that reducing livestock numbers increased plant cover and the number of plant species.
- One controlled study in Israel found that reducing grazing increased plant biomass. However, one randomized, site comparison on the island of Gomera, Spain found that reducing grazing did not increase plant cover and one replicated, controlled study in the UK found that the number of plant species did not change .
- One replicated, controlled study in the UK found no change in the cover of rush or herbaceous species as a result of a reduction in grazing. Two site comparison studies in France and the Netherlands found that grass cover and sedge cover were lower in ungrazed sites than in grazed sites. One randomized, controlled study in the USA found a mixed effect of reducing grazing on grass cover.

3.3 Change type of livestock

- Two replicated, before-and-after studies and one controlled study in Spain and the UK found changing the type of livestock led to mixed effects on shrub cover. However, in two of these studies changing the type of livestock reduced the cover of herbaceous species. One replicated, controlled, before-and-after study found that grazing with both cattle and sheep, as opposed to grazing with sheep, reduced cover of purple moor grass, but had no effect on four other plant species.

3.4 Shorten the period during which livestock can graze

- One replicated, controlled, before-and-after study in the UK found that shortening the period in which livestock can graze had mixed effects on heather, bilberry, crowberry, and grass cover.
- One replicated, randomized, controlled study in the UK found that grazing in only winter or summer did not affect the heather or grass height compared to year-round grazing.

Interventions

3.1 Use fences to exclude livestock from shrublands

- Two replicated, controlled, randomized studies (one of which was also a before-and-after trial) and one controlled before-and-after trial in the UK[5,7,10] found that using fences to exclude livestock increased shrub cover or abundance. Two replicated, controlled, randomized studies in Germany[6] and the UK[10] found that using fences increased shrub biomass[6] or the biomass and height of individual heather plants[10]. Two controlled studies (one of which was a before-and-after study) in Denmark[1] and the UK[13] found that heather presence or cover was higher in fenced areas that in areas that were not fenced. However, one site comparison study in the USA[11] found that using fences led to decreased cover of woody plants. Three replicated, controlled studies (one of which was a before and after study) in the USA[2] and the UK[4,12] found that fencing either had a mixed effect on shrub cover or did not alter shrub cover.
- One randomized, replicated, controlled, paired study in the UK[9] found that using fences to exclude livestock did not alter the number of plant species, but did increase vegetation height and biomass. One controlled, before-and-after study in the UK[13] found that fenced areas had lower species richness than unfenced areas.
- One randomized, replicated, controlled, before-and-after trial in the UK[5] and one site comparison study in the USA[11] found that using fences to exclude livestock led to a decline in grass cover. However, four controlled studies (one of which a before-and-after trial) in the USA[2], the UK[12,13], and Finland[3] found that using fences did not alter cover of grass species. One site comparison study in the USA[11] and one replicated, controlled study in the UK[4] recorded an increase in grass cover.
- One controlled study in Finland[3] found that using fences to exclude livestock did not alter the abundance of herb species and one site comparison in the USA[11] found no difference in forb cover between fenced and unfenced areas. One replicated, controlled study in the USA[2] found fencing had a mixed effect on herb cover.

Background

Livestock grazing can alter shrubland habitats by changing plant structure, composition, and diversity (Alkemade et al 2013). High grazing pressure can reduce the cover of woody species in shrublands, leading to an increase in grass cover or unvegetated areas. Using fences to exclude livestock from shrublands could reduce the negative impacts of overgrazing.

Related interventions: Reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J. & Jeuken, M. (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proceedings of the National Academy of Sciences*, 110, 20900-20905.

A controlled study in 1974–1978 in a heathland in Denmark (1) found that using fences to exclude livestock from shrublands increased the presence of common heather *Calluna vulgaris* but did not affect the presence of wavy-hair grass *Deschampsia flexuosa*. Five years after fence construction, common heather was present in 70% of fenced plots while common heather was only present in 13% of unfenced plots. However, the percentage of plots in which wavy-hair grass was present did not differ significantly between fenced (82%) and unfenced areas (81%). In 1974 eighteen 25 m^2 areas were fenced to exclude livestock. Every year in 1974–1978 vegetation was recorded in eighteen 1 m^2 plots located in the fenced areas and thirty-two 1 m^2 plots in the unfenced areas.

A replicated, controlled study in 1950–1996 in sagebrush steppe in Idaho, USA (2) found that fencing to reduce grazing had mixed effects on shrub, grass, forb, and herb cover. Cover of shrubs in ungrazed areas was lower (21%) than in areas that were grazed only in spring (27%) and not significantly different to shrub cover in areas that were grazed only in autumn (19%). Grass and forb cover were not significantly different in ungrazed areas (grass: 16%, forb: 10%) and areas that were grazed in spring or autumn only (grass: 15–17%, forb: 7–12%). Herb cover in ungrazed areas was lower (25%) than in areas grazed only in autumn (30%) and not significantly different from herb cover in areas grazed only in the spring (23%). In 1950 six areas were fenced, two of which were subsequently grazed by sheep in spring only, two of which were grazed in autumn only, and two of which were not grazed. Vegetation cover was recorded in June 1995 and 1996 in eight randomly placed 1.75 m^2 quadrats in each of the fenced areas.

A controlled study in 1989–1995 in upland heathland in northern Finland (3) found that using fences to exclude herbivores did not alter the abundance five shrub species, two herb species, and two grass species. After six years, the cover of five shrub species was not different in areas that were fenced (0–21%) and areas that were left unfenced (0–12%). The same pattern was true for two of two herb species (fenced: 0–10%; unfenced: 0–9%) and two of two grass species (fenced: 1–42%; unfenced: 1–42%). In 1989 twenty 2,000 cm^2 blocks were cut from a natural heath habitat and transplanted to an area with no vegetation. Following this, 10 blocks were fenced and another 10 blocks were left unfenced. Vegetation cover was assessed every year in 1990–1995 using a 625 cm^2 plastic sheet with 50 holes drilled in it.

A replicated, controlled, before-and-after trial in 1990-1996 in two moorland sites in Derbyshire, UK (4) found that after using fences to exclude sheep the cover of crowberry *Empetrum nigrum* and grass was higher and the cover of mat-grass *Nardus stricta* was lower in both sites, whereas the effects on cover of bilberry *Vaccinium myrtillus* and heather *Calluna vulgaris* were mixed. In both sites and after six years, cover of crowberry and grass was higher and the cover of mat-grass was lower after excluding sheep (crowberry: 25–28%; grass: 64–92%; mat-grass: 6–8%) than before grazing restriction (crowberry: 16%; grass: 55–81%; mat-grass: 13–15%). Additionally, in one of the sites and over the same period, cover of bilberry decreased (from 62% to 45%) and of heather increased (from 28% to 39%). Over the same period and in plots with year-round grazing, the cover of bilberry declined in one site from 73% to 56% and the cover of grass declined the other site from 81% to 66%. The heights of bilberry and heather increased respectively from 12.5–16 to 17.9–20.5 cm and from 19–24.7 to 30–32.7 cm. In each site, sheep were excluded by fencing from two areas of 50 m x 10 m and two nearby areas had year-round grazing. Vegetation height and cover was recorded annually in August.

A replicated, controlled, randomized, before-and-after trial in 1993–1999 in four heathland sites in the UK (5) found that using fences to exclude livestock increased the cover of heather *Calluna vulgaris* and reduced grass cover. In four of four cases, after six years heather cover in areas that were fenced increased by 5–22% relative to the same areas before fencing, whereas heather cover in areas that were not fenced decreased by 23–31%. In three of four cases, after six years, grass cover declined by 9–27% in areas that were fenced, whereas in areas that were not fenced grass cover increased by 19–30%. In 1993 two 60 m^2 plots were fenced and two plots were left unfenced at each site. Nitrogen, phosphorous, and potassium were applied to half of the fenced and unfenced plots. Twelve 1 m^2 quadrats were randomly placed in the plots and vegetation cover was estimated by eye every year in 1993-1999.

A replicated, controlled, randomized study in 2001–2002 in a heathland in Germany (6) found that using fences to exclude sheep increased the biomass of heather *Calluna vulgaris* and wavy hair grass *Deschampsia flexuosa*. After 1 year, the biomass of heather was higher in plots that had been fenced (8,270 kg/ha) than in unfenced plots (6,259 kg/ha). Similarly, the biomass of wavy hair-grass was higher in plots that had been fenced (404 kg/ha) than in unfenced plots (303 kg/ha). In 2001 forty 2 m^2 plots were randomly located in the heathland. Plots were divided in two with one half fenced and the other left open to grazing sheep. In 2002 plants were harvested from plots, then air dried and weighed to estimate biomass.

A replicated, controlled, randomized study in 2002–2006 in two degraded moorlands in the UK (7,8) found that using fences to exclude livestock increased the abundance of heather *Calluna vulgaris* plants in one of two sites after three years, but decreased the presence of heather in the other case. At one site heather plant density was higher in areas that were fenced to exclude livestock (38 plants/m^2) than in unfenced areas (16 plants/m^2), while at the other site there was no significant difference between fenced and unfenced areas. Similarly, at one site heather plants were present in fewer of the fenced plots (39%) than the in unfenced plots (46%), while at the other site there was no significant difference between fenced and unfenced areas. At each site fifty-four 100 m^2 plots were established. Half of each plot was fenced with the other half left unfenced. Plant cover was estimated annually, between 2003 and 2006, using nine 1 m^2 quadrats in each plot.

A randomized, replicated, paired, controlled study in 1997–2003 in a heathland site in the UK (9) found that fencing to exclude livestock increased vegetation height and biomass, but had a mixed effect on the number of plant species. After six years and in five of six comparisons, vegetation was taller in fenced areas (32–137 cm) than in unfenced areas (4–16 cm). Plant biomass was higher in fenced areas (1352–2832 g/m^2) than in unfenced areas (751 g/m^2). In one of two comparisons the number of plant species in fenced areas was lower (9 species) than in unfenced areas (17 species) but in one of two comparisons there was no significant difference in the number of plant species (fenced: 16 species, unfenced 17 species). The site was grazed by approximately 20 sheep throughout the study. Twenty four 4 x 4 m plots that were fenced to exclude livestock were established at the site, along with 12 unfenced plots. Half of the fenced plots could be accessed by rabbits that were present at the site. All plots were paired. In 2003 vegetation height was measured in each plot using a ruler and vegetation was harvested from subplots adjacent to plots to calculate biomass. Vegetation cover of all plant species was recorded in plots 2003.

A replicated, controlled, randomized study in 2002–2010 in a former heathland in the UK (10) found that in two of three cases using fences to exclude livestock increased the height and biomass of heather *Calluna vulgaris* plants. After eight years, fenced areas had taller heather plants (31 cm) than unfenced areas grazed by sheep or both sheep and cattle (11–12 cm), but areas grazed by just cattle did not differ significantly in height (27 cm). Heather plants in fenced areas also had higher biomass (17 g) than those in areas grazed by sheep (2 g) or both sheep and cattle (3 g), but heather plants in areas grazed by only cattle did not have significantly lower biomass (12 g). In 2002, nine 5–7 ha paddocks were selected. Paddocks were grazed with cattle, sheep, or left ungrazed. In each paddock six 10 x 10 m plots were established. These plots were divided into four 4 x 4 m subplots two of which were fenced to reduce grazing and two of which were left unfenced. Vegetation height was recorded in each subplot in May 2010. In May 2010 heather was also cut and weighed to calculate biomass.

A site comparison study in 1958–2008 in sagebrush scrub in Nevada, USA (11) found that using fences to exclude livestock decreased cover of woody plants and increased cover of grasses, but did not alter forb cover after 50 years. In fenced areas cover of woody plants (10%) was lower than in unfenced areas (38%), but for grass species the opposite was true (fenced: 32%, unfenced: 5%). There was no significant difference in the cover of forb species between fenced (10%) and unfenced areas (6%). In the 1950s part of the site was fenced to exclude livestock. In 2008 vegetation cover was estimated in 10 randomly placed 1 m^2 quadrats in both the fenced and unfenced areas.

A replicated, controlled study in a heathland site in the UK (12) found that fencing to exclude livestock had no effect on vegetation composition and did not alter the abundance of bentgrass *Agrostis spp.,* festuca species *Festuca spp.,* rush *Juncus spp.,* moor grass *Molinia spp.,* sedge *Carex spp.,* heather *Calluna spp.,* heath *Erica spp.,* or *Myrica spp.*. Vegetation in grazed areas has a similar community composition to that found in ungrazed areas (data presented as graphical analysis). There were no significant differences in the abundance of bentgrass, festuca, rush, moor grass, sedge, heather, heath, or *Myrica spp.* between grazed and ungrazed areas (data not presented). There were 0.12 cattle/ha and 0.08 horses/ha in the grazed part of the site. Four fenced plots were established at the site along with four unfenced plots. Within each plot vegetation cover was estimated.

A controlled, before-and-after trial in 2003–2012 in a heathland previously affected by fire in Surrey, UK (13) found that cover of dwarf shrubs increased more in fenced areas than in unfenced areas, that cover of purple-moor grass *Molinia caerulea* remained similar in fenced and unfenced areas, and that the number of plant species was higher in unfenced areas. Before fencing, the cover of dwarf shrubs was similar in areas that were subsequently fenced (4–8% cover) and unfenced (5–8% cover). However, after nine years fenced areas had higher cover of dwarf shrubs (38–54%) than unfenced areas (27–36%). Before fencing, cover of purple moor grass was also not significantly different between areas that were subsequently fenced (11–47%) and those that were unfenced (19–45%) and this remained the case nine years after fencing (fenced: 12–63% cover; unfenced: 16–42% cover). The number of plant species was lower in fenced areas than unfenced areas (data presented as model results). The entire heathland was burned by wildfire in 2003. Cattle were introduced to the area in 2005, but three areas were fenced to exclude cattle. In 2003, 2010, and 2012 vegetation cover was recorded in fifty-eight 1 m^2 quadrats placed in the fenced area and 116 quadrats in the unfenced area.

(1) Bülow-Olsen, A. (1980) Changes in the species composition in an area dominated by *Deschampsia flexuosa* (L.) trin. as a result of cattle grazing. *Biological Conservation*, 18, 257-270.
(2) Bork, E.W., West, N.E. & Walker, J.W. (1998) Cover components on long-term seasonal sheep grazing treatments in three-tip sagebrush steppe. *Journal of Range Management*, 293-300.
(3) Virtanen, R. (1998) Impact of grazing and neighbour removal on a heath plant community transplanted onto a snowbed site, NW Finnish Lapland. *Oikos*, 81, 359-367.
(4) Welch, D. (1998) Response of bilberry *Vaccinium myrtillus* L. stands in the Derbyshire Peak District to sheep grazing, and implications for moorland conservation. *Biological Conservation*, 83, 155-164.
(5) Hartley, S.E. & Mitchell, R.J. (2005) Manipulation of nutrients and grazing levels on heather moorland: changes in Calluna dominance and consequences for community composition. *Journal of Ecology*, 93, 990-1004.
(6) Fottner, S., Härdtle, W., Niemeyer, M., Niemeyer, T., Von Oheimb, G., Meyer, H. & Mockenhaupt, M. (2007) Impact of sheep grazing on nutrient budgets of dry heathlands. *Applied Vegetation Science*, 10, 391-398.
(7) Mitchell, R.J., Rose, R.J. & Palmer, S.C.F. (2008) Restoration of Calluna vulgaris on grass-dominated moorlands: The importance of disturbance, grazing and seeding. *Biological Conservation*, 141, 2100-2111.
(8) Mitchell, R.J., Rose, R.J. & Palmer, S.C.F. (2009) The effect of restoration techniques on non-target species: Case studies in moorland ecosystems. *Applied Vegetation Science*, 12, 81-91.
(9) Denyer, J.L., Hartley, S.E. & John, E.A. (2010) Both bottom-up and top-down processes contribute to plant diversity maintenance in an edaphically heterogeneous ecosystem. *Journal of Ecology*, 98, 498-508.
(10) Critchley, C.N.R., Mitchell, R.J., Rose, R.J., Griffiths, J.B., Jackson, E., Scott, H. & Davies, O.D. (2013) Re-establishment of *Calluna vulgaris* (L.) Hull in an eight-year grazing experiment on upland acid grassland. *Journal for Nature Conservation*, 21, 22-30.
(11) Rickart, E.A., Bienek, K.G. & Rowe, R.J. (2013) Impact of Livestock Grazing on Plant and Small Mammal Communities in the Ruby Mountains, Northeastern Nevada. *Western North American Naturalist*, 73, 505-515.
(12) Wilkie, M., *Mixed herbivore grazing on a lowland heath system: quantifying the collective impacts for conservation management*. 2013, University of Southampton.
(13) Groome, G.M. & Shaw, P. (2015) Vegetation response to the reintroduction of cattle grazing on an English lowland valley mire and wet heath. *Conservation Evidence*, 12, 33-39.

3.2 Reduce number of livestock

- Two before-and-after trials in the UK[1] and South Africa[7], and one replicated, controlled study in the UK[3] found that the reducing[1,3] or stopping[6], grazing increased the abundance[1], or cover[3,6] of shrubs. Two site comparison studies in the UK[2,9] found that cover of common heather declined in sites with high livestock density, but increased in sites with low livestock density. One site comparison study in the Netherlands[13] found that dwarf shrub cover was higher in ungrazed sites. One replicated, randomized, before-and-after study in Spain[10] found that reducing grazing increased the cover of western gorse. One randomized, controlled trial and one before-and-after trial in the USA[5,11] found that stopping grazing did not increase shrub abundance. One site comparison study in France[8] found that ungrazed sites had a higher cover of ericaceous shrubs, but a lower cover of non-ericaceous shrubs than grazed sites.

- One replicated, randomized, controlled study in the UK[5] found that reducing grazing increased vegetation height. However, one replicated, controlled, paired site, site comparison study in the UK[12] found that reducing grazing led to a reduction in the height of heather plants.
- Two site comparison studies in France[8] and the Netherlands[14] found that ungrazed sites had a lower number of plant species than grazed sites. One replicated, controlled, paired, site comparison study in Namibia and South Africa[15] found that reducing livestock numbers increased plant cover and the number of plant species.
- One controlled study in Israel[16] found that reducing grazing increased plant biomass. However, one randomized, site comparison on the island of Gomera, Spain[13] found that reducing grazing did not increase plant cover and one replicated, controlled study in the UK[3] found that the number of plant species did not change .
- One replicated, controlled study in the UK[3] found no change in the cover of rush or herbaceous species as a result of a reduction in grazing. Two site comparison studies in France[8] and the Netherlands[14] found that grass cover[8,14] and sedge cover[14] were lower in ungrazed sites than in grazed sites. One randomized, controlled study in the USA[11] found a mixed effect of reducing grazing on grass cover.

Background

Reducing grazing intensity by reducing livestock numbers may allow plants to grow taller and allow species that cannot tolerate heavy grazing to grow. However, it may also reduce the abundance of non-shrub plant species.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A before-and-after trial in 1983–1990 at a moorland site in the UK (1) found that reducing sheep density increased the abundance of shrub and grass species. Cover was higher seven years after sheep removal for the shrubs common heather *Calluna vulgaris* (16%) and bilberry *Vaccinium myrtillus* (14%) than before removal (heather: 0%; bilberry: 1%). Cover and biomass of wavy-hair grass *Deschampsia flexuosa* were also higher seven years after sheep removal (cover: 83%; biomass: 56 g/plot) than before sheep removal (cover: 41%; biomass: 9 g/plot). Between 1982 and 1990 sheep numbers were reduced from 2.5 ewes/ha to 0.3 ewes/ha (with some fluctuations between). Vegetation cover was measured each spring at 1 m intervals along 10 permanent transects per plot.

A site comparison in 1967-1987 in 15 heathland sites in the UK (2) found that common heather *Calluna vulgaris* cover decreased at sites with high livestock density. Over 20 years cover of common heather increased in sites with low livestock density but decreased in sites with high livestock density (no data reported). Ten point quadrats were used to estimate vegetation cover at each sites in July or August every two years. Dung was counted to assess herbivore abundance at each site.

A replicated, controlled, paired study in 1968–1990 in 22 heathlands sites in the UK (3) found that reducing the number of livestock increased cover of heather *Calluna vulgaris*, had no effect on cover of rush and herbaceous species, as well as the number of plant species, and reduced grass cover. Sites where grazing had been stopped had higher cover of heather than sites that were grazed, but cover of the dwarf shrubs cross-leaved heath *Erica tetralix,* bell heather *Erica cinerea,* or bilberry *Vaccinium myrillus* did not differ significantly between ungrazed and grazed sites (data not presented). Cover of grass species was lower in sites where grazing had stopped than in sites that were grazed (data not presented). Rush and herbaceous cover did not differ significantly between ungrazed and grazed areas, and the same was true for the number of plant species in each site (data not presented). Sites were paired based on soil type and details of previous land-use. Sheep were removed from ungrazed sites in 1964–1987. In the summers of 1989 and 1990 four to eighteen 1 m^2 quadrats were placed in each site and the cover of each plant species assessed.

A replicated, site comparison in 1994 at three heathlands in the UK (4) found that reducing the abundance of livestock had mixed effects on the cover of shrubs, grasses, and herbaceous plant species. Reducing the abundance of livestock increased cover of shrub species in one of nine comparisons (ungrazed: 80%, grazed: 45%) but reduced cover of shrub species in three of nine comparisons (ungrazed: 0-2%, grazed: 3-8%). For one of eight comparisons cover of grass species was lower in grazed (9%) than ungrazed areas (32%) but for three of eight comparisons cover of grass species was higher in grazed (3-8%) than ungrazed areas (0%). For three of six comparisons cover of herbaceous species was higher in grazed (2-3%) than in ungrazed areas (0%) while for the remaining three comparisons cover did not differ in grazed and ungrazed areas. At each site one area was grazed and another area was not grazed. At each site 5-15 quadrats were located randomly and cover of plant species estimated by eye.

A replicated, randomized, controlled trial between 1989 and 1995 in wet heathland in Northumberland, UK (5) found that reducing the number of sheep increased vegetation height after six years. Vegetation was taller in plots where grazing was light (37 cm) or moderate (37 cm) when compared to heavily grazed areas (12 cm). Heather *Calluna vulgaris* shoots were also longer in areas where grazing was reduced (63 cm) than in areas that were heavily grazed (44 cm). Four blocks, each composed of two 0.3 plots, were fenced in 1989. Within each block one plot had a density of 0.7 sheep/ha, and one plot had 1.4 sheep/ha. Nearby grazed heath with 2.1 sheep/ha was used for comparisons. Vegetation height was measured twice a year between 1989 and 1995 at 40 random locations in each plot using a sward stick

A before-and-after study in 1986–1992 in desert scrub in Arizona, USA (6) found that removal of cattle did not affect the abundance of shrubs, herbaceous plants, or trees. Five years after cattle had been removed, the density of shrubs was not significantly higher than in the same area before cattle removal (data reported as a density index). The same pattern was seen for herbaceous plants and trees. In 1987 all cattle were removed from the area. Prior to removal the stocking rate of the area was approximately 0.5 cattle/ha. Two transects, measuring 0.8–1.6 km in length were established in the area. Vegetation was sampled along the transects in September/October in 1986, 1989, and 1992.

A before-and-after trial in 1935–2004 in karoo habitat in Western Cape, South Africa (7) found that stopping livestock grazing led to increases in the cover of shrubs and trees, decreases in the cover of succulent plants, and no change in grass cover after 67 years. In three of four locations shrub cover was higher 67 years after grazing stopped (33–56%) than when the area was grazed (30–40%). Tree cover increased in two of four cases (before: 1–5%, after: 12–13%), while grass cover did not significantly change in four of four cases (before: 0–1%, after: 1–2%). However, in one of four cases the cover of succulent plants was lower 67 years after grazing was halted (38%) than before grazing stopped (60%). In 1935 all cattle were removed from the site. In 1935 vegetation cover was visually estimated in seven hundred and two 900 m^2 quadrats and in 2004 in seventy 900 m^2 quadrats distributed across four distinct areas of the site.

A site comparison study in 2006 in six heathland sites in France (8) found that sites not grazed by cattle had a lower number of plant species, lower cover of grass and non-ericaceous shrubs, but higher cover of ericaceous shrubs. Ungrazed sites had a lower number of plant species and cover of grass (species: 7–8 species/plot, grass: 2–24% cover) than grazed sites (species: 13–14 species/plot, grass: 47–54% cover). Three of the four ungrazed sites also had lower cover of non-ericaceous shrubs (9–58%) than grazed sites (66-67%). However, cover of ericaceous shrubs was higher in ungrazed sites (86-95%) than in grazed sites (56-63%). Two moderately grazed sites and four ungrazed sites were selected for study. In 2006 four 1 m^2 plots were placed at each site and plant cover estimated.

A site comparison in 10 heathland sites that were subject to grazing in the UK (9) found that the cover of common heather *Calluna vulgaris* increased in sites with low sheep density and declined in areas with high sheep density. Common heather cover increased in sites where there were fewer than two sheep/ha and declined when there were greater than two sheep/ha (data reported as model results). Heather cover was estimated in seventy four plots across the 10 sites. Stocking density at the sites varied between zero and six sheep/ha.

A replicated, randomized, before-and-after trial between 2002 and 2006 in a heathland in Northern Spain (10) found that reducing livestock numbers increased the cover of western gorse *Ulex gallii* and the height of plants. After four years cover of western gorse was higher in lightly grazed plots (18%) than in heavily grazed plots (9%). Plants in lightly grazed plots were taller (27 cm) than in more heavily grazed plots (17 cm). There were no differences between lightly and heavily grazed plots in the cover of dwarf heather species (43% vs 34%), tall heather species (9% vs 6%), or herbaceous plant species (25% vs 27%). In addition there were no differences in plant species richness between lightly and heavily grazed plots (27 vs 28 species). In 2002 six 0.6 ha heathland plots were fenced. Each plot was randomly allocated either a high (15 goats/ha) or a low (7 goats/ha) grazing pressure. In each plot 100 random points were used to survey vegetation cover. Plant height was measured using a sward stick every 10 cm along a 50 m transect in each plot.

A randomized, controlled study in 2001–2004 in a sagebrush-steppe habitat affected by wildfire in Idaho, USA (11) found that areas that were not grazed did not have higher shrub abundance than areas that were grazed, but there was mixed effect on grass abundance. Cover of the shrubs threetip sagebrush *Artemesia tripartita* and bitterbrush *Purshia tridentata* did not differ significantly between ungrazed (sagebrush: 1 plant/10 m^2, bitterbrush: 0.3 plants/10 m^2) and grazed areas (sagebrush: 2–4 plants/10 m^2, bitterbrush: 0–0.6 plants/10 m^2). Cover of bluebunch wheatgrass *Pseudoroegneria spicata* was higher in ungrazed (9.4%) than grazed areas (7.3%), but the abundance of drooping brome *Bromus tectorum* was lower in ungrazed (10 plants/10 m^2) than grazed areas (12–60 plants/10 m^2). In 2000 a fire burnt 474 ha of the site. Twenty four 2.4–3.3 ha paddocks were established in 2001. Twenty paddocks were grazed by sheep (stocking rate 120 sheep/ha) and four were not. Two 15 m x 1 m transects were established in each paddock and surveyed to estimate vegetation cover annually in 2001–2004.

A replicated, controlled, paired side, site comparison study in 2007–2009 in sixteen heathland sites in Scotland, UK (12) found that reducing sheep numbers reduced the height of heather (plants of the family Ericaceae). In sites without sheep heather was shorter (13–34 cm) than in sites where sheep were present (17–32 cm). Sheep were removed from eight sites and eight sites were grazed by sheep. All sites were grazed by red deer *Cervus elaphus*, but deer numbers were higher in areas where sheep had been removed. Six to twelve 10 x 10 m plots were established at each site. Within each plot vegetation height and cover was measured at 40 points.

A randomized, site comparison in 1975–2005 in coastal shrubland on the island of Gomera, Spain (13) found that reducing the number of goats did not increase plant cover after 30 years. There was no significant difference in plant cover between areas where goats had been removed (67%) and areas where goats were present (67%). Goat abundance in grazed areas was low – 0.1 goat/ha. Twenty 30 m transects were randomly located in grazed areas and 16 in ungrazed areas. Plant cover was assessed every 30 cm.

A site comparison study in 2011 in coastal heathland in the Netherlands (14) found that ungrazed areas had fewer plant species, lower sedge *Carex* spp. and grass cover, but higher cover of dwarf shrubs. Ungrazed areas has a lower number of plant species (5 species/plot) than grazed areas (6 species/plot). Ungrazed areas also had lower sedge and grass cover than areas that were grazed (data not reported). However, cover of dwarf shrubs was higher in ungrazed areas than in grazed areas (data not reported). Grazed and ungrazed areas were separated with a fence. Grazed areas were stocked with sheep at a density of 5.7 sheep/ha. Thirty-two plots were located in the ungrazed area and 33 in the grazed area. At each plot a point frame was used to estimate cover of different plant species.

A replicated, controlled, paired site, site comparison study in 2005–2009 in three karoo shrubland sites in Namibia and South Africa (15) found that reducing livestock numbers increased plant cover in three of three sites and increased the number of plant species in one of three sites. In three of three sites, areas where livestock numbers were low had higher plant cover (13–39%) than areas with high livestock numbers (8–29%). In one of three sites plant species richness was higher in areas with low livestock numbers (15 species) than areas with high livestock numbers (12 species), while at the other two sites there was no significant difference in plant species richness (low grazing: 23–36 species, high grazing: 24–34 species). High and low livestock areas were separated by a fence. Vegetation cover was monitored in 2005–2009 using between sixteen and twenty 100 m^2 plots in both areas with low and high livestock numbers.

A controlled study in 1992–2008 in an arid shrubland in Israel (16) found that reducing goat numbers increased plant biomass after 16 years. Plant biomass was higher in areas with low goat numbers (0.16 kg/m^2) when compared to nearby heavily grazed areas (0.07 kg/m^2). In 1992 goat numbers were reduced at the site to <0.5 goats/ha. In 2008 fifteen quadrats measuring 20 cm x 30 cm were placed in both the light and heavily grazed areas and all vegetation was removed. Vegetation was dried for 48 hours at 60°C, then weighed to estimate biomass.

(1) Anderson, P. & Radford, E. (1994) Changes in vegetation following reduction in grazing pressure on the National Trust's Kinder Estate, Peak District, Derbyshire, England. *Biological Conservation*, 69, 55-63.

(2) Welch, D. & Scott, D. (1995) Studies in the Grazing of Heather Moorland in Northeast Scotland. VI.20-Year Trends in Botanical Composition. *Journal of Applied Ecology*, 32, 596-611.

(3) Hope, D., Picozzi, N., Catt, D.C. & Moss, R. (1996) Effects of reducing sheep grazing in the Scottish Highlands. *Journal of Range Management*, 49, 301-310.

(4) Bullock, J.M. & Pakeman, R.J. (1997) Grazing of lowland heath in England: Management methods and their effects on healthland vegetation. *Biological Conservation*, 79, 1-13.

(5) Hulme, P.D., Merrell, B.G., Torvell, L., Fisher, J.M., Small, J.L. & Pakeman, R.J. (2002) Rehabilitation of degraded Calluna vulgaris (L.) Hull-dominated wet heath by controlled sheep grazing. *Biological Conservation*, 107, 351-363.

(6) Krueper, D., Bart, J. & Rich, T.D. (2003) Response of vegetation and breeding birds to the removal of cattle on the San Pedro River, Arizona, USA. *Conservation Biology*, 17, 607-615.

(7) Rahlao, S.J., Hoffman, M.T., Todd, S.W. & McGrath, K. (2008) Long-term vegetation change in the Succulent Karoo, South Africa following 67 years of rest from grazing. *Journal of Arid Environments*, 72, 808-819.

(8) Gachet, S., Sarthou, C., Bardat, J. & Ponge, J.-F. (2009) The state of change of *Erica scoparia* L. heathland through cattle grazing and oak colonization. *Revue d'Ecologie, Terre et Vie*, 64, 3-17.

(9) Pakeman, R.J. & Nolan, A.J. (2009) Setting sustainable grazing levels for heather moorland: a multi-site analysis. *Journal of Applied Ecology*, 46, 363-368.

(10) Celaya, R., Jáuregui, B.M., García, R.R., Benavides, R., García, U. & Osoro, K. (2010) Changes in heathland vegetation under goat grazing: Effects of breed and stocking rate. *Applied Vegetation Science*, 13, 125-134.

(11) Roselle, L., Seefeldt, S.S. & Launchbaugh, K. (2010) Delaying sheep grazing after wildfire in sagebrush steppe may not affect vegetation recovery. *International Journal of Wildland Fire*, 19, 115-122.

(12) DeGabriel, J.L., Albon, S.D., Fielding, D.A., Riach, D.J., Westaway, S. & Irvine, R.J. (2011) The presence of sheep leads to increases in plant diversity and reductions in the impact of deer on heather. *Journal of Applied Ecology*, 48, 1269-1277.

(13) Bermejo, L.A., de Nascimento, L., Mata, J., Fernández-Lugo, S., Camacho, A. & Arévalo, J.R. (2012) Responses of plant functional groups in grazed and abandoned areas of a Natural Protected Area. *Basic and Applied Ecology*, 13, 312-318.

(14) Damgaard, C., Thomsen, M.P., Borchsenius, F., Nielsen, K.E. & Strandberg, M. (2013) The effect of grazing on biodiversity in coastal dune heathlands. *Journal of coastal conservation*, 17, 663-670.

(15) Hanke, W., Böhner, J., Dreber, N., Jürgens, N., Schmiedel, U., Wesuls, D. & Dengler, J. (2014) The impact of livestock grazing on plant diversity: an analysis across dryland ecosystems and scales in southern Africa. *Ecological Applications*, 24, 1188-1203.

(16) Leu, S., Mussery, A. & Budovsky, A. (2014) The Effects of Long Time Conservation of Heavily Grazed Shrubland: A Case Study in the Northern Negev, Israel. *Environmental Management*, 54, 309-319.

3.3 Change type of livestock

- Two replicated, before-and-after studies[2,3] and one controlled study[1] in Spain[1,2] and the UK[3] found changing the type of livestock led to mixed effects on shrub cover. However, in two of these studies changing the type of livestock reduced the cover of herbaceous species[1,2]. One replicated, controlled, before-and-after study[3] found that grazing with both cattle and sheep, as opposed to grazing with sheep, reduced cover of purple moor grass, but had no effect on four other plant species.

Background

Changing the type of livestock that graze in shrublands may help to reduce grazing pressure on particular plant species that were previously damaged by overgrazing, thereby allowing recovery of populations of these plants. Changes in the type of livestock may also lead to changes in the structure of the community, such as the height of plants.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A controlled study in 2001–2003 in a heathland affected by burning in northern Spain (1) found that grazing with sheep instead of goats led to an increase in the cover of gorse *Ulex europeaus* and lower cover of herbaceous plants, but to no difference in the cover of heather *Calluna vulgaris* or in total plant biomass. After two years, gorse cover in plots grazed by sheep (27% cover) was higher than that in plots grazed by goats (14% cover). Cover of herbaceous plants was lower in areas grazed by sheep (27% cover) than those grazed by goats (42% cover). However, heather cover did not differ from between areas grazed by sheep (1% cover) and areas grazed by goats (1% cover). Plant biomass also did not differ significantly between areas grazed by sheep (10 tonnes/ha) and areas grazed by goats (9 tonnes/ha). In 2001 eight 0.3 ha plots were established with Gallega sheep, and eight plots with Cashmere goats. Stocking rate was approximately 10 animals/ha. Plant cover was recorded every year in 2001–2003 using point quadrats placed along six 13-metre-long transects in each plot. The vegetation in five randomly placed 0.2 m^2 quadrats was harvested and dried for biomass estimation.

A replicated, controlled, before-and-after study in 2001-2006 in degraded wet heath in Northumberland, UK (2) found that grazing with both cattle and sheep, as opposed to just grazing with sheep, reduced purple moor grass *Molinia caerulea* cover, had mixed effects on cover of common heather *Calluna vulgaris*, and had no effect on the cover of four other plant species. Cover of *Molinia caerulea* declined after the introduction of cattle into areas grazed by sheep (after: 15-19%, before: 12-13%), but increased in areas that were only grazed by sheep (after: 20-19%, before: 29-13%). Common heather cover declined in one of two areas grazed by sheep and cattle (before: 13%, after 20%), but one of two areas saw no significant change over time (before: 14%, after 12%). Common heather cover declined in areas grazed by only sheep (before: 12-21%, after: 8-18%). The cover of common sedge *Carex nigra*, reed species *Juncus* spp., hare's-tail cottongrass *Eriophorum vaginatum*, and mat grass *Nardus stricta* did not change significantly over time in areas that were grazed by sheep and cows (before: 2-11%, after: 3-14%). The heathland was split into four areas by fencing, two of which were stocked with both sheep and cattle, and two of which were stocked only with sheep. The entire area was grazed by sheep from 1995 and cows were introduced in 2003. Vegetation cover was recorded in one hundred and ninety six 1 m^2quadrats in July–August 2001, and 2003-2006.

A replicated, randomized, before-and-after trial between 2002 and 2006 in a heathland in northern Spain (3) found that plots grazed by cashmere goats had higher cover of dwarf heather species but lower herbaceous species cover and number of plant species than those grazed by celtiberic goats. After four years, cover of dwarf heather species was higher in plots grazed by cashmere goats (32%) than in plots grazed by celtiberic goats (15%). However, cover of herbaceous species was lower in plots grazed by cashmere goats (cashmere: 30%; celtiberic: 47%), as was the number of plant species (cashmere: 23 species/plot; celtiberic: 26 species/plot). There were no significant differences in plant height (17 cm vs 13 cm), or western gorse *Ulex galli* cover (8% vs 11%) between plots grazed by cashmere or celtiberic goats. In 2002, six 0.6 ha heathland plots were fenced. Each plot was randomly allocated to be stocked with celtiberic goats (12 goats/ha) or a cashmere goats (15 goats/ha). In each plot 100 random points were used to survey vegetation cover. Plant height was measured using a sward stick every 10 cm along a 50 m transect in each plot.

(1) Jáuregui, B.M., Celaya, R., Garcia, U. & Osoro, K. (2007) Vegetation dynamics in burnt heather-gorse shrublands under different grazing management with sheep and goats. *Agroforestry Systems*, 70, 103-111.
(2) Critchley, C.N.R., Adamson, H.F., McLean, B.M.L. & Davies, O.D. (2008) Vegetation dynamics and livestock performance in system-scale studies of sheep and cattle grazing on degraded upland wet heath. *Agriculture, Ecosystems & Environment*, 128, 59-67.
(3) Celaya, R., Jáuregui, B.M., García, R.R., Benavides, R., García, U. & Osoro, K. (2010) Changes in heathland vegetation under goat grazing: Effects of breed and stocking rate. *Applied Vegetation Science*, 13, 125-134.

3.4 Shorten the period during which livestock can graze

- One replicated, controlled, before-and-after study in the UK[1] found that shortening the period in which livestock can graze had mixed effects on heather, bilberry, crowberry, and grass cover.
- One replicated, randomized, controlled study in the UK[2] found that grazing in only winter or summer did not affect the heather or grass height compared to year-round grazing.

Background
High grazing pressure can reduce the cover of woody species in shrublands, leading to an increase in grass cover or unvegetated areas. Shortening the period during which livestock can graze is a potential solution to overgrazing.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock; change type of livestock (section 3.3); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A replicated, controlled, before-and-after study in 1990-1996 in two moorland sites in Derbyshire, UK (1) found that restricting grazing to summer or winter had mixed effects on grass cover in and the cover of crowberry *Empetrum nigrum*, bilberry *Vaccinium myrtillus,* and heather *Calluna vulgaris*. In one site and after six years, grass cover was higher after restricting grazing (77%) than before grazing restriction (75%), while in another site it was lower (after: 62%, before: 81%). Over the same period, the cover of grass in plots with year-round grazing declined (from 77% to 52%). In one site, cover of crowberry was higher after restricting grazing (13%) than before grazing restriction (5%). In one site, cover of bilberry was lower after restricting grazing (50%) than before grazing restriction (68%), whereas cover of heather was higher after restricting grazing (28%) than before restriction (20%). Over the same period, the cover of bilberry in plots with year-round grazing also declined (from 73% to 56%). In each site, sheep were excluded by fencing from four areas of 25 m x 20 m during a six-month period over summer (April to October) or winter (October to April) and two nearby areas had year-round grazing. Vegetation height and cover was recorded annually in August.

A replicated, randomized, controlled study in 1989–1995 in wet heathland in Northumberland, UK (2) found that after six years only allowing grazing in winter or summer there was little difference in heather *Calluna vulgaris* height compared to areas exposed to year-round grazing. Heather height did not significantly differ in plots where grazing was only allowed in winter (38 cm), plots where grazing was only allowed in summer (38 cm), and plots where grazing was allowed year round (38 cm). The same was true for grass height (winter only: 37 cm; summer only: 33 cm; year-round: 31 cm). Four blocks, each composted of three 0.3 plots were fenced in 1989. Within each block one plot was grazed only in winter, one only in summer, and one year round. All plots had a density of 0.7 sheep/ha. Vegetation height was measured twice a year between 1989 and 1995 at 40 random locations using a sward stick.

(1) Welch, D. (1998) Response of bilberry Vaccinium myrtillus L. stands in the Derbyshire Peak District to sheep grazing, and implications for moorland conservation. *Biological Conservation*, 83, 155-164.
(2) Hulme, P.D., Merrell, B.G., Torvell, L., Fisher, J.M., Small, J.L. & Pakeman, R.J. (2002) Rehabilitation of degraded *Calluna vulgaris* (L.) Hull-dominated wet heath by controlled sheep grazing. *Biological Conservation*, 107, 351-363.

4. Threat: Energy production and mining

Background
Energy production and mining can cause dramatic impact on shrublands as they often result in complete removal of vegetation as well as reducing connectivity between existing shrubland habitats (Holmes 2001). The use of toxic chemicals in mining can also result in spillages with potentially disastrous consequences for surrounding ecosystems.

Related threats: development including buildings and infrastructure (Chapters 2 & 6) harvesting from shrublands i.e. biological resource use (Chapter 5); human intrusions and disturbance e.g. vehicles (Chapter 7); pollution (Chapter 10). Related interventions: habitat restoration (Chapters 13 & 14).

Holmes, P.M. (2001) Shrubland restoration following woody alien invasion and mining: effects of topsoil depth, seed source, and fertilizer addition. *Restoration Ecology*, 9, 71-84.

Key messages

4.1 Maintain habitat corridors in areas of energy production or mining

We captured no evidence for the effects on shrublands of maintaining habitat corridors in areas of energy production or mining.

Interventions

4.1 Maintain habitat corridors in areas of energy production or mining

We captured no evidence for the effects on shrublands of maintaining habitat corridors in areas of energy production or mining.

Background
The maintenance of habitat corridors in areas with widespread human land use has been suggested as a method to retain connectivity between sites (Beier and Noss 1998). This connectivity may help to maintain interactions between plant and animals such as pollination and seed dispersal, which can positively influence plant populations.

Related interventions: Maintain habitat corridors in developed areas (section 2.2); maintain habitat corridors over or under roads (section 6.1); add topsoil after mining operations have ceased (section 13.8).

Beier, P. & Noss, R.F. (1998) Do habitat corridors provide connectivity? *Conservation Biology*, 12, 1241-1252.

5. Threat: Biological resource use

Background

Shrubland species are exploited by humans as food, firewood, and, in the case of flowering plants, for aesthetic reasons. In particular, fynbos ecosystems in South Africa face pressures from harvesting of wild flowers, which may lead to local extinction of the exploited species (Privett *et al.* 2014). This kind of exploitation of shrublands can result in declines in the populations of plant species and alteration of vegetation structure (Thompson *et al.* 2016).

Related threats: Energy production and mining (Chapter 4); human intrusions and disturbance (Chapter 7); pollution (Chapter 10). Related interventions: habitat restoration (Chapters 13 & 14).

Privett, S.D.J., Krug, R.M., Forbes, G. & Gaertner, M. (2014) Wild flower harvesting on the Agulhas Plain, South Africa: Impact of harvesting intensity under a simulated commercial harvesting regime for two re-seeding and two re-sprouting fynbos species. South African Journal of Botany, 94, 270-275.

Thompson, P. S., Douglas, D. J., Hoccom, D. G., Knott, J., Roos, S., & Wilson, J. D. (2016). Environmental impacts of high-output driven shooting of Red Grouse *Lagopus lagopus scotica*. *Ibis*, 158(2), 446-452.

Key messages

5.1 Legally protect plant species affected by gathering

- We captured no evidence for the effects on shrublands of legally protecting the species affected by gathering.

5.2 Place signs to deter gathering of shrubland species

- We captured no evidence for the effects of placing signs to deter gathering of terrestrial species on shrublands.

5.3 Reduce the frequency of prescribed burning

- We captured no evidence for the effects on shrublands of reducing the frequency of prescribed burning.

Interventions - Gathering of terrestrial plants

5.1 Legally protect plant species affected by gathering

We captured no evidence for the effects of legally protecting the species affected by gathering on shrublands.

Background

Gathering of plants may involve removal of the whole plant (e.g. for sale as an ornamental species) or removal of plant parts, such as flowers or fruits. Gathering of certain species can be prohibited or limited by national legislation. In addition, international agreements such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) can be used to control the trade of certain species, potentially reducing the motivation for their harvest.

Related interventions: Place signs to deter gathering of shrubland species (section 5.3); legally protect shrubland (section 12.1); legally protect habitat around shrublands (section 12.2).

5.2 Place signs to deter gathering of shrubland species

We captured no evidence for the effects on shrublands of placing signs to deter gathering of shrubland species.

Background

In shrublands where plant species have been harvested signs could be installed to encourage people to not harvest these plants. Installation of signs has been shown to be effective in other contexts, such as reducing disturbance of nesting birds (Williams *et al.* 2017).

Related interventions: Re-route paths to reduce disturbance (section 7.1); use signs to reduce disturbance (section 7.2); plant spiny shrubs to act as barriers to people (section 7.3); raise awareness of shrubland conservation (section 15.1); provide education programmes about shrubland (section 15.2).

Williams, D.R., Child, M.F., Dicks, L.V., Ockendon, N., Pople, R.G., Showler, D.A., Walsh, J.C., zu Ermgassen, E.K.H.J. & Sutherland, W.J. (2017) Bird Conservation. Pages 95-244 in: W.J. Sutherland, L.V. Dicks, N. Ockendon & R.K. Smith (eds) *What Works in Conservation 2017*. Open Book Publishers, Cambridge, UK.

Interventions - Management of shrubland for game hunting

Background

In the UK heathlands are extensively used for shooting of red grouse *Lagopus lagopus scotica* a subspecies of willow ptarmigan *Lagopus lagopus.* Game management may involve controlled burning which can result in a reduction in the height of shrub species (Thompson *et al*. 2016), as well as an increase in the heterogeneity of heathland habitat (Sotherton *et al.* 2017).

Thompson, P. S., Douglas, D. J., Hoccom, D. G., Knott, J., Roos, S., & Wilson, J. D. (2016). Environmental impacts of high-output driven shooting of Red Grouse *Lagopus lagopus scotica*. *Ibis*, 158(2), 446-452.

Sotherton, N., Baines, D. & Aebischer, N.J. (2017) An alternative view of moorland management for Red Grouse Lagopus lagopus scotica. Ibis, 159, 693-698.

5.3 Reduce the frequency of prescribed burning

We captured no evidence for the effects of reducing the frequency of prescribed burning on shrublands.

Background

Prescribed burning is often used in the context of game management in the UK to create a mosaic of differently aged heathland patches. These patches provide areas of shorter, succulent heather *Calluna* spp. on which red grouse *Lagopus lagopus scotica* can feed and taller, denser areas which can be used as cover (Harris et al, 2011). However, burning can, in some cases, lead to a loss of shrubs from shrublands and an increase in grasses and herbaceous plants (Bradstock *et al.* 1997, Hobbs & Gimingham 1987). Reducing the frequency of prescribed burning may help to increase shrub cover.

Related interventions: Use prescribed burning to mimic natural fire cycle (section 8.1); use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.19); cut and use prescribed burning to control grass (section 9.20); burn shrublands to reduce concentration of pollutants (section 10.7).

Bradstock, R. A., Tozer, M. G., & Keith, D. A. (1997). Effects of high frequency fire on floristic composition and abundance in a fire-prone heathland near Sydney. *Australian Journal of Botany*, 45(4), 641-655.

Harris, M. P., Allen, K. A., McAllister, H. A., Eyre, G., Le Duc, M. G., & Marrs, R. H. (2011). Factors affecting moorland plant communities and component species in relation to prescribed burning. Journal of Applied Ecology, 48(6), 1411-1421.

Hobbs, R. J., & Gimingham, C. H. (1987). Vegetation, fire and herbivore interactions in heathland. *Advances in ecological research*, 16, 87-173.

6. Threat: Transportation and service corridors

Background
The building of roads, rail, and other transport infrastructure, as well as service corridors such as pipelines and electrical lines, can fragment habitat, limiting dispersal of animals and plant seeds and pollen (Coffin, 2007). Traffic can also increase the pollution that plants and animals are exposed to, such as heavy metals, salts, ozone, and nutrients, as well as facilitating the arrival of potentially invasive or problematic species or increasing rates of habitat clearance (Laurance *et al.* 2009, van der Ree *et al.* 2015)

Related threats: harvesting from shrublands i.e. biological resource use (Chapter 5); infrastructure such as roads, rail, and gas lines (Chapter 6); human intrusions and disturbance e.g. vehicles (Chapter 7); pollution (Chapter 10). Related interventions: habitat restoration (Chapters 13 & 14).

Coffin, A. W. (2007). From roadkill to road ecology: a review of the ecological effects of roads. Journal of Transport Geography, 15(5), 396-406.

Laurance, W. F., Goosem, M., & Laurance, S. G. (2009). Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution, 24(12), 659-669.

van der Ree, R., Smith, D. J., & Grilo, C. (2015). Handbook of road ecology. John Wiley & Sons.

Key messages

6.1 Maintain habitat corridors over or under roads and other transportation corridors

- We captured no evidence for the effects of maintaining habitat corridors over or under roads and other transportation corridors on shrublands.

6.2 Create buffer zones beside roads and other transportation corridors

- We captured no evidence for the effects on shrublands of creating buffer zones beside roads and other transportation corridors.

Interventions

6.1 Maintain habitat corridors over or under roads and other transportation corridors

We captured no evidence for the effects on shrublands of maintaining habitat corridors over or under roads and other transportation corridors.

Background
The maintenance of habitat corridors in areas with widespread human land use has been suggested as a method to retain connectivity between sites (Beier and Noss, 1998). This connectivity may help to maintain interactions between plant and animals such as pollination and seed dispersal, which can aid survival of plant populations and increase plant diversity.

Related interventions: Maintain habitat corridors in developed areas (section 2.2); maintain habitat corridors in areas of energy production (section 4.1); improve connectivity between shrubland areas to allow species movements and habitat shifts in response to climate change (section 11.2), legally protect shrubland (section 12.1)

Beier, P., & Noss, R. F. (1998). Do habitat corridors provide connectivity? Conservation Biology, 12(6), 1241-1252.

6.2 Create buffer zones beside roads and other transportation corridors

We captured no evidence for the effects on shrublands of creating buffer zones beside roads and other transportation corridors.

Background

Building buffer zones adjacent to roads and other transportation corridors has been suggested as a way to reduce their impact on surrounding habitats (Spellerberg, 1998). Creating buffer zones increases the distances between roads and adjacent habitat. In particular buffer zones may help to reduce the inputs of pollutants from vehicle exhausts to nutrient-poor shrubland ecosystems (Angold 1997, Milton *et al.* 2015).

Related interventions: Legally protect habitat around shrublands (section 12.2).

Angold, P. G. (1997). The impact of a road upon adjacent heathland vegetation: effects on plant species composition. Journal of Applied Ecology, 409-417.

Milton S.J., Dean R.J., Sielecki L.E. & van der Ree R. (2015) The function and management of roadside vegetation. Pages 373-382 In: der Ree R., Smith D. J., & Grilo C. (eds). Handbook of road ecology. John Wiley & Sons.

Spellerberg, I. A. N. (1998). Ecological effects of roads and traffic: a literature review. Global Ecology and Biogeography, 7(5), 317-333.

7. Threat: Human intrusions and disturbance

Background
Humans can negatively impact natural habitats when they use them for recreation. Common sources of impact include hiking, camping, mountain biking, off-road vehicles, and horse-riding (Newsome *et al.* 2012), which may lead to damage to vegetation and increased erosion. This problem has been particularly prevalent in shrublands that have been subject to high pressure as a result of tourism (Gallet & Roze 2001). Human intrusions may also increase the spread of invasive and problematic species, as well as the accidental ignition of fires.

Related threats: harvesting from shrublands i.e. biological resource use (Chapter 5); infrastructure such as roads, rail, and gas lines (Chapter 6); changes in the frequency and intensity of fire (Chapter 8). Related interventions: habitat restoration (Chapters 13 & 14).

Gallet, S. & Roze, F. (2001) Resistance of Atlantic Heathlands to trampling in Brittany (France): influence of vegetation type, season and weather conditions. Biological Conservation, 97, 189-198.

Newsome D., Moore S. A., & Dowling R. K. (2012). *Natural area tourism: Ecology, impacts and management* (Vol. 58). Channel view publications.

Key messages

7.1 Re-route paths to reduce habitat disturbance

One before-and-after trial in Australia found that closing paths did not alter shrub cover, but did increase the number of plant species.

7.2 Use signs and access restrictions to reduce disturbance

We captured no evidence for the effects of placing signs to discourage access to sensitive areas of shrub habitat on shrublands.

7.3 Plant spiny shrubs to act as barriers to people

We captured no evidence for the effects of planting spiny shrubs to act as barriers to people on shrublands.

Interventions

7.1 Re-route paths to reduce habitat disturbance

- One before-and-after trial in Australia[1] found that closing paths did not alter shrub cover, but did increase the number of plant species in an alpine shrubland.

Background
Closing or re-routing paths may reduce trampling by humans and disturbance from bikes and other vehicles. This may allow plants to recover from human disturbance.

Related interventions: Use signs and access restrictions to reduce disturbance (section 7.2); plant spiny shrubs to act as barriers to people (section 7.3).

A before-and-after trial between 2001 and 2011 in alpine shrubland in Victoria, Australia (1) found that closing paths to reduce habitat disturbance increased the number of plant species, but did not alter shrub cover. After paths were closed former tracks had a higher number of plant species (15 species) than prior to paths being closed (12 species), as well as a higher number of species than areas that were adjacent to paths (12 species). Shrub cover on tracks did not differ significantly before (22%) or after (21%) closure, and this was not significantly different to adjacent areas (33%). Before path closure shrubs in areas adjacent to tracks were taller (26 cm) than those on tracks (17 cm) but after closure there was no significant difference in shrub heights between areas adjacent to tracks (14 cm) and former tracks (20 cm). Horse riding tracks were closed in 2001. In 2001 and 2011 vegetation cover was surveyed using forty 25 m^2 plots. Plots were either placed on tracks or directly adjacent to tracks.

(1) de Bie, K. & Vesk, P.A. (2014) Ecological indicators for assessing management effectiveness: A case study of horse riding in an Alpine National Park. *Ecological Management and Restoration*.

7.2 Use signs and access restrictions to reduce disturbance

We captured no evidence for the effects of placing signs to discourage access to sensitive areas of shrub habitat on shrublands.

Background
Signs can be installed to discourage people from accessing sensitive areas of shrubland. Installation of signs has been shown to be effective in other contexts, such as reducing disturbance of nesting birds (Williams *et al*. 2017).

Related interventions: Re-route paths (section 7.1); plant spiny shrubs to act as barriers to people (section 7.3).

Williams, D.R., Child, M.F., Dicks, L.V., Ockendon, N., Pople, R.G., Showler, D.A., Walsh, J.C., zu Ermgassen, E.K.H.J. & Sutherland, W.J. (2017) Bird Conservation. Pages 95-244 in: W.J. Sutherland, L.V. Dicks, N. Ockendon & R.K. Smith (eds) What Works in Conservation 2017. Open Book Publishers, Cambridge, UK.

7.3 Plant spiny shrubs to act as barriers to people

We captured no evidence for the effects of planting spiny shrubs to act as barriers to people on shrublands.

Background
Planting spiny shrubs in sensitive shrubland areas may help to reduce access by people therefore reducing negative impacts such as trampling. However, planting of some spiny plants, such as cacti can result in spread of invasive species (Essl & Kobler 2009; Novoa *et al*. 2015). As such any use of this intervention should first assess the potential risks associated with introducing spiny plants, particularly if they are not-native to the region of interest.

Related interventions: Re-route paths to reduce habitat disturbance (section 7.1); Use signs and access restrictions to reduce disturbance (section 7.2).

Essl, F. & Kobler, J. (2009) Spiny invaders – Patterns and determinants of cacti invasion in Europe. *Flora - Morphology, Distribution, Functional Ecology of Plants*, 204, 485-494.
Novoa, A., Kaplan, H., Kumschick, S., Wilson, J.R.U. & Richardson, D.M. (2015) Soft Touch or Heavy Hand? Legislative Approaches for Preventing Invasions: Insights from Cacti in South Africa. *Invasive Plant Science and Management*, 8, 307-316.

8. Threat: Natural system modifications

Background

Humans often aim to maximize direct benefits to human society from ecosystems leading to modifications that degrade and convert natural habitats. This chapter addresses interventions that can be used to manage these alterations in order to conserve shrubland biodiversity.

In shrublands wildfires are often supressed to reduce damage to human property and life (Keeley, 2002). For example, in the Sierra Nevada mountain range in California, USA approximately 45% of chapparal shrublands have not burned since 1910 partly as a result of fire suppression (Keeley *et al.* 2005). Suppression of fire may result in a reduction in the abundance of seeds of some plant species in seed banks as well as increased mortality when wildfires do occur (Keeley *et al.* 2005). Human activities may also increase the frequency of fires for examples as a result of intentional burning, campfires, or escaped agricultural fires (Salafsky *et al.* 2008). Very frequent fires can lead to a loss of shrubs from shrublands and an increase in grasses and herbaceous plants (Bradstock *et al.* 1997, Hobbs & Gimingham 1987).

Changes in traditional shrubland management such as cessation of livestock grazing, cutting of turf, cutting of vegetation for fuel, and harvesting of vegetation for fodder also reduce disturbance, potentially resulting in an increase in woody plants and tree species (Webb 1998). To manage these disturbances conservation managers may wish to mimic or reinstate traditional management techniques.

Related threats: harvesting from shrublands i.e. biological resource use (Chapter 5); infrastructure such as roads, rail, and gas lines (Chapter 6); human intrusions and disturbance e.g. vehicles (Chapter 7). Related interventions: habitat restoration (Chapters 13 & 14).

Bradstock, R. A., Tozer, M. G., & Keith, D. A. (1997). Effects of high frequency fire on floristic composition and abundance in a fire-prone heathland near Sydney. *Australian Journal of Botany*, 45(4), 641-655.

Hobbs, R. J., & Gimingham, C. H. (1987). Vegetation, fire and herbivore interactions in heathland. *Advances in ecological research*, 16, 87-173.

Keeley, J. E. (2002). Fire management of California shrubland landscapes. *Environmental Management*, 29(3), 395-408.

Keeley, J.E., Pfaff, A.H. & Safford, H.D. (2005) Fire suppression impacts on postfire recovery of Sierra Nevada chaparral shrublands. *International Journal of Wildland Fire*, 14, 255-265.

Salafsky N., Salzer D., Stattersfield A. J., Hilton-Taylor C., Neugarten R., Butchart S.H., Collen B., Cox N., Master L.L., O'Connor S. and Wilkie D (2008). A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology*, 22(4), 897-911.

Webb, N.R. (1998) The traditional management of European heathlands*. Journal of Applied Ecology*, 35, 987-990.

Key messages - Modified fire regime

8.1 Use prescribed burning to mimic natural fire cycle

We captured no evidence for the effects on shrublands of using prescribed burning to mimic the natural fire cycle on shrublands.

8.2 Use prescribed burning to reduce potential for large wild fires

We captured no evidence for the effects on shrublands of using prescribed burning approaches to reduce the potential for large wild fires on shrublands.

8.3 Cut strips of shrubland vegetation to reduce the spread of fire

We captured no evidence for the effects on shrublands of cutting strips of vegetation to reduce the spread of fire.

Key messages - Modified vegetation management

8.4 Reinstate the use of traditional burning practices

- One before and after study in the UK found that prescribed burning initially decreased the cover of most plant species, but that their cover subsequently increased. A systematic review of five studies from the UK found that prescribed burning did not alter species diversity.
- A replicated, controlled study in the UK found that regeneration of heather was similar in cut and burned areas. A systematic review of five studies, from Europe found that prescribed burning did not alter grass cover relative to heather cover.

8.5 Use cutting/mowing to mimic grazing

- One systematic review of three studies in lowland heathland in North Western Europe found that mowing did not alter heather abundance relative to grass abundance. A site comparison in Italy found that mowing increased heather cover.
- Two replicated, randomized, before-and-after trials in Spain (one of which was controlled) found that using cutting to mimic grazing reduced heather cover.
- One replicated, randomized, controlled, before-and-after trial in Spain found that cutting increased the number of plant species. However, a replicated, randomized, before-and-after trial1 found that the number of plant species only increased in a minority of cases.
- One replicated, randomized, before-and-after trial found that cutting to mimic grazing increased grass cover. A site comparison in Italy found that mowing increased grass cover.
- One site comparison study in Italy found a reduction in tree cover.

8.6 Increase number of livestock

- Two site comparison studies in the UK found that cover of common heather declined in sites with a high density of livestock. One site comparison in the Netherlands found that dwarf shrub cover was lower in grazed areas than in ungrazed areas. One before-and-after study in Belgium found that grazing increased cover of heather. One site comparison in France found that areas grazed by cattle had higher cover of non-ericaceous shrubs, but lower cover of ericaceous shrubs. One before-and-after study in the Netherlands found that increasing the number of livestock resulted in an increase in the number of common heather *Calluna vulgaris* and cross-leaved heath *Erica tetralix* seedlings. One randomized, replicated, paired, controlled study in the USA found that increasing the number of livestock did not alter shrub cover. One replicated, site comparison study and one before-and-after study in the UK and Netherlands found that increasing grazing had mixed effects on shrub and heather cover.
- Three site comparisons in France, Greece, and the Netherlands found that grazed areas had a higher number of plant species than ungrazed areas. One before-and-after study in Belgium found the number of plant species did not change after the introduction of grazing. One replicated, before-and-after study in the Netherlands found a decrease in the number of plant species.
- One before-and-after study in the Netherlands found that increasing the number of livestock resulted in a decrease in vegetation height. One replicated, before-and-after trial

in France found that grazing to control native woody species increased vegetation cover in one of five sites but did not increase vegetation cover in four of five sites.

- A systematic review of four studies in North Western Europe found that increased grazing intensity increased the cover of grass species, relative to heather species. One before-and-after study and two site comparisons in the Netherlands and France found areas with high livestock density had higher grass and sedge cover than ungrazed areas. One randomized, replicated, paired, controlled study in the USA found that increasing the number of livestock reduced grass and herb cover. One before-and-after study in Spain found that increasing the number of ponies in a heathland site reduced grass height. One replicated, site comparison in the UK and one replicated before-and-after study in the Netherlands found that increasing cattle had mixed effects on grass and herbaceous species cover.
- One before-and-after study in the Netherlands found that increasing the number of livestock resulted in a decrease in vegetation height. One replicated, before-and-after trial in France found that grazing to control native woody species increased vegetation cover in one of five sites but did not increase vegetation cover in four of five sites.

Modified fire regime

Background

Increases in fire frequency can result in a loss of shrub species, an increase in grass cover, and potentially increases in invasive species (Bradstock et al. 1997, Hobbs & Gimingham 1987, van Wilgen et al. 2010). However, a decrease in fire frequency, as a result of fire suppression, can lead to an increase in woody plant cover, particularly trees (Paritsis et al. 2015). In some contexts prescribed fire is seen as a method to maintain and enhance shrubland biodiversity (Davies et al. 2008, 2016). In order to maintain shrubland vegetation conservation managers may wish to use interventions to modify fire regimes. However, managing fire is a complex problem that must take into consideration goals that are often in conflict, such as protection of human life and property from fire, and biodiversity goals (van Wilgen 2013).

There is a large body of literature on the effects of fire on shrublands that does not meet the inclusion criteria for this synopsis, primarily because studying the effects of fire is difficult. Ideally studies of the effects of fire should be long-term, but funding and other practicalities often limit the length of studies (Lindenmayer & Likens, 2009). As a result, many of the studies of the effects of fire on shrublands use computer modelling (e.g. Cary et al. 2009), are correlative, and/or do not measure the effects of fire on shrubland plant biodiversity, and so do not meet the inclusion criteria for this synopsis.

Bradstock, R. A., Tozer, M. G., & Keith, D. A. (1997). Effects of high frequency fire on floristic composition and abundance in a fire-prone heathland near Sydney. *Australian Journal of Botany*, 45(4), 641-655.

Cary, G.J., Flannigan, M.D., Keane, R.E., Bradstock, R.A., Davies, I.D., Lenihan, J.M., Li, C., Logan, K.A. & Parsons, R.A. (2009) Relative importance of fuel management, ignition management and weather for area burned: evidence from five landscape fire succession models. International Journal of Wildland Fire, 18, 147-156.

Davies, M.G., Gray, A., Hamilton, A. & Legg, C.J. (2008) The future of fire management in the British uplands. International Journal of Biodiversity Science & Management, 4, 127-147.

Davies, G.M., Kettridge, N., Stoof, C.R., Gray, A., Marrs, R., Ascoli, D., Fernandes, P.M., Allen, K.A., Doerr, S.H., Clay, G.D., McMorrow, J. & Vandvik, V. (2016) Informed debate on the use of fire for peatland management means acknowledging the complexity of socio-ecological systems. Nature Conservation, 16, 59-77.

Hobbs, R. J., & Gimingham, C. H. (1987). Vegetation, fire and herbivore interactions in heathland. *Advances in ecological research*, 16, 87-173.
Lindenmayer, D.B. & Likens, G.E. (2009) Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology & Evolution, 24, 482-486.
Paritsis J., Veblen T. T. & Holz A. (2015) Positive fire feedbacks contribute to shifts from Nothofagus pumilio forests to fire-prone shrublands in Patagonia. *Journal of Vegetation Science*, 26: 89–101.
van Wilgen, B.W., Forsyth, G.G., De Klerk, H., Das, S., Khuluse, S. & Schmitz, P. (2010) Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. Journal of Applied Ecology, 47, 631-638.
van Wilgen, B.W. (2013) Fire management in species-rich Cape fynbos shrublands. *Frontiers in Ecology and the Environment*, 11, E35-E44.

8.1 Use prescribed burning to mimic natural fire cycle

We captured no evidence for the effects on shrublands of using prescribed burning to mimic the natural fire cycle on shrublands.

Background
Prescribed fire is commonly used to reduce fuel loads in shrublands in an attempt to supress wildfires. For the purposes of this synopsis we do not consider this to be a conservation intervention as it is often not used to benefit biodiversity but rather to reduce the risk of fires for human life and property. However, prescribed fire can be used to mimic the natural fire cycle of some shrublands to benefit biodiversity. Correlative studies suggest that such an approach may benefit shrubland vegetation, but that the timing of fires is critical for their effectiveness (Brown *et al.* 1991).

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.19); cut and use prescribed burning to control grass (section 9.20); cut and burn bracken (section 9.27); burn shrublands to reduce concentration of pollutants (section 10.6).

Brown, P.J., Manders, P.T., Bands, D.P., Kruger, F.J. & Andrag, R.H. (1991) Prescribed burning as a conservation management practice: A case history from the Cederberg mountains, Cape Province, South Africa. Biological Conservation, 56, 133-150.

8.2 Use prescribed burning to reduce potential for large wild fires

We captured no evidence for the effects on shrublands of using prescribed burning approaches to reduce the potential for large wild fires on shrublands.

Background
Prescribed burning has often been used in an attempt to reduce the hazard to human life and property that may be associated with large wildfires (Fernandes & Botelho 2003). However, prescribed burning may also be used in an attempt to reduce the risk of catastrophic wildfire that could result in the loss of shrubland habitat and associated biodiversity (Fernandes *et al.* 2013).

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.19); cut and use prescribed burning to control grass (section 9.20); cut and burn bracken (section 9.27); burn shrublands to reduce concentration of pollutants (section 10.6).

Fernandes, P. M., & Botelho, H. S. (2003). A review of prescribed burning effectiveness in fire hazard reduction. International Journal of wildland fire, 12(2), 117-128.

Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A. & Molina, D. (2013) Prescribed burning in southern Europe: developing fire management in a dynamic landscape. Frontiers in Ecology and the Environment, 11, e4-e14.

8.3 Cut strips of shrubland vegetation to reduce the spread of fire

We captured no evidence for the effects on shrublands of cutting strips of vegetation to reduce the spread of fire.

Background

Cutting of 'firebreaks' creates gaps in shrublands that can act as a barrier to slow or stop the spread of fire. These firebreaks are commonly used to protect human property and life, rather than to benefit biodiversity. For the purposes of this synopsis we only considered studies that examined the effect of firebreaks that were explicitly cut to protect shrubland biodiversity. In addition, many of the studies of the effect of firebreaks are not empirical, and use modelling approaches to assess their effects on the spread of fire and effects on biodiversity (e.g. Cary *et al*. 2009, Taylor *et al.* 2013).

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1); use prescribed burning to reduce potential wildfires (section 8.2); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.19); cut and use prescribed burning to control grass (section 9.20); cut and burn bracken (section 9.27); burn shrublands to reduce concentration of pollutants (section 10.6).

Cary, G.J., Flannigan, M.D., Keane, R.E., Bradstock, R.A., Davies, I.D., Lenihan, J.M., Li, C., Logan, K.A. & Parsons, R.A. (2009) Relative importance of fuel management, ignition management and weather for area burned: evidence from five landscape fire succession models. International Journal of Wildland Fire, 18, 147-156.

Taylor, M.H., Rollins, K., Kobayashi, M. & Tausch, R.J. (2013) The economics of fuel management: Wildfire, invasive plants, and the dynamics of sagebrush rangelands in the western United States. Journal of Environmental Management, 126, 157-173.

Modified vegetation management

Background

Shrubland vegetation often depends upon regular disturbances. Reduction in these disturbances can result in increases in woody vegetation, particularly trees. Management interventions that may be used to compensate for this reduction in disturbance include traditional burning, cutting or mowing, and grazing.

8.4 Reinstate the use of traditional burning practices

- One before and after study in the UK[1] found that prescribed burning initially decreased the cover of most plant species, but that their cover subsequently increased. A systematic review of five studies from the UK[3] found that prescribed burning did not alter species diversity.
- A replicated, controlled study in the UK[2] found that regeneration of heather was similar in cut and burned areas. A systematic review of five studies, from Europe[4] found that prescribed burning did not alter grass cover relative to heather cover.

Background

Traditional burning practices in shrublands are used to create a mosaic of differently aged shrub vegetation and increase habitat openness, as well as to limit succession (Bartolomé *et al*. 2005, Fernandes *et al.* 2013, Moreira *et al.* 2011).

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1); use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.19); cut and use prescribed burning to control grass (section 9.20); cut and burn bracken (section 9.27); burn shrublands to reduce concentration of pollutants (section 10.6).

Bartolomé, J., Plaixats, J., Fanlo, R. & Boada, M. (2005) Conservation of isolated Atlantic heathlands in the Mediterranean region: effects of land-use changes in the Montseny biosphere reserve (Spain). Biological Conservation, 122, 81-88.

Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A. & Molina, D. (2013) Prescribed burning in southern Europe: developing fire management in a dynamic landscape. Frontiers in Ecology and the Environment, 11, e4-e14.

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F. & Bilgili, E. (2011) Landscape – wildfire interactions in southern Europe: Implications for landscape management. Journal of Environmental Management, 92, 2389-2402.

A before-and-after study in 1978–1983 in two heathland sites in the UK (1) found that prescribed burning initially decreased cover of most plant species, but that their cover subsequently increased. Cover of common heather *Calluna vulgaris* was lower immediately after burning than before burning (after: 5–42%, before: 52–100%) but this increased after three years to 9–63% cover. Similarly cover of the shrubs bell heather *Erica cinerea* (immediately after: 2–24%, before: 55–92%, after three years: 21–85%) and bearberry *Arctosaphylos uva-ursi* (immediately after: 2–43%, before: 46–97%, after three years: 5–65%) initially decreased following fire and then increased after three years. The number of plant species was lower immediately after prescribed burning than before burning (after: 4–11 species, before: 10–31 species) but this increased after three years to 19–30 species. No statistical analyses were carried out in this study. Fourteen areas of the two heathland sites were burned in 1978 or 1979. Four 1 m^2 quadrats were placed in each burned area and cover of plant species recorded three times a year in 1978–1980, including before burning took place.

A replicated study in 1987–1989 in a moorland site in the Yorkshire, UK (2) found that heather *Calluna vulgaris* regeneration was similar in burned and cut areas. After two years, cover of heather did not differ between burned (young heather: 58%; old heather: 29%) and cut areas (young heather: 77%; old heather: 17%). Additionally, after two years, neither shoot nor seedling growth differed significantly between burned (shoot: 37 cm; seedling: 21 cm) and cut areas (shoot: 34 cm; seedling: 26 cm). Heather was burned in six plots and cut in six others. During the study the plots were exposed to light grazing by sheep. Vegetation was sampled annually in July using 0.25 m^2 quadrants placed in the centre of each plot.

A systematic review of five studies of the impact of prescribed burning on lowland dry heathland vegetation in the UK (3) found that prescribed burning did not alter the diversity (presented as Simpson's diversity) or number of plant species of heathland sites. There was no evidence of publication bias that would influence the outcomes of the systematic review. The systematic review summarised the impacts of prescribed burning at 12 sites from five studies, with six of the sites representing before-and-after trials and the remaining six representing site comparisons. Of 280 potentially relevant references only five presented information on the impacts of prescribed fire that could be used by the systematic review.

A systematic review of five studies of the impact of prescribed burning on lowland heathland vegetation in North Western Europe (4) found that burning did not increase the cover of grass species, relative to heather species. There was no evidence of publication bias that would influence the outcomes of the systematic review. The systematic review summarised the impacts of burning at eight sites from five studies, four of which represented before-and-after trials. Of 266 potentially relevant references only five presented information on the impacts of burning that could be used by the systematic review.

(1) Hobbs, R.J. & Gimingham, C.H. (1984) Studies on Fire in Scottish Heathland Communities II. Post-Fire Vegetation Development. *Journal of Ecology*, 72, 585-610.
(2) Liepert, C., Gardner, S. & Rees, S. (1993) Managing heather moorland: impacts of burning and cutting on Calluna regeneration. *Journal of Environmental Planning and Management*, 36, 283-293.
(3) Stewart, G., Coles, C. & Pullin, A. (2004) Does burning of UK sub-montane, dry dwarf-shrub heath maintain vegetation diversity. *Systematic Review*, 1-29.
(4) Newton, A.C., Stewart, G.B., Myers, G., Diaz, A., Lake, S., Bullock, J.M. & Pullin, A.S. (2009) Impacts of grazing on lowland heathland in north-west Europe. *Biological Conservation*, 142, 935-947.

8.5 Use cutting/mowing to mimic grazing

- One systematic review of three studies in lowland heathland in North Western Europe[1] found that mowing did not alter heather abundance relative to grass abundance. A site comparison in Italy[4] found that mowing increased heather cover.
- Two replicated, randomized, before-and-after trials in Spain[1,2] (one of which was controlled) found that using cutting to mimic grazing reduced heather cover.
- One replicated, randomized, controlled, before-and-after trial in Spain[2] found that cutting increased the number of plant species. However, a replicated, randomized, before-and-after trial[1] found that the number of plant species only increased in a minority of cases.
- One replicated, randomized, before-and-after trial[2] found that cutting to mimic grazing increased grass cover. A site comparison in Italy[4] found that mowing increased grass cover.
- One site comparison study in Italy4 found a reduction in tree cover.

Background
Many shrublands depend on disturbances such as grazing to reduce succession that leads

to an increase in woody plant species and conversion to forest. In addition, grazing may help to maintain plant diversity and the populations of plant species that depend on disturbance. However, in some cases grazing by livestock may no longer be economically viable and so cutting or mowing have been used to replace it. This cutting may be able to limit the growth of woody species and invasion of trees. For interventions that deal directly with the removal of problematic species such as trees see Chapter 9 'Invasive and other problematic species.'

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11); use grazing or alter livestock type to control grass (section 9.19; increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A replicated, randomized, controlled, before-and-after trial in 1998–2003 in three heathlands in Northern Spain (1) found that cutting heather *Calluna vulgaris* to mimic livestock grazing increased the number of plant species in one of three cases but reduced the cover of heather in three of three cases after two years. In one of three cases, the number of plant species in areas that had been cut was higher two years after cutting (9 species/plot) than before cutting (7 species/plot) and the number of species was higher after cutting than in areas that had not been cut (5 species/plot). Data on the number of plant species was not reported for two of the three heathland sites. In the three heathlands cover of heather after cutting (5–11%) was lower than before cutting (55–83%) and cover after cutting was also lower than in areas that had not been cut (76–83%). In 1998 in each site all heather plants were cut in five randomly selected plots, while the other five plots heather plants were not cut. Vegetation cover was assessed in each plot before cutting and then in 1999–2000.

A replicated, randomized, before-and-after study in 1998–2003 in three heathlands in Northern Spain (2) found that using cutting to mimic livestock grazing did not increase the number of plant species or cover of cross-leaved heath *Erica tetralix,* but reduced the cover of heather *Calluna vulgaris*, and increased grass cover. In the three sites, five years after cutting the number of plant species (4–12 species/plot) was not significantly higher than before cutting (4–11 species/plot). Cover of heather decreased in three of three cases from 55–83% cover before cutting to 9–17% cover after cutting. Cover of cross-leaved heath was not significantly higher after cutting (19-33% cover) than before cutting (13-33% cover). Cutting increased grass cover from 2–22% cover before cutting to 7–38% cover after cutting. Ten 1 m^2 plots were established in each of the three sampled sites. In 1998 in each site all heather and cross-leaved heath plants were cut in five randomly selected plots, while the other five plots were not cut. Vegetation cover was assessed in each plot before cutting and then in every year in 1999–2003.

A systematic review of three studies of the impact of cutting to control tree species on lowland heathland vegetation in North Western Europe (3) found that mowing did increase the cover of grass species, relative to heather species. There was no evidence of publication bias that would influence the outcomes of the systematic review. The systematic review summarised the impacts of cutting at eight sites from three studies, all of which represented before-and-after trials. Of 266 potentially relevant references only three presented information on the impacts of cutting that could be used by the systematic review.

A replicated, site comparison study in 1999–2012 in a dry heathland in Northern Italy (4) found that mowed areas had higher heather and grass cover, but lower cover of other shrubs and trees compared to unmowed areas. After 12 years, cover of heather was higher in mowed plots (15%) than in unmowed plots (11%). Grass cover averaged 66% in mowed sites but declined from 49% to 23% in unmowed sites. Cover of other shrubs was lower in mown plots (11%) than unmown plots (26%). Tree cover averaged 8% in mowed sites but tree cover increased from 13% to 40% over 12 years in unmowed plots. Fifteen plots with a radius of 50 m were located in a heathland. Six of these plots were mowed every year and nine plots were never mowed. In late spring 1999–2012 plots were surveyed and the cover of plant species was estimated.

(1) Calvo, L., Alonso, I., Frenandez, A.J. & De Luis, E. (2005) Short-term study of effects of fertilisation and cutting treatments on the vegetation dynamics of mountain heathlands. *Plant Ecology*, 179, 181-191.
(2) Calvo, L., Alonso, I., Marcos, E. & De Luis, E. (2007) Effects of cutting and nitrogen deposition on biodiversity in Cantabrian heathlands. *Applied Vegetation Science*, 10, 43-52.
(3) Newton, A.C., Stewart, G.B., Myers, G., Diaz, A., Lake, S., Bullock, J.M. & Pullin, A.S. (2009) Impacts of grazing on lowland heathland in north-west Europe. *Biological Conservation*, 142, 935-947.
(4) Borghesio, L. (2014) Can fire avoid massive and rapid habitat change in Italian heathlands? *Journal for Nature Conservation*, 22, 68-74.

8.6 Increase number of livestock

- Two site comparison studies in the UK[2,9] found that cover of common heather declined in sites with a high density of livestock. One site comparison in the Netherlands[13] found that dwarf shrub cover was lower in grazed areas than in ungrazed areas. One before-and-after study in Belgium[6] found that grazing increased cover of heather. One site comparison in France[7] found that areas grazed by cattle had higher cover of non-ericaceous shrubs, but lower cover of ericaceous shrubs. One before-and-after study in the Netherlands[1] found that increasing the number of livestock resulted in an increase in the number of common heather *Calluna vulgaris* and cross-leaved heath *Erica tetralix* seedlings. One randomized, replicated, paired, controlled study in the USA[10] found that increasing the number of livestock did not alter shrub cover. One replicated, site comparison study[3] and one before-and-after study[4] in the UK[3] and Netherlands[4] found that increasing grazing had mixed effects on shrub[3] and heather cover[4].
- Three site comparisons in France[7], Greece[11], and the Netherlands[13] found that grazed areas had a higher number of plant species than ungrazed areas. One before-and-after study in Belgium[6] found the number of plant species did not change after the introduction of grazing. One replicated, before-and-after study in the Netherlands[4] found a decrease in the number of plant species.
- One before-and-after study in the Netherlands[1] found that increasing the number of livestock resulted in a decrease in vegetation height. One replicated, before-and-after trial in France[5] found that grazing to control native woody species increased vegetation cover in one of five sites but did not increase vegetation cover in four of five sites.
- A systematic review of four studies in North Western Europe[8] found that increased grazing intensity increased the cover of grass species, relative to heather species. One before-

and-after study and two site comparisons in the Netherlands[1,13] and France[7] found areas with high livestock density had higher grass[1,7,13] and sedge[13] cover than ungrazed areas. One randomized, replicated, paired, controlled study in the USA[10-] found that increasing the number of livestock reduced grass and herb cover. One before-and-after study in Spain[12] found that increasing the number of ponies in a heathland site reduced grass height. One replicated, site comparison in the UK[3] and one replicated before-and-after study in the Netherlands[4] found that increasing cattle had mixed effects on grass[3,4] and herbaceous species[4] cover.

- One before-and-after study in the Netherlands[1] found that increasing the number of livestock resulted in a decrease in vegetation height. One replicated, before-and-after trial in France[5] found that grazing to control native woody species increased vegetation cover in one of five sites but did not increase vegetation cover in four of five sites.

Background

Many shrublands depend on disturbances such as grazing to reduce succession that leads to an increase in woody plant species and conversion to forest. However, in many cases grazing by livestock has declined as it is no longer economically viable. Reintroduction of livestock may help to reduce the number of woody species in a shrubland and reduce the possibility of succession to forest.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A before-and-after study in 1972–1978 in a heathland site in the Netherlands (1) found that increasing the number of livestock resulted in a decrease in vegetation height, but increased grass cover and the number of seedlings of common heather *Calluna vulgaris* and cross-leaved heath *Erica tetralix*. After six years vegetation height had decreased by approximately 20 cm when compared to the period before grazing started. Grass cover and the number of common heather and cross-leaved heath seedlings were higher after six years of grazing than before grazing started (no data presented). No statistical tests were carried out in this study. In 1972 sheep were introduced to the area at a density of three sheep/ha. One hundred and nine plots (of undefined size) were placed at the site and vegetation cover was recorded yearly in 1972-1978.

A site comparison in 1967-1987 in 15 heathland sites in the UK (2) found that common heather *Calluna vulgaris* cover decreased at sites with high livestock density. Over 20 years cover of common heather increased in sites with low livestock density but decreased in sites with high livestock density (no data reported). Ten point quadrats were used to estimate vegetation cover at each sites in July or August every two years. Dung was counted to assess herbivore abundance at each site.

A replicated, site comparison study in 1994 at three heathlands in the UK (3) found that increasing the abundance of livestock had mixed effects on the cover of shrubs, grasses, and herbaceous plant species. Increasing the abundance of livestock decreased cover of shrub species in one of nine comparisons (grazed: 45%, ungrazed: 80%) but increased cover of shrub species in three of nine comparisons (grazed: 3–8%, ungrazed: 0–2%). For one of eight comparisons grass cover was lower in grazed (9%) than ungrazed areas (32%) but for three of eight comparisons grass cover was higher in grazed (3–8%) than ungrazed areas (0%). For three of six comparisons cover of herbaceous species was higher in grazed (2–3%) than in ungrazed areas (0%) while for the remaining three comparisons cover did not differ in grazed and ungrazed areas. At each site one area was grazed and another area was not grazed. At each site 5–15 quadrats were located randomly and cover of plant species estimated by eye.

A replicated, before-and-after trial in 1983–1993 in two heathlands in the Netherlands (4) found that cattle grazing increased cover of heather *Calluna vulgaris* in one of two sites, the cover of wavy-hair grass *Deschampsia flexuosa* in one of two sites, and, despite an initial increase, it reduced the number of plant species in two of two sites. After ten years and in one heathland, heather cover increased from 20% before grazing to 95%, while the cover of wavy hair-grass did not change significantly (before: 0% cover, after: 1% cover). However, in another heathland, heather cover decreased from 69% before grazing to 59% ten years later, while the cover of wavy hair-grass increased from 16% to 60% over the same period. In both sites grazing increased the number of plant species from 3–5 species/plot before implementation of grazing, to 9–11 species/plot after 5 years, followed by a decline to 5–9 species/plot 10 years after grazing. In 1983, cattle were introduced in the two heathlands (approximately 0.2 cows/ha). Three 25 m^2 plots were located in one heathland and six in the other. Vegetation cover was recorded in each plot annually between 1983 and 1993.

A replicated, before-and-after trial in 1996–1998 in coastal heathland in France (5) found that grazing to control native woody species increased vegetation cover in one of five sites, but did not increase it in four of five sites (data presented as vegetation cover index). Between nine and ten sheep were introduced to each of five paddocks in 1996. Vegetation was surveyed every one to ten months in four 10 m transects in each paddock using a point quadrat

A replicated, before-and-after trial in 1978–2003 in dry, wet and moist heathland habitat in Flanders, Belgium (6) found that extensive grazing increased vegetation cover of heather *Calluna vulgaris* but did not increase species richness over a period of 25 years. Vegetation cover of heather was higher after 25 years of extensive grazing than prior to it (data presented in arcsine units). However, species richness did not change significantly (5, 8 and 6 species in 1978 vs 5.5, 9 and 7 species in 2003, for dry, moist, and wet heathland respectively). Extensive grazing (0.1 cow/ha) was conducted annually from May to September in a 220 ha reserve. Vegetation was sampled in 28, 5 and 19 plots in dry, moist, and wet heathland respectively in 1978 (prior to initiation of grazing) and in 2003 (25 years after grazing initiation). Extensive grazing was supplemented locally with mechanical management practices, like tree-cutting or mowing.

A site comparison study in 2006 in six heathland sites in France (7) found that areas grazed by cattle had a higher number of plant species, higher cover of grass and non-ericaceous shrubs, but lower cover of ericaceous shrubs. Grazed sites had a higher number of plant species and cover of grass (species: 13–14 species/plot, grass: 47–54% cover) than ungrazed sites (species: 7–8 species/plot, grass: 2–24% cover). Grazed sites also had higher cover of non-ericaceous shrubs (66–67%) than three of the four ungrazed sites (9–58%).

However, cover of ericaceous shrubs was lower in grazed sites (56–63%) than in ungrazed sites (86–95%). No statistical tests were carried out in this study. Two moderately grazed sites and four ungrazed sites were selected for study. In 2006 four 1 m^2 plots were placed at each site and plant cover estimated.

A systematic review of four studies of the impact of grazing on lowland heathland vegetation in North Western Europe (8) found that grazing increased the cover of grass species, relative to heather species. There was no evidence of publication bias that would influence the outcomes of the systematic review. The systematic review summarised the impacts of grazing at 15 sites from four studies, with 12 of the sites representing before-and-after trials and the remaining three representing site comparisons. Of 266 potentially relevant references only four presented information on the impacts of grazing that could be used by the systematic review.

A site comparison in 10 heathland sites that were subject to grazing in the UK (9) found that the cover of common heather *Calluna vulgaris* increased in sites with low sheep density and declined in areas with high sheep density. Common heather cover increased in sites where there were fewer than two sheep/ha and declined when there were greater than two sheep/ha (data reported as model results). Heather cover was estimated in seventy four plots across the 10 sites. Stocking density at the sites varied between zero and six sheep/ha.

A randomized, replicated, paired, controlled study in 1936-2009 in eight sagebrush steppe sites in Oregon, USA (10) found that increasing the number of livestock decreased grass and herb cover, but did not significantly alter shrub cover. Grass and herb cover in grazed areas were lower (grass: 9%, herb: 17%) than in areas that were not grazed (grass: 18%, herb: 24%). However, shrub cover was not significantly different in grazed (16%) and ungrazed (16%) areas. Eight 2 ha fenced areas excluding livestock were established in 1936, and areas adjacent to the fenced areas were grazed by cattle from 1936-2008. Four 20 m transects were established in each study area and vegetation cover was assessed using a line intercept method.

A replicated site comparison in Greece in 66 shrubland sites (11) found that grazed sites had higher total plant species richness, as well as higher species richness of annual and perennial forbs, annual grasses, but lower species richness of tall shrubs; species richness of perennial grasses and small shrubs was not affected by grazing. Total plant species richness was higher in grazed than ungrazed plots (grazed: 32-38 species/plot, ungrazed: 22 species/plot). The same trend was true for annual forbs (grazed: 9-12 species/plot, ungrazed: 4 species/plot), perennial forbs (grazed: 6-7 species/plot, ungrazed: 6 species/plot), and annual grasses (grazed: 3-4 species/plot, ungrazed: 1 species/plot). However, in one of three cases species richness of tall shrubs was lower in grazed than ungrazed plots (grazed: 2 species/plot, ungrazed 1 species/plot). Species richness of perennial grasses (grazed: 2 species/plot, ungrazed: 2 species/plot) and small shrubs (grazed: 6 species/plot, ungrazed 6 species/plot) did not differ significantly between grazed and ungrazed plots. In each site 100 m^2 plots were used and vegetation cover and species richness estimated. Grazing intensity at each site was assessed by expert opinion.

A before-and-after study in winter 2006/2007 in a heathland in Northern Spain (12) found that increasing the number of ponies present at the site reduced grass height in most cases. After one month and in nine of fifteen areas, grass was shorter in areas that were grazed (9-21 cm) than in the same areas prior to grazing (13-–38 cm). In October 2006 fences were constructed around the site. Five Basque pottoka ponies were released at the site in December 2006, giving a density of 6.3 ponies/ha. Vegetation height was measured using a ruler in 120 quadrats before and after grazing (dates unspecified).

A site comparison study in 2011 in coastal heathland in the Netherlands (13) found that areas that were grazed had more plant species, as well as higher sedge *Carex* spp. and grass cover than ungrazed areas, but had lower cover of dwarf shrubs. Grazed areas had a higher number of plant species (6 species/plot) than areas that were not grazed (5 species/plot). Grazed areas also had higher sedge and grass cover than areas that were not grazed (data not reported). However, cover of dwarf shrubs was lower in grazed areas than in ungrazed areas (data not reported). Grazed and ungrazed areas were separated with a fence. Grazed areas were stocked with sheep at a density of 5.7 sheep/ha. Thirty-two plots were located in the ungrazed area and 33 in the grazed area. At each plot a point frame was used to estimate cover of different plant species.

(1) Bakker, J.P., De Bie, S., Dallinga, J.H., Tjaden, P. & De Vries, Y. (1983) Sheep-Grazing as a Management Tool for Heathland Conservation and Regeneration in the Netherlands. *Journal of Applied Ecology*, 20, 541-560.

(2) Welch, D. & Scott, D. (1995) Studies in the Grazing of Heather Moorland in Northeast Scotland. VI.20-Year Trends in Botanical Composition. *Journal of Applied Ecology*, 32, 596-611.

(3) Bullock, J.M. & Pakeman, R.J. (1997) Grazing of lowland heath in England: Management methods and their effects on healthland vegetation. *Biological Conservation*, 79, 1-13.

(4) Bokdam, J. & Gleichman, J.M. (2000) Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. *Journal of Applied Ecology*, 37, 415-431.

(5) Gallet, S. & Roze, F. (2001) Conservation of heathland by sheep grazing in Brittany (France): Importance of grazing period on dry and mesophilous heathlands. *Ecological Engineering*, 17, 333-344.

(6) Piessens, K., Aerts, N. & Hermy, M. (2006) Long-term (1978-2003) effects of an extensive grazing regime on plant species composition of a heathland reserve. *Belgian Journal of Botany*, 49-64.

(7) Gachet, S., Sarthou, C., Bardat, J. & Ponge, J.-F. (2009) The state of change of Erica scoparia L. heathland through cattle grazing and oak colonization. *Revue d'Ecologie, Terre et Vie*, 64, 3-17.

(8) Newton, A.C., Stewart, G.B., Myers, G., Diaz, A., Lake, S., Bullock, J.M. & Pullin, A.S. (2009) Impacts of grazing on lowland heathland in north-west Europe. *Biological Conservation*, 142, 935-947.

(9) Pakeman, R.J. & Nolan, A.J. (2009) Setting sustainable grazing levels for heather moorland: a multi-site analysis. *Journal of Applied Ecology*, 46, 363-368.

(10) Davies, K.W., Bates, J.D., Svejcar, T.J. & Boyd, C.S. (2010) Effects of Long-Term Livestock Grazing on Fuel Characteristics in Rangelands: An Example From the Sagebrush Steppe. *Rangeland Ecology & Management*, 63, 662-669.

(11) Papanikolaou, A.D., Fyllas, N.M., Mazaris, A.D., Dimitrakopoulos, P.G., Kallimanis, A.S. & Pantis, J.D. (2011) Grazing effects on plant functional group diversity in Mediterranean shrublands. *Biodiversity and Conservation*, 20, 2831.

(12) Aldezabal, A., Mandaluniz, N. & Laskurain, N. (2013) Gorse (Ulex spp.) use by ponies in winter: Is the spatial pattern of browsing independent of the neighbouring vegetation? *Grass and Forage Science*, 68, 49-58.

(13) Damgaard, C., Thomsen, M.P., Borchsenius, F., Nielsen, K.E. & Strandberg, M. (2013) The effect of grazing on biodiversity in coastal dune heathlands. *Journal of coastal conservation*, 17, 663-670.

9. Threat: Invasive and other problematic species

Background

Invasive or problematic species are those which 'have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance' (Salafsky et al. 2008). This chapter focuses on interventions that aim to remove or reduce the negative impacts of invasive or problematic species to benefit shrubland vegetation.

Invasive or problematic plants can directly influence shrubland species by competing with them for resources, in some cases resulting in the loss of shrubland plants and dominance of invasive or problematic species. Invasive non-native plant species are thought to have impacted shrublands in Mediterranean climates particularly heavily (Rouget et al., 2003; Seabloom et al., 2006). However, most shrubland regions are facing problems with invasive or problematic species. Examples include Australian *Acacia* spp. in South African fynbos (Le Maitre et al. 2011), purple pampas grass *Cortaderia jubata* in California (Lambrinos, 2000), and bracken *Pteridium aquilinum* in heathlands in the UK (Marrs and Hicks, 1986).

Invasive or problematic animals can also cause conservation problems in shrublands. For example, grazing by non-native herbivore species can alter their structure and species composition (Beltran *et al.* 2014). Invertebrate species may also damage shrubs through herbivory, such as the heather beetle *Lochmaea suturalis* which in the UK can result in die-off of heather and its replacement by grass species (Berdowski and Zeilinga 1987).

Related threats: animals and plants introduced for agriculture (Chapter 3); infrastructure such as roads, rail, and gas lines (Chapter 6); human intrusions and disturbance e.g. vehicles (Chapter 7); pollution (Chapter 10). Chapter 8 contains some of the same interventions as this chapter *but only when they are used to restore a past disturbance regime*.

Related interventions: habitat restoration (Chapters 13 & 14).

Beltran R.S., Kreidler N., Van Vuren D.H., Morrison S.A., Zavaleta E.S., Newton K., Tershy B.R. & Croll D.A. (2014) Passive Recovery of Vegetation after Herbivore Eradication on Santa Cruz Island, California. Restoration Ecology, 22, 790-797.

Berdowski J., & Zeilinga R. (1987). Transition from Heathland to Grassland: Damaging Effects of the Heather Beetle. Journal of Ecology, 75(1), 159-175.

Lambrinos, J.G. (2000). The impact of the invasive alien grass Cortaderia jubata (Lemoine) on an endangered mediterranean-type shrubland in California. Diversity and Distributions, 6, 217-231.

Le Maitre D.C., Gaertner M., Marchante E., Ens E.J., Holmes P.M., Pauchard A., O'Farrell P.J., Rogers A.M., Blanchard R., Blignaut J. & Richardson D.M (2011). Impacts of invasive Australian acacias: implications for management and restoration. Diversity and Distributions, 17, 1015-1029.

Marrs R.H. & Hicks M.J. (1986) Study of vegetation change at Lakenheath Warren: a re-examination of AS Watt's theories of bracken dynamics in relation to succession and vegetation management. Journal of Applied Ecology, 1029-1046.

Rouget M., Richardson D.M., Cowling R.M., Lloyd J.W., & Lombard A.T. (2003) Current patterns of habitat transformation and future threats to biodiversity in terrestrial ecosystems of the Cape Floristic Region, South Africa. Biological Conservation, 112, 63-85.

Salafsky N., Salzer D., Stattersfield A.J., Hilton-Taylor C., Neugarten R., Butchart S.H., Collen B., Cox N., Master L.L., O'Connor S. & Wilkie (2008) A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conservation Biology, 22, 897-911.

Seabloom E.W., Williams J.W., Slayback D., Stoms D.M., Viers J.H. & Dobson A.P. (2006) Human impacts, plant invasion, and imperiled plant species in California. Ecological Applications, 16(4), 1338-1350.

Key Messages – Problematic tree species

9.1 Apply herbicide to trees

- One controlled before-and-after study in South Africa found that using herbicide to control trees increased plant diversity, but not shrub cover. One randomized, replicated, controlled study in the UK found that abundance of common heather seedlings increased after the application of herbicide to trees.

9.2 Cut trees

- One randomized, replicated, controlled study in the UK found that cutting trees increased heather cover. One replicated, controlled study in South Africa found that cutting trees increased grass cover. One site comparison study also in South Africa found that after clearing of non-native trees the number of plant species was similar to a nearby uninvaded site.

9.3 Cut trees and remove leaf litter

- One before-and-after trial in the Netherlands found that cutting trees and removing the litter layer increased the cover of two heather species and of three grass species.

9.4 Cut trees and remove tree seedlings

- One controlled, before-and-after trial in South Africa found that cutting trees and removing seedlings increased plant diversity and shrub cover.

9.5 Cut/mow shrubland to control trees

We captured no evidence for the effect on shrubland of cutting/mowing to control trees

9.6 Use prescribed burning to control trees

- One randomized, replicated, controlled, before-and-after trial in USA found that burning to control trees did not change cover of two of three grass species.
- One randomized, controlled study in Italy found that prescribed burning to control trees reduced cover of common heather, increased cover of purple moor grass, and had mixed effects on the basal area of trees.

9.7 Use grazing to control trees

- One randomized, controlled, before-and-after study in Italy1 found that grazing to reduce tree cover reduced cover of common heather and the basal area of trees, but did not alter cover of purple moor grass.

9.8 Cut trees and increase livestock numbers

We captured no evidence for the effects on shrublands of controlling tree species by cutting and increasing grazing intensity of livestock.

9.9 Cut trees and apply herbicide

- One controlled study in the UK found that cutting trees and applying herbicide increased the abundance of heather seedlings. However, one replicated, controlled study in the UK found that cutting silver birch trees and applying herbicide did not alter cover of common heather when compared to cutting alone. One controlled, before-and-after trial in South Africa found that cutting of invasive orange wattle trees and applying herbicide did not increase shrub cover. One replicated, controlled study in South Africa found no change in the number of shrub species.
- Two controlled studies in South Africa found that cutting trees and applying herbicide increased the total number of plant species and plant diversity.

- One replicated, controlled study in the UK found that cutting and applying herbicide reduced cover of silver birch trees.

9.10 Cut trees and use prescribed burning

- One replicated, before-and-after trial in the USA found that cutting western juniper trees and using prescribed burning increased the cover of herbaceous plants.
- One replicated, randomized, controlled, before-and-after trial in the USA found that cutting western juniper trees and using prescribed burning increased cover of herbaceous plants but had no effect on the cover of most shrubs.
- One controlled study in South Africa found that cutting followed by prescribed burning reduced the cover of woody plants but did not alter herbaceous cover.

9.11 Increase number of livestock and use prescribed burning to control trees

- One randomized, controlled, before-and-after study in Italy[1] found that prescribed burning and grazing to reduce tree cover reduced the cover of common heather and the basal area of trees. However, it did not alter the cover of purple moor grass.

Key messages - Problematic grass species

9.12 Cut/mow to control grass

- One controlled study in the UK found that mowing increased the number of heathland plants in one of two sites. The same study found that the presence of a small minority of heathland plants increased, but the presence of non-heathland plants did not change. One replicated, controlled study in the UK found that cutting to control purple moor grass reduced vegetation height, had mixed effects on purple moor grass cover and the number of plant species, and did not alter cover of common heather.
- One replicated, controlled study in the UK found that mowing did not increase the presence of heather or wavy-grass relative to rotovating or cutting turf.
- Two randomized, controlled studies in the USA found that mowing did not increase shrub seedling abundance or the cover of native forb species. Both studies found that mowing reduced grass cover but in one of these studies grass cover recovered over time.

9.13 Cut/mow to control grass and sow seeds of shrubland plants

- One randomized, replicated, controlled study in the USA found that the biomass of sagebrush plants in areas where grass was cut and seeds sown did not differ from areas where grass was not cut, but seeds were sown.
- One randomized controlled study in the USA found that cutting grass and sowing seeds increased shrub seedling abundance and reduced grass cover
- One randomized, replicated, controlled study in the USA found that sowing seeds and mowing did not change the cover of non-native plants or the number of native plant species.

9.14 Rake to control grass

- A randomized, replicated, controlled, paired study in the USA found that invasive grass cover was lower in areas that were raked than in areas that were not raked, but cover of native plants did not differ.

9.15 Cut/mow and rotovate to control grass

- One controlled study in the UK found that mowing followed by rotovating increased the number of heathland plants in one of two sites. The same study found mowing and rotovating increased the presence of a minority of heathland and non-heathland plant species.

9.16 Use herbicide to control grass

- Two randomized, controlled studies in the UK and the USA found that spraying with herbicide did not affect the number of shrub or heathland seedlings. One randomized, controlled study in the UK found that applying herbicide increased the abundance of one of four heathland plants, but reduced the abundance of one shrubland species. One randomized, replicated, controlled study in the UK reported no effect on the cover of common heather. One randomized, replicated study in the UK reported mixed effects of herbicide application on shrub cover.
- Two randomized, controlled studies in the USA and the UK found that herbicide application did not change the cover of forb species. However, one randomized, controlled, study in the USA found that herbicide application increased native forb cover and one randomized, controlled study in the UK found that applying herbicide increased cover of heathland species.
- Four of five controlled studies (two of which were replicated) in the USA found that grass cover or non-native grass cover were lower in areas where herbicides were used to control grass than areas were herbicide was not used. Two randomized, replicated, controlled studies in the UK found that herbicide reduced cover of purple moor grass, but not cover of three grass/reed species. Two randomized, controlled studies in the UK found that herbicide application did not reduce grass cover.

9.17 Apply herbicide and sow seed of shrubland plants to control grass

- One randomized, controlled study in the USA found that areas where herbicide was sprayed and seeds of shrubland species were sown had more shrub seedlings than areas that were not sprayed or sown with seeds.
- One randomized, replicated, controlled study in the USA found that spraying with herbicide and sowing seeds of shrubland species did not increase the cover of native plant species, but did increase the number of native plant species.
- One of two studies in the USA found that spraying with herbicide and sowing seeds of shrubland species reduced non-native grass cover. One study in the USA found that applying herbicide and sowing seeds of shrubland species did not reduced the cover of non-native grasses.

9.18 Apply herbicide and remove plants to control grass

- One randomized, replicated, controlled, paired study in the USA found that areas sprayed with herbicide and weeded to control non-native grass cover had higher cover of native grasses and forbs than areas that were not sprayed or weeded, but not a higher number of native plant species. The same study found that spraying with herbicide and weeding reduced non-native grass cover.

9.19 Use grazing or alter livestock type to control grass

- One replicated, controlled, before-and-after study in the Netherlands[1] found that grazing to reduce grass cover had mixed effects on cover of common heather and cross-leaved heath.
- One replicated, controlled, before-and-after study in the Netherlands[1] found that cover of wavy-hair grass increased and one before-and-after study in Spain[2] found a reduction in grass height.

9.20 Use prescribed burning to control grass

- One replicated controlled, paired, before-and-after study in the UK found that prescribed burning to reduce the cover of purple moor grass, did not reduce its cover but did reduce the cover of common heather.

- One randomized, replicated, controlled study in the UK found that prescribed burning initially reduced vegetation height, but this recovered over time.

9.21 Cut and use prescribed burning to control grass

- One randomized, replicated, controlled, paired, before-and-after study in the UK found that burning and cutting to reduce the cover of purple moor grass reduced cover of common heather but did not reduce cover of purple moor grass.

9.22 Use herbicide and prescribed burning to control grass

- One randomized, replicated, controlled, paired, before-and-after study in the UK found that burning and applying herbicide to reduce the cover of purple moor grass reduced cover of common heather but did not reduce cover of purple moor grass.

9.23 Strip turf to control grass

- One controlled study in the UK found that cutting and removing turf increased the number of heathland plants. The same study found that the presence of a small number of heathland plants increased, and that the presence of a small number of non-heathland plants decreased.
- One replicated, controlled study in the UK found that presence of heather was similar in areas where turf was cut and areas that were mown or rotovated.
- One replicated, controlled study in the UK found that the presence of wavy hair grass was similar in areas that were cut and those that were mown or rotovated.

9.24 Rotovate to control grass

- One replicated, controlled study in the UK found that rotovating did not alter the presence of heather compared to mowing or cutting. The same study found that wavy hair grass presence was not altered by rotovating, relative to areas that were mown or cut.

9.25 Add mulch to control grass

- One randomized, controlled study in the USA found that areas where mulch was used to control grass cover had a similar number of shrub seedlings to areas where mulch was not applied. The same study found that mulch application did not reduce grass cover.

9.26 Add mulch to control grass and sow seed

- One randomized, controlled study in the USA found that areas where mulch was used to control grass cover had a similar number of shrub seedlings to areas where mulch was not applied. The same study found that mulch application did not reduce grass cover.

9.27 Cut/mow, rotovate and sow seeds to control grass

- One controlled study in the UK found that mowing followed by rotovating, and spreading clippings of heathland plants increased the number of heathland species. The same study found an increase in the presence for a minority of heathland and non-heathland species.

Key messages - Bracken

9.28 Use herbicide to control bracken

- One controlled, before-and-after trial in the UK found that applying herbicide to control bracken increased the number of heather seedlings. However, two randomized, controlled studies in the UK found that spraying with herbicide did not increase heather cover.
- One randomized, controlled study in the UK found that applying herbicide to control bracken increased heath vegetation biomass. One replicated, randomized, controlled study in the UK found that application of herbicide increased the number of plant species in a heathland site. However, one replicated, randomized, controlled study in the UK found that spraying bracken with herbicide had no effect on species richness or diversity.

- One randomized, controlled study in the UK found that applying herbicide to control bracken increased the cover of wavy hair-grass and sheep’s fescue. One controlled study in the UK found that applying herbicide to control bracken increased the cover of gorse and the abundance of common cow-wheat.
- One controlled, before-and-after trial UK found that application of herbicide reduced abundance of bracken but increased the number of silver birch seedlings. Three randomized, controlled studies in the UK found that application of herbicide reduced the biomass or cover of bracken. However, one controlled study in the UK found that applying herbicide did not change the abundance of bracken.

9.29 Cut to control bracken

- One randomized, controlled, before-and-after trial in Norway and one randomized, controlled study in the UK found that cutting bracken increased the cover or biomass of heather. However, two randomized, replicated, controlled studies in the UK found that cutting bracken did not increase heather cover or abundance of heather seedlings.
- One randomized, replicated, controlled study in the UK found that cutting to control bracken increased the species richness of heathland plant species. However, another randomized, replicated, controlled study in the UK found that cutting to control bracken did not alter species richness but did increase species diversity.
- One randomized, replicated, controlled study in the UK found that cutting bracken increased cover of wavy hair-grass and sheep’s fescue. One controlled study in the UK found that cutting bracken did not increase the abundance of gorse or common cow-wheat.
- One randomized, controlled, before-and-after trial in Norway and two randomized, controlled studies in the UK found that cutting bracken reduced bracken cover or biomass. One randomized, replicated, controlled, paired study the UK found that cutting had mixed effects on bracken cover. However, one controlled study in the UK found that cutting bracken did not decrease the abundance of bracken.

9.30 Cut and apply herbicide to control bracken

- One randomized, controlled study in the UK found that cutting and applying herbicide to control bracken did not alter heather biomass. One randomized, controlled, before-and-after trial in Norway found that cutting and applying herbicide increased heather cover. A randomized, replicated, controlled, paired study in the UK found that cutting and using herbicide had no significant effect on the cover of seven plant species.
- One replicated, randomized, controlled study in the UK found that cutting bracken followed by applying herbicide increased plant species richness when compared with applying herbicide followed by cutting
- Three randomized, controlled studies (one also a before-and-after trial, and one of which was a paired study) in the UK and Norway found that cutting and applying herbicide reduced bracken biomass or cover.

9.31 Cut and burn bracken

We captured no evidence for the effects of cutting and burning bracken on shrublands.

9.32 Cut bracken and rotovate

- One controlled study in the UK found that cutting followed by rotovating to control bracken did not increase total plant biomass or biomass of heather.

9.33 Use herbicide and sow seed of shrubland plants to control bracken

We captured no evidence for the effects on shrublands of using herbicide and sowing seed of shrubland plants.

9.34 Increase livestock numbers to control bracken

- We captured no evidence for the effects on shrublands of controlling bracken by increasing grazing intensity.

9.35 Use 'bracken bruiser' to control bracken

- One randomized, replicated, controlled, before-and-after, paired study in the UK found that bracken bruising increased bracken cover, though bracken cover also increased in areas where bracken bruising was not done. There was no effect on the number of plant species or plant diversity.

9.36 Use herbicide and remove leaf litter to control bracken

- One randomized, controlled study in the UK found that using herbicide and removing leaf litter did not increase total plant biomass after eight years. The same study found that for three of six years, heather biomass was higher in areas where herbicide was sprayed and leaf litter was removed than in areas that were sprayed with herbicide.

9.37 Use herbicide and increase livestock numbers to control bracken

We captured no evidence for the effects on shrublands of controlling bracken by using herbicide and grazing.

Key messages - Problematic animals

9.38 Use fences to exclude large herbivores

- One controlled study in the USA found that using fences to exclude deer increased the height of shrubs, but not shrub cover.

9.39 Reduce numbers of large herbivores

- One before-and-after trial in the USA found that removing sheep, cattle and horses increased shrub cover and reduced grass cover. One replicated study in the UK[1] found that reducing grazing pressure by red deer increased the cover and height of common heather.

9.40 Use biological control to reduce the number of problematic invertebrates

We captured no evidence for the effects on shrublands of using biological control to reduce the numbers of herbivorous invertebrates.

Problematic tree species

Background

When tree species colonise shrublands in large numbers they fundamentally alter habitat structure. Trees can supress growth of shrubland species by outcompeting them for light (Holmes and Cowling 1997).

Holmes P.M. & Cowling R.M. (1997) The effects of invasion by *Acacia saligna* on the guild structure and regeneration capabilities of South African fynbos shrublands. Journal of Applied Ecology, 34, 317-332.

9.1 Apply herbicide to trees

- One replicated, controlled, before-and-after study in South Africa[2] found that using herbicide to control trees increased plant diversity but did not increase shrub cover.
- One randomized, replicated, controlled study in the UK[1] found that herbicide treatment of trees increased the abundance of common heather seedlings.

Background

Application of herbicide can be used to control problematic trees and may aid recovery of shrubland vegetation.

Related interventions: Cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); increase number of livestock and use prescribed burning to control trees (section 9.11); use herbicide to control grass (section 9.16); apply herbicide and sow seeds of shrubland plants to control grass (section 9.17); apply herbicide and remove plants to control grass (section 9.18); use herbicide to control bracken (section 9.28); cut and apply herbicide to control bracken (section 9.30); use herbicide and sow seed of shrubland plants to control bracken (section 9.33); use herbicide and remove leaf litter to control bracken (section 9.36); use herbicide and grazing intensity to control bracken (section 9.37).

A randomized, replicated, controlled study in 1979–1981 in a heathland in Cambridgeshire, UK (1) found that using herbicide to control silver birch *Betula pendula* saplings sometimes increased the abundance of heather *Calluna vulgaris* and birch seedlings while reducing the abundance of silver birch saplings. In one of three cases, plots treated with herbicide had more heather seedlings (64 seedlings/m^2) than untreated plots (4 seedlings/m^2). In three of three cases, plots treated with herbicide had fewer birch saplings (0–1 saplings/m^2) than untreated plots (20 saplings /m^2). However, in two of three cases, birch seedlings were more abundant in plots treated with herbicide (24–54 seedlings/m^2) than in untreated plots (7 seedlings/m^2). The herbicides fosamine, 2,4,5-T, and triclopyr were each applied in four 4 m^2 plots in 1979, and in four plots no herbicide was applied. Density of birch and heather plants was estimated annually in 1980-1981 in all plots.

A replicated, controlled, before-and-after study in 2013–2014 in a fynbos site in Cape Town, South Africa (2) found that spraying invasive orange wattle *Acacia saligna* trees with herbicide increased plant diversity, but not shrub cover. Plant species diversity was higher in areas treated with herbicide than in untreated areas (data presented as model results). However, shrub cover in areas treated with herbicide (2%) did not differ from untreated areas (5%). In April 2013 herbicide was sprayed on orange wattle saplings in ten 25 m^2 plots, while another ten plots were left untreated. The cover and diversity of plant species was assessed using 1 m^2 quadrats placed inside each plot.

(1) Marrs, R.H. (1984) Birch control on lowland heaths: mechanical control and the application of selective herbicides by foliar spray. *Journal of Applied Ecology*, 21, 703-716.
(2) Krupek, A., Gaertner, M., Holmes, P.M. & Esler, K.J. (2016) Assessment of post-burn removal methods for *Acacia saligna* in Cape Flats Sand Fynbos, with consideration of indigenous plant recovery. *South African Journal of Botany*, 105, 211-217.

9.2 Cut trees

- One randomized, replicated, controlled study in the UK[1] found that cutting birch trees increased density of heather seedlings but not that of mature common heather plants.

- One replicated, controlled study in South Africa[2] found that cutting non-native trees increased herbaceous plant cover but did not increase cover of native woody plants.
- One site comparison study in South Africa[3] found that cutting non-native *Acacia* trees reduced shrub and tree cover.

Background
This section considers the cutting of mature trees, but not mowing to control trees. Cutting targets only trees, whereas mowing cuts all plants in a community.

Related interventions: Apply herbicide to trees (section 9.1); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); increase number of livestock and use prescribed burning to control trees (section 9.11); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.23); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A randomized, replicated, controlled study in 1979–1981 in a heathland in Cambridgeshire, UK (1) found that cutting and pulling of silver birch *Betula pendula* increased the density of heather *Calluna vulgaris* seedlings but not that of mature common heather plants. There were more heather seedlings in plots where silver birch saplings had been cut or pulled (83–126 seedlings/m^2) than in plots where silver birch saplings had not been cut or pulled (4 seedlings/m^2), but there was no significant difference in mature heather density (cut/pulled: 8-11 plants/m^2; uncut: 12 plants/m^2). In two of three cases, areas where silver birch saplings had been cut or pulled had fewer silver birch saplings (0–5 saplings/m^2) than areas where silver birch saplings had not been cut or pulled (20 saplings /m^2), but in three of three cases there was no significant difference in the abundance of birch seedlings (cut/pulled: 9–19 seedlings/m^2; uncut: 7 seedlings/m^2). In four 4 m^2 plots birch saplings were pulled out of the ground in 1979, in four plots birch saplings were cut in 1979, in four plots birch saplings were cut in 1979 and 1980, and in four plots birch saplings were not cut or pulled. Abundance of birch and heather plants was estimated annually in 1980-1981 in all plots.

A replicated, controlled study in 2010–2012 in fynbos habitat invaded by non-native trees in Western Cape Province, South Africa (2) found that cutting non-native trees reduced their cover and increased herbaceous plant cover, but did not increase cover of native woody plants. After two years, the cover of native woody species was not significantly different in areas where non-native trees were cut (6%) and areas where non-native trees were not cut (10%), but was lower than in a relatively undisturbed fynbos site (60%). Cover of native herbaceous plants was higher in areas that were cut (5%) than areas that were not cut (0%) or in an undisturbed site (0%). In areas where non-native trees were cut their cover was lower (22%) than in areas where they were not cut (56%), but higher than in a relatively undisturbed fynbos site (7%). In 2010 non-native trees were cut and removed from part of the site. Eight 25 m^2 plots were established in areas where trees were cut, eight in areas where trees were not cut, and four in a nearby undisturbed fynbos site. Vegetation cover was estimated in the plots in 2011 and 2012.

A site comparison study in 1999–2014 in two fynbos sites in Eastern Cape, South Africa (3) found that after clearing non-native acacia *Acacia* spp. the number of plant species was similar to that found in a nearby undisturbed, but cover of trees and shrubs was lower and grasses higher. After 15 years the number of plant species at the site where non-native acacia trees had been cleared (13 species) was not significantly different from that at an undisturbed site (15 species). The cover of trees and shrubs was lower at the site that had been cleared (39%) than in the undisturbed site (69%). Grass cover was higher in the site that had been cleared (27%) than in the undisturbed site (11%). In 1999 non-native acacia trees were cleared from a fynbos site. In 2014 three 100 m^2 plots were established where non-native acacias were cleared and three in an undisturbed site nearby. Vegetation cover in each plot was assessed in June 2014.

(1) Marrs, R.H. (1984) Birch control on lowland heaths: mechanical control and the application of selective herbicides by foliar spray. *Journal of Applied Ecology*, 21, 703-716.
(2) Ruwanza, S., Gaertner, M., Esler, K.J. & Richardson, D.M. (2013) The effectiveness of active and passive restoration on recovery of indigenous vegetation in riparian zones in the Western Cape, South Africa: A preliminary assessment. *South African Journal of Botany*, 88, 132-141.
(3) Ndou, E. & Ruwanza, S. (2016) Soil and vegetation recovery following alien tree clearing in the Eastern Cape Province of South Africa. *African Journal of Ecology*.

9.3 Cut trees and remove leaf litter

- One before-and-after trial in the Netherlands[1] found that cutting trees and removing the litter layer increased the cover of two heather species and of three grass species.

Background

This section considers the cutting of trees combined with removal of leaf litter. The cutting of trees may reduce their abundance while the removal of leaf litter may aid the propagation of shrubland plant species.

Related interventions: Apply herbicide to trees (section 9.1); cut trees (section 9.2); cut trees and remove tree seedlings (section 9.4); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); increase number of livestock and use prescribed burning to control trees (section 9.11); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A before-and-after trial in 1989–1994 in a formerly forested wet heathland in the Netherlands (1) found that cutting trees and removing the leaf litter layer increased the cover of two heather and three grass species. Fifteen years after trees were cut and leaf litter removed, the cover of common heather *Calluna vulgaris* and cross-leaved heath *Erica* *tetralix* (heather: 3%; cross-leaved heath: 2%) was higher than before cutting and removal of leaf litter (heather: 0%; cross-leaved heath: 0%). This pattern was also seen for purple moor-grass *Molinia caerulea* (before: 0%; after: 18%), bulbous rush *Juncus bulbosus* (before: 0%; after: 9%), and sharp flower rush *Juncus acutiflorus* (before: 0%; after: 7%). All trees were cut and the leaf litter removed in winter 1989. Twelve permanent plots measuring either 1 m^2 or 4 m^2 were established at the site in 1989 and vegetation cover was recorded in July or August for every year in 1989–1994.

(1) Jansen, A.J.M., de Graaf, M.C.C. & Roelofs, J.G.M. (1996) The restoration of species-rich heathland communities in the Netherlands. *Vegetatio*, 126, 73-88.

9.4 Cut trees and remove tree seedlings

- A controlled, before-and-after study in South Africa[1] found that cutting orange wattle trees and removing seedlings of the same species increased plant diversity and shrub cover.

Background
This section considers the cutting of trees combined with removal of tree seedlings. The cutting of trees may reduce their abundance while the removal of seedlings of tree species may help to limit any subsequent population increases.

Related interventions: Apply herbicide to trees (section 9.1); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); Increase number of livestock and use prescribed burning to control trees (section 9.11); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut to control bracken (section 9.25); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A controlled, before-and-after study in 2013-2014 in a fynbos site in Cape Town, South Africa (1) found that cutting of invasive orange wattle *Acacia saligna* trees, followed by removal of the species' seedlings increased plant diversity and shrub cover. Plant species diversity was higher in areas where orange wattle trees were cut and had seedlings removed than areas where no cutting or seedling removal had been carried out (data as model results). Cutting and removal of seedlings also led to higher shrub cover (10% cover) compared to areas that had not been cut or had seedlings removed (5% cover). In April 2013 orange wattle saplings were cut using loppers and seedlings removed by hand in ten 25 m^2 plots, while another 10 plots were left uncut. The cover of plant species was assessed using 1 m^2 quadrats placed inside each plot.

(1) Krupek, A., Gaertner, M., Holmes, P.M. & Esler, K.J. (2016) Assessment of post-burn removal methods for *Acacia saligna* in Cape Flats Sand Fynbos, with consideration of indigenous plant recovery. *South African Journal of Botany*, 105, 211-217.

9.5 Cut/mow shrubland to control trees

We found no evidence for the effect on shrubland of cutting/mowing to control trees.

Background
This section considers the mowing of shrubland to control problematic tree species. Mowing reduces the height of all species in a plant community and should not be confused with cutting of trees.

Related interventions: Apply herbicide to trees (section 9.1); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); Increase number of livestock and use prescribed burning to control trees (section 9.11); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

9.6 Use prescribed burning to control trees

- One randomized, replicated, controlled, before-and-after trial in USA[1] found that burning to control trees did not change cover of two of three grass species.
- One randomized, controlled study in Italy[2] found that prescribed burning to control trees reduced cover of common heather, increased cover of purple moor grass, and had mixed effects on the basal area of trees.

Background
This section considers the use of prescribed fire to control problematic tree species in shrublands. Fire may damage or kill trees therefore reducing competition between trees and shrubland vegetation. This may allow shrubland plants to increase in abundance.

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1); use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.20); cut and use prescribed burning to control grass (section 9.21); cut and burn bracken (section 9.31); burn shrublands to reduce concentration of pollutants (section 10.6).

A randomized, replicated, controlled, before-and-after trial in 2003-2004 in two sagebrush ecosystems in California, USA (1) found that using fire to control western juniper *Juniperus occidentalis* did not change the cover of two out of three grass species after one year. In both sites the cover of squirreltail *Hordeum jubatum* and sandberg bluegrass *Poa secunda* did not significantly differ after burning from the cover before burning, and cover did not differ from areas that had not been burned (no data reported). However, in one of the two sites the cover of bluebunch wheatgrass *Pseudoroegneria spicata* was lower after burning than before burning, and cover was lower in areas that had been burned than in areas that had not been burned (results presented as model results). Five blocks were established in two sites. Each block consisted of three 0.4 ha plots, two of which were burned and one of which was left unburnt. Cover of grasses was estimated in 2004 using two 30 x 60 cm plots within each 0.4 ha plot.

A randomized, controlled, before-and-after study in 2005–2009 in a heathland invaded by aspen *Populus tremuloides* and silver birch *Betula pendula* in Italy (2) found that prescribed burning to reduce tree cover reduced the cover of common heather *Calluna vulgaris*, increased the cover of purple moor grass *Molinia arundinacea* and had mixed effects on the basal area of trees. After five years, cover of common heather declined in areas that were burned (before: 78%, after: 0%) but showed little change in areas that were not burned (before: 72%, after: 72%). Common heather cover in areas that had been burned once increased to 37% but in areas that were burned yearly cover remained at 0%. Purple moor grass cover increased in areas that were burned (before: 76%, after: 94%), and cover also increased in unburned areas (before: 79%, after 91%). Basal area of trees declined one year after burning (before: 3 m^2/ha, after: 0.5 m^2/ha) and remained at this level for areas that were burned yearly, but increased to 2 m^2/ha after five years in areas that were only burned once. In winter 2005 nine 650 m^2 plots were burned, another six plots were burned every year in 2005–2009, and six plots were not burned. No statistical analyses were carried out in this study. Five 2 x 2 m quadrats were placed in each plot and the diameter of trees within them measured. Cover of common heather and purple moor grass was estimated using a 10 m transect in each plot along which the presence of both species was recorded every 20 cm.

(1) Ellsworth, L.M. & Kauffman, J.B. (2010) Native Bunchgrass Response to Prescribed Fire in Ungrazed Mountain Big Sagebrush Ecosystems. *The Journal of the Association for Fire Ecology*, 6, 86-96.
(2) Ascoli, D., Lonati, M., Marzano, R., Bovio, G., Cavallero, A. & Lombardi, G. (2013) Prescribed burning and browsing to control tree encroachment in southern European heathlands. *Forest Ecology and Management*, 289, 69-77.

9.7 Use grazing to control trees

- One randomized, controlled, before-and-after study in Italy[1] found that grazing to reduce tree cover reduced cover of common heather and the basal area of trees, but did not alter cover of purple moor grass.

Background
Livestock can damage and kill tree seedlings as a result of grazing and trampling. This can potentially be used to limit the growth and spread of problematic tree species in shrublands.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A randomized, controlled, before-and-after study in 2005-2009 in a heathland invaded by aspen *Populus tremuloides* and silver birch *Betula pendula* in Italy (1) found that grazing to reduce tree cover reduced the cover of common heather *Calluna vulgaris* and the basal area of trees but did not alter the cover of purple moor grass *Molinia arundinacea*. After five years, the cover of common heather in grazed areas was similar (77%) to than that in areas that were not burned (77%). Purple moor grass cover was similar between grazed (84%) and ungrazed areas (88%). The basal area of trees was lower in grazed (3.2 m^2/ha) than in ungrazed areas (4.6 m^2/ha). No statistical analyses were carried out in this study. Starting in spring 2006 nine 650 m^2 plots were grazed by goats for five years, and another six plots were not grazed. Five 2 x 2 m quadrats were placed in each plot and diameter of trees within them measured. Cover of common heather and purple moor grass was estimated using a 10 m transect in each plot along which the presence of both species was noted every 20 cm.

(1) Ascoli, D., Lonati, M., Marzano, R., Bovio, G., Cavallero, A. & Lombardi, G. (2013) Prescribed burning and browsing to control tree encroachment in southern European heathlands. *Forest Ecology and Management*, 289, 69-77.

9.8 Cut trees and increase livestock numbers

We captured no evidence for the effects on shrublands of controlling tree species by cutting and increasing grazing intensity of livestock.

Background
Cutting trees may kill them or slow growth and combining this with an increase in grazing intensity may also reduce the spread of problematic tree species by reducing the abundance of seedlings.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

9.9 Cut trees and apply herbicide

- One controlled study in the UK[1] found that cutting trees and applying herbicide increased the abundance of heather seedlings. However, one replicated, controlled study in the UK[2] found that cutting silver birch trees and applying herbicide did not alter cover of common heather when compared to cutting alone. One controlled, before-and-after trial in South

Africa[4] found that cutting of invasive orange wattle trees and applying herbicide did not increase shrub cover. One replicated, controlled study in South Africa[3] found no change in the number of shrub species.

- Two controlled studies in South Africa[3,4] found that cutting trees and applying herbicide increased the total number of plant species and plant diversity.
- One replicated, controlled study in the UK[2] found that cutting and applying herbicide reduced cover of silver birch trees.

Background

Some tree species can survive cutting by resprouting. Cutting combined with application of herbicide aims to kill trees that might otherwise resprout after cutting.

Related interventions: Apply herbicide to trees (section 9.1); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and use prescribed burning (section 9.10); Increase number of livestock and use prescribed burning to control trees (section 9.11); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A controlled study in 1979–1981 in a heathland in Cambridgeshire, UK (1) found that cutting birch *Betula pendula* saplings and spraying with herbicide sometimes increased the abundance of heather *Calluna vulgaris* seedlings. After two years and in one of three cases, there were more heather seedlings in areas where silver birch saplings had been cut and sprayed with herbicide (64 seedlings/m^2) than in plots where silver birch saplings had not been cut or sprayed (4 seedlings/m^2). Areas where trees had been cut and herbicide had been applied had fewer silver birch saplings (2-4 saplings/m^2) than those where herbicide had not been used (20 saplings/m^2). However, the opposite was true in two of three cases for silver birch seedlings (cut and herbicide: 24-54 seedlings/m^2; uncut and no herbicide: 7 seedlings/m^2). The herbicides fosamine ammonium, 2,4,5-T, and triclopyr were each applied in four 4 m^2 plots in 1979 followed by cutting in 1980, and in four plots no herbicide or cutting was applied. Additionally, each herbicide was applied in four 4 m^2 plots in 1980 following cutting in 1979, and in another four plots no herbicide or cutting was applied. Abundance of silver birch and heather plants was estimated annually in 1980-1981 in all plots.

A replicated, controlled, before-and-after, paired study in 1980–1985 in a heathland in the UK (2) found that cutting silver birch trees *Betula pendula* and applying herbicide reduced their abundance when compared to cutting alone, and increased cover of wavy-hair grass *Deschampsia flexuosa*, but did not alter cover of common heather *Calluna vulgaris*. In four of four years, areas where silver birch had been cut and herbicide applied had lower number of silver birch (0–3 trees/200 m^2) than areas where cutting alone was used (7–10 trees/200 m^2). Cutting silver birch trees and applying herbicide did not alter cover of common heather relative to cutting alone (no data presented). After five years cover of wavy-hair grass was higher in plots where silver birch was cut and herbicide used (26–37%) than in plots where cutting along was carried out (8%). In January 1980 sixteen 10 x 20 m plots were established. All silver birch trees in the plots were cut at a height of 10 cm and removed from the site. Following this, in four plots all stumps were painted with the herbicide 2,4,5-T, in four plots the herbicide fosamine was sprayed, in four plots both fosamine and 2,4,5-T were used, and in four plots no herbicide was applied. In July 1980, 1981, 1982, and 1985 the number of silver birch trees in plots were counted. Vegetation cover was estimated in plots by eye.

A replicated, controlled study in 2008–2014 in two fynbos sites in Eastern Cape, South Africa (3) found that cutting and applying herbicide to invasive rose gum *Eucalyptus grandis* trees increased the total number of plant species, did not alter the number of shrub or tree species and increased the number of grass species. The number of plant species was higher in areas that were cut and treated with herbicide (10 species) than in areas that were not (4 species), and the number of plant species was not significantly different from uninvaded fynbos (12 species). The number of tree and shrub species in areas that were cut and treated with herbicide was not significantly different from that in areas which were not cut or treated with herbicide or uninvaded fynbos (cut and herbicide: 4 species, not cut with no herbicide: 3 species, uninvaded fynbos: 7 species). However, the number of grass species in areas that were cut and treated with herbicide (2 species) was higher than in areas that were not cut or treated with herbicide (0 species) or uninvaded fynbos (1 species). In 2008 rose gum trees were cut and herbicide applied in part of two fynbos areas. In 2014 three 100 m^2 plots were placed in each of the areas where trees had been cut and herbicide applied, areas where trees had not been cut, and uninvaded fynbos at each site. Vegetation cover and number of species were estimated in each plot. Herbicide name and concentration is not given.

A controlled, before-and-after trial between 2013 and 2014 in a fynbos site in Cape Town, South Africa (4) found that cutting of invasive orange wattle *Acacia saligna* trees, followed by herbicide treatment, increased plant diversity, but not shrub cover. Plant species diversity was higher in areas that had been cut and had herbicide applied than areas where no cutting or herbicide application had been carried out (data as model results). However, shrub cover in areas that had been cut and had herbicide applied (4%) was not significantly different from areas that had not been cut or had herbicide applied (5%). In April 2013 in ten 25 m^2 plots the orange wattle saplings were cut and herbicide (active ingredients Triclopyr 120 g/l and Aminopyralid 12 g/l) was applied to their cut stems, while another ten plots were left uncut. The cover of plant species was assessed using 1 m^2 quadrats placed inside each plot.

(1) Marrs, R.H. (1984) Birch control on lowland heaths: mechanical control and the application of selective herbicides by foliar spray. *Journal of Applied Ecology*, 21, 703-716.

(2) Marrs, R. (1987) Studies on the conservation of lowland Calluna heaths. I. Control of birch and bracken and its effect on heath vegetation. *Journal of applied ecology*, 163-175.

(3) Kerr, T.F. & Ruwanza, S. (2016) Does *Eucalyptus grandis* invasion and removal affect soils and vegetation in the Eastern Cape Province, South Africa? *Austral Ecology*, 41, 328-338.

(4) Krupek, A., Gaertner, M., Holmes, P.M. & Esler, K.J. (2016) Assessment of post-burn removal methods for Acacia saligna in Cape Flats Sand Fynbos, with consideration of indigenous plant recovery. *South African Journal of Botany*, 105, 211-217.

9.10 Cut trees and use prescribed burning

- One replicated, before-and-after trial in the USA[1] found that cutting western juniper trees and using prescribed burning increased the cover of herbaceous plants.
- One replicated, randomized, controlled, before-and-after trial in the USA[2] found that cutting western juniper trees and using prescribed burning increased cover of herbaceous plants but had no effect on the cover of most shrubs.
- One controlled study in South Africa[3] found that cutting followed by prescribed burning reduced the cover of woody plants but did not alter herbaceous cover.

Background
Some tree species can survive cutting by resprouting. Cutting combined with prescribed burning aims to kill trees that might otherwise resprout after cutting.

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1);use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); use prescribed burning to control grass (section 9.20); cut and use prescribed burning to control grass (section 9.21); cut and burn bracken (section 9.31); burn shrublands to reduce impacts of pollutants (section 10.6).

A replicated, before-and-after trial in 1997–2006 at a sagebrush steppe site in Oregon, USA (1) found that cutting and burning of western juniper *Juniperus occidentalis* trees followed by prescribed burning increased the cover of herbaceous plants. After nine years, herbaceous plant cover was higher after cutting and burning (29%) than before cutting and burning (6%). In ten 0.5 ha plots all western juniper trees were cut using chainsaws and then burned. Herbaceous plant cover was estimated before cutting and burning and then after burning in 1998–2001 and 2006 using ten randomly located 0.2 m^2 quadrats in each 0.5 ha plot.

A replicated, randomized, controlled, before-and-after trial in 2002–2006 in two sagebrush steppe sites in Idaho, USA (2) found that cutting of western juniper *Juniperus occidentalis* followed by prescribed burning had no effect on the cover of most shrubs, but increased cover of herbaceous species. After three years, big sagebrush *Artemisia tridentata*, mountain snowberry *Symphoricarpos oreophilus*, and gray rabbitbush *Ericameria nauseosa* cover was not significantly different between areas that had been cut and burned and unburned, uncut areas (data reported as model results). Cover of snowbrush *Ceanothus velutinus* was higher in cut and burned areas than in unburned, uncut areas (data reported as model results). Cutting and burning increased herb cover (45% cover) relative to uncut, unburned areas (18% cover). Cutting and burning of western juniper trees reduced their numbers from 424 trees/ha to 2 trees/ha after 3 years. Trees were cut and burned in forty 1 ha plots with a further twenty 1 ha plots left uncut and unburnt. Four 6 x 50 m transects located on each 1 ha plot were surveyed to estimate western juniper numbers. Four 2 x 50 m transects/plot were used to survey shrub cover. To survey herbaceous cover 0.2 m^2 quadrats were placed every 2 m along transect lines.

A controlled study in 2010-2012 in fynbos habitat invaded by non-native trees in Western Cape Province, South Africa (3) found that cutting of non-native trees, followed by burning, reduced the cover of non-native trees and native woody plants but did not alter herbaceous cover. After two years, areas where non-native trees were cut and burned had a lower non-native trees cover (41%) than areas where they were not cut or burnt (56%), but a higher cover than in a relatively undisturbed fynbos site (7%). Cover of native woody species was lower in areas where non-native trees were cut and burned (0%) than in areas that were not cut or burnt (10%), and also lower than in a relatively undisturbed fynbos site (60%). Cover of native herbaceous plants was not significantly different in areas that were cut and burned (1%) and areas that were not cut or burnt (0%) or in an undisturbed site (0%). In 2010 non-native trees were cleared and burned on part of the site. Eight 25 m^2 plots were established in areas where trees had been cut and burned, eight in areas where trees were not cut or burned, and four in a nearby undisturbed fynbos site. Vegetation cover was estimated in the plots in 2011 and 2012.

(1) Bates, J.D. & Svejcar, T.J. (2009) Herbaceous Succession After Burning of Cut Western Juniper Trees. *Western North American Naturalist*, 69, 9-25.
(2) Bates, J.D., Davies, K.W. & Sharp, R.N. (2011) Shrub-Steppe Early Succession Following Juniper Cutting and Prescribed Fire. *Environmental Management*, 47, 468-481.
(3) Ruwanza, S., Gaertner, M., Esler, K.J. & Richardson, D.M. (2013) The effectiveness of active and passive restoration on recovery of indigenous vegetation in riparian zones in the Western Cape, South Africa: A preliminary assessment. *South African Journal of Botany*, 88, 132-141.

9.11 Increase number of livestock and use prescribed burning to control trees

- One randomized, controlled, before-and-after study in Italy[1] found that prescribed burning and grazing to reduce tree cover reduced the cover of common heather and the basal area of trees. However, it did not alter the cover of purple moor grass.

Background
Fire may damage or kill trees therefore reducing competition between trees and shrubland vegetation. Combining this with grazing may help to reduce regrowth and recruitment of young trees.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A randomized, controlled, before-and-after study in 2005–2009 in a heathland invaded by aspen *Populus tremuloides* and silver birch *Betula pendula* in Italy (1) found that prescribed burning and grazing to reduce tree cover reduced the cover of common heather *Calluna vulgaris* and basal area of trees but did not alter the cover of purple moor grass *Molinia arundinacea*. After five years, the cover of common heather in areas that were burned and grazed was lower (83%) than that in areas that were not burned (36%). Cover of purple moor grass was similar between burned and grazed areas (89%) and areas that were not burned or grazed (88%). Additionally, the basal area of trees was lower in burned and grazed areas (0.5 m^2/ha) than in areas that had not been burned or grazed (4.6 m^2/ha). In winter 2005 twelve 650 m^2 plots were burned and subsequently grazed by goats for five years, and another six plots were not burned or grazed. No statistical analyses were carried out in this study. Five 2 x 2 m quadrats were placed in each plot and diameter of trees within them measured. Cover of common heather and purple moor grass was estimated using a 10 m transect in each plot along which the presence of both species was noted every 20 cm.

(1) Ascoli, D., Lonati, M., Marzano, R., Bovio, G., Cavallero, A. & Lombardi, G. (2013) Prescribed burning and browsing to control tree encroachment in southern European heathlands. *Forest Ecology and Management*, 289, 69-77.

Problematic grass species

Background

Both native and non-native grass species can form dense vegetation in which the seeds of shrubland species struggle to germinate. Non-native grasses are a particular problem in shrublands in Western USA. For example, monocultures of the invasive grass species *Bromus tectorum* have been estimated to cover approximately 20,000 km^2 or 5% of the Great Basin region in Western USA (Bradley & Mustard 2005), threatening native sagebrush shrubland habitats. Similarly, in some north-western European heathlands wavy-hair grass *Deschampsia flexuosa* has replaced heather species as a dominant plant species, partly as a result of high rates of nitrogen deposition (Britton *et al.* 2003).

Bradley, B.A. & Mustard, J.F. (2005) Identifying land cover variability distinct from land cover change: Cheatgrass in the Great Basin. Remote Sensing of Environment, 94, 204-213.
Britton, A., Marrs, R., Pakeman, R. & Carey, P. (2003) The influence of soil-type, drought and nitrogen addition on interactions between *Calluna vulgaris* and *Deschampsia flexuosa*: implications for heathland regeneration. *Plant Ecology*, 166, 93-105.

9.12 Cut/mow to control grass

- One controlled study in the UK[1] found that mowing increased the number of heathland plants in one of two sites. The same study found that the presence of a small minority of heathland plants increased, but the presence of non-heathland plants did not change. One replicated, controlled study in the UK[4] found that cutting to control purple moor grass reduced vegetation height, had mixed effects on purple moor grass cover and the number of plant species, and did not alter cover of common heather.
- One replicated, controlled study in the UK[2] found that mowing did not increase the presence of heather or wavy-grass relative to rotovating or cutting turf.
- Two randomized, controlled studies in the USA[3,5] found that mowing did not increase shrub seedling abundance[3] or the cover of native forb species[5]. Both studies found that mowing reduced grass cover but in one of these studies[5] grass cover recovered over time.

Background

Mowing involves cutting all vegetation in a shrubland. Doing this may allow shrubland species to become established at sites dominated by grasses.

Related interventions: Apply herbicide to trees (section 9.1); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); cut/mow to control grass and sow seed of shrubland plants (section 9.13); rake to control grass (section 9.14); cut/mow and rotovate to control grass (section 9.15); use herbicide to control grass (section 9.16); apply herbicide and sow seeds to control grass (section 9.17); apply herbicide and remove plants to control grass (section 9.18); use grazing or alter livestock type to control grass (section 9.19) use controlled burning to control grass (section 9.20); cut and use prescribed burning to control grass (section 9.21); use prescribed herbicide and prescribed burning to control grass (section 9.22); strip turf to control grass (section 9.23); rotovate to control grass (section 9.24); add mulch to control grass (section 9.25); add mulch and sow seeds to control grass (section 9.26); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A controlled study in 1983–1989 in two heathlands that had been converted to grasslands in Dorset, UK (1) found that mowing increased the number of heathland plant species in one of two cases, increased the presence of heathland plant species in one of sixteen cases, and did not alter the presence of non-heathland plant species. After six years, areas that were mown had a higher number of heathland plant species (6 species) than areas that had not been mown (5 species). However, heathland plant species only had a higher presence in mown plots (present in 55% of plots) than in unmown plots (11%) in one of sixteen comparisons. The presence of non-heathland species did not differ significantly between mown plots (present in 0–86% of plots) and unmown plots (present in 0-64% of plots). In 1983 five 25 m^2 plots were mown and five plots were left unmown. In 1989 four 1 m^2 quadrats divided into twenty-five 20 x 20 cm squares were placed in each plot and the presence of plant species in each square recorded.

A replicated, controlled study in 1996–1998 in a heathland invaded by wavy hair-grass *Deschampsia flexuosa* in Breckland, UK (2) found that mowing did not decrease the presence of wavy-hair grass or increase the presence of heather *Calluna vulgaris* relative to rotovating or cutting turf. After two years, wavy hair-grass presence in plots that had been mown (100% of plots) was not significantly different to presence in rotovated plots (99% of plots) or plots where turf had been cut (98% of plots). Heather presence did not differ significantly between plots that had been mown (5%) and those that had been rotovated (10%) or where turf was cut (24%). In August 1996 grass was cut to a height of 10 cm or less in 1–2 ha blocks, several 0.5 ha areas were rotovated, and in five 4 m^2 turf and soil were removed to a depth of 10 cm. Five 4 m^2 plots were established in each of the areas subject to different interventions. Each plot was divided into a grid of 20 x 20 cm squares and species presence was recorded in each square twice a year in 1996–1998.

A randomized, controlled study in 1997-1999 in sagebrush scrub habitat that had been invaded by grass and burnt by wildfires in California, USA (3) found that cutting invasive grasses did not increase the seedling abundance of seven of seven shrub species but did reduce grass cover. After one year, the number of shrub seedlings in areas where grasses were cut did not differ from that of areas where cutting was not carried out (0 seedlings/m^2). Grass cover in areas where invasive grasses were cut was lower (15%) than areas where invasive grasses were not cut (84%). In 1997-1998 all grass was removed by hand from five randomly located 5 x 5 m plots, while in five other plots no grass was removed. In spring 1997 plots were surveyed for grasses using two 0.25 x 0.5 m quadrats/plot and two 0.5 x 1 m quadrats/plot for shrubs.

A randomized, replicated, controlled study in 1995–1999 at a moorland site in the UK (4) found that cutting to control purple moor grass *Molinia caerulea* initially reduced vegetation height, had mixed effects on the number of plant species and cover of purple moor grass, and had no effect on the cover of common heather *Calluna vulgaris*. After eight months and in three of three cases, areas that were cut had shorter vegetation (8-21 cm) than areas that were not cut (26 cm), but after 44 months vegetation was only shorter in one of three cases (cut: 17 cm, uncut: 31 cm). After eight months and in one of three cases, cut areas had lower purple moor grass cover than areas that were not cut and after 44 months areas that were cut showed no significant difference in cover of purple moor grass when compared to uncut areas (no data presented). After 44 months in one of three cases areas that were cut contained more plant species (9 species) than areas that were not cut (6 species). The cover of common heather did not differ significantly between areas that were cut and those that were not. In December 1995 two blocks were established at the site. Each block was divided into four plots, one of which was cut once, one of which was cut twice, one of which was cut three times, and one of which was left uncut. In June–August of 1996–1999 the plant species cover and vegetation height were surveyed using forty-eight 1 m^2 quadrats placed in each plot.

A randomized, controlled study in 1999-2004 in sage scrub habitat in California, USA (5) found that mowing to control invasive grass species had no effect on native forb cover and while it initially reduced the cover of invasive grasses, this subsequently increased. One year after mowing, cover of native forbs did not differ from mown and unmown plots (1%) and after five years cover was still not significantly different between mown (5%) and unmown plots (3%). Two years after mowing, mown plots had lower cover of invasive grass species (12%) than unmown plots (18%). However, after five years, cover of invasive grasses increased in mown plots (23%) and was not significantly different to that found in unmown plots (33%). Twenty 1 m^2 plots were mown annually in 1999-2001, while twenty other plots were not mown. Plant cover in the plots was assessed annually in 2000-2004.

(1) Smith, R.E.N., Webb, N.R. & Clarke, R.T. (1991) The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57, 221-234.
(2) Britton, A.J., Marrs, R.H., Carey, P.D. & Pakeman, R.J. (2000) Comparison of techniques to increase Calluna vulgaris cover on heathland invaded by grasses in Breckland, south east England. *Biological Conservation*, 95, 227-232.
(3) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.
(4) Milligan, A., Putwain, P., Cox, E., Ghorbani, J., Le Duc, M. & Marrs, R. (2004) Developing an integrated land management strategy for the restoration of moorland vegetation on Molinia caerulea-dominated vegetation for conservation purposes in upland Britain. *Biological Conservation*, 119, 371-385.
(5) Cox, R.D. & Allen, E.B. (2008) Stability of exotic annual grasses following restoration efforts in southern California coastal sage scrub. *Journal of Applied Ecology*, 45, 495-504.

9.13 Cut/mow to control grass and sow seed of shrubland plants

- One randomized, replicated, controlled study in the USA[1] found that the biomass of sagebrush plants in areas where grass was cut and seeds sown did not differ from areas where grass was not cut, but seeds were sown.
- One randomized controlled study in the USA[2] found that cutting grass and sowing seeds increased shrub seedling abundance and reduced grass cover
- One randomized, replicated, controlled study in the USA[3] found that sowing seeds and mowing did not change the cover of non-native plants or the number of native plant species.

Background

Mowing reduces the length of all vegetation. Combined with sowing of seeds this practice may limit the growth of grasses while allowing shrubland plants to become established at grass dominated sites.

Related interventions: Apply herbicide to trees (section 9.1); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrublands to control trees (section 9.5); use prescribed burning to control trees (section 9.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); cut/mow to control grass (section 9.11); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A randomized, replicated, controlled study in 1993–1994 in sagebrush scrub habitat invaded by non-native grasses in California, USA (1) found that in areas where invasive grasses were cut and seeds of shrubs were sown, the biomass of sagebrush *Artemisia californica* plants did not differ from areas where invasive grasses were not cut but seeds were sown. In areas where invasive grasses were cut and shrub seeds were sown the biomass of sagebrush individuals (141 g) was not significantly different to those in areas where only shrub seeds were sown (50–119 g). In March 1993 invasive grasses were removed in three 1 m x 1.2 m plots after which sagebrush seeds were sown, while in 12 plots grasses were not removed and seeds were sown. Sagebrush plants were harvested in May-June 1994.

A randomized, controlled study in 1997–1999 in a sagebrush scrub habitat that had been invaded by grass and burnt by wildfires in California, USA (2) found that cutting invasive grasses followed by sowing of shrub seeds increased shrub seedling abundance and reduced grass cover. After one year, areas where grasses were cut and seeds were sown had more shrub seedlings (1-23 seedlings/m^2) than areas that were not cut or sown with seeds (0 seedlings/m^2). In areas where invasive grasses were cut and seeds were sown, grass cover was lower (13%) than in areas where invasive grasses were not cut or seeds sown (84%). In 1997–1998 grass was cut by hand in five randomly located 5 m x 5 m plots, after which seeds of native shrubs were sown, while in five other plots no grass was cut and seeds were not sown. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

A randomized, replicated, controlled study in 2005–2006 in sagebrush scrub habitat, dominated by exotic grass species in California, USA (3) found that sowing seeds of native species, followed by mowing, did not reduce the cover of non-native species nor did it increase the cover or number of native plant species. In areas that were seeded and mown cover of non-native plant species (43%) was not significantly different from areas that had been seeded but not mown (63%). Cover and number of native plant species were also not significantly different in areas that had been seeded and mown (cover: 18%; number of species: 5) compared to areas that had been seeded but not mown (cover: 24%; number of species: 4). In 2005 five 5 m^2 plots were sown with seeds of shrubland species and mown, while five other plots were sown with seeds but not mown. Plant cover was measured in 0.5 m^2 quadrats placed in each plot.

(1) Eliason, S.A. & Allen, E.B. (1997) Exotic Grass Competition in Suppressing Native Shrubland Re-establishment. *Restoration Ecology*, 5, 245-255.
(2) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.
(3) Marushia, R.G. & Allen, E.B. (2011) Control of Exotic Annual Grasses to Restore Native Forbs in Abandoned Agricultural Land. *Restoration Ecology*, 19, 45-54.

9.14 Rake to control grass

- A randomized, replicated, controlled, paired study in the USA[1] found that invasive grass cover was lower in areas that were raked than areas that were not raked, but cover of native plants did not differ.

Background
Raking can be used to reduce the length of grass as well as pulling out individual plants. In addition, it may create disturbances to topsoil allowing shrubland species to establish.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); disturb vegetation (section 13.6).

A randomized, replicated, controlled, paired study in 2005–2008 in creosote bush shrubland that was invaded by non-native grasses in California, USA (1) found that raking decreased invasive grass cover but did not increase the number of annual plant species, and also reduced the cover of native grasses and forb species in two of four cases. In four of four cases areas that were raked had lower non-native grass cover (36–39%) than areas that were not raked (60–65%). In four of four cases the number of annual plant species in areas that had been raked (2–4 species/plot) did not differ significantly from the areas that had not been raked (3–4 species/plot). However, in two of four cases cover of native grass and forb species was lower in areas that had been raked (4–18%) than in areas that had not been raked (23–37%). In January 2006 and 2008 twelve 8 m x 8 m plots were raked to remove invasive grasses while twelve other plots were not raked. Plant cover was recorded in March-April 2006 and 2008 in 0.5 m^2 quadrats located in each plot.

(1) Steers, R.J. & Allen, E.B. (2010) Post-Fire Control of Invasive Plants Promotes Native Recovery in a Burned Desert Shrubland. *Restoration Ecology*, 18, 334-343.

9.15 Cut/mow and rotovate to control grass

- One controlled study in the UK[1] found that mowing followed by rotovating increased the number of heathland plant species in one of two sites. The same study found that the presence of a minority of heathland and non-heathland species increased.

Background

Mowing reduces the length of vegetation and when combined with rotovation it may create areas of bare earth where shrubland plant species can establish.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); cut trees (section 9.2); cut/mow shrublands to control trees (section 9.5); cut to control bracken (section 9.29); cut and apply herbicide to control bracken (section 9.30); cut and burn bracken (section 9.31); cut bracken and rotovate (section 9.32).

A controlled study in 1983–1989 in two former heathlands converted to grasslands in Dorset, UK (1) found that mowing followed by rotovating increased the number of heathland plant species in one of two cases, and increased the presence of heathland plant species in three of 16 comparisons, but increased the presence of non-heathland plant species for two of 22 comparisons. After six years and in one of two cases, areas that were mown and rotovated had a higher number of heathland plant species (6 species) than areas that were not mown and rotovated (5 species). Presence of heathland plant species was higher in areas that had been mown and rotovated than in areas that had not been mown and rotovated in two of 16 comparisons (cut: present in 10–56% of plots, uncut: present in 3–11% of plots). Presence of non-heathland plant species was higher in areas that had been mown and rotovated than in areas that had not been mown and rotovated in two of 22 comparisons (cut: present in 3–6% of plots, uncut: present in 2–4% of plots). In 1983 five 25 m^2 plots were mown and rotovated and five plots were left unmown and unrotovated. In 1989 four 1 m^2 quadrats divided into twenty-five 20 cm x 20 cm squares were placed in each plot and the presence of plant species in each square recorded.

(1) Smith, R.E.N., Webb, N.R. & Clarke, R.T. (1991) The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57, 221-234.

9.16 Use herbicide to control grass

- Two randomized, controlled studies in the UK[1] and the USA[2] found that spraying with herbicide did not affect the number of shrub or heathland seedlings. One randomized, controlled study in the UK[1] found that applying herbicide increased the abundance of one of four heathland plants, but reduced the abundance of one shrubland species. One randomized, replicated, controlled study in the UK reported no effect on the cover of common heather[5]. One randomized, replicated study in the UK[4] reported mixed effects of herbicide application on shrub cover.
- Two randomized, controlled studies in the USA[6] and the UK[8] found that herbicide application did not change the cover of forb species. However, one randomized, controlled, study in the USA[7] found that herbicide application increased native forb cover and one randomized, controlled study in the UK[8] found that applying herbicide increased cover of heathland species.

- Four of five controlled studies (two of which were replicated) in the USA[2,3,7, 9] found that grass cover[2, 3, 7] or non-native grass cover[9] were lower in areas where herbicides were used to control grass than areas were herbicide was not used. Two randomized, replicated, controlled studies in the UK[3, 4] found that herbicide reduced cover of purple moor grass[3, 4], but not cover of three grass/reed species[3]. Two randomized, controlled studies in the UK[5, 8] found that herbicide application did not reduce grass cover.

Background
One potential method for controlling problematic grass species is to use herbicide. This may kill grass species and allow shrubland plant species to establish in areas where grass dominates.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); apply herbicide to trees (section 9.1); use herbicide to control bracken (section 9.28); cut and apply herbicide to control bracken (section 9.30); use herbicide and sow seed of shrubland plants to control bracken (section 9.33); use herbicide and remove leaf litter to control bracken (section 9.36); use herbicide and livestock to control bracken (section 9.37).

A randomized, controlled study in 1988–1993 in former heathland in Dorset, UK (1) found that spraying grass with herbicide did not change the number of seedlings of heathland species after one year but after three years it reduced the abundance of one of four heathland plant species and increased the abundance of one of four heathland plant species. After one year and for seven of seven heathland species, the number of seedlings in plots sprayed with herbicide (0–0.1 seedlings/m^2) did not differ significantly from plots that were not sprayed with herbicide (0–0.2 seedlings/m^2). After three years, the abundance of one of four heathland plant species was higher in plots that had been sprayed with herbicide (0.8 plants/m^2) compared to plots that were not sprayed (0.4 plants/m^2). However, the abundance of one of four heathland plant species was lower in plots that had been sprayed with herbicide (0.7 plants/m^2) than in plots that had not been sprayed with herbicide (3.2 plants/m^2). In 1989 glyphosate herbicide was sprayed on three 500 m^2 plots at a rate of 5 litres/ha and three plots were left unsprayed. In 1990–1991 the number of seedlings was recorded in seven 0.5 m x 1 m quadrats which were placed in each plot. In 1993 the number of plant shoots was recorded in three 1 m^2 quadrats which were randomly placed in each plot.

A randomized, controlled study in 1997–1999 in sagebrush scrub habitat that had been invaded by grass and burnt by wildfires in California, USA (2) found that spraying invasive grasses with herbicide did not increase the seedling abundance of seven of seven shrub species but did reduce invasive grass cover. After one year, the number of seedlings of seven shrub species did not differ between areas sprayed with herbicide and unsprayed areas (sprayed: 0 seedlings/m^2; unsprayed: 0 seedlings/m^2). Grass cover in areas where invasive grasses were sprayed with herbicide was lower (4%) than areas where invasive grasses were not sprayed (84%). In 1997–1998 grass was sprayed with the grass-specific herbicide Fusilade in five randomly located 5 x 5 m plots, while in five other plots no herbicide was used. In spring 1997 plots were surveyed for grasses using two 0.25 x 0.5 m quadrats/plot and two 0.5 x 1 m quadrats/plot for shrubs.

A randomized, replicated, controlled study in 1996–1999 in moorland in the UK (3) found that herbicide application to control grass initially reduced cover of purple moor grass *Molinia caerulea* and had no effect on cover of wavy-hair grass *Deschampsia flexuosa*, heath bedstraw *Galium saxatile*, and heath rush *Juncus squarosus*. After one year, cover of purple moor grass was lower in plots that had been sprayed with herbicide (29–45%) than in unsprayed plots (59%). After four years and in one of five comparisons, cover of purple moor grass was lower in plots sprayed with herbicide (35%) than in unsprayed plots (54%), but in four of five comparisons there was no difference in cover of purple moor grass (herbicide: 48-53%, no herbicide: 54%). The cover of wavy-hair grass, heath bedstraw, and heath rush did not differ significantly between plots sprayed with herbicide and unsprayed plots. Three blocks were established at the site, and divided into 12 plots, 11 of which were sprayed with different herbicides and one of which was left unsprayed. Cover of plant species was estimated using 1 m^2 quadrats in August 1996, August 1997, and July 1999.

A randomized, replicated, controlled study in 1995–2000 in four moorland sites in the UK (4) found that applying herbicide reduced the cover of purple moor grass *Molinia caerulea* as well as cover of the three plant species, increased the cover of four plant species, and had mixed effects on the cover of six other plant species. In five of five years, areas where herbicide was used had a lower cover of purple moor grass (9-32%) than areas where herbicide was not applied (40-45%). The cover of common heather *Calluna vulgaris*, crowberry *Empetrum nigrum*, bilberry *Vaccinium myrtillus* was lower in areas where herbicide was applied than in areas where it was not applied (no data reported). The cover of cross-leaved heath *Erica tetralix*, *Juncus squarrosus*, *Polytrichum commune*, sphagnum spp. was higher in areas where herbicide was applied than in areas where it was not applied (no data reported). Application of herbicide had an inconsistent effect on the cover of sweet vernal grass *Anthoxanthum odouratum*, wavy-hair grass *Deschampsia flexuosa*, common cottongrass *Eriophorum angustifolium*, *Eriophorum vaginatum*, deergrass *Trichophorum cespitosum* and bog cranberry *Vaccinium oxycoccus* (no data reported). In 1995 two blocks were established on each site and half of each block was burned. Fencing was established to limit grazing in two plots within each burned area but one plot was left unfenced. Within each plot glyphosate herbicide was applied in two subplots and one subplot was not sprayed. Cover of each species was estimated in four 1 m^2 quadrats which were randomly placed in each plot.

A randomized, replicated, controlled study in 1995-1999 at a moorland site in the UK (5) found that applying herbicide to control purple moor grass *Molinia caerulea* had a mixed effect on vegetation height, and did not significantly alter the number of plant species, cover purple moor grass, or cover of common heather *Calluna vulgaris*. In one of four comparisons areas where herbicide had been applied had shorter vegetation (15 cm) than areas where herbicide was not applied (19 cm), in three of four cases there was no significant difference in vegetation height. There was no significant difference in the cover of purple moor grass or common heather, or the number of plant species in areas where herbicide was applied and areas where herbicide was not applied (no data presented). In December 1995 two blocks were established at the site. Each block was divided into four plots, one of which was cut once, one of which was cut twice, one of which was cut three times, and one of which was left uncut. In a sub-plot within each plot the herbicide quizalofop-ethyl was applied. In June–August of 1996–1999 the plant species cover and vegetation height were surveyed using forty-eight 1 m^2 quadrats placed in each plot. A randomized, controlled study in 1999–2004 in sage scrub habitat in California, USA (6) found that using grass-specific herbicide to control invasive grass species reduced the cover of invasive grasses but had no effect on native forb cover. After one year, areas where herbicide was applied had lower cover of invasive grass species (37%) than areas where no herbicide was applied (52%). After five years, cover of invasive grasses in herbicide treated areas (12%) was still lower than in areas not treated with herbicide (31%). After one year, cover of native forbs was not significantly different in areas where herbicide had been sprayed (4%) and in unsprayed areas (2%), but was higher in sprayed plots in one of five subsequent years (sprayed: 0–32% cover; unsprayed: 1–39% cover). Twenty 1 m^2 plots were sprayed with the herbicide Fusilade II in 1999 and 2000, while twenty other plots were not sprayed. Plant cover in the plots was assessed annually in 1999–2004.

A randomized, replicated, controlled, paired site study in 2005–2008 in creosote bush shrubland that was invaded by non-native grasses in California, USA (7) found that spraying with herbicide reduced the cover of non-native grasses in four of four cases, increased the number of annual plant species in two of four cases and increased cover of native grass and forb species in three of four cases. In four of four cases, areas sprayed with herbicide had lower non-native grass cover (0–27%) than areas where no herbicide was sprayed (40–65%). In two of four cases, areas where herbicide had been sprayed had more annual plant species (7 species/plot) than areas that had not been sprayed (4–5 species/plot). In three of four cases where herbicide was sprayed cover of native grass and forb species was higher (58–89% cover) than areas where no herbicide was sprayed (22–37% cover). In January 2006 and 2008 twelve 8 x 8 m plots were sprayed with the grass specific herbicide Fusilade-II while in twelve other plots herbicide was not sprayed. Plant cover was recorded in March-April 2006 and 2008 in 0.5 m^2 quadrats located in each plot.

A randomized, controlled study in 1988–2005 in former heathland in Dorset, UK (8) found that spraying grass with herbicide increased the cover of heathland species, but did not reduce the cover of grasses or forbs. After 17 years, the cover of heathland species was higher in plots sprayed with herbicide (45%) than in unsprayed plots (16%). There was no significant difference in the cover of grasses or forbs in plots sprayed with herbicide (grasses: 36%, forbs: 54%) and unsprayed plots (grasses: 59%, forbs: 27%). In 1989 glyphosate herbicide was sprayed on three 500 m^2 plots and three plots were not sprayed with herbicide. In 2005 the cover of plants was recorded in four 1 m^2 quadrats which were randomly placed in each plot.

A replicated, controlled study in 2008–2011 in two sagebrush steppe sites in California, USA (9) that had been invaded by non-native grasses found that spraying with herbicide reduced cover of non-native grasses in the majority of cases, but did not alter cover of perennial grasses. In four of six cases cover of the non-native grasses medusahead *Taeniatherum caput-medusae* and downy brome *Bromus tectorum* was lower in areas sprayed with herbicide (0–6%) than in unsprayed areas (2–52%) and in two cases there was no significant difference (sprayed: 0–1%, unsprayed: 0–1%). Cover of perennial grasses did not differ significantly between areas that had been sprayed with herbicide (3–12%) and unsprayed areas (4–6%). Twenty 30 x 30 m plots were established at two sites, 16 were sprayed with herbicides in October 2008, while four other plots were not sprayed with herbicide. Shrubland seed was sown in all plots in September 2009. Plots were surveyed in June 2009–2001 by randomly placing between five and 15 quadrats in each plot.

(1) Pywell, R.F., Webb, N.R. & Putwain, P.D. (1995) A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32, 400-411.
(2) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.
(3) Milligan, A.L., Putwain, P.D. & Marrs, R.H. (2003) A field assessment of the role of selective herbicides in the restoration of British moorland dominated by Molinia. *Biological Conservation*, 109, 369-379.
(4) Marrs, R., Phillips, J., Todd, P., Ghorbani, J. & Le Duc, M. (2004) Control of Molinia caerulea on upland moors. *Journal of Applied Ecology*, 41, 398-411.
(5) Milligan, A., Putwain, P., Cox, E., Ghorbani, J., Le Duc, M. & Marrs, R. (2004) Developing an integrated land management strategy for the restoration of moorland vegetation on Molinia caerulea-dominated vegetation for conservation purposes in upland Britain. *Biological Conservation*, 119, 371-385.
(6) Cox, R.D. & Allen, E.B. (2008) Stability of exotic annual grasses following restoration efforts in southern California coastal sage scrub. *Journal of Applied Ecology*, 45, 495-504.
(7) Steers, R.J. & Allen, E.B. (2010) Post-Fire Control of Invasive Plants Promotes Native Recovery in a Burned Desert Shrubland. *Restoration Ecology*, 18, 334-343.
(8) Pywell, R.F., Meek, W.R., Webb, N.R., Putwain, P.D. & Bullock, J.M. (2011) Long-term heathland restoration on former grassland: The results of a 17-year experiment. *Biological Conservation*, 144, 1602-1609.
(9) Kyser, G.B., Wilson, R.G., Zhang, J. & DiTomaso, J.M. (2013) Herbicide-Assisted Restoration of Great Basin Sagebrush Steppe Infested With Medusahead and Downy Brome. *Rangeland Ecology & Management*, 66, 588-596.

9.17 Apply herbicide and sow seeds of shrubland plants to control grass

- One randomized, controlled study in the USA[1] found that areas where herbicide was sprayed and seeds of shrubland species were sown had more shrub seedlings than areas that were not sprayed or sown with seeds.
- One randomized, replicated, controlled study in the USA[2] found that spraying with herbicide and sowing seeds of shrubland species did not increase the cover of native plant species, but did increase the number of native plant species.
- One of two studies in the USA[1] found that spraying with herbicide and sowing seeds of shrubland species reduced non-native grass cover. One study in the USA[2] found that applying herbicide and sowing seeds of shrubland species did not reduced the cover of non-native grasses.

Background

Applying herbicide may help to control problematic grass species while sowing seeds may help shrubland plant species become established.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); apply herbicide to trees (section 9.1); use herbicide to control bracken (section 9.28); cut and apply herbicide to control bracken (section 9.30); use herbicide and sow seed of shrubland plants to control bracken (section 9.33); use herbicide and remove leaf litter to control bracken (section 9.36); use herbicide and livestock to control bracken (section 9.37).

A randomized, controlled study in 1997–1999 in sagebrush scrub habitat that had been invaded by grass and burnt by wildfires in California, USA (1) found that spraying invasive grasses with herbicide followed by sowing of shrub seeds increased the seedling abundance of shrub species and reduced grass cover. After one year, areas where grasses were sprayed with herbicide and sown with seeds had more shrub seedlings (1–29 seedlings/m^2) than unsprayed areas (0 seedlings/m^2). Additionally, grass cover in areas where invasive grasses were sprayed with herbicide was lower (3%) than in unsprayed areas (84%). In 1997–1998 grass was sprayed with herbicide, and shrub seeds were subsequently sown in five randomly located 5 x 5 m plots, while in five other plots herbicide was not used and no seeds were sown. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

A randomized, replicated, controlled study in 2005–2006 in sagebrush scrub habitat, dominated by non-native grasses in the USA (2) found that sowing seeds, followed by spraying with herbicide did not reduce the cover of non-native species nor did it increase the cover of native species, but it did increase the number of native plant species. In areas that were seeded and sprayed with herbicide, cover of non-native plant species (40%) was not significantly different from areas that had been seeded but not sprayed with herbicide (63%). Native species cover was also not significantly different in areas that had been seeded and sprayed with herbicide (40%) compared to areas that had been seeded but not sprayed (cover 24%). However, areas that were seeded and sprayed with herbicide had a higher number of native plant species (7 species) than areas that were seeded but not sprayed (5 species). In 2005 five 5 m^2 plots were sown with seeds of shrubland species and sprayed with herbicide, while five other plots were sown with seeds but not sprayed with herbicide. Plant cover was measured in a 0.5 m^2 quadrat placed in each plot.

(1) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.
(2) Marushia, R.G. & Allen, E.B. (2011) Control of Exotic Annual Grasses to Restore Native Forbs in Abandoned Agricultural Land. *Restoration Ecology*, 19, 45-54.

9.18 Apply herbicide and remove plants to control grass

- One randomized, replicated, controlled, paired study in the USA[1] found that areas sprayed with herbicide and weeded to control non-native grass cover had higher cover of native grasses and forbs than areas that were not sprayed or weeded, but not a higher number of native plant species. The same study found that spraying with herbicide and weeding reduced non-native grass cover.

Background
Combining the application of herbicide with removal of grass may help to reduce the abundance of problematic grass species, and thus help shrubland plants to increase in size and cover.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); apply herbicide to trees (section 9.1); use herbicide to control bracken (section 9.28); cut and apply herbicide to control bracken (section 9.30); use herbicide and sow seed of shrubland plants (section 9.33); use herbicide and remove leaf litter to control bracken (section 9.36); use herbicide and livestock to control bracken (section 9.37).

A randomized, replicated, controlled, paired study in 2005–2008 in creosote bush shrubland invaded by non-native grasses in California, USA (1) found that spraying with herbicide, followed by weeding, decreased invasive grass cover, increased the cover of native grass and forb species, but did not increase the number of annual plant species. Areas that were sprayed with herbicide and were weeded had lower non-native grass cover (0–38%) than areas that were not sprayed or weeded (40–65%). Also, areas that were sprayed with herbicide and weeded had lower had higher cover of native grass and forb species (20–87%) than areas that were not sprayed or weeded (13–36%). However, the number of native annual plants was not significantly different in areas that had been sprayed with herbicide and weeded (4–18%) and unsprayed and unweeded areas (23–37%). In January 2006 and 2008 twelve 8 m x 8 m plots were sprayed with the grass specific herbicide Fusilade-II and then weeded by hand while twelve other plots were not sprayed with herbicide or weeded. Plant cover was recorded in March-April 2006 and 2008 in 0.5 m^2 quadrats located in each plot.

(1) Steers, R.J. & Allen, E.B. (2010) Post-Fire Control of Invasive Plants Promotes Native Recovery in a Burned Desert Shrubland. *Restoration Ecology*, 18, 334-343.

9.19 Use grazing or alter livestock type to control grass

- One replicated, controlled, before-and-after study in the Netherlands[1] found that grazing to reduce grass cover had mixed effects on cover of common heather and cross-leaved heath.
- One replicated, controlled, before-and-after study in the Netherlands[1] found that cover of wavy-hair grass increased and one before-and-after study in Spain[2] found a reduction in grass height.

Background
Livestock often preferentially feed on palatable grasses. Increasing the number of livestock or altering the type of livestock therefore may reduce grass cover of problematic species and allow shrubland plant species to increase in cover.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.39).

A replicated, controlled, before-and-after study in 1983-1993 in four heathland sites in the Netherlands (1) found that grazing to reduce grass cover increased the cover of wavy hair-grass *Deschampsia flexuosa* and had mixed effects on the cover of common heather *Calluna vulgaris*, cross-leaved heath *Erica tetralix*, and purple-moor grass *Molinia caerulea*. Cover of wavy hair-grass was higher after grazing was introduced than prior to the introduction of grazing (after: 82–91%, before: 51–54%) and was also higher than in ungrazed (after: 23–61%, before: 76–77%). Cover of common heather increased in one of two sites after grazing (after: 22%, before: 0%), while in the other grazed site it was not significantly different when compared to cover prior to grazing (after: 0%, before: 0%). After the introduction of grazing neither cross leaved heath cover (after: 7%, before: 6%) nor purple-moor grass cover changed significantly (after: 37–87%, before: 33–73%). In 1983 the grazed areas were stocked at a density of 0.2 cows/ha and fences were constructed in parts of the sites to exclude livestock. In 1983–1993 a small number of trees were cleared from the sites. Point quadrats were used in each area to assess vegetation cover (number of quadrats not specified).

A before-and-after study in winter 2006/2007 in a heathland in Northern Spain (2) found that increasing the number of ponies present at the site reduced grass height in most cases. After one month and in nine of fifteen areas, grass was shorter in areas that were grazed (9-21 cm) than in the same areas prior to grazing (13-–38 cm). In October 2006 fences were constructed around the site. Five Basque pottoka ponies were released at the site in December 2006, giving a density of 6.3 ponies/ha. Vegetation height was measured using a ruler in 120 quadrats before and after grazing (dates unspecified).

(1) Bokdam, J. & Gleichman, J.M. (2000) Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. *Journal of Applied Ecology*, 37, 415-431.
(2) Aldezabal, A., Mandaluniz, N. & Laskurain, N. (2013) Gorse (Ulex spp.) use by ponies in winter: Is the spatial pattern of browsing independent of the neighbouring vegetation? *Grass and Forage Science*, 68, 49-58.

9.20 Use prescribed burning to control grass

- One replicated controlled, paired, before-and-after study in the UK[1] found that prescribed burning to reduce the cover of purple moor grass, did not reduce its cover but did reduce the cover of common heather.
- One randomized, replicated, controlled study in the UK[2] found that prescribed burning initially reduced vegetation height, but this recovered over time.

Background
This section considers the use of prescribed fire to control problematic grass species in shrublands. Fire may damage or kill grasses therefore reducing competition between with other shrubland vegetation. This may allow shrubland plants to increase in abundance.

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1);use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); all interventions related to control of grass (sections 9.12-9.27); cut and burn bracken (section 9.31); burn shrublands to reduce concentration of pollutants (section 10.6).

A randomized, replicated, controlled, paired, before-and-after study in 1996-1999 in wet heathland in Northumberland, UK (1) found that burning to reduce the cover of purple-moor grass *Molinia caerulea* reduced cover of common heather *Calluna vulgaris* but did not reduce cover of purple-moor grass. Cover of common heather was lower after burning than before burning (after: 20-50%, before: 71-97%) and was lower than in plots that were not burned (68-93%). Cover of purple-moor grass in plots that had been burned was not significantly different to that in plots that had not been burned (no data presented). In April 1996 six 10 x 10 m plots were burned and six plots were not burned. In 995 five 1 m^2 quadrats were established in each plot and vegetation was surveyed in July 1995 and 1997-1999. The area was used for livestock and density of sheep varied from 0.66 to 1.5 ewes/ha.

A randomized, replicated, controlled study in 1995–2000 in four moorland sites in the UK (2) found that prescribed burning to reduce the cover of purple moor grass *Molinia caerulea* initially reduced vegetation height, but this subsequently recovered. Immediately after prescribed burning vegetation height was lower in burned plots than in unburned plots, however after five years there was no longer a difference in height between burned and unburned plots (no data reported). In 1995 two blocks were established on each site and half of each block was burned. Fencing was established to limit grazing in two plots within each burned area but one plot was left unfenced. Within each plot the herbicide glyphosate was applied in two subplots and one subplot was not sprayed. Vegetation height was measured in 20 random locations with a sward stick in each plot.

(1) Ross, S., Adamson, H. & Moon, A. (2003) Evaluating management techniques for controlling *Molinia caerulea* and enhancing *Calluna vulgaris* on upland wet heathland in northern England, UK. *Agriculture, ecosystems & environment*, 97, 39-49.
(2) Marrs, R., Phillips, J., Todd, P., Ghorbani, J. & Le Duc, M. (2004) Control of *Molinia caerulea* on upland moors. *Journal of Applied Ecology*, 41, 398-411.

9.21 Cut and use prescribed burning to control grass

- One randomized, replicated, controlled, paired, before-and-after study in the UK found that burning and cutting to reduce the cover of purple moor grass reduced cover of common heather but did not reduce cover of purple moor grass.

Background
Fire may damage or kill grasses therefore reducing competition between with other shrubland vegetation. Mowing/cutting may further reduce their cover allowing other shrubland vegetation to increase in abundance.

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1);use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.20); cut and use prescribed burning to control grass (section 9.21); burn shrublands to reduce concentration of pollutants (section 10.6).

A randomized, replicated, controlled, paired, before-and-after study in 1996-1999 in wet heathland in Northumberland, UK (1) found that burning and cutting to reduce the cover of purple-moor grass *Molinia caerulea* reduced cover of common heather *Calluna vulgaris* but did not reduce cover of purple-moor grass. Cover of common heather was lower after burning than before cutting and burning (after: 19-58%, before: 70-94%) and was lower than in plots that were not cut or burned (68-93%). Cover of purple-moor grass in plots that had been cut and burned was not significantly different to that in plots that had not been cut and burned (no data reported). In April 1996 six 10 x 10 m plots were cut and burned and six plots were not cut or burned. In 1995 five 1 m^2 quadrats were established in each plot and vegetation was surveyed in July 1995 and 1997-1999. The area was used for livestock and density of sheep varied from 0.66 to 1.5 ewes/ha 9.21

(1) Ross, S., Adamson, H. & Moon, A. (2003) Evaluating management techniques for controlling Molinia caerulea and enhancing Calluna vulgaris on upland wet heathland in northern England, UK. *Agriculture, ecosystems & environment*, 97, 39-49.

9.22 Use herbicide and prescribed burning to control grass

- One randomized, replicated, controlled, paired, before-and-after study in the UK found that burning and applying herbicide to reduce the cover of purple moor grass reduced cover of common heather but did not reduce cover of purple moor grass.

Background
Fire may damage or kill grasses therefore reducing competition between with other shrubland vegetation. Applying herbicide may further reduce their cover allowing other shrubland vegetation to increase in abundance.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); apply herbicide to trees (section 9.1); use herbicide to control bracken (section 9.28); cut and apply herbicide to control bracken (section 9.30); use herbicide and sow seed of shrubland plants to control bracken (section 9.33); use herbicide and remove leaf litter to control bracken (section 9.36); use herbicide and livestock to control bracken (section 9.37).

A randomized, replicated, controlled, paired, before-and-after study in 1996-1999 in wet heathland in Northumberland, UK (1) found that burning and applying herbicide to reduce the cover of purple-moor grass *Molinia caerulea* reduced cover of common heather *Calluna vulgaris* but did not reduce cover of purple-moor grass. Cover of common heather was lower after than before burning and applying herbicide (after: 26-68%, before: 70-99%) and was lower than in plots that were not burned or sprayed with herbicide (68-93%). Cover of purple-moor grass in plots that had been burned and sprayed with herbicide was not significantly different to that in plots that had not been burned or sprayed with herbicide (no data presented). In April 1996 six 10 x 10 m plots were burned and sprayed with herbicide and six plots were not burned or sprayed with herbicide. In 1995 five 1 m^2 quadrats were established in each plot and vegetation was surveyed in July 1995 and 1997-1999. The area was used for livestock and density of sheep varied from 0.66 to 1.5 ewes/ha.

(1) Ross, S., Adamson, H. & Moon, A. (2003) Evaluating management techniques for controlling Molinia caerulea and enhancing Calluna vulgaris on upland wet heathland in northern England, UK. *Agriculture, ecosystems & environment*, 97, 39-49.

9.23 Strip turf to control grass

- One controlled study in the UK[1] found that cutting and removing turf increased the number of heathland plants. The same study found that the presence of a small number of heathland plants increased, and that the presence of a small number of non-heathland plants decreased.
- One replicated, controlled study in the UK[2] found that presence of heather was similar in areas where turf was cut and areas that were mown or rotovated.
- One replicated, controlled study in the UK[2] found that the presence of wavy hair grass was similar in areas that were cut and those that were mown or rotovated.

Background

Turf was traditionally stripped so that it could be used as fuel. However, reduction in the use of this technique is thought to have resulted in an increase in grass species in some shrublands (Bokdam and Gleichman 2000). Reintroducing turf cutting may help to reduce the abundance of problematic grass species.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); strip topsoil (section 13.7); plant turf (section 13.22).

Bokdam, J. & Gleichman, J.M. (2000) Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. *Journal of Applied Ecology*, 37, 415-431.

A controlled study in 1983–1989 in two former heathlands converted to grasslands in Dorset, UK (1) found that cutting and removing turf increased the number of heathland plant species in two of two cases, increased the presence of heathland plant species in seven of 16 cases, and reduced the presence of a minority of non-heathland plant species for four of 22 cases. After six years, areas where turf had been cut and removed had a higher number of heathland plant species (6–7 species) than areas where turf was not cut (5 species). Presence of heathland plant species was higher in plots where turf was cut than in plots that were uncut in seven of 16 comparisons (cut: 6–87%, uncut: 0–55%), and lower in two of 16 comparisons (cut: 6–37%, uncut: 16-68%). Presence of non-heathland plant species was higher in plots where turf had been cut than in uncut plots in four of 22 comparisons (cut: 4–79%, uncut: 0–15%), and lower in four of 22 comparisons (cut: 1-5%, uncut: 7–26%). In 1983 turf was cut and removed from five 25 m^2 plots and in five plots turf was left uncut. In 1989 four 1 m^2 quadrats divided into twenty-five 20 cm x 20 cm squares were placed in each plot and the presence of plant species in each square recorded.

A replicated, controlled study in 1996–1998 in a heathland invaded by wavy hair-grass *Deschampsia flexuosa* in Breckland, UK (2) found that cutting turf did not decrease the presence of wavy-hair grass or increase the presence of heather *Calluna vulgaris* compared to mowing or rotovating. After two years, wavy hair-grass presence in plots where turf had been cut (98%) was not significantly different to presence in mown (100%) or rotovated plots (99%). After two years, heather presence did not differ significantly between plots where turf was cut (24%) and those that had been rotovated (10%) or mown (5%). In August 1996 in five 4 m^2 areas turf and soil were removed to a depth of 10 cm, a number of 0.5 ha areas were rotovated, and grass was cut to a height of 10 cm or less in a number of 1–2 ha blocks. Five 4 m^2 plots were established in each of the areas subject to different interventions. Each plot was divided into a grid of 20 cm x 20 cm squares and presence of species was recorded in each square twice a year in 1996–1998.

(1) Smith, R.E.N., Webb, N.R. & Clarke, R.T. (1991) The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57, 221-234.
(2) Britton, A.J., Carey, P.D., Pakeman, R.J. & Marrs, R.H. (2000) A comparison of regeneration dynamics following gap creation at two geographically contrasting heathland sites. *Journal of Applied Ecology*, 37, 832-844.

9.24 Rotovate to control grass

- One replicated, controlled study in the UK[1] found that rotovating did not alter the presence of heather compared to mowing or cutting. The same study found that wavy hair grass presence was not altered by rotovating, relative to areas that were mown or cut.

Background
Rotovators are machines that have a series of blades that rotate to pierce and disturb soil. Using them disturbs soil and thus may help to control grass species while creating areas of bare ground that may be colonised by shrubland plants.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); cut bracken and rotovate (section 9.32).

A replicated, controlled study in 1996–1998 in a heathland invaded by wavy hair-grass *Deschampsia flexuosa* in Breckland, UK (1) found that rotovating did not decrease the presence of wavy-hair grass or increase the presence of heather *Calluna vulgaris* relative to mowing or cutting turf. After two years, wavy hair-grass presence in plots that had been rotovated (99% of plots) was not significantly different to presence in mown plots (100% of plots) or plots where turf had been cut (98% of plots). After two years, heather presence did not differ significantly between plots that had been rotovated (10% of plots) and those that had been mown (5% of plots) or where turf was cut (24% of plots). In August 1996 a number of 0.5 ha areas were rotovated, grass was cut to a height of 10 cm or less in a number of 1-2 ha blocks, and in five 4 m^2 areas turf and soil were removed to a depth of 10 cm. Five 4 m^2 plots were established in each of the areas subject to different interventions. Each plot was divided into a grid of 20 cm x 20 cm squares and presence of species was recorded in each square twice a year in 1996–1998.

(1) Britton, A.J., Marrs, R.H., Carey, P.D. & Pakeman, R.J. (2000) Comparison of techniques to increase Calluna vulgaris cover on heathland invaded by grasses in Breckland, south east England. *Biological Conservation*, 95, 227-232.

9.25 Add mulch to control grass

- One randomized, controlled study in the USA[1] found that areas where mulch was used to control grass cover had a similar number of shrub seedlings to areas where mulch was not applied. The same study found that mulch application did not reduce grass cover.

Background
Mulch is usually an organic material such as leaves, grass cuttings, or wood chips that is applied to the top layer of soils. Using mulch directly on unwanted plants can reduce the amount of light they receive and therefore may reduce their abundance.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); add mulch and fertilizer to soil (section 13.14); add manure (section 13.15); add peat to soil (alongside planting/seeding) (section 14.2); add mulch to soil (alongside planting/seeding) (section 14.3); add mulch and fertilizer to soil (alongside planting/seeding) (section 14.4); add topsoil (alongside planting/seeding) (section 14.8).

A randomized, controlled study in 1997–1999 in sagebrush scrub habitat that had been invaded by grass and burnt by wildfires in California, USA (1) found that adding mulch did not increase the seedling abundance of shrub species or reduce grass cover. After one year, the number of seedlings for seven of seven shrub species did not differ between areas where mulch had been added (0 seedlings/m^2) and areas without mulch (0 seedlings/m^2). There was also no significant difference in grass cover between areas where mulch had been added (85%) and areas where mulch was not added (84%). In 1997 seeds were sown in five randomly located 5 m x 5 m plots, while in five other plots no seeds were sown. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

(1) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.

9.26 Add mulch to control grass and sow seed

- One randomized, controlled study in the USA[1] found that areas where mulch was used to control grass cover had a similar number of shrub seedlings to areas where mulch was not applied. The same study found that mulch application did not reduce grass cover.

Background

Mulch is usually an organic material such as leaves, grass cuttings, or wood chips that is applied to the top layer of soils. Using mulch directly on unwanted plants can reduce the amount of light they receive and therefore may reduce their abundance. Combining this with the addition of seeds of shrubland plants may aid on the establishment of shrubland species.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); add mulch and fertilizer to soil (section 13.14); add manure (section 13.15); add peat to soil (alongside planting/seeding) (section 14.2); add mulch to soil (alongside planting/seeding) (section 14.3); add mulch and fertilizer to soil (alongside planting/seeding) (section 14.4); add topsoil (alongside planting/seeding) (section 14.8).

A randomized, controlled study in 1997–1999 in sagebrush scrub habitat that had been invaded by grass and burnt by wildfires in California, USA (1) found that adding mulch, followed by seeding with shrub seeds, increased the seedling abundance of one of seven shrub species but did not reduce grass cover. After one year, areas where mulch and shrub seeds were added did not have a significantly higher number of shrub seedlings for two of seven species (1 seedlings/m^2) than areas where mulch and seed were not added (0 seedlings/m^2). There was also no significant difference in grass cover between areas where mulch and seeds had been added (76%) and areas where neither mulch, nor seeds were added (84%). In 1997 mulch was added to five randomly located 5 m x 5 m plots which were subsequently sown with seeds from native shrubs, while in five other plots no mulch or seeds were added. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

(1) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.

9.27 Cut/mow, rotovate and sow seeds to control grass

- One controlled study in the UK[1] found that mowing followed by rotovating, and spreading clippings of heathland plants increased the number of heathland species. The same study found an increase in the presence for a minority of heathland and non-heathland species.

Background
Cutting and mowing can reduce the length of grass, and rotovating can disturb soil and roots, thus inhibiting recovery of grasses. Spreading seed of shrubland plants can help them to become established and outcompete regrowing grasses.

Related interventions: all interventions related to control of grass (sections 9.12-9.27); cut bracken and rotovate (sections 9.32).

A controlled trial in 1983–1989 in two former heathlands converted to grasslands in Dorset, UK (1) found that mowing followed by rotovating and the spreading of clippings of heathland plants, increased the number of heathland plant species in two of two cases, and increased the presence of heathland plant species in three of 16 comparisons, but increased the presence of non-heathland plant species for two of 22 comparisons. After six years and in two of two cases, areas that had been mown, rotovated and spread with heathland clippings had a higher number of heathland plant species (4–7 species) than areas that had not been mown, rotovated, and spread with clippings (1–5 species). Presence of heathland plant species was higher in plots that were mown, rotovated and spread with heathland clippings (1–16%) than in plots that were not mown, rotovated, and spread with clippings in three of 16 comparisons (0%). Presence of non-heathland plant species was also higher in plots that were mown, rotovated and spread with heathland clippings (12%) than in plots that were not mown, rotovated, and spread with clippings in one of 22 comparisons (4%). In 1983 five 25 m^2 plots were mown and rotovated and subsequently spread with clippings harvested from a nearby mature heathland and five plots were left unmown and unrotovated, and were not spread with clippings. In 1989 four 1 m^2 quadrats divided into twenty-five 20 cm x 20 cm squares were placed in each plot and the presence of plant species in each square recorded.

(1) Smith, R.E.N., Webb, N.R. & Clarke, R.T. (1991) The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57, 221-234.

Bracken

Background

Bracken *Pteridium aquilinum* is a large fern species found on all continents except Antarctica (Page 1976). This species has been a particular concern for heathland managers in the UK, where the species can form dominant stands which limit the growth of other plant species as well as reducing the number of nesting sites for birds of prey (Pakeman and Marrs 1992). Bracken's range in the UK has expanded over the last 200 years due to changes in land management, and a reduction in traditional uses such as animal feed and thatch (Marrs and Watt 2006).

Page, C.N. (1976) The taxonomy and phytogeography of bracken—a review. *Botanical Journal of the Linnean Society*, 73, 1-34.

Pakeman, R.J. & Marrs, R.H. (1992) The conservation value of bracken *Pteridium aquilinum* (L.) Kuhn-dominated communities in the UK, and an assessment of the ecological impact of bracken expansion or its removal. *Biological Conservation*, 62, 101-114.

Marrs, R.H. & Watt, A.S. (2006) Biological Flora of the British Isles: *Pteridium aquilinum* (L.) Kuhn. *Journal of Ecology*, 94, 1272-1321.

9.28 Use herbicide to control bracken

- One controlled, before-and-after trial in the UK[1] found that applying herbicide to control bracken increased the number of heather seedlings. However, two randomized, controlled studies in the UK[3,4] found that spraying with herbicide did not increase heather cover.
- One randomized, controlled study in the UK[2] found that applying herbicide to control bracken increased heath vegetation biomass. One replicated, randomized, controlled study in the UK[7] found that application of herbicide increased the number of plant species in a heathland site. However, one replicated, randomized, controlled study in the UK[8] found that spraying bracken with herbicide had no effect on species richness or diversity.
- One randomized, controlled study in the UK[4] found that applying herbicide to control bracken increased the cover of wavy hair-grass and sheep's fescue. One controlled study in the UK[4] found that applying herbicide to control bracken increased the cover of gorse and the abundance of common cow-wheat.
- One controlled, before-and-after trial UK[1] found that application of herbicide reduced abundance of bracken but increased the number of silver birch seedlings. Three randomized, controlled studies in the UK[2,5,8] found that application of herbicide reduced the biomass[2] or cover[5,8] of bracken. However, one controlled study in the UK[6] found that applying herbicide did not change the abundance of bracken.

Background

Application of herbicide may kill bracken plants thereby allowing other shrubland species to become established.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); apply herbicide to trees (section 9.1); cut trees and apply herbicide (section 9.9); use herbicide to control grass (section 9.16); apply herbicide and sow seeds of shrubland plants to control grass (section 9.17); apply herbicide and remove plants to control grass (9.18); use herbicide and prescribed burning to control grass (section 9.22).

A controlled, before-and-after trial between 1980 and 1982 in a heathland in Suffolk, UK (1) found that the application of herbicide reduced abundance of bracken *Pteridium aquilinum* and increased the number of heather *Calluna vulgaris* and silver birch *Betula pendula* seedlings. After two years, the number of heather seedlings and silver birch seedlings was higher in plots that had been treated with Krenite (heather: 44; silver birch: 9) than in untreated plots (heather: 11; silver birch: 1). The number of fern fronds in plots treated with the herbicide Krenite (476 fronds/plots) was lower than in untreated plots (731 fronds/plot), but higher than pre-treatment levels (325 fronds/plot). Four areas were selected for study on the heathland. Each area was divided into four 5 m x 10 m plots which were either treated with the herbicide Krenite, the herbicide 2,4,5-T, both Krenite and 2,4,5-T or left untreated. The numbers of heather fronts and colonising heather seedlings in plots was monitored annually between 1980 and 1982.

A randomized, controlled study in 1978–1990 in a heathland in Suffolk, UK (2) found that application of herbicide reduced the biomass of bracken *Pteridium aquilinum*, and increased heath vegetation biomass. After 12 years, biomass of bracken was 76–85% lower in areas where bracken had been sprayed with herbicide, than in unsprayed areas. Heath vegetation biomass was higher in areas that were sprayed with herbicide than in areas that were not sprayed (data presented in log units). In 1978 twelve 18 m^2 plots were established. In four plots bracken was sprayed with the herbicide asulam in 1978, four plots were sprayed with asulam in 1978 and 1979, and in four plots were not sprayed. Vegetation cover was assessed every year in three 1 m^2 plots which were randomly located in each plot. Heath vegetation was cut in 20 cm x 20 cm areas in each quadrat and dried to allow biomass to be calculated.

A replicated, randomized, controlled, paired study in 1992-1995 in a former heathland invaded by bracken *Pteridium aquilinum* in the Wirral, UK (3) found that spraying with herbicide to reduce the cover of bracken did not increase the number of common heather *Calluna vulgaris* seedlings relative to cutting. In eight of eight cases plots that were sprayed with herbicide did not have a significantly higher number of common heather seedlings than plots that were cut (herbicide: 8-20 seedlings/m^2, cut: 1-76 seedlings/m^2). Three 15 x 5 m plots were cut once a year, three plots were cut twice a year, and three plots were sprayed with the herbicide asulam. Cover of plants was assessed in three 1m^2 quadrats in each plot in September 1993 and June 1994. A randomized, controlled study in 1978–1996 in heathland invaded by bracken *Pteridium aquilinum* in Suffolk, UK (4) found that spraying with herbicide did not increase heather *Calluna vulgaris* cover, but did increase cover of wavy hair-grass *Deschampsia flexuosa* and sheep's fescue *Festuca ovina*. After 10 years and in two of four cases, heather cover was higher in areas where bracken was sprayed with herbicide (22–28%) than in unsprayed areas (0%), but after 18 years the cover of heather in all plots declined to 0%. After 18 years, cover of wavy-hair grass and sheep's fescue was higher in one of four cases where bracken was sprayed (wavy hair-grass: 9%; sheep's fescue: 17%) than where it was not (wavy hair-grass: 0%; sheep's fescue: 0%). In 1978 twelve 70 m^2 plots were established. In 1978-1996 bracken was sprayed with asulam in eight plots, and four other plots were not sprayed. The vegetation cover in three quadrats/plot was surveyed every year in 1978-1996.

A randomized, replicated, controlled, paired study in 1993-1995 at a heathland site in Suffolk, UK (5) found that using herbicide to control bracken *Pteridium aquilinum* reduced bracken cover, but had no significant effect on the cover of seven other plant species. In two of two cases bracken cover in areas where herbicide was sprayed (16-47%) was lower than in areas that were not sprayed (4-12%). The cover of the following plants did not differ significantly in sprayed and unsprayed areas: common heather *Calluna vulgaris* (sprayed: 0%, unsprayed: 0%), sedge species *Carex* spp. (sprayed: 0-1%, unsprayed: 1-7%), wavy-hair grass *Deschampsia flexuosa* (sprayed: 0-12%, unsprayed: 0-4%), sheep's fescue *Festuca ovina* (sprayed:0% , unsprayed: 0-5%), Yorkshire fog *Holcus lanatus* (sprayed: 0%, unsprayed: 0%), sheep's sorrel *Rumex acetosella* (sprayed: 1%, unsprayed:3-5%), and woodland ragwort *Senecio sylvaticus* (sprayed: 0%, unsprayed: 0%). In 1993 three 8 x 8m plots were sprayed with the herbicide asulam, and three plots were not cut. In July 1994 and 1995 plant cover was assessed in two 1 m^2 quadrats placed in each plot.

A controlled study in 2002–2007 in a heathland in Exmoor, UK (6) found that using herbicide to control bracken *Pteridium aquilinum* increased the cover of gorse *Ulex europaeus* and the abundance of common cow-wheat *Melampyrum pratense*, but did not decrease the abundance of bracken. After five years, gorse cover was higher in areas treated with herbicide (42%) than in untreated areas (21%). There were more cow-wheat plants in plots treated with herbicide (0.7) than in untreated plots (0.4). Additionally, after five years, bracken abundance in plots that had been treated with herbicide (5) was not significantly different to that in untreated plots (7). In 2002 the herbicide asulox was applied in six 40 m x 20 m with a further six plots remaining unsprayed. Abundance and cover of plants was recorded in 30 randomly placed quadrats in each plot.

A replicated, randomized, controlled study in 1993–2003 in three heathland sites in Cannock and the Peak District, UK (7) found that spraying bracken *Pteridium aquilinum* with the herbicide asulam increased heathland species richness. In plots where asulam was applied, species richness was higher ten years after herbicide spraying (4.9–7.6) than one year after spraying (4.5–7.1). However, over the same period species richness decreased in unsprayed plots (one year after: 3.2–4.9; 10 years after: 2.6–3.9) (data presented as model results). Ten years after treatment, species composition in sprayed and unsprayed plots did not differ significantly from unsprayed plots (data presented as ordination results). Between four and twelve 10 x 12 m and 10 x 5 m plots were selected and the herbicide asulam was sprayed in August 2003. Vegetation was monitored annually in June using 1 x 1 m quadrats.

A randomized, replicated, controlled, before-and-after, paired study in 2005–2013 in a site dominated by bracken *Pteridium aquilinum* in the UK (8) found that spraying with herbicide reduced bracken cover and had no effect on the number of plant species or plant diversity. In plots that were sprayed with herbicide bracken cover declined over eight years (before: 26%, after: 2%) while in unsprayed plots bracken cover increased (before: 24%, after 75%). Neither the number of plant species (no data presented) nor plant diversity (presented as Shannon-Weiner index) differed significantly between sprayed and unsprayed plots. In 2005 three 20 x 20 m plots were sprayed with the herbicide asulam and every emergent bracken frond was sprayed in 2006–2012. Three other plots were not sprayed. Plots were paired. In 2005–2013 plant cover was assessed by eye in five 1 m^2 quadrats which were randomly located in each plot.

(1) Marrs, R.H. (1985) The effects of potential bracken and scrub control herbicides on lowland Calluna and grass heath communities in East Anglia, UK. *Biological Conservation*, 32, 13-32.
(2) Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and the restoration of heathland. I. Control of bracken. *Journal of Applied Ecology*, 29, 195-203.
(3) Snow, C. & Marrs, R. (1997) Restoration of Calluna heathland on a bracken Pteridium-infested site in north west England. *Biological Conservation*, 81, 35-42.

(4) Marrs, R.H., Johnson, S.W. & Duc, M.G.L. (1998) Control of bracken and restoration of heathland. VIII. The regeneration of the heathland community after 18 years of continued bracken control or 6 years of control followed by recovery. *Journal of Applied Ecology*, 35, 857-870.
(5) Paterson, S., Pakeman, R. & Marrs, R. (2000) Describing vegetation succession after bracken control: Evaluation of the REBRA model. *Journal of Environmental management*, 59, 31-45.
(6) Brook, S., McCracken, M. & Bulman, C.R. (2007) Post-burn bracken Pteridium aquilinum control to manage habitat for the heath fritillary butterfly Mellicta athalia on Exmoor, Somerset, England. *Conservation Evidence*, 4, 81-87.
(7) Alday, J.G., Cox, E.S., Pakeman, R.J., Harris, M.P.K., LeDuc, M.G. & Marrs, R.H. (2013) Overcoming resistance and resilience of an invaded community is necessary for effective restoration: a multi-site bracken control study. *Journal of Applied Ecology*, 50, 156-167.
(8) Milligan, G., Cox, E., Alday, J., Santana, V., McAllister, H., Pakeman, R., Le Duc, M. & Marrs, R. (2016) The effectiveness of old and new strategies for the long-term control of Pteridium aquilinum, an 8-year test. *Weed Research*, 56, 247-257.

9.29 Cut to control bracken

- One randomized, controlled, before-and-after trial in Norway[6] and one randomized, controlled study in the UK[1] found that cutting bracken increased the cover[6] or biomass[1] of heather. However, two randomized, replicated, controlled studies in the UK[2,3] found that cutting bracken did not increase heather cover[3] or abundance of heather seedlings[2].
- One randomized, replicated, controlled study in the UK[7] found that cutting to control bracken increased the species richness of heathland plant species. However, another randomized, replicated, controlled study in the UK[8] found that cutting to control bracken did not alter species richness but did increase species diversity.
- One randomized, replicated, controlled study in the UK[3] found that cutting bracken increased cover of wavy hair-grass and sheep’s fescue. One controlled study in the UK[5] found that cutting bracken did not increase the abundance of gorse or common cow-wheat.
- One randomized, controlled, before-and-after trial in Norway[6] and two randomized, controlled studies in the UK[1,8] found that cutting bracken reduced bracken cover[6,8] or biomass[1]. One randomized, replicated, controlled, paired study the UK[4] found that cutting had mixed effects on bracken cover. However, one controlled study in the UK[5] found that cutting bracken did not decrease the abundance of bracken.

Background
Cutting of bracken may help to control the species. This intervention may also help to break up the leaf litter of bracken and therefore aid recovery of shrubland plant species.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrubland to control trees (section 9.5); cut trees and increase livestock numbers (sections 9.6); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27).

A randomized, controlled study in 1978–1990 in a heathland in Suffolk, UK (1) found that annual cutting of bracken *Pteridium aquilinum* increased the biomass of heather *Calluna vulgaris* and reduced the biomass of bracken after 12 years. In two of seven years heather biomass was higher in areas that had been cut than in areas that were not cut (data presented in log units), but heather biomass was not significantly higher in the remaining five years. In six of seven years bracken biomass was 14–99% lower in areas where bracken had been cut, than in areas that were not cut. In 1978 twelve 18 m^2 plots were established. In four plots bracken was cut annually in 1978–1990, in four plots bracken was cut twice a year in 1978–1990, and in four plots bracken was not cut. Vegetation cover was assessed every year in three 1 m^2 plots which were randomly located in each plot. Vegetation was cut in 20 cm x 20 cm areas in each quadrat and dried to calculate biomass.

A replicated, randomized, controlled, paired study in 1992-1995 in a former heathland invaded by bracken *Pteridium aquilinum* in the Wirral, UK (2) found that cutting to reduce the cover of bracken did not increase the number of common heather *Calluna vulgaris* seedlings relative to spraying with herbicide. In eight of eight cases plots that were cut did not have a significantly higher number of common heather seedlings than plots that were sprayed with herbicide (cut: 1-76 seedlings/m^2, herbicide: 8-20 seedlings/m^2). Three 15 x 5 m plots were cut once a year, three plots were cut twice a year, and three plots were sprayed with the herbicide asulam. Cover of plants was assessed in three 1m^2 quadrats in each plot in September 1993 and June 1994.

A randomized, replicated, controlled study in 1978–1996 in heathland invaded by bracken *Pteridium aquilinum* in Suffolk, UK (3) found that repeatedly cutting bracken did not increase heather *Calluna vulgaris* cover, but did increase cover of wavy hair-grass *Deschampsia flexuosa* and sheep's fescue *Festuca ovina*. After 1-0 years and in one of four cases, areas where bracken was cut had higher cover of heather (38%) than where bracken was not cut (0%), but after 18 years heather cover in cut plots was 0%. Cover of wavy-hair grass and sheep's fescue was higher in two of four cases after 18 years where bracken was cut (wavy hair-grass: 30%; sheep's fescue: 17%) than where it was not (wavy hair-grass: 0%; sheep's fescue: 0%). In 1978 twelve 70 m^2 plots were established. Between 1978 and 1996 bracken was cut once a year in four plots, twice a year in four plots, and four other plots were never cut. Vegetation cover in plots was surveyed annually using three quadrats in each plot in 1978–1996.

A randomized, replicated, controlled, paired study in 1993-1995 at a heathland site in Suffolk, UK (4) found that cutting to control bracken *Pteridium aquilinum* had mixed effects on bracken cover and wavy-hair grass *Deschampsia flexuosa*, but no significant effect on the cover of six other plant species. In three of four cases bracken cover in areas that were cut (16-47%) was lower than in areas that were not cut (89-93%), in one case there was no difference in bracken cover (cut:85%, uncut 89-93%). In one of four cases cover of wavy-hair grass was higher in areas that were cut (18%) than in areas that were not cut (0%), but in three of four cases there was no significant difference in wavy-hair grass cover (cut: 0-10%, uncut 0-4%). The cover of the following plants did not differ significantly in cut and uncut areas: common heather *Calluna vulgaris* (cut: 0%, uncut: 0%), sedge species *Carex* spp. (cut: 0%, uncut: 1-7%), sheep's fescue *Festuca ovina* (cut:0-15% , uncut: 0-5%), Yorkshire fog *Holcus lanatus* (cut: 0%, uncut: 0%), sheep's sorrel *Rumex acetosella* (cut: 0-7%, uncut:3-5%), and woodland ragwort *Senecio sylvaticus* (cut: 0%, uncut: 0%). In 1993-1995 three 8 x 8m plots were cut one a year, three plots were cut twice a year, and three plots were not cut. In July 1994 and 1995 plant cover was assessed in two 1 m^2 quadrats placed in each plot.

A controlled study in a heathland in 2002–2007 in the United Kingdom (5) found that using cutting to control bracken *Pteridium aquilinum* did not increase the abundance of gorse *Ulex europaeus* or of common cow-wheat *Melampyrum pratense* or decrease the abundance of bracken. After five years, gorse cover was not significantly different in areas where bracken had been cut (26%) compared to where it had not been cut (21%). The abundance of common cow-wheat and bracken in areas where bracken had been cut (cow-wheat: 3 plants/quadrat; bracken: 12 bracken stems/quadrat) was not significantly different to that where bracken had not been cut (cow-wheat: 0.4 plants/quadrat; bracken: 7 bracken stems/quadrat). In 2002–2005 bracken was cut in six 40 m x 20 m plots with a further six plots remaining uncut. Abundance and cover of plants was recorded every year in thirty 1 m^2 quadrats randomly placed in each plot.

A randomized, controlled, before-and-after trial in 1997-2001 in a heathland invaded by bracken *Pteridium aquilinum* in Norway (6) found that repeatedly cutting bracken increased the heather cover and reduced bracken cover. Cutting bracken increased heather cover from 3–5% before cutting to 14–26% four years after cutting started, while heather cover in uncut plots was approximately 1% for all four years of the experiment. Cutting reduced bracken cover from 75–76% before cutting to 2–17% four years after cutting started, while bracken cover in uncut plots remained above 75% during the four years of the experiment. Twelve 25 m^2 plots were randomly allocated to be cut either once a year, twice a year or were left uncut. In plots which were cut bracken was cut to a length of 20–30 cm in July. Three 0.25 m^2 quadrats were placed in each plot and used to monitor vegetation cover annually.

A replicated, randomized, controlled study in 1993–2003 in four heathland sites in Cannock and the Peak District, UK (7) found that cutting of bracken *Pteridium aquilinum* increased heathland species richness and moved heathland species composition towards pre-invasion conditions. In both plots where bracken was cut once and twice per year, species richness was higher ten years after cutting (bracken cut once a year: 6.5–9.8; bracken cut twice a year: 6.8–10.1) than one year after cutting (bracken cut once a year: 4.3–6.2; bracken cut twice a year: 3.7–6.7). However, over the same period species richness decreased in uncut plots (one year after: 3.2–4.9; 10 years after: 2.6–3.9) (data presented as model results). Ten years after treatment, species composition in plots where bracken was cut was significantly different from uncut plots and closer to pre-invasion conditions (data presented as ordination results). Between four and twelve plots measuring 10 x 12 m, 10 x 5 m and 6 x 5 m were selected and bracken was cut once a year in June in three of four sites, and twice a year (June and August) in all four. Vegetation was monitored annually in June using 1 x 1 m quadrats.

A randomized, replicated, controlled, before-and-after, paired study in 2005–2013 in a site dominated by bracken *Pteridium aquilinum* in the UK (8) found that cutting decreased bracken cover, had no effect on the number of plant species, and increased plant diversity. In plots that were cut bracken cover declined over eight years (before: 26–27%, after: 2%) while in plots where bracken was not cut bracken cover increased (before: 24%, after 75%). There was no difference in the number of plant species found in plots that had been cut and those that were not cut. Over eight years in plots where bracken was cut plant diversity increased, while in uncut plots it declined (data presented as Shannon-Weiner index). In

2005–2012 three 20 x 20 m plots were cut twice a year, three plots were cut twice a year, and three plots were not cut. All plots were paired such that they were located next to the different treatments. In 2005–2013 plant cover was assessed by eye in five 1 m^2 quadrats which were randomly located in each plot.

(1) Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and the restoration of heathland. I. Control of bracken. *Journal of Applied Ecology*, 29, 195-203.
(2) Snow, C. & Marrs, R. (1997) Restoration of Calluna heathland on a bracken Pteridium-infested site in north west England. *Biological Conservation*, 81, 35-42.
(3) Marrs, R.H., Johnson, S.W. & Duc, M.G.L. (1998) Control of bracken and restoration of heathland. VIII. The regeneration of the heathland community after 18 years of continued bracken control or 6 years of control followed by recovery. *Journal of Applied Ecology*, 35, 857-870.
(4) Paterson, S., Pakeman, R. & Marrs, R. (2000) Describing vegetation succession after bracken control: Evaluation of the REBRA model. *Journal of Environmental management*, 59, 31-45.
(5) Brook, S., McCracken, M. & Bulman, C.R. (2007) Post-burn bracken Pteridium aquilinum control to manage habitat for the heath fritillary butterfly Mellicta athalia on Exmoor, Somerset, England. *Conservation Evidence*, 4, 81-87.
(6) Maren, I.E., Vandvik, V. & Ekelund, K. (2008) Restoration of bracken-invaded Calluna vulgaris heathlands: Effects on vegetation dynamics and non-target species. *Biological Conservation*, 141, 1032-1042.
(7) Alday, J.G., Cox, E.S., Pakeman, R.J., Harris, M.P.K., LeDuc, M.G. & Marrs, R.H. (2013) Overcoming resistance and resilience of an invaded community is necessary for effective restoration: a multi-site bracken control study. *Journal of Applied Ecology*, 50, 156-167.
(8) Milligan, G., Cox, E., Alday, J., Santana, V., McAllister, H., Pakeman, R., Le Duc, M. & Marrs, R. (2016) The effectiveness of old and new strategies for the long-term control of Pteridium aquilinum, an 8-year test. *Weed Research*, 56, 247-257.

9.30 Cut and apply herbicide to control bracken

- One randomized, controlled study in the UK[1] found that cutting and applying herbicide to control bracken did not alter heather biomass. One randomized, controlled, before-and-after trial in Norway[3] found that cutting and applying herbicide increased heather cover. A randomized, replicated, controlled, paired study in the UK[2] found that cutting and using herbicide had no significant effect on the cover of seven plant species.
- One replicated, randomized, controlled study in the UK[1] found that cutting bracken followed by applying herbicide increased plant species richness when compared with applying herbicide followed by cutting
- Three randomized, controlled studies (one also a before-and-after trial, and one of which was a paired study) in the UK[1,2] and Norway[3] found that cutting and applying herbicide reduced bracken biomass[1] or cover[2,3].

Background
Combining cutting and application of herbicide to control bracken may help to reduce the cover of bracken, therefore helping shrubland species to become established or increase in cover.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); cut trees (section 9.2); cut trees and remove leaf litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrubland to control trees (section 9.5); cut trees and increase livestock numbers (sections 9.6); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed o shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); apply herbicide to trees (section 9.1); cut trees and apply herbicide (section 9.9); use herbicide to control grass (section 9.16); apply herbicide and sow seeds of shrubland plants to control grass (section 9.17); apply herbicide and remove plants to control grass (section 9.18); use herbicide and prescribed burning to control grass (section 9.22).

A randomized, controlled study in 1978–1990 in a heathland in Suffolk, UK (1) found that spraying with herbicide, followed by annual cutting, reduced the biomass of bracken *Pteridium aquilinum*, but did not increase heather *Calluna vulgaris* biomass. After 12 year, bracken biomass was 82–99% lower in areas where bracken had been cut and sprayed with herbicide, than in areas that were not cut or sprayed. In two of nine years heather biomass was higher in areas that had been sprayed with herbicide and cut annually, than in areas that were not sprayed with herbicide and not cut (data presented in log units). In 1978 twelve 18 m^2 plots were established. In four plots bracken was sprayed with the herbicide asulam (application rate: 4.4 kg active ingredient/ha) and cut annually in 1978–1990, and in four plots bracken was not cut or sprayed with herbicide. Vegetation cover was assessed every year in three 1 m^2 plots which were randomly located in each plot. Vegetation was cut in one 20 cm x 20 cm area in each quadrat and dried to calculate biomass.

A randomized, replicated, controlled, paired study in 1993-1995 at a heathland site in Suffolk, UK (2) found that cutting and using herbicide reduced bracken *Pteridium aquilinum* cover, but had no significant effect on the cover of seven other plant species. In four of four cases bracken cover in areas that were cut and sprayed with herbicide was lower (7-63%) than in areas that were not cut or sprayed (4-12%). The cover of the following plants did not differ significantly in sprayed and cut areas and areas that were not sprayed or cut: common heather *Calluna vulgaris* (cut and sprayed: 0-2%, unsprayed and uncut: 0%), sedge species *Carex* spp. (cut and sprayed: 0%, unsprayed and uncut: 1-7%), wavy-hair grass *Deschampsia flexuosa* (cut and sprayed: 0-14%, unsprayed and uncut: 0-4%), sheep's fescue *Festuca ovina* (cut and sprayed:0% , unsprayed and uncut: 0-5%), Yorkshire fog *Holcus lanatus* (cut and sprayed: 0%, unsprayed and uncut: 0%), sheep's sorrel *Rumex acetosella* (cut and sprayed: 1-13%, unsprayed and uncut:3-5%), and woodland ragwort *Senecio sylvaticus* (cut and sprayed: 0%, unsprayed: 0%). Three 8 x 8 m plots were cut and then sprayed with the herbicide asulam in 1993, three plots were spraye with asulam in 1993 and cut in 1994, and three plots were not cut or sprayed. In July 1994 and 1995 plant cover was assessed in two 1 m^2 quadrats placed in each plot.

A randomized, controlled, before-and-after trial in 1997-2003 in a heathland invaded by bracken *Pteridium aquilinum* in Norway (3) found that annual cutting of bracken and application asulam herbicide increased the cover of heather *Calluna vulgaris* and reduced cover of bracken. After six years, heather cover in areas where bracken was cut and herbicide applied increased from 2–4% before cutting and application of herbicide to 13–47%, while in plots that were not cut or sprayed with herbicide heather cover remained at approximately 1%. In areas that were cut and treated with herbicide, bracken cover dropped from 75% before cutting and herbicide application to 1–3%, while in areas that were not cut or sprayed with herbicide, bracken cover remained above 75%. Twelve 25 m^2 plots were randomly allocated to be either cut and receive herbicide applications of asulam or gratil or remain uncut with no herbicide application. In plots which were cut, bracken was annually cut 20–30 cm above the ground, in July. Three 0.25 m^2 quadrats were placed in each plot and used to monitor vegetation cover annually.

A replicated, randomized, controlled study in 1993–2003 in three heathland sites in Cannock and the Peak District, UK (4) found that cutting bracken *Pteridium aquilinum* and then spraying asulam increased heathland species richness but spraying asulam and then cutting did not. In plots where bracken was cut and then asulam was applied, species richness was higher ten years after treatment (5.2–8.1) than after one year 4–6.3). However, in plots where bracken was first sprayed and then cut, species richness was lower ten years after treatment (3.1–5.5) than after one year (3.6–6.1). Over the same period species richness decreased in untreated plots (one year after: 3.2–4.9; 10 years after: 2.6–3.9) (data presented as model results). Ten years after treatment, species composition in plots where bracken had been treated was not significantly different from untreated plots (data presented as ordination results). Between six and eighteen 10 x 12 m and 10 x 5 m plots were selected and cutting of bracken and application of herbicide took place between June and August 1993. In one site treatments were repeated in August 1999. Vegetation was monitored annually in June using 1 x 1 m quadrats.

(1) Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and the restoration of heathland. I. Control of bracken*. Journal of Applied Ecology*, 29, 195-203.
(2) Paterson, S., Pakeman, R. & Marrs, R. (2000) Describing vegetation succession after bracken control: Evaluation of the REBRA model*. Journal of Environmental management*, 59, 31-45.
(3) Maren, I.E., Vandvik, V. & Ekelund, K. (2008) Restoration of bracken-invaded Calluna vulgaris heathlands: Effects on vegetation dynamics and non-target species*. Biological Conservation*, 141, 1032-1042.
(4) Alday, J.G., Cox, E.S., Pakeman, R.J., Harris, M.P.K., LeDuc, M.G. & Marrs, R.H. (2013) Overcoming resistance and resilience of an invaded community is necessary for effective restoration: a multi-site bracken control study*. Journal of Applied Ecology*, 50, 156-167.

9.31 Cut and burn bracken

We captured no evidence for the effects of cutting and burning bracken on shrublands.

Background
Cutting and burning bracken may help to control the cover and density of the species. In addition, burning may reduce bracken leaf litter which may increase the likelihood of shrubland species becoming established.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); cut trees (section 9.2); cut trees and remove lead litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrubland to control trees (section 9.5); use prescribed burning to control trees (section 9.6); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); use herbicide and prescribed burning to control grass (section 9.22); cut/mow, rotovate, and sow seeds to control grass (section 9.27).

9.32 Cut bracken and rotovate

- One controlled study in the UK[1] found that cutting followed by rotovating to control bracken did not increase total plant biomass or biomass of heather.

Background
Cutting bracken may help to control its cover and density by removing aboveground fronds, while rotovating could damage plant rhizomes which may further help to control the spread of the species.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); cut trees (section 9.2); cut trees and remove lead litter (section 9.3); cut trees and remove tree seedlings (section 9.4); cut/mow shrubland to control trees (section 9.5); cut trees and increase livestock numbers (section 9.8); cut trees and apply herbicide (section 9.9); cut trees and use prescribed burning (section 9.10); cut/mow to control grass (section 9.12); cut/mow to control grass and sow seed of shrubland plants (section 9.13); cut/mow and rotovate to control grass (section 9.15); cut and use prescribed burning to control grass (section 9.21); cut/mow, rotovate, and sow seeds to control grass (section 9.27); cut/mow and rotovate to control grass (section 9.15); rotovate to control grass (section 9.24).

A randomized, controlled trial in 1978–1986 in a heathland in Suffolk, UK (1) found that rotovating soil after removal of bracken *Pteridium aquilinium* did not increase total plant biomass or biomass of heather *Calluna vulgaris* when compared to plots that were not rotovated (data reported in log units). In 1978 all plots were sprayed with the herbicide asulam. Four 12 m^2 plots were rotovated to dig bracken leaf litter into soil and four plots were not rotovated. Vegetation was visually estimated annually in each plot in June or July in 1979–1986.

(1) Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and restoration of heathland.III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*, 29, 212-217.

9.33 Use herbicide and sow seed of shrubland plants to control bracken

We captured no evidence for the effects on shrublands of using herbicide and sowing seed of shrubland plants.

Background
Cutting may help to control bracken and sowing seed may allow propagation and subsequent spreading of shrubland plants.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); apply herbicide to trees (section 9.1); cut trees and apply herbicide (section 9.9); use herbicide to control grass (section 9.16); apply herbicide and sow seeds of shrubland plants to control grass (section 9.17); apply herbicide and remove plants to control grass (section 9.18); use herbicide and prescribed burning to control grass (section 9.22); plant individual plants (section 13.17); sow seed (section 13.18); sow seeds and plant individual plants (section 13.19); spread clippings (section 13.20); plant turf (section 13.22); all interventions in chapter 14.

9.34 Increase livestock numbers to control bracken

We captured no evidence for the effects on shrublands of controlling bracken by increasing grazing intensity.

Background
Increasing the grazing intensity at a site may help to control bracken.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.18); use fences to exclude large herbivores (section 9.38); reduce numbers of large herbivores (section 9.36).

9.35 Use 'bracken bruiser' to control bracken

- One randomized, replicated, controlled, before-and-after, paired study in the UK[1] found that bracken bruising increased bracken cover, though bracken cover also increased in areas where bracken bruising was not done.There was no effect on the number of plant species or plant diversity.

Background
Bracken bruisers are lightweight rollers that can be pulled behind a tractor or other vehicle. They aim to crush and damage bracken, thereby limiting its growth.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); disturb vegetation (section 13.5).

A randomized, replicated, controlled, before-and-after, paired study in 2005–2013 in a site dominated by bracken *Pteridium aquilinum* in the UK (1) found that 'bracken bruising' increased bracken cover and had no effect on the number of plant species or plant diversity. In plots where a bracken bruiser was used bracken cover increased over eight years (before: 23–24%, after: 64–74%) while in plots that where a bracken bruiser was not used bracken cover also increased (before: 24%, after: 75%). There was no significant difference in the number of plant species found in plots where a bracken bruiser had been used and those where it was not (no data presented). There was no significant difference in the plant diversity of plots where a bracken bruiser was used and those that where it was not (data presented as Shannon-Weiner index). In 2005-2012 a bracken bruiser was used twice a year in three 20 x 20 m plots and in three other plots no bracken bruiser was used. Plots were paired. In 2005–2013 plant cover was assessed by eye in five 1 m^2 quadrats which were randomly located in each plot.

(1) Milligan, G., Cox, E., Alday, J., Santana, V., McAllister, H., Pakeman, R., Le Duc, M. & Marrs, R. (2016) The effectiveness of old and new strategies for the long-term control of Pteridium aquilinum, an 8-year test. *Weed Research*, 56, 247-257.

9.36 Use herbicide and remove leaf litter to control bracken

- One randomized, controlled study in the UK[1] found that using herbicide and removing leaf litter did not increase total plant biomass after eight years. The same study found that for three of six years, heather biomass was higher in areas where herbicide was sprayed and leaf litter was removed than in areas that were sprayed with herbicide.

Background

Applying herbicide to bracken may help to control it and removing leaf litter may help to create bare ground, thus allowing heathland plants to become established.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); apply herbicide to trees (section 9.1); cut trees and apply herbicide (section 9.9); use herbicide to control grass (section 9.16); apply herbicide and sow seeds of shrubland plants to control grass (section 9.17); apply herbicide and remove plants to control grass (section 9.18); use herbicide and prescribed burning to control grass (section 9.22).

A randomized, controlled study in 1978–1986 in a heathland in Suffolk, UK (1) found that the application of herbicide to bracken *Pteridium aquilinium* followed by the removal of leaf litter and did not increase total plant biomass after eight years, but increased the biomass of heather *Calluna vulgaris* in three of six years. In August 1978 all plots were sprayed with the herbicide asulam. After herbicide application, leaf litter was removed in four 12 m^2 plots and in four plots leaf litter was not removed. Vegetation was visually estimated annually in each plot June or July in 1979-1986.

(1) Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and restoration of heathland.III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*, 29, 212-217.

9.37 Use herbicide and increase livestock numbers to control bracken

We captured no evidence for the effects on shrublands of controlling bracken by using herbicide followed by increased grazing.

Background

Using herbicide in combination with increasing grazing intensity may help to control bracken.

Related interventions: all interventions related to the control of bracken (sections 9.28-9.37); apply herbicide to trees (section 9.1); cut trees and apply herbicide (section 9.9); use herbicide to control grass (section 9.16); apply herbicide and sow seeds of shrubland plants to control grass (section 9.17); apply herbicide and remove plants to control grass (section 9.18); use herbicide and prescribed burning to control grass (section 9.22); increase number of livestock (section 8.6).

Problematic animals

Background
Both non-native and native animals can present threats to shrublands. For example, herbivores such as deer may reduce the height of shrubs and limit the regeneration of some shrublands, potentially resulting in conversion to grassland. Other taxa, including multiple invertebrates, may damage shrub species resulting in widespread die off.

9.38 Use fences to exclude large herbivores

- One controlled study in the USA[1] found that using fences to exclude deer increased the height of shrubs, but not shrub cover.

Background
High densities of large herbivores such as deer or non-native feral livestock have been shown to reduce species diversity and limit the regeneration of shrublands in some parts of the world (Perea *et al*. 2014). Using fences to exclude these species from shrublands may help plants to increase in height and cover.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); reduce numbers of large herbivores (section 9.39).

Perea, R., Girardello, M. & San Miguel, A. (2014) Big game or big loss? High deer densities are threatening woody plant diversity and vegetation dynamics. *Biodiversity and Conservation*, 23, 1303-1318.

A controlled study in 2001–2006 in chaparral shrubland that had been cut to reduce wildfires in California, USA (1) found that using fences to exclude deer from shrubland increased the height of shrubs, but not shrub cover after three years. In plots that were fenced to exclude deer, shrubs were taller in one of two years (67 cm) than in plots that were not fenced (55 cm). However, shrub cover in plots that were fenced was not significantly different to that in plots that were not fenced (data not presented). Fuel reduction treatments to reduce wildfire risk were carried out in all plots in 2001–2003. In 2003 mesh fences 1.5 m tall were built around five 2.5 m^2 quadrats and five quadrats were left unfenced. The height and cover of vegetation in all quadrats was assessed by eye in 2005 and 2006.

(1) Potts, J.B., Marino, E. & Stephens, S.L. (2010) Chaparral shrub recovery after fuel reduction: a comparison of prescribed fire and mastication techniques. *Plant Ecology*, 210, 303-315.

9.39 Reduce numbers of large herbivores

- One before-and-after trial in the USA[2] found that removing sheep, cattle and horses increased shrub cover and reduced grass cover. One replicated study in the UK[1] found that reducing grazing pressure by red deer increased the cover and height of common heather.

Background

High densities of large herbivores such as deer or non-native feral livestock have been shown to reduce species diversity and limit the regeneration of shrublands in some parts of the world (Perea et al. 2014). Reducing the number of large herbivores in shrubland areas may allow vegetation to increase in height and cover.

Related interventions: Use fences to exclude livestock from shrublands (section 3.1); reduce number of livestock (section 3.2); change type of livestock (section 3.3); shorten period during which livestock can graze (section 3.4); use cutting/mowing to mimic grazing (section 8.5); increase number of livestock (section 8.6); use grazing to control trees (section 9.7); cut trees and increase livestock numbers (section 9.8); increase number of livestock and use prescribed burning to control trees (section 9.11) use grazing or alter livestock type to control grass (section 9.19); increase grazing intensity to control bracken (section 9.34); use fences to exclude large herbivores (section 9.38).

Perea, R., Girardello, M. & San Miguel, A. (2014) Big game or big loss? High deer densities are threatening woody plant diversity and vegetation dynamics. *Biodiversity and Conservation*, 23, 1303-1318.

A replicated study in 1991–2001 in two moorland sites in the Cairngorms, UK (1) found that reducing grazing pressure by red deer *Cervus elaphus* increased the cover and height of heather *Calluna vulgaris.* Nine years after the reduction of grazing pressure by deer, the cover of heather had increased by 6% in one site and by 2% in the other. Additionally, mean height of heather increased from 17 cm to 19 cm in one site and from 25 cm to 29 cm in the other. Deer numbers were reduced by culling and, in one site, grazing pressure was also reduced by localized winter feeding. As a result, between 1992 and 2001, the mean number of deer pellet groups on 60 m^2 plots felt from 26.3 to 22.9 in one site and from 17.2 to 5.7 in the other. Sampling plots of 15 m x 4 m (90 in one site and 96 in the other) were visited annually and, at each plot, 25 measures of heather height were taken. Additionally, heather cover was measured at each plot using a sampling stick with four 8 cm diameter circles at 10 positions and by counting the circles containing heather.

A before-and-after trial from 1980 to 2012 in coastal shrubland on Santa Cruz island, USA (2) found that reducing grazing pressure by removing sheep, cattle, and horses increased shrub cover and reduced grass cover. After 20 years, cover of woody species was higher after the removal of sheep, cattle, and horses (24%) than before removal (1%), but cover of herbaceous plants did not differ significantly (after: 66%, before: 60%). Cover of bare ground was lower after the removal of sheep, cattle, and horses (9%) than before removal (39%). Sheep, cattle, and horses were removed from the island between 1981 and 1989. In 1980 and 2012 twenty 30 m transects were used to survey vegetation. Every 1 m along the transects the vegetation type was identified and cover was estimated.

(1) Welch, D., Scott, D., Mitchell, R. & Elston, D.A. (2006) Slow recovery of heather (Calluna vulgaris L.(Hull)) in Scottish moorland after easing of heavy grazing pressure from red deer (Cervus elaphus L.). *Botanical Journal of Scotland*, 58, 1-17.
(2) Beltran, R.S., Kreidler, N., Van Vuren, D.H., Morrison, S.A., Zavaleta, E.S., Newton, K., Tershy, B.R. & Croll, D.A. (2014) Passive Recovery of Vegetation after Herbivore Eradication on Santa Cruz Island, California. *Restoration Ecology*, 22, 790-797.

9.40 Use biological control to reduce the number of problematic invertebrates

We captured no evidence for the effects on shrublands of reducing numbers of herbivorous invertebrates by using biological control.

Background

Biological control refers to the introduction of natural enemies (e.g. virus, fungus or invertebrates) to control a problematic species. In the UK one such invertebrate species is the heather beetle *Lochmaea suturalis*. This species can cause die-off of heather, resulting in conversion to grassland.

Organisms introduced as a form of biological control can themselves become problematic or invasive species and as such before their introduction any likely negative impacts should be thoroughly assessed.

10. Threat: Pollution

Background

Pollution is defined as the 'introduction of excess material or energy (Salafsky et al. 2008).' Common types of pollution include nutrients from the runoff of agricultural fertilizers, herbicide runoff, and air-borne pollutants such as acid-rain, nitrogen deposition or vehicle pollutants.

Shrublands often occur in areas that have low nutrient availability. As such, any pollution resulting in an addition of nutrients could potentially result in an increase in trees and eventual conversion to woodland as well as causing a reduction in shrubland vegetation. Similarly, many shrublands have characteristic levels of acidity, for example, heathlands in Western Europe tend to be acid. Nitrogen pollution has been shown to reduce soil pH and lead to a reduction in shrub cover and an increase in grass cover in some heathlands (Bobbink, Hornung and Roelofs 1998).

Related threats: agriculture (Chapter 3); infrastructure such as roads, rail, and gas lines (Chapter 6).

Related interventions: habitat restoration (Chapters 13 & 14).

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H., Collen, B., Cox, N., Master, L.L., O'Connor, S. & Wilkie (2008). A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology*, 22(4), 897-911.

Bobbink, R., Hornung, M. & Roelofs, J.G.M. (1998) The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. *Journal of Ecology*, 86, 717-738.

Key messages

10.1 Plant vegetation to act as a buffer to exclude pollution

We captured no evidence for the effects on shrublands of planting vegetation to act as a buffer to exclude pollution.

10.2 Reduce pesticide use on nearby agricultural/forestry land

We captured no evidence for the effects on shrublands of reducing pesticide use on nearby agricultural/forestry land.

10.3 Reduce herbicide use on nearby agricultural/forestry land

We captured no evidence for the effects on shrublands of reducing herbicide use on nearby agricultural/forestry land.

10.4 Reduce fertilizer use on nearby agricultural/forestry land

We captured no evidence for the effects on shrublands of reducing fertilizer use on nearby agricultural/forestry land.

10.5 Mow shrublands to reduce impact of pollutants

- One randomized, replicated, controlled study in the UK found that mowing to reduce the impact of nitrogen deposition did not alter shoot length of common heater or the number of purple moor grass seedlings.
- One controlled study in the UK found that mowing a heathland affected by nitrogen pollution did not alter the cover or shoot length of heather compared to areas where prescribed burning was used.

10.6 Burn shrublands to reduce impact of pollutants

- One randomized, replicated, controlled study in the UK found that prescribed burning to reduce the impact of nitrogen deposition did not alter the shoot length of common heather or the number of purple moor grass seedlings compared to mowing.
- A controlled study in the UK found that burning to reduce the concentration of pollutants in a heathland affected by nitrogen pollution did not alter the cover or shoot length of heather relative to areas that were mowed.

10.7 Add lime to shrubland to reduce the impacts of sulphur dioxide pollution

We captured no evidence for the effects on shrublands of adding lime to shrubland to reduce the impacts of sulphur dioxide pollution.

Interventions

10.1 Plant vegetation to act as a buffer to exclude pollution

We captured no evidence for the effects on shrublands of planting vegetation to act as a buffer to exclude pollution.

Background

Planting vegetation adjacent to roads to act as a buffer has been suggested as a way to reduce their impact on surrounding habitats (Spellerberg, 1998). In particular buffer zones may help to reduce the inputs of pollutants from vehicle exhausts to nutrient-poor shrubland ecosystems (Angold, 1997).

Related interventions: Legally protect habitat around shrublands (section 12.2); plant individual plants (section 13.16); sow seeds (section 13.17); sow seeds and plant individual plants (section 13.18); spread clippings (section 13.19); plant turf (section 13.21).

Spellerberg, I. A. N. (1998). Ecological effects of roads and traffic: a literature review. *Global Ecology and Biogeography*, 7(5), 317-333.

Angold, P. G. (1997). The impact of a road upon adjacent heathland vegetation: effects on plant species composition. *Journal of Applied Ecology*, 409-417.

10.2 Reduce pesticide use on nearby agricultural/forestry land

We captured no evidence for the effects on shrublands of reducing pesticide use on nearby agricultural/forestry land.

Background

Reducing pesticide use on agricultural or forestry land may help to reduce any impacts on nearby shrublands and allow vegetation to recover.

10.3 Reduce herbicide use on nearby agricultural/forestry land

We captured no evidence for the effects on shrublands of reducing herbicide use on nearby agricultural/forestry land.

Background

Reducing herbicide use on agricultural or forestry land may help to reduce any impacts on nearby shrublands and allow vegetation to recover.

10.4 Reduce fertilizer use on nearby agricultural/forestry land

We captured no evidence for the effects on shrublands of reducing fertilizer use on nearby agricultural/forestry land.

Background
Reducing fertilizer use on agricultural or forestry land may help to reduce any impacts on nearby shrublands and allow vegetation to recover.

10.5 Mow shrublands to reduce impacts of pollutants

- One randomized, replicated, controlled study in the UK[1] found that mowing to reduce the impact of nitrogen deposition did not alter shoot length of common heater or the number of purple moor grass seedlings.
- One controlled study in the UK[2] found that mowing a heathland affected by nitrogen pollution did not alter the cover or shoot length of heather compared to areas where prescribed burning was used.

Background
Pollutants such as nitrogen can accumulate in the soils and vegetation of shrublands. Mowing or cutting of vegetation may help to reduce nitrogen pools and aid recovery of plant species supressed by pollution.

A randomized, replicated, controlled study in 1998-2000 in a lowland heathland site Surrey, UK (1) found that mowing to reduce the impact of nitrogen deposition did not alter the shoot length of common heather *Calluna vulgaris* or the number of purple moor grass *Deschampsia flexuosa* seedlings when compared to prescribed burning. In areas that were mowed common heather shoot length did not differ significantly (13-15 cm) from shoot length in areas where prescribed burning was used (13 cm). The number of purple moor grass seedlings did not differ significantly between areas that were mowed and areas that where prescribed burning was used (mowed: 1-1.5 seedlings/plot; burned: 1.6 seedlings/plot). In January 1998 four 4 x 4 m plot were established. Nitrogen was added to each plot as a mist of ammonium sulfate to simulate nitrogen deposition. Each plot was divided into four subplots, two of which were mowed, one of which was burned using prescribed burning methods, and one of which was burned to simulate a wildfire. Shoot length and cover were measured in 25 points in each subplot in October 1998-2000. Seedlings establishment was recorded in September 1999.

A controlled study in 1998-2000 in a heathland site in Surrey, UK (2) found that mowing to reduce the concentration of pollutants did not alter the cover or shoot length of heather *Calluna vulgaris* relative to areas where prescribed burning was undertaken. After two years, heather cover did not differ significantly between mowed areas (77–88% cover) and areas where prescribed burning was undertaken (83%). Additionally, heather shoot length did not differ significantly between mowed areas (14–16 cm) and areas where prescribed burning was undertaken (14 cm). In 1998 eight 16 m^2 plots were mowed and four plots were burned. Vegetation cover and shoot length were estimated every year in 1998-2000.

(1) Power, S.A., Barker, C.G., Allchin, E., Ashmore, M.R. & Bell, J. (2001) Habitat management: a tool to modify ecosystem impacts of nitrogen deposition? *The Scientific World Journal*, 1, 714-721.
(2) Barker, C.G., Power, S.A., Bell, J.N.B. & Orme, C.D.L. (2004) Effects of habitat management on heathland response to atmospheric nitrogen deposition. *Biological Conservation*, 120, 41-52.

10.6 Burn shrublands to reduce impacts of pollutants

- One randomized, replicated, controlled study in the UK[1] found that prescribed burning to reduce the impact of nitrogen deposition did not alter the shoot length of common heather or the number of purple moor grass seedlings compared to mowing.
- A controlled study in the UK[2] found that burning to reduce the concentration of pollutants in a heathland affected by nitrogen pollution did not alter the cover or shoot length of heather relative to areas that were mowed.

Background
Pollutants such as nitrogen can accumulate in the soils and vegetation of shrublands. Burning of vegetation may help to reduce nitrogen pools and aid recovery of plant species supressed by pollution.

Related interventions: Reduce the frequency of prescribed burning (section 5.4); use prescribed burning to mimic natural fire cycle (section 8.1);use prescribed burning to reduce potential wildfires (section 8.2); cut vegetation to reduce the spread of wildfire (section 8.3); reinstate the use of traditional burning (section 8.4); use prescribed burning to control trees (section 9.6); cut trees and use prescribed burning (section 9.10); use prescribed burning to control grass (section 9.20); cut and use prescribed burning to control grass (section 9.21).

A randomized, replicated, controlled study in 1998-2000 in a lowland heathland site in Surrey, UK (1) found that prescribed burning to reduce the impact of nitrogen deposition did not alter the shoot length of common heather *Calluna vulgaris* or the number of purple moor grass *Deschampsia flexuosa* seedlings when compared to mowing. In areas that were burned common heather shoot length did not differ significantly (13cm) from shoot length in areas that were mowed (13-15 cm). The number of purple moor grass seedlings did not differ significantly between areas where prescribed burning was used and areas that were mowed (burned: 1.6 seedlings/plot; mowed: 1-1.5 seedlings/plot). In January 1998 four 4 x 4 m plot were established. Nitrogen was added to each plot as a mist of ammonium sulfate to simulate nitrogen deposition. Each plot was divided into four subplots, two of which were mowed, one of which was burned using prescribed burning methods, and one of which was burned to simulate a wildfire. Shoot length and cover were measured in 25 points in each subplot in October 1998-2000. Seedlings establishment was recorded in September 1999.

A controlled study in 1998-2000 in a heathland site in Surrey, UK (2) found that burning to reduce the concentration of pollutants did not alter the cover or shoot length of heather *Calluna vulgaris* relative to areas that were mowed. After two years, heather cover did not differ significantly between areas where prescribed burning was carried out (83%)

and mowed areas (77-88% cover). Additionally, heather shoot length did not differ significantly between areas where prescribed burning was undertaken (14 cm) and mowed areas (14-16 cm). In 1998 eight 16 m^2 plots were mowed and four plots were burned. Vegetation cover and shoot length were estimated every year in 1998-2000.

(1) Power, S.A., Barker, C.G., Allchin, E., Ashmore, M.R. & Bell, J. (2001) Habitat management: a tool to modify ecosystem impacts of nitrogen deposition? *The Scientific World Journal*, 1, 714-721.
(2) Barker, C.G., Power, S.A., Bell, J.N.B. & Orme, C.D.L. (2004) Effects of habitat management on heathland response to atmospheric nitrogen deposition. *Biological Conservation*, 120, 41-52.

10.7 Add lime to shrubland to reduce the impacts of sulphur dioxide pollution

- We captured no evidence for the effects on shrublands of adding lime to reduce the impacts of sulphur dioxide pollution.

Background

Acid rain associated with sulphur dioxide pollution can damage plants and influence the habitat suitability for shrubland communities. Lime can be added to increase the capacity of the soil to retain a stable pH.

11. Threat: Climate change and severe weather

Background
Climate change and severe weather have the potential to wipe out sensitive species or habitat by making local environmental conditions unsuitable (Garcia *et al.* 2014). Management of climate change and severe weather is, however, very difficult because of these threats operate at very large scales.

Related threats: energy production and mining (Chapter 4); infrastructure such as roads, rail, and gas lines (Chapter 6); invasive and problematic species which may colonise shrublands as a result of changes in climate (Chapter 9); pollution (Chapter 10).

Related interventions: habitat restoration (Chapters 13 & 14).

Garcia, R.A., Cabeza, M., Rahbek, C. & Araújo, M.B. (2014) Multiple dimensions of climate change and their implications for biodiversity. *Science*, *344*, 1247579.

Key messages

11.1 Restore habitat in area predicted to have suitable climate for shrubland species in the future

We captured no information about the effects on shrublands of restoring habitat in areas predicted to have a suitable climate for shrubland species in the future.

11.2 Improve connectivity between areas of shrubland to allow species movements and habitat shifts in response to climate change

We captured no information about the effects on shrublands of improving connectivity between areas of shrubland to allow species movements in response to climate change

Interventions

11.1 Restore habitat in area predicted to have suitable climate for shrubland species in the future

We captured no information about the effects on shrublands of restoring habitat in areas predicted to have a suitable climate for shrubland species in the future.

Background
The creation or restoration of habitat in areas that are predicted to have suitable climates in the future has previously been suggested as a method to counter the negative effects of climate change (Harris et al 2006). Doing this may help to maintain shrubland habitat and species as climate changes.

Related interventions: All interventions in chapters 13 and 14 are relevant to shrubland restoration.

Harris, J.A., Hobbs, R.J., Higgs, E. & Aronson, J. (2006) Ecological restoration and global climate change. *Restoration Ecology*, 14, 170-176.

11.2 Improve connectivity between areas of shrubland to allow species movements and habitat shifts in response to climate change

We captured no information about the effects on shrublands of improving connectivity between areas of shrubland to allow species movements in response to climate change.

Background

Improving connectivity between shrubland areas may allow species to move between shrubland habitats as climate changes and alters the suitability of sites for shrubland species.

Related interventions: Maintain habitat corridors in developed areas (section 2.2); maintain habitat corridors in areas of energy production (section 4.1); maintain habitat corridors over or under roads (section 6.1).

12. Habitat protection

Background
This chapter covers the protection of shrublands through law and economic incentives. Such protection is designed to reduce habitat loss, fragmentation, and degradation from threats such as those detailed in chapters 2-10.

Related threats: residential and commercial development (Chapter 2); agriculture & aquaculture (Chapter 3); transport infrastructure (Chapter 6); pollution (Chapter 10).

Related interventions: habitat restoration (Chapters 13 & 14).

Key messages

12.1 Legally protect shrubland

We captured no evidence of the effect on shrublands of legally protecting shrubland habitat.

12.2 Legally protect habitat around shrubland

We captured no evidence of the effect on shrublands of legally protecting shrubland habitat around shrubland.

Interventions

12.1 Legally protect shrubland

We captured no evidence of the effect on shrublands of legally protecting shrubland habitat.

Background
Legal protection can be given to habitats on a local, national, or international scale. Levels of protection vary for habitats and may range from protection against all but light human use to allowing sustainable use of natural resources. Depending on the level of protection, human activities that are likely to affect protected habitats may be against the law or require licences from a government licensing authority.

Please note that studies comparing shrubland vegetation inside and outside of a protected area are not included as they do not directly test the effect of legally protecting shrubland. Any differences in vegetation may have existed before protected areas were designated.

12.2 Legally protect habitat around shrubland

We captured no evidence of the effect on shrublands of legally protecting habitat around shrublands.

Background
Legally protecting habitat around shrubland sites may help to reduce threats from spreading into shrublands such as clearance for agriculture, invasive species, or pollution from urban areas. These protected areas would provide a buffer around shrublands.

Related interventions: Plant vegetation to act as a buffer to exclude pollution (section 10.1).

13. Habitat restoration and creation

Background
This chapter addresses the restoration of shrublands. Interventions in this chapter can be used to address multiple threats detailed in previous chapters.

We define restoration as the 'process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Clewell *et al* 2004).' Restoration may aim to return an ecosystem to its previous condition but in practice this is rarely achievable.

Shrubland restoration is likely to work best in situations where human disturbances have either been of low intensity or for a relatively limited period of time (Bakker & Berendse 1999). This increases the likelihood that seed of shrubland species will be present in the soil, therefore allowing plant communities to regenerate (Bossuyt & Hermy 2003). However, where seed banks are not present plants may need to be introduced to restore shrubland habitats.

Related threats: interventions in this chapter apply to the majority of threats in Chapters 2-11.

Bakker, J.P. & Berendse, F. (1999) Constraints in the restoration of ecological diversity in grassland and heathland communities. Trends in Ecology & Evolution, 14, 63-68.

Bossuyt, B. & Hermy, M. (2003) The Potential of Soil Seedbanks in the Ecological Restoration of Grassland and Heathland Communities. Belgian Journal of Botany, 136, 23-34.

Clewell A., Aronson J. & Winterhalder, K. (2004). The SER international primer on ecological restoration. Ecological Restoration, 2, 206-207.

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H., Collen, B., Cox, N., Master, L.L., O'Connor, S. & Wilkie (2008). A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology*, 22(4), 897-911.

Key messages – General restoration

13.1 Restore/create habitat connectivity between shrublands

- We captured no evidence of the effect on shrublands of restoring or creating habitat connectivity of shrublands.

13.2 Allow shrubland to regenerate without active management

- Five before-and-after trials (two of which were replicated) in the USA, UK, and Norway, found that allowing shrubland to recover after fire without any active management increased shrub cover or biomass. One replicated, paired, site comparison in the USA found that sites that were allowed to recover without active restoration had similar shrub cover to unburned areas. One controlled, before-and-after trial in the USA found no increase in shrub cover. One before-and-after trial in Norway found an increase in heather height. One before-and-after trial in Spain found that there was an increase in seedlings for one of three shrub species. One before-and-after study in Spain found that cover of woody plants increased, but the number of woody plant species did not.
- One before-and-after trial in South Africa found that there was an increase in vegetation cover, but not in the number of plant species. Two replicated, randomized, controlled, before-and-after trials in Spain and Portugal found that there was an increase in the cover of woody plant species. One before-and-after trial in South Africa found an increase in a minority of plant species. One replicated, before-and-after study in South Africa found that the height of three protea species increased after recovery from fire.

- Two before-and-after trials in the USA and UK found that allowing shrubland to recover after fire without active management resulted in a decrease in grass cover or biomass. One controlled, before-and-after trial in the USA found an increase in the cover of a minority of grass species. One before-and-after study in Spain found that cover of herbaceous species declined. One replicated, before-and-after study in the UK found mixed effects on cover of wavy hair grass.
- One controlled, before-and-after trial in the USA found no increase in forb cover. One replicated, randomized, controlled before-and-after trial in Spain found that herb cover declined after allowing recovery of shrubland after fire.

Key messages - Modify physical habitat

13.3 Remove trees/crops to restore shrubland structure

- We captured no evidence of the effect on shrublands of removing trees/crops to restore shrubland structure.

13.4 Remove trees, leaf litter, and topsoil

- We captured no evidence of the effect on shrublands of removing trees, leaf litter and soil surface.

13.5 Disturb vegetation

- One randomized, replicated, controlled study in the UK found that vegetation disturbance did not increase the abundance or species richness of specialist plants but increased the abundance of generalist plants.

13.6 Disturb topsoil

- A controlled study in a former pine plantation in South Africa found that digging soil did not alter vegetation cover or the density of native plants.
- One randomized, replicated, controlled study in the UK found that soil disturbance did increased the abundance or species richness of specialist and generalist plant species.

13.7 Strip topsoil

- Two randomized, replicated, controlled studies in the UK found that removal of topsoil did not increase heather cover or cover of heathland species1. However, one controlled study in the UK found an increase in heather cover.
- One randomized, replicated, controlled study in the UK found that removing topsoil increased the cover of both specialist and generalist plant species, but did not increase species richness.
- One randomized, replicated, paired, controlled study in the UK found that removal of topsoil increased cover of annual grasses but led to a decrease in the cover of perennial grasses. One controlled study in the UK found that removal of turf reduced cover of wavy hair grass.
- One controlled, before-and-after trial in the UK found that stripping surface layers of soil increased the cover of gorse and sheep’s sorrel as well as the number of plant species.

13.8 Add topsoil

- Two randomized, controlled studies in the UK found that the addition of topsoil increased the cover or abundance of heathland plant species. One replicated, site comparison in Spain3 found an increase in the abundance of woody plants. One randomized, controlled study in the UK1 found an increase in the number of seedlings for a majority of heathland plants.
- One controlled study in Namibia found that addition of topsoil increased plant cover and the number of plant species, but that these were lower than at a nearby undisturbed site.

- One randomized, controlled study in the UK found an increase in the cover of forbs but a reduction in the cover of grasses.

13.9 Add peat to soil

- We captured no evidence of the effect on shrublands of adding peat to soils to encourage recolonization.

13.10 Remove leaf litter

- One randomized, controlled study in the UK found that removing leaf litter did not alter the presence of heather.

13.11 Burn leaf litter

- We captured no evidence of the effect on shrublands of burning leaf litter.

13.12 Add sulphur to soil

- One randomized, replicated, controlled study in the UK found that adding sulphur to the soil did not increase the number of heather seedlings in the majority of cases.

13.13 Use erosion blankets/mats to aid plant establishment

- One replicated, randomized, controlled study in the USA found that using an erosion control blanket increased the height of two shrub species.
- One replicated, randomized, controlled study in the USA did not find an increase in the number of shrub species, but one controlled study in China did find an increase in plant diversity following the use of erosion control blankets. The same study found an increase in plant biomass and cover.

13.14 Add mulch and fertilizer to soil

- One randomized, controlled study in the USA found that adding mulch and fertilizer did not increase shrub seedling abundance nor did it led to a change in grass cover.

13.15 Add manure to soil

- One replicated, randomized, controlled study in South Africa found that adding manure increased plant cover and the number of plant species.

13.16 Irrigate degraded shrublands

- One replicated, randomized, controlled study in the USA found that irrigation increased shrub cover.

Key messages - Introduce vegetation or seed

13.17 Plant individual plants

- One replicated, randomized, controlled study in the USA found that planting California sagebrush plants did not increase the cover of native plant species compared to sowing of seeds or a combination of planting and sowing seeds. One replicated, randomized, controlled study in South Africa found that planting *Brownanthus pseudoschlichtianus* plants increased plant cover, but not the number of plant species.
- One study in the USA found that a majority of planted plants survived after one year.

13.18 Sow seeds

- Five of six studies (including three replicated, randomized, controlled studies, one site comparison study and one controlled study) in the UK, South Africa, and the USA found that sowing seeds of shrubland species increased shrub cover. One of six studies in the UK found no increase in shrub cover. One replicated site comparison in the USA found in sites where seed containing Wyoming big sagebrush was sown the abundance of the plant was higher than in sites where it was not sown. One replicated, randomized, controlled study in the USA found that shrub seedling abundance increased after seeds were sown. One study in the USA found very low germination of hackberry seeds when they were sown.One replicated, randomized, controlled study in the USA found that the community composition of shrublands where seeds were sown was similar to that found in undisturbed shrublands. One randomized, controlled study in the UK found an increase in the cover of heathland plants when seeds were sown.

- One replicated, randomized, controlled study in South Africa1 found that sowing seeds increased plant cover. One replicated, randomized, controlled study in the USA found that areas where seeds were sown did not differ significantly in native cover compared to areas where shrubland plants had been planted. One controlled study in the USA found higher plant diversity in areas where seeds were sown by hand than in areas where they were sown using a seed drill.
- Two of three studies (one of which was a replicated, randomized, controlled study) in the USA found that sowing seeds of shrubland species resulted in an increase in grass cover. One randomized, controlled study in the UK found no changes in the cover of grasses or forbs.

13.19 Sow seeds and plant individual plants

- One replicated, controlled study in the USA found that planting and sowing of seeds did not increase cover of native plant species compared to sowing of seeds, or planting alone.

13.20 Spread clippings

- One randomized, controlled study in the UK found that the addition of shoots and seeds of heathland plants did not increase the abundance of mature plants for half of plant species. One randomized, controlled study in the UK found that the frequency of heather plants was not significantly different in areas where heather clippings had been spread and areas where they were not spread.
- One replicated, randomized, controlled study in the UK found an increase in the number of heather seedlings, but not of other heathland species. One randomized, controlled study in the UK found that the addition of shoots and seeds increased the number of seedlings for a minority of species.
- One replicated, randomized, controlled study in South Africa found that plant cover and the number of plant species did not differ significantly between areas where branches had been spread and those where branches had not been spread.

13.21 Build bird perches to encourage colonisation by plants

- One replicated, controlled study in South Africa found that building artificial bird perches increased the number of seeds at two sites, but no shrubs became established at either of these sites.

13.22 Plant turf

- Two randomized, controlled studies in the UK found that planting turf from intact heathland sites increased the abundance or cover of heathland species. One of these studies also found that planting turf increased the seedling abundance for a majority of heathland plant species.
- One randomized, controlled study in the UK found that planting turf increased forb cover, and reduced grass cover.
- One randomized, replicated, controlled study in Iceland found that planting large turves from intact heathland sites increased the number of plant species, but smaller turves did not.

General restoration

13.1 Restore/create habitat connectivity between shrublands

We captured no evidence of the effect on shrublands of restoring or creating habitat connectivity of shrublands.

Background

Increasing connectivity between sites may help to maintain interactions between plant and animals such as pollination and seed dispersal, which can aid survival of plant populations and increase plant diversity (Beier and Noss, 1998).

Beier, P., & Noss, R. F. (1998). Do habitat corridors provide connectivity? Conservation Biology, 12(6), 1241-1252.

13.2 Allow shrubland to regenerate without active management

- Five before-and-after trials (two of which were replicated) in the USA[1,9] UK[2,8], and Norway[10], found that allowing shrubland to recover after fire without any active management increased shrub cover or biomass. One replicated, paired, site comparison in the USA[3] found that sites that were allowed to recover without active restoration had similar shrub cover to unburned areas. One controlled, before-and-after trial in the USA[5] found no increase in shrub cover. One before-and-after trial in Norway[10] found an increase in heather height. One before-and-after trial in Spain[7] found that there was an increase in seedlings for one of three shrub species. One before-and-after study in Spain[6] found that cover of woody plants increased, but the number of woody plant species did not.
- One before-and-after trial in South Africa[11] found that there was an increase in vegetation cover, but not in the number of plant species. Two replicated, randomized, controlled, before-and-after trials in Spain[14] and Portugal[15] found that there was an increase in the cover of woody plant species. One before-and-after trial in South Africa[4] found an increase in a minority of plant species. One replicated, before-and-after study in South Africa[13] found that the height of three protea species increased after recovery from fire.
- Two before-and-after trials in the USA[1] and UK[2] found that allowing shrubland to recover after fire without active management resulted in a decrease in grass cover or biomass. One controlled, before-and-after trial in the USA[5] found an increase in the cover of a minority of grass species. One before-and-after study in Spain[6] found that cover of herbaceous species declined. One replicated, before-and-after study in the UK[8] found mixed effects on cover of wavy hair grass.
- One controlled, before-and-after trial in the USA[5] found no increase in forb cover. One replicated, randomized, controlled before-and-after trial in Spain[14] found that herb cover declined after allowing recovery of shrubland after fire.

Background

After some types of degradation it may be feasible to allow shrublands to recover without any active management. This may allow shrubland plants to recolonize sites over time.

A before-and-after trial in 1936–1966 in a sagebrush scrub shrubland affected by fire in Idaho, USA (1) found that allowing shrubland to recover from disturbance without any active restoration increased biomass of big sagebrush *Artemisia tridentata* and decreased grass biomass after 30 years. After 30 years of recovery, biomass of big sagebrush was higher (325 kg/ha) than in the same areas immediately after fire had occurred (2 kg/ha). However, the areas' grass biomass did not differ significantly after 30 years of recovery (164 kg/ha) from grass biomass in the same areas immediately following fire (158 kg/ha). In 1936 the shrublands were burned. Following this vegetation cover was assessed in four hundred 9.3 m^2 quadrats in 1936, 1937, 1939, 1948, and 1966.

A before-and-after trial in 1961–1971 in a heathland affected by fire in Dorset, UK (2) found that allowing shrubland to recover without active restoration increased cover of two of four shrub species, and decreased cover of two of two grass species and bracken *Pteridium aquilinum*. After the heathland was allowed to recover for 10 years, cover of common heather *Calluna vulgaris* and bell heather *Erica cinerea* increased, but cover of cross-leaved heath *Erica tetralix* and dwarf gorse *Ulex minor* did not increase (data presented as index). After a 10 years recovery, the cover of purple-moor grass *Molinia caerulea* and bristle bent *Agrostis setacea* was not significantly different to cover immediately after the fire (data presented as index). However, the cover of bracken was lower than immediately after fire than after 10 years of recovery (data presented as index). In 1961 and 1971 vegetation cover of plant species was estimated at 157 points.

A replicated, paired, site comparison study of seven shrublands that had been previously burned in New Mexico and Texas, USA (3) found that sites that were allowed to recover without active restoration had a similar shrub cover to unburned sites, but higher grass cover. Shrub cover did not differ between sites after seven years (burned: 7%; unburned: 9%). After seven years of recovery grass cover was higher (53%) than in unburned sites (35%). Seven sites that had been burned between three and seven years ago and seven paired unburned sites were selected. Plant species and their percentage cover were recorded within fifty 0.1 m^2 plots/site. A before-and-after trial in 1980–1981 in grassy fynbos habitat previously affected by fire in Eastern Cape Province, South Africa (4) found that allowing recovery of vegetation without any active restoration increased the abundance of three of twenty plant species. After one year, three of twenty plant species had higher abundance (3–12 plants/m^2) than immediately after the fire (2–6 plants/m^2). In August 1980 fire burned the majority of the site. Twelve 1 m^2 quadrats were placed at the site and abundance of plants was recorded every month between December 1980 and December 1981.

A controlled, before-and-after trial in 1981–1983 in a sagebrush scrub habitat that had been burnt in a wildfire in Utah, USA (5) found that allowing shrubland to recover without active restoration did not increase cover of shrub, or forb species, but did increase cover of two of eight grass species. After two years of recovery, the cover of five of five shrubs (0–1%) was not significantly different than immediately after burning (0%), and was lower than in unburned areas for one of five shrubs (3%). The same pattern was true for seven of seven forb species (after recovery: 0%, immediately after fire: 0%). Cover of two of eight grass species was higher after two years of recovery (5–50%) than immediately after fire (0%). Wildfire occurred in July 1981. Cover of plants was assessed visually in four 1000 m^2 plots every year in 1981–1983.

A before-and-after study in 1989-1994 in rockrose shrublands in northern Spain (6) found that allowing shrubland to recover after severe disturbance without any active restoration increased the cover of woody plants, reduced the number of species and cover of herbaceous plants, but did not increase the number of woody plant species after five years. In three of three cases, after five years, cover of woody plants in plots was higher (50-64% cover) than the in same plots immediately after they were disturbed (1-25% cover), but was lower than the same plots before they were disturbed (79-91% cover). In three of three cases the number and cover of herbaceous species after five years was lower (species: 2-7; cover: 2-12%) than that immediately after disturbance (species: 6-16; cover: 17-61%), but cover after five years was higher than herbaceous cover prior to disturbance (0-3% cover). However, in three of three cases the number of woody species did not differ significantly after five years (2-3 species) and the same areas immediately after disturbance (1-3 species). Three 100 m^2 plots were established in the shrublands in 1989 and were either burnt, ploughed, or cut. Each year in 1989-1994 five 1 m^2 quadrats were placed in each plot and vegetation estimated visually. A before-and-after trial in 1991–1994 in a heathland that had previously been burnt by wildfire in southern Spain (7) found that allowing recovery without active restoration increased the number of seedlings of common heather *Calluna vulgaris*, but not of rock rose *Cistus populifolius* and *Genista triacanthos*. After three years of recovery, the number of seedlings of heather (29 seedlings/m^2) was higher than found in the first year after fire (0 seedlings/m^2). However, the numbers of rock rose (7 seedlings/m^2), and *Genista triacanthos* (7 seedlings/m^2) seedlings was not higher after three years than in the first year after fire (rock rose: 8 seedlings/m^2, *Genista triacanthos*: 6 seedlings/m^2). A wildfire occurred in 1991. The abundance of seedlings was recorded annually in 50 randomly located 1 m^2 quadrats in 1992–1994.

A replicated, before-and-after trial in 1996–1998 in two heathlands in the UK (8) found that allowing shrubland to recover from disturbance without any active restoration increased cover of heather *Calluna vulgaris* in two of two sites, but increased cover of wavy-hair grass *Deschampsia flexuosa* in one of two sites. After two years of recovery, heather cover increased from 0% to 21–85% in both sites. However, at one site, the cover of wavy-hair grass increased from 0% to 8%, while at the other site wavy-hair grass cover was 0% before recovery and 0% after two years of recovery. All vegetation in randomly placed plots of 1 m^2, 0.25 m^2, and 0.0625 m^2 was removed and the top 15 cm of soil broken up with a spade. Vegetation cover in each plot was recorded in April and October of each year in 1996–1998.

A replicated, before-and-after trial in 1993–1998 in 90 sage scrub and chaparral shrubland sites that had been burned by wildfire in California, USA (9) found that allowing shrublands to recover without active restoration increased shrub cover. After five years of recovery, shrub cover was higher (45–92%) than it had been immediately after wildfires (4–15%). Sites were 0.1 ha areas where wildfires had burned in the previous year. At each site twenty 1 m^2 quadrats were used to estimate plant cover and density.

A before-and-after trial in 1999–2002 in 16 heathlands that had previously been burned in central Norway (10) found that allowing recovery without any active restoration increased the cover and height of common heather *Calluna vulgaris*. Areas that had been allowed to recover had higher cover one year after burning than immediately after burning (data presented as log units). Common heather plants were taller after one year of recovery (1.8–6.8 cm) than immediately after burning (0.2–4.2 cm). Sixteen heathland sites were burned in 1999–2001. Three 1 m^2 plots were placed at each site and vegetation cover and height were monitored in 2001–2002.

A before-and-after trial in 2000–2004 in two fynbos habitats previously affected by fire in Western Cape, South Africa (11) found that allowing shrubland to recover without active restoration increased vegetation cover but not plant species richness. After four years of recovery, vegetation cover was higher (84–94 cm^2) than immediately after the site was burned (62–27 cm^2). However, after four years of recovery plant species richness did not increase significantly (before: 3–5 species, after: 3–4 species). In 2000 wildfires burned both sites. Two 1 m wide transects consisting of forty-nine to seventy-eight 1 m^2 quadrats were used to survey vegetation cover in 2001, 2002, and 2004.

A replicated, randomized, controlled study between 1998 and 2008 in sagebrush scrub in Oregon, USA (12) found that allowing shrubland to recover from disturbance without any active restoration increased shrub cover to a level similar to that found in undisturbed shrublands, while annual grass cover was higher than seen in undisturbed shrublands and perennial grass cover was lower. Ten years after all vegetation was removed shrub cover had increased from 2% to 22%, similar to the cover of 24% seen in undisturbed shrublands. Over 10 years perennial grass cover increased from 0% to 10% but was still lower than the cover of 25% found in undisturbed shrubland. Annual grass cover increased from 2% to 7% and this was higher than the 2% cover seen in undisturbed shrubland. However, annual forb cover declined from 20% to 3%, similar to the cover of 1% seen in undisturbed shrubland. Perennial forb cover did not show a significant change over time (1% vs 2%) and was not significantly different from cover seen in undisturbed shrubland (1%). In 1998 all vegetation was removed from five 36 m^2 plots using glyphosate herbicide with a further five plots receiving no treatment. Vegetation cover was estimated in five 0.2 m^2 quadrats in each experimental plot between 1999 and 2008.

A replicated, before-and-after study in 1996–2011 in two fynbos sites in South Africa (13) that had previously been burned found that allowing the sites to recover without any active management led to an increase in the height of three protea species. At one site *Leucadendron eucalyptifolium* and forest sugarbush *Protea mundii* were taller six years after burning (*L. eucalyptifolium:* 140 cm, forest sugarbush: 127 cm) than one year after burning (*L. eucalyptifolium*: 62 cm, forest sugarbush: 62 cm). At the other site oleanderleaf protea *Protea neriifolia* were taller after 15 years (148 cm) than 10 years after burning (92 cm). One of the sites was burned in a prescribed fire and the other in a wildfire. The height of 100 seedlings of oleanderleaf protea was recorded in April 1996 at one site and the height of 100 *L. eucalyptifolium* and forest sugarbush seedlings was recorded in 2008 at the other. Plant height was recorded annually until 2011.

A replicated, randomized, controlled, before-and-after trial in a shrubland in southern Spain (14) found that allowing shrubland to recover from fire without any active restoration increased cover of woody plants but reduced cover of herb species after three years. Three years after fire, cover of woody species was higher (67%) than one year after fire (21%) and was not significantly different from cover before fire occurred (75%) or cover in unburnt plots (73%). The cover of herb species was lower three years after fire (18%) than one year after fire (54%), but cover was not significantly different to unburnt plots (14%). Twelve 625 m^2 plots were established and randomly assigned to be burned, or left unburnt. Before burning and for three years afterwards twenty 1 m^2 quadrats per plot were used to assess cover of plant species. Seedling density was assessed using 25 cm x 25 cm quadrats.

A replicated, randomized, controlled, before-and-after trial between 2002 and 2006 in a shrubland in Central Portugal (15) found that allowing shrubland to recover from fire without any active restoration increased the cover of woody species after four years but not to pre-fire levels. Four years after fire, cover of woody plant species was higher (70%) than one year after fire (47%) but not as high as before fire occurred (98%). The cover of perennial herb species was higher four years after fire (9%) than one year after fire (5%), both of which were higher than pre-fire levels (1%). Four years after fire the cover of bracken *Pteridium aquilinum* was higher (2%) than pre-fire levels (0%). Twelve 0.2 hectare plots were established in the shrubland, eight of which were subsequently burned and four of which were left unburned. Vegetation cover was estimated using twenty 1 m^2 quadrats which were surveyed before burning and annually for four years afterwards.

(1) Harniss, R.O. & Murray, R.B. (1973) 30 years of vegetal change following burning of sagebrush-grass range. *Journal of Range Management*, 26, 322-325.
(2) Brian, M.V., Mountford, M.D., Abbott, A. & Vincent, S. (1976) The Changes in Ant Species Distribution During Ten Years Post-Fire Regeneration of a Heath. *Journal of Animal Ecology*, 45, 115-133.
(3) Ahlstrand, G.M. (1982) Response of Chihuahuan Desert Mountain Shrub Vegetation to Burning. *Journal of Range Management*, 35, 62-65.
(4) Richardson, G.R., Lubke, R.A. & Guilarmod, A.J. (1984) Regeneration of grassy fynbos near Grahamstown (eastern Cape) after fire. *South African Journal of Botany*, 3, 153-162.
(5) West, N.E. & Hassan, M.A. (1985) Recovery of Sagebrush-Grass Vegetation Following Wildfire. *Journal of Range Management*, 38, 131-134.
(6) Tárrega, R., Luis-Calabuig, E. & Alonso, I. (1995) Comparison of the regeneration after burning, cutting and ploughing in a Cistus ladanifer shrubland. *Plant Ecology*, 59-67.
(7) Ojeda, F., Marañón, T. & Arroyo, J. (1996) Postfire regeneration of a mediterranean heathland in Southern Spain. *International Journal of Wildland Fire*, 6, 191-198.
(8) Britton, A.J., Carey, P.D., Pakeman, R.J. & Marrs, R.H. (2000) A comparison of regeneration dynamics following gap creation at two geographically contrasting heathland sites. *Journal of Applied Ecology*, 37, 832-844.
(9) Keeley, J.E., Fotheringham, C.J. & Baer-Keeley, M. (2005) Determinants of postfire recovery and succession in Mediterranean-climate shrublands of California. *Ecological Applications*, 15, 1515-1534.
(10) Nilsen, L.S., Johansen, L. & Velle, L.G. (2005) Early stages of Calluna vulgaris regeneration after burning of coastal heath in central Norway. *Applied Vegetation Science*, 8, 57-64.
(11) Reinecke, M.K., Pigot, A.L. & King, J.M. (2008) Spontaneous succession of riparian fynbos: Is unassisted recovery a viable restoration strategy? *South African Journal of Botany*, 74, 412-420.
(12) Boyd, C.S. & Svejcar, T.J. (2011) The influence of plant removal on succession in Wyoming big sagebrush. *Journal of Arid Environments*, 75, 734-741.
(13) Kraaij, T., Cowling, R.M., Wilgen, B.W. & Schutte-Vlok, A. (2013) Proteaceae juvenile periods and post-fire recruitment as indicators of minimum fire return interval in eastern coastal fynbos. *Applied Vegetation Science*, 16, 84-94.
(14) Céspedes, B., Torres, I., Pérez, B., Luna, B. & Moreno, J.M. (2014) Burning season does not affect post-fire regeneration but fire alters the balance of the dominant species in a seeder-dominated Mediterranean shrubland. *Applied Vegetation Science*, 17, 711-725.
(15) Céspedes, B., Luna, B., Pérez, B., Urbieta, I.R. & Moreno, J.M. (2014) Burning season effects on the short-term post-fire vegetation dynamics of a Mediterranean heathland. *Applied Vegetation Science*, 17, 86-96.

Modify physical habitat

13.3 Remove trees/crops to restore shrubland structure

We captured no evidence of the effect on shrublands of removing trees/crops to restore shrubland structure.

Background

The removal of trees/crops in former shrublands may encourage colonization by shrubland plants by reducing the number of other plants competing for resources.

13.4 Remove trees, leaf litter and topsoil

We captured no evidence of the effect on shrublands of removing trees, leaf litter and soil surface.

Background
Removing trees allows more light to reach the ground, potentially increasing the germination of shrubland species. Removing topsoil and leaf litter in addition to this may further increase the probability of seed germination.

13.5 Disturb vegetation

- One randomized, replicated, controlled study in the UK[1] found that vegetation disturbance did not increase the abundance or species richness of specialist plants but increased the abundance of generalist plants.

Background
Disturbing vegetation reduces ground cover, allowing more light to reach the ground, and potentially increasing the germination of shrubland species.

A randomized, replicated, controlled study in 2009–2010 in heathland in Breckland, UK (1) found that vegetation disturbance did not increase the abundance or species richness of specialist plants but increased the abundance of generalist plants. For specialist plants, abundance and species richness in disturbed plots (abundance: 46–48; species richness: 8–10) did not differ significantly from undisturbed plots (abundance: 22–27; species richness: 5–6). For one of two cases generalist plant abundance was significantly higher in disturbed (68–76) than in undisturbed plots (31–40), but in one of two cases there was no significant difference (disturbed: 45-64, undisturbed: 31-40). Species richness did not differ significantly between disturbed and undisturbed areas (disturbed: 10-12, undisturbed: 6-7). In February 2009 eighteen 150 x 4-5 m plots located within the trackways of forest stands were disturbed using cutters attached to a tractor, while the vegetation in nine plots was not disturbed. In each plot, plant species richness and abundance were recorded using twenty 1 x 1 m quadrats in May–August of 2009 and 2010. Species were classified as generalists if they were ubiquitous in forest and as generalists if likely to benefit from heathland connectivity.

(1) Pedley, S.M., Franco, A.M.A., Pankhurst, T. & Dolman, P.M. (2013) Physical disturbance enhances ecological networks for heathland biota: A multiple taxa experiment. *Biological Conservation*, 160, 173-182.

13.6 Disturb topsoil

- A controlled study in a former pine plantation in South Africa[1] found that digging soil did not alter vegetation cover or the density of native plants.

- One randomized, replicated, controlled study in the UK[2] found that soil disturbance did increased the abundance or species richness of specialist and generalist plant species.

Background
Disturbing soil reduces ground cover, allowing more light to reach the ground, as well as potentially bringing any shrubland seeds to the surface. This may help to increase the germination of the seeds of shrubland species.

Related interventions: Strip topsoil (section 13.7); add topsoil (section 13.8); add peat to soil (section 13.9).

A randomized, replicated, controlled study in 2009–2010 in heathland in Breckland, UK (1) found that soil disturbance by disking increased the abundance and species richness of both specialist and generalist plants between three and six months after treatment but only increased the abundance of generalists one year after treatment. Between three and six months after disking, abundance and species richness of specialists and generalists was higher in disked (abundance: 91; species richness: 18, respectively for specialist and generalist plants) than in untreated plots (abundance: 40; species richness: 7, respectively for specialist and generalist plants). However, one year after treatment, abundance of generalist plants was higher in disked (75) than in untreated plots (31) but neither the abundance of specialist plants nor the species richness of generalist or specialist plants differ significantly between treated and untreated plots (abundance of specialists: 57 vs 27; species richness of generalists: 11 vs 6; species richness of specialists: 9 vs 5, respectively for treated and untreated plots). Disking using a tractor-pulled disc harrow which disrupted the vegetation while provoking shallow soil disturbance was conducted in nine 150 m x 4–5 m plots located in trackways within forest stands in February 2009. Nine plots were left untreated. At each plot, plant species richness and abundance were recorded using twenty 1 m x 1 m quadrats between May and August of both 2009 and 2010. Species were classified as generalists if ubiquitous in forest and as generalists if likely to benefit from heathland connectivity.

A controlled study between 1997 and 1999 in a former pine plantation in Western Cape, South Africa (2) found that digging over the soil did not increase vegetation cover or the density of native plants after two years. Vegetation cover in plots where soil was dug over (45% cover) was not significantly different from that in areas that were not dug over (53% cover). The same was true for the density of native plants (dug over: 8 plants/m2, not dug over: 7 plants/m2). Forty 4 m2 plots were located in a former pine plantation that had been felled and burned. Twenty plots were dug to a depth of 10–15 cm and the soil turned over. The remaining twenty plots were left undug. A 1 m2 quadrat was placed in each plot and used to estimate vegetation cover for two years.

(1) Pedley, S.M., Franco, A.M.A., Pankhurst, T. & Dolman, P.M. (2013) Physical disturbance enhances ecological networks for heathland biota: A multiple taxa experiment. *Biological Conservation*, 160, 173-182.
(2) Holmes, P.M. & Foden, W. (2001) The effectiveness of post-fire soil disturbance in restoring fynbos after alien clearance. *South African Journal of Botany*, 67, 533-539.

13.7 Strip topsoil

- Two randomized, replicated, controlled studies in the UK[1,3] found that removal of topsoil did not increase heather cover[3] or cover of heathland species[1]. However, one controlled study in the UK[2] found an increase in heather cover.
- One randomized, replicated, controlled study in the UK[5] found that removing topsoil increased the cover of both specialist and generalist plant species, but did not increase species richness.
- One randomized, replicated, paired, controlled study in the UK[1] found that removal of topsoil increased cover of annual grasses but led to a decrease in the cover of perennial grasses. One controlled study in the UK[2] found that removal of turf reduced cover of wavy hair grass.
- One controlled, before-and-after trial in the UK[4] found that stripping surface layers of soil increased the cover of gorse and sheep's sorrel as well as the number of plant species.

Background

Stripping topsoil may help to reduce fertility of soils as well as removing seeds that are found in topsoil. Both of these outcomes may aid the establishment of shrubland plants.

Related interventions: Disturb topsoil (section 13.6); add topsoil (section 13.8); add peat to soil (section 13.9).

A randomized, replicated, paired, controlled study in 1993–2002 in three former grassland sites in the UK (1) found that removal of topsoil did not alter cover of heathland species or cover of forbs, but increased cover of annual grasses and led to a decrease in perennial grasses. After nine years, cover of heathland species and forbs did not differ significantly between areas where topsoil was removed (heathland species: 1%, forbs: 11%) and areas where topsoil was not removed (heathland species: 0%, forbs: 8%). Cover of annual grasses was higher in areas where topsoil was removed (13%) than in areas where it was not removed (1%). However, the cover of perennial grasses was lower in areas where topsoil was removed (22%) than in areas where topsoil was not removed (83%). In 1993 topsoil was removed from twelve 3 x 3 m plots while in twelve other plots topsoil was not removed. The cover of plant species in each plot was estimated in July and August 2002 using a point quadrat.

A controlled study in 1995–2005 in a former heathland in central England, UK (2) reported that turf removal promoted an increase in heather *Calluna vulgaris* and reduced the dominance of wavy hair-grass *Deschampsia flexuosa.* After 10 years, the percentage cover of heather was higher in the area where turf had been stripped (65%) than in the unstripped area (1%). Additionally, the percentage cover of wavy-hair grass was lower in the stripped (5%) than in the unstripped area (80%) whereas the percentage cover of bracken *Pteridium aquilinum* did not change between stripped and unstripped areas (5%) (results are not based on statistical tests). In October/November 1995 turf was removed to a depth of approximately 10 cm from an area of about 600 m² of wavy hair-grass-dominated acid grassland using a mini-digger with a dozer attachment. Vegetation cover was visually estimated in April 2005.

A replicated, randomized, controlled study in 1994–2003 in two agricultural fields in Suffolk, UK (3) found that removal of topsoil did not increase the cover of common heather *Calluna vulgaris* in two of two comparisons, after nine years. In two of two comparisons cover of common heather in areas where topsoil had been stripped was not significantly different (0%) to cover in areas where it had not (0%). In 1994 the top 35–45 cm of soil were stripped in four 80 m^2 plots while in four other plots soil was not stripped. In April 2003 five 2500 cm^2 quadrats were placed in each plot and the cover of all plant species recorded.

A controlled, before-and-after trial in 2007–2008 in a former heathland now dominated by trees in Essex, UK (4) found that stripping the top layers of soil increased the cover of gorse *Ulex europaeus* and sheep's sorrel *Rumex acetosella*, as well as the number of plant species. The cover of gorse increased in plots where soil had been stripped (before: 0%; after: 2%) and this cover was higher than in plots that had not been stripped (before: 0%; after: 0%). The cover of sheep's sorrel also increase in plots where soil had been stripped (before: 0%; after: 1%) and this was also higher than in plots where soil had not been stripped (before: 0%; after: 1%). After soil stripping, the number of plant species in stripped plots was higher than in unstripped plots (stripped plots: 1.5 species/quadrat; unstripped plots: 0.6 species/quadrat). Leaf litter and topsoil was stripped in ten 50 cm x 50 cm quadrats, while in another ten quadrats topsoil was left unstripped. Vegetation cover in the quadrats was assessed four times between May 2007 and July 2008.

A randomized, replicated, controlled study in 2009–2010 in heathland in Breckland, UK (5) found that stripping of top soil increased the abundance of generalist plants in six out of six comparisons, the abundance of specialist plants in five out of six comparisons but only increased the species richness of specialist plants in two out of six comparisons. For generalist plants, abundance was higher in stripped (50–76) than in unstripped plots (31–40) in six out of six comparisons but species richness did not differ significantly between stripped (9–14) and unstripped plots (6–7). For specialist plants, abundance was higher in stripped (62–83) than in unstripped plots (22–27) in five out of six comparisons but species richness was only higher in stripped (11–12) than in unstripped plots (5–6) in two out of six comparisons. In nine plots soil and litter were inverted in plough lines that alternated with 30–40 cm strips of intact vegetation, in another nine plots turf and top-soil were inverted and biomass was retained and buried and in nine plots more vegetation, root mat, litter and organic soil were removed. Nine plots were left untreated. At each plot, plant species richness and abundance were recorded using twenty 1 m x 1 m quadrats between May and August of both 2009 and 2010. Species were classified as generalists if ubiquitous in forest and as generalists if likely to benefit from heathland connectivity.

(1) Allison, M. & Ausden, M. (2004) Successful use of topsoil removal and soil amelioration to create heathland vegetation. *Biological Conservation*, 120, 221-228.
(2) Wilton-Jones, G. & Ausden, M. (2005) Restoring heathland vegetation by turf-stripping wavy hair-grass Deschampsia flexuosa dominated grassland at The Lodge RSPB Reserve, Bedfordshire, England. *Conservation Evidence*, 2, 66-67.
(3) Walker, K.J., Warman, E.A., Bhogal, A., Cross, R.B., Pywell, R.F., Meek, B.R., Chambers, B.J. & Pakeman, R. (2007) Recreation of lowland heathland on ex-arable land: assessing the limiting processes on two sites with contrasting soil fertility and pH. *Journal of Applied Ecology*, 44, 573-582.
(4) Gardiner, T. & Vaughan, A. (2008) Responses of ground flora and insect assemblages to tree felling and soil scraping as an initial step to heathland restoration at Norton Heath Common, Essex, England. *Conservation Evidence*, 5, 95-100.
(5) Pedley, S.M., Franco, A.M.A., Pankhurst, T. & Dolman, P.M. (2013) Physical disturbance enhances ecological networks for heathland biota: A multiple taxa experiment. *Biological Conservation*, 160, 173-182.

13.8 Add topsoil

- Two randomized, controlled studies in the UK[1,4] found that the addition of topsoil increased the cover or abundance of heathland plant species. One replicated, site comparison in Spain[3] found an increase in the abundance of woody plants. One randomized, controlled study in the UK[1] found an increase in the number of seedlings for a majority of heathland plants.
- One controlled study in Namibia[2] found that addition of topsoil increased plant cover and the number of plant species, but that these were lower than at a nearby undisturbed site.
- One randomized, controlled study in the UK[4] found an increase in the cover of forbs but a reduction in the cover of grasses.

Background
Adding topsoil from shrublands to degraded shrubland sites may help to increase the number of seeds in the soil, thereby increasing the probability of shrubland plants becoming established. The addition of topsoil may also help to increase soil fertility or reduce the effects of processes that dramatically alter soil structure, such as mining or quarrying.

Related interventions: Disturb topsoil (section 13.6); strip topsoil (section 13.7); add peat to soil (section 13.9).

A randomized, controlled study in 1988–1993 in former heathland in Dorset, UK (1) found that stripping soil followed by adding topsoil from a nearby heathland increased the number of seedlings for five of seven heathland species after one year, and increased the abundance of four of six heathland species after three years. For five of seven heathland species the number of seedlings in plots where soil was stripped and topsoil was added (1–286 seedlings/m^2) was higher than in plots where soil was not stripped and topsoil was not added (0 seedlings/m^2). The abundance of four of six heathland plant species was higher in plots where soil was stripped and topsoil was added (1–43 shoots/m^2) compared to plots where soil was not stripped and topsoil was not added (0–4 shoots/m^2). In 1989 topsoil at a nearby mature heathland site was stripped to a depth of 5 cm. Between 11 and 12 tonnes of topsoil were applied to three 500 m^2 plots and mixed using a rotary cultivator and in three plots no topsoil was added. In 1990–1991 the number of seedlings was recorded in seven 0.5 m x 1 m quadrats which were placed in each plot. In 1993 the number of plant shoots was recorded in three 1 m^2 quadrats which were randomly placed in each plot.

A controlled study in 2006 in Karoo shrublands in Namibia (2) found that addition of topsoil to areas damaged by excavation increased the number of plant species and plant cover, but these were lower than found at a nearby undisturbed shrubland. The number of plant species was higher in areas where topsoil was added (5 species) than in areas where topsoil was not added (2 species), but was not as high as in undisturbed shrubland (15 species). Areas where topsoil was added also had higher vegetation cover (15%) than areas where topsoil was not added (1%) but vegetation cover was higher in undisturbed shrubland (28%). Two previously excavated areas were restored in 2006 by using a bulldozer to add topsoil. Four previously excavated areas did not have topsoil added. The previously excavated areas and nearby undisturbed shrubland were surveyed in October 2006 using a minimum of thirty 1 m^2 quadrats in each area.

A replicated, site comparison study in 2008 of 31 former coal mines in northern Spain (3) found that adding topsoil increased the abundance of woody plant species. The 26 sites where topsoil had been added contained more woody species, and resembled later succession sites (see Alday et al, 2011 for details) than those where no topsoil was added (data reported as model results). The five mines where no topsoil was added were dominated by herbaceous species (e.g. Lettuce *Lactuca* spp., Skeletonweed *Chondrilla* spp.). Thirty one open-cast mines were selected. They varied in age since abandonment between one and 40 years. At 26 of these sites topsoil had previously been added, while at five sites no restoration had been carried out. At each mine ten 1 m^2 quadrats were located randomly and the percentage cover of all plant species assessed once in 2008.

A randomized, controlled study in 1988–2005 in former heathland in Dorset, UK (4) found that stripping soil followed by adding topsoil from a nearby heathland increased the cover of heathland species and forbs, and reduced the cover of grasses after 17 years. The cover of heathland species and forbs was higher in plots where topsoil was added (heathland: 82%, forbs: 87%) than in plots where it was not (heathland: 16%; forbs: 27%). Grass cover was lower in plots where topsoil was added (16%) than in plots where it was not (59%). In 1989 topsoil at a nearby mature heathland site was stripped to a depth of 5 cm. Topsoil of three 500 m^2 plots was removed and heathland topsoil spread, while in three plots no topsoil was spread. In 2005 the cover of plants was recorded in four 1 m^2 quadrats which were randomly placed in each plot.

(1) Pywell, R.F., Webb, N.R. & Putwain, P.D. (1995) A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32, 400-411.
(2) Burke, A. (2008) The effect of topsoil treatment on the recovery of rocky plain and outcrop plant communities in Namibia. *Journal of Arid Environments*, 72, 1531-1536.
(3) Alday, J.G., Marrs, R.H. & Martínez Ruiz, C. (2011) Vegetation succession on reclaimed coal wastes in Spain: The influence of soil and environmental factors. *Applied Vegetation Science*, 14, 84-94.
(4) Pywell, R.F., Meek, W.R., Webb, N.R., Putwain, P.D. & Bullock, J.M. (2011) Long-term heathland restoration on former grassland: The results of a 17-year experiment. *Biological Conservation*, 144, 1602-1609.

13.9 Add peat to soil

We captured no evidence of the effect on shrublands of adding peat to soils to encourage recolonization.

Background
Adding peat to shrubland soil can increase its acidity. This may encourage colonization by shrubland plants that depend on acid conditions, such as those found in western European heathlands.

Related interventions: Strip topsoil (section 13.7); add topsoil (section 13.8); add peat to soil (section 13.9).

13.10 Remove leaf litter

- One randomized, controlled study in the UK[1] found that removing leaf litter did not alter the presence of heather.

Background

Removal of leaf litter may help to increase the amount of light that reaches the soil surface, thereby increasing the probability that shrubland plants will be able to colonize.

Related interventions: Burn leaf litter (section 13.11)

A randomized, controlled study between 1991 and 2004 in a former pine plantation in Kent, United Kingdom (1) found that 12 years after removing leaf litter the frequency of heather *Calluna vulgaris* was the same as in areas where leaf litter was not removed. After 12 years there was no significant difference in the frequency of heather between areas where leaf litter was removed (heather present in 99% of plots) and areas where leaf litter was not removed (heather present in 69% of plots). Four blocks consisting of two 25 m^2 plots were located in the plantation. In one plot leaf litter was removed and in the other leaf litter was not removed. In each plot ten 0.25 m^2 quadrats were used to record the frequency of heather plants.

(1) Allison, M. & Ausden, M. (2006) Effects of removing the litter and humic layers on heathland establishment following plantation removal. *Biological Conservation*, 127, 177-182.

13.11 Burn leaf litter

We captured no evidence of the effect on shrublands of burning leaf litter.

Background
Burning leaf litter may help to increase the amount of light that reaches the soil surface, and this may help to increase the probability of colonization by shrubland plants.

Related interventions: Remove leaf litter (section 13.10).

13.12 Add sulphur to soil

- One randomized, replicated, controlled study in the UK[1] found that adding sulphur to the soil of a former agricultural field did not increase the number of heather seedlings in five of six cases.

Background
Adding sulphur to soil can make it more acid, which can in turn promote colonization by shrubland plants that depend on acid conditions.

A randomized, replicated, controlled study in 1993–1996 in a former agricultural field in Suffolk, UK (1) found that adding sulphur to soils increased the number of common heather *Calluna vulgaris* seedlings in one of six cases and reduced vegetation cover in four of six cases. In one of six cases, the number of common heather seedlings was higher in areas where sulphur was added to soils (4 seedlings/plot) than in plots where no sulphur had been added (0 seedlings/plot). In four of six cases vegetation cover in areas where sulphur was added to soils was lower (7–48% cover) than in areas where sulphur was not added to soils (92% cover). In fifteen 5 m x 5 m randomly located plots sulphur was added to topsoil while in three other plots no sulphur was added. All plots were rotavated prior to addition of sulphur. In July 1994–1996 vegetation cover was surveyed using 1 m^2 quadrats located in the centre of each plot.

(1) Owen, K.M. & Marrs, R.H. (2000) Creation of heathland on former arable land at Minsmere, Suffolk, UK: the effects of soil acidification on the establishment of Calluna and ruderal species. *Biological Conservation*, 93, 9-18.

13.13 Use erosion blankets/mats to aid plant establishment

- One replicated, randomized, controlled study in the USA[1] found that using an erosion control blanket increased the height of two shrub species.
- One replicated, randomized, controlled study in the USA[1] did not find an increase in the number of shrub species, but one controlled study in China[2] did find an increase in plant diversity following the use of erosion control blankets. The same study found an increase in plant biomass and cover.

Background

Erosion blankets/mats may help to reduce the amount of erosion at degraded shrubland sites. This reduction in erosion can help to aid the establishement of shrubland plants.

A replicated, randomized, controlled study in 2008–2009 in sagebrush scrub shrubland that had been burnt in wildfires in California, USA (1) found that using an erosion control blanket did not increase the number of shrubs, or forb cover and did not reduce the cover of non-native forbs and grasses, but did increase the height of California sagebrush *Artemisia californica* and common deerweed *Lotus scoparius*. After one year, both California sagebrush (47 cm) and common deerweed (57 cm) were taller in areas where erosion control blankets had been laid than in areas where they had not (California sagebrush: 33 cm; common deerweed: 48 cm). In January 2008 a straw-based erosion control blanket was laid in four 8 m x 20 m plots, while in four other plots no blanket was laid. In July 2009 vegetation was surveyed by placing three 20 m transects in each plot and vegetation recorded every 1 m.

A controlled study in 2010 in an arid shrubland in Xin-jiang, China (2) found that stabilizing sand using reed mats and then planting native shrubs increased plant cover, biomass and plant species diversity. Areas where sand had been stabilized had higher plant cover (28% cover) than areas that had not been stabilized (17% cover). The same pattern was true for biomass (stabilized: 121 g/m^2, unstabilized: 87 g/m^2) and plant species diversity (data presented as model results). Sand was stabilized by placing reed cuttings in a checkerboard pattern. Native shrubs were then planted where reed cuttings were placed. In 2010 ten 100 m^2 plots were used to sample areas that had been stabilized and eleven 100 m^2 were used to sample areas that had not.

(1) McCullough, S.A. & Endress, B.A. (2012) Do Postfire Mulching Treatments Affect Plant Community Recovery in California Coastal Sage Scrub Lands? *Environmental Management*, 49, 142-150.
(2) Liu, H., Tao, Y.E., Qiu, D., Zhang, D. & Zhang, Y. (2013) Effects of Artificial Sand Fixing on Community Characteristics of a Rare Desert Shrub. *Conservation Biology*, 27, 1011-1019.

13.14 Add mulch and fertilizer to soil

- One randomized, controlled study in the USA[1] found that adding mulch and fertilizer did not increase the seedling abundance of seven shrub species. The same study also reported no change in grass cover.

Background
Adding mulch may help to retain moisture in soil at shrublands in arid sites, as well as reducing the germination of problematic/invasive species. Adding fertilizer may help to stimulate the growth of any shrubland plants already present.

A randomized, controlled study in 1997–1999 in a sagebrush scrub shrubland that had been invaded by grass and burnt by wildfires in California, USA (1) found adding mulch, followed by addition of nitrogen fertilizer did not increase the seedling abundance of seven shrub species or reduce grass cover after one year. The areas where mulch and fertilizer were added did not differ in the number of shrub seedlings for seven of seven species (0 seedlings/m^2) from areas where mulch and fertilizer were not added (0 seedlings/m^2). There was also no significant difference in grass cover between areas where mulch and fertilizer had been added (83%) and areas where mulch and fertilizer were not added (84%). In 1997 mulch and fertilizer were added to five randomly located 5 m x 5 m plots, while in five other plots no mulch or fertilizer were added. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

(1) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.

13.15 Add manure to soil

- One replicated, randomized, controlled study in South Africa[1] found that adding manure increased plant cover and the number of plant species.

Background
Adding manure to shrubland soils may help to stimulate the growth of any shrubland species that are present or encourage germination of seeds present in the soil.

A replicated, randomized, controlled study between 2007 and 2011 in a karoo shrubland in Richtersveld, South Africa (1) found that adding manure to increase colonisation increased plant cover and the number of plant species. After three years, plant cover of areas where manure was added (7%) was higher than that in areas where manure was not added (4%). Similarly, the number of plant species in areas where manure was added (11 species) was higher than in areas where manure was not added (7 species). Five 1 ha blocks were divided using a fence to exclude cattle. In each block goat and sheep manure was spread in one 10 m x 10 m plot while another plot was left without manure addition. Vegetation in each 10 m x 10 m plot was assessed annually between 2008 and 2011.

(1) Hanke, W., Wesuls, D., Münchberger, W. & Schmiedel, U. (2015) Tradeoffs in the Rehabilitation of a Succulent Karoo Rangeland. *Land Degradation and Development*, 26, 833-842.

13.16 Irrigate degraded shrublands

- One replicated, randomized, controlled study at two sites in USA[1] found that temporary irrigation increased shrub cover.

Background
Irrigation may help to promote the growth of shrubland plants, particularly in arid shrublands.

A replicated, randomized, controlled study in 2008–2011 in two former pastures in Nevada, USA (1) found that temporary irrigation increased shrub cover. After three years, areas where temporary irrigation was used had higher shrub cover than areas where no irrigation had been carried out (not data reported). At each site fifteen 27 m x 9.3 m plots were irrigated for the first two years of the experiment (2008 and 2009) while fifteen other plots were not irrigated. Grasses and shrubs were planted in all plots before irrigation began. In 2009 and 2011 shrub cover was assessed in all plots.

(1) Porensky, L.M., Leger, E.A., Davison, J., Miller, W.W., Goergen, E.M., Espeland, E.K. & Carroll-Moore, E.M. (2014) Arid old-field restoration: Native perennial grasses suppress weeds and erosion, but also suppress native shrubs. *Agriculture, Ecosystems & Environment*, 184, 135-144.

Introduce vegetation or seeds

13.17 Plant individual plants

- One replicated, randomized, controlled study in the USA[1] found that planting California sagebrush plants did not increase the cover of native plant species compared to sowing of seeds or a combination of planting and sowing seeds. One replicated, randomized, controlled study in South Africa[3] found that planting *Brownanthus pseudoschlichtianus* plants increased plant cover, but not the number of plant species.
- One study in the USA[2] found that a majority of planted plants survived after one year.

Background
This section considers the introduction of shrubland plants by planting. If successful this planting can restore shrubland vegetation almost immediately.

Related interventions: Sow seeds (section 13.8); all interventions in chapter 14.

A replicated, randomized, controlled study in a degraded sagebrush scrubland habitat in California, USA (1) found that planting California sagebrush *Artemisia californica* plants did not increase cover of native plant species compared to sowing of seeds, or a combination of planting and sowing seeds. Native plant species cover in areas where California sagebrush was planted (2%) was not higher than in areas where seeds were sown (2–9%) or areas where plants were planted and seeds sown (7–14%). California sagebrush plants were planted in six randomly located 1 m^2 plots, while six plots were sown with seeds of shrubland plants, and another six plots were planted with plants and sown with seeds. Plant cover was recorded every year in May-July in the 1 m^2 plots. Year of the study is not provided.

A study in 2007–2008 in a desert site disturbed by road building in Arizona, USA (2) found that planting shrubs resulted in a high shrub survival rate. After one year, the survival rate of 10 shrub species was high (86%). Seeds were collected from species in the wild and sown in pots in April 2006. In January-February 2007 plants were planted at the site. Survival of all plants was recorded in January 2008.

A replicated, randomized, controlled study between 2007 and 2011 in a karoo shrubland in Richtersveld, South Africa (3) found that planting of *Brownanthus pseudoschlichtianus* plants increased plant cover but not the number of plant species. After three years, the plant cover of areas where *B. pseudoschlichtianus* plants were planted (8%) was higher than that in areas where there was no planting (4%). The number of plant species in areas where *B. pseudoschlichtianus* plants were planted (8 species) was not significantly different from areas where shrubland plants were not planted (7 species). Five 1 ha blocks were divided using a fence to exclude cattle. In each block *B. pseudoschlichtianus* one 10 m x 10 m plot while another plot was left without addition of plants. Vegetation in each 10 m x 10 m plot was assessed annually between 2008 and 2011.

(1) DeSimone, S.A. (2011) Balancing Active and Passive Restoration in a Nonchemical, Research-Based Approach to Coastal Sage Scrub Restoration in Southern California. *Ecological Restoration*, 29, 45-51.
(2) Abella, S.R., O'Brien, K.L. & Weesner, M.W. (2015) Revegetating Disturbance in National Parks: Reestablishing Native Plants in Saguaro National Park, Sonoran Desert. *Natural Areas Journal*, 35, 18-25.
(3) Hanke, W., Wesuls, D., Münchberger, W. & Schmiedel, U. (2015) Tradeoffs in the Rehabilitation of a Succulent Karoo Rangeland. *Land Degradation and Development*, 26, 833-842.

13.18 Sow seeds

- Five of six studies (including three replicated, randomized, controlled studies, one site comparison study and one controlled study) in the UK[4,11], South Africa[5], and the USA[7,12] found that sowing seeds of shrubland species increased shrub cover. One of six studies in the UK[3] found no increase in shrub cover. One replicated site comparison in the USA[6] found in sites where seed containing Wyoming big sagebrush was sown the abundance of the plant was higher than in sites where it was not sown. One replicated, randomized, controlled study in the USA[2] found that shrub seedling abundance increased after seeds were sown. One study in the USA[14] found very low germination of hackberry seeds when they were sown.One replicated, randomized, controlled study in the USA[10] found that the community composition of shrublands where seeds were sown was similar to that found in undisturbed shrublands. One randomized, controlled study in the UK[9] found an increase in the cover of heathland plants when seeds were sown.
- One replicated, randomized, controlled study in South Africa[1] found that sowing seeds increased plant cover. One replicated, randomized, controlled study in the USA[8] found that areas where seeds were sown did not differ significantly in native cover compared to areas where shrubland plants had been planted. One controlled study in the USA[13] found

higher plant diversity in areas where seeds were sown by hand than in areas where they were sown using a seed drill.

- Two of three studies (one of which was a replicated, randomized, controlled study) in the USA[7,12] found that sowing seeds of shrubland species resulted in an increase in grass cover. One randomized, controlled study in the UK[9] found no changes in the cover of grasses or forbs.

Background

This section considers the introduction of shrubland plants by the sowing of seeds. This intervention can aid colonisation of shrubland plants in sites that lack the seed of shrubland plants in their soils.

Related interventions: Plant individual plants (section 13.17); spread clippings (sectin 13.20); all interventions in chapter 14.

A replicated, randomized, controlled study in 1995–1998 in a former maritime pine *Pinus pinaster* plantation in the Cape Peninsula, South Africa (1) found that in five of nine cases sowing seeds of shrubland species increased plant cover. After three years and in five of nine cases, plant cover in areas where seeds of shrubland species were sown was higher (17–95% cover) than areas where seeds were not sown (4–79%). Seeds were sown in seventy-two 4 m x 4 m plots and in 33 plots no seeds were sown. After sowing seeds mulch was spread over plots to stop seeds from being blown away. In each plot four 1 m x 1 m quadrats were established and vegetation cover assessed five times in 1995–1998.

A randomized, controlled study in 1997–1999 in a sagebrush scrub shrubland that had been invaded by grass and burnt by wildfires in California, USA (2) found that sowing shrub seeds increased the seedling abundance of two of seven shrub species, but did not reduce grass cover. After one year, the areas where seeds had been sown had a significantly higher number of shrub seedlings for two of seven species (3–4 seedlings/m^2) than areas that were not seeded (0 seedlings/m^2). There was also no significant difference in grass cover between areas where seeds had been sown (82%) and areas that were not seeded (84%). In 1997 seeds were sown in five randomly located 5 m x 5 m plots, while in five other plots no seeds were sown. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

A replicated, randomized, controlled study in 1994–2003 in two agricultural fields in Suffolk, UK (3) found that sowing seeds of heathland species did not increase the cover of common heather *Calluna vulgaris*. After nine years, cover of common heather was not significantly different in areas where heathland seeds had been sown (0%) to that in areas where seeds had not been sown (0%). In 1994–1995 a mixture of common heather, grass, and herb seeds were sown in twelve 80 m^2 plots and in four other plots no seeds were sown. In April 2003 five 2500 cm^2 quadrats were placed in each plot and the cover of all plant species recorded.

A replicated, randomized, controlled study between 2002 and 2006 in two degraded moorlands in the UK (4) found that sowing heather *Calluna vulgaris* seeds increased the cover of heather. After three years, heather cover was higher in plots where heather seeds were sown (7%) than in plots where seeds were not sown (1%). At each site fifty-four 100 m^2 plots were established. On half of each plot heather seeds were sown by hand at a rate of 26000 seeds/m^2. Plant cover was estimated in nine 1 m^2 quadrats in each plot annually between 2003 and 2006.

A controlled study in 1998–2006 in a fynbos site previously invaded by non-native trees in Western Cape, South Africa (5) found that sowing seeds of fynbos species increased shrub cover, but did not alter the cover of non-native species, or native forbs. After eight years, cover of shrub species was higher in areas where seeds had been sown (20%) than where seeds had not been sown (2%). However, cover of native forbs and non-native species did not differ between areas that had been seeded and those that had not (no data provided). In 1997 all non-native trees were felled. Subsequently, a wildfire burned the area in 1998. In 1998 seeds of species typical of fynbos were sown in five 50 m^2 plots, while in five plots no seeds were sown. Four 1 m^2 quadrats were placed in each plot and vegetation cover assessed in 2006.

A replicated site comparison study in 1984–1999 in eleven sagebrush shrubland sites affected by wildfire in Nevada, USA (6) found that sowing seed containing Wyoming big sagebrush *Artemisia tridentata wyomingensis* increased the density of Wyoming big sagebrush plants. Areas where Wyoming big sagebrush seed was sown had a higher density of Wyoming big sagebrush than areas where their seed was not sown (results presented as model results). All study sites burned in wildfires in 1984-1997 and seed mixes containing Wyoming big sagebrush seed sown at an unspecified number of sites, while other sites were either not sown with seed or sown with mixes that did not contain Wyoming big sagebrush seed. Wyoming big sagebrush density was recorded at least once at all sites following the sowing of seed.

A site comparison study in 1994–2003 in sagebrush scrub habitat that had previously been burnt by wildfire in Utah, USA (7) found that sowing seeds increased shrub and perennial grass cover, but decreased cover of weeds. After nine years, shrub cover in areas where seeds had been sown was higher (10%) than in areas where seeds had not been sown (0%), but not significantly different to that found in undisturbed shrublands (13%). Perennial grass cover was also higher in areas where seeds had been sown (5%) than in unsown areas (0%) but was also higher than that found in undisturbed areas (1%). Cover of weeds was lower in areas where seeds had been sown (2.3%) than in unsown areas (55%), and it was also lower than in undisturbed areas (12%). In 1994 a wildfire burned part of the study area. Part of the burned area was subsequently seeded with a mixture of native and non-native shrubs and grasses, while another part was not seeded. A nearby unburned area was also used for comparison. In 2003 twenty 0.25 m^2 quadrats were randomly located in each area and vegetation cover estimated.

A replicated, randomized, controlled study in a degraded sagebrush scrubland habitat in California, USA (8) found that sowing seeds did not increase cover of native plant species compared to planting, or a combination of planting and sowing seeds. Native plant species cover in areas where seeds were sown (2–9%) was not higher than in areas where plants were planted (2%) or areas where plants were planted and seeds sown (7–14%). Six randomly located 1 m^2 plots were sown with seeds of shrubland plants, while six plots were planted with California sagebrush *Artemisia californica* plants, and another six plots were planted with plants and sown with seeds. Plant cover was recorded every year in May-July in the 1 m^2 plots.

A randomized, controlled study in 1988–2005 in former heathland in Dorset, UK (9) found that the addition of shoots and seeds from a nearby heathland increased the cover of heathland species, but did not reduce the cover of grasses or forbs. After 17 years, cover of heathland species was higher in plots where shoots and seeds were spread (44%) than in plots where they were not (16%). There was no significant difference in the cover of grasses or forbs in plots where shoots and seeds were spread (grasses: 36%, forbs: 54%) and plots where they were not (grasses: 59%, forbs: 27%). In 1989 shoots and seeds harvested from a nearby heathland were spread on three 500 m^2 plots and three plots were seeded. In 2005 the cover of plants was recorded in four 1 m^2 quadrats which were randomly placed in each plot.

A replicated, randomized, controlled study between 1984 and 2009 in a sagebrush steppe ecosystem in Colorado, USA (10) found that sowing seeds of late successional shrubland plants produced a plant community which was similar to undisturbed shrublands after 25 years. Sowing seeds of late succession shrubland plants resulted in a plant community that was similar to undisturbed shrublands (no data presented). However, sowing seeds of early succession shrubland plants resulted in a plant community that resembled plots that had been left unseeded (results presented as model results). In 1984 four blocks consisting of six 500 m^2 plots each were established. Within each block all vegetation and the top 5 cm of soil were removed. Plots were randomly assigned to be sown with late successional shrubland seeds, early successional shrubland seeds, or to be left unseeded. Adjacent to blocks a number of shrubland plots were left undisturbed.

A replicated, randomized, controlled study from 2002 to 2010 in a former heathland in mid-Wales, UK (11) found that in the majority of cases sowing heather *Calluna vulgaris* seeds increased heather cover. After eight years, sowing of heather seeds increased heather cover in eight of twelve cases (1–30% cover) when compared to areas where no sowing had been carried out (0–7% cover). Nine paddocks 5–7 hectares in size were selected. Paddocks were grazed with cattle, sheep, or left ungrazed. In each paddock six 10 m x 10 m plots were established. Plots were randomly selected to be disturbed using a rotavator, trampled by cattle, or left undisturbed. These plots were divided into four 5 m x 5 m plots with one plot bring grazed but not seeded, one plot being grazed and seeded, one plot not being grazed nor seeded and one plot being seeded but not grazed.

A replicated, randomized, controlled study from 2009 to 2012 in a sagebrush ecosystem that had previously been burnt in Oregon, USA (12) found that sowing grass and sagebrush *Artemisia tridentata* seeds led to increased grass and sagebrush cover. After three years, sagebrush cover was higher where grass and sagebrush seeds were sown (6%) than where grass seeds or no seeds were sown (both 0%). Grass cover was higher in blocks where grass seeds (8%) or grass and sagebrush seeds were sown (6%), compared to blocks where no seeds were sown (4%). Fifteen 15 m x 30 m plots were randomly assigned to be sown with perennial herbaceous plant seeds, sagebrush and perennial herbaceous plant seeds, or no seeds. Vegetation cover was measured annually between 2010 and 2012 using sixty 0.2 m^2 quadrats.

A controlled study in 2010–2011 in sagebrush scrub invaded by non-native grasses in California, USA (13) found that sowing seeds by hand resulted in a higher density of shrub seedlings and plant species indicative of disturbance than using a seed drill. In two of two trials the densities of shrub seedlings were higher where seeds had been sown by hand (11–17 seedlings/quadrat) than where they were sown using a seed drill (3–5 seedlings/quadrat). In one of two trials the densities of seedlings of plant species indicative of disturbance were higher where seeds had been sown by hand (6 seedlings/quadrat) than where they had been sown using a seed drill (3 seedlings/quadrat). In December 2010 nine 18.5 m^2 plots were sown with native seeds by hand, and in another nine plots seeds were sown using a seed drill. Seedling density was measured in June 2011 in 25 cm x 25 cm quadrats placed in each plot.

A study in 2014–2015 in a shrubland in Utah, USA (14) found that sowing seeds of the shrub hackberry *Celtis reticulata* led to very low germination rates. After eight months, 41 of 2600 (1.6%) hackberry seeds had successfully germinated. However, after 12 months only 19 of the 41 seedlings had survived. In October 2014 seeds were collected from hackberry plants. Later in October 2014 2600 of the seeds were sown under boulders, with 100 placed under each boulder. The site was visited to check for signs of germination in May-November 2015.

(1) Holmes, P.M. (2001) Shrubland Restoration Following Woody Alien Invasion and Mining: Effects of Topsoil Depth, Seed Source, and Fertilizer Addition. *Restoration Ecology*, 9, 71-84.

(2) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.

(3) Walker, K.J., Warman, E.A., Bhogal, A., Cross, R.B., Pywell, R.F., Meek, B.R., Chambers, B.J. & Pakeman, R. (2007) Recreation of lowland heathland on ex-arable land: assessing the limiting processes on two sites with contrasting soil fertility and pH. *Journal of Applied Ecology*, 44, 573-582.

(4) Mitchell, R.J., Rose, R.J. & Palmer, S.C.F. (2008) Restoration of Calluna vulgaris on grass-dominated moorlands: The importance of disturbance, grazing and seeding. *Biological Conservation*, 141, 2100-2111.

(5) Pretorius, M.R., Esler, K.J., Holmes, P.M. & Prins, N. (2008) The effectiveness of active restoration following alien clearance in fynbos riparian zones and resilience of treatments to fire. *South African Journal of Botany*, 74, 517-525.

(6) Eiswerth, M.E., Krauter, K., Swanson, S.R. & Zielinski, M. (2009) Post-fire seeding on Wyoming big sagebrush ecological sites: Regression analyses of seeded nonnative and native species densities. *Journal of Environmental Management*, 90, 1320-1325.

(7) Gardner, E.T., Anderson, V.J. & Johnson, R.L. (2009) Arthropod and Plant Communities as Indicators of Land Rehabilitation Effectiveness in a Semiarid Shrubsteppe. *Western North American Naturalist*, 69, 521-536.

(8) DeSimone, S.A. (2011) Balancing Active and Passive Restoration in a Nonchemical, Research-Based Approach to Coastal Sage Scrub Restoration in Southern California. *Ecological Restoration*, 29, 45-51.

(9) Pywell, R.F., Meek, W.R., Webb, N.R., Putwain, P.D. & Bullock, J.M. (2011) Long-term heathland restoration on former grassland: The results of a 17-year experiment. *Biological Conservation*, 144, 1602-1609.

(10) Hoelzle, T.B., Jonas, J.L. & Paschke, M.W. (2012) Twenty-five years of sagebrush steppe plant community development following seed addition. *Journal of Applied Ecology*, 49, 911-918.

(11) Critchley, C.N.R., Mitchell, R.J., Rose, R.J., Griffiths, J.B., Jackson, E., Scott, H. & Davies, O.D. (2013) Re-establishment of Calluna vulgaris (L.) Hull in an eight-year grazing experiment on upland acid grassland. *Journal for Nature Conservation*, 21, 22-30.

(12) Davies, K.W., Bates, J.D., Madsen, M.D. & Nafus, A.M. (2014) Restoration of mountain big sagebrush steppe following prescribed burning to control Western Juniper. *Environmental Management*, 53, 1015-1022.

(13) Kimball, S., Lulow, M.E., Mooney, K.A. & Sorenson, Q.M. (2014) Establishment and Management of Native Functional Groups in Restoration. *Restoration Ecology*, 22, 81-88.

(14) Stevens, M.T., Holland, D.L. & Tanner, N.V. (2016) Netleaf hackberry seeds planted near boulders in the foothills of the Wasatch Mountains: germination, survival, and patterns of establishment. *Western North American Naturalist*, 76, 452-458.

13.19 Sow seeds and plant individual plants

- One replicated, controlled study in the USA[1] found that planting California sagebrush and sowing of seeds did not increase cover of native plant species compared to sowing of seeds, or planting alone.

Background
Combining the sowing of seeds and planting of shrubland plants may help to rapidly restore shrubland vegetation as well as increasing colonization by the seedlings of shrubland plants.

Related interventions: Plant individual plants (section 13.17); sow seeds (section 13.18); spread clippings (section 13.20); all intervention in chapter 14.

A replicated, randomized, controlled study in a degraded sagebrush scrubland habitat in California, USA (1) found that planting California sagebrush *Artemisia californica* plants followed by sowing of seeds did not increase cover of native plant species compared to only sowing of seeds, or only planting. Native plant species cover in areas where California sagebrush was planted and seeds were sown (7–14%) was not higher than areas where either seeds were sown (2–9%) or California sagebrush plants were planted (2%). California sagebrush plants were planted in six randomly located 1 m^2 plots which were then sown with seeds, while six plots were only sown with seeds of shrubland plants, and another six plots were only planted with California sagebrush plants. Plant cover was recorded 1 m^2 plots, every year between May and July. Year of the study is not provided.

(1) DeSimone, S.A. (2011) Balancing Active and Passive Restoration in a Nonchemical, Research-Based Approach to Coastal Sage Scrub Restoration in Southern California. *Ecological Restoration*, 29, 45-51.

13.20 Spread clippings

- One randomized, controlled study in the UK[1] found that the addition of shoots and seeds of heathland plants did not increase the abundance of mature plants for half of plant species. One randomized, controlled study in the UK[3] found that the frequency of heather plants was not significantly different in areas where heather clippings had been spread and areas where they were not spread.
- One replicated, randomized, controlled study in the UK[2] found an increase in the number of heather seedlings, but not of other heathland species. One randomized, controlled study in the UK[1] found that the addition of shoots and seeds increased the number of seedlings for a minority of species.
- One replicated, randomized, controlled study in South Africa[1] found that plant cover and the number of plant species did not differ significantly between areas where branches had been spread and those where branches had not been spread.

Background
Spreading clippings may help to increase the colonization of shrubland plants as a result of introducing seed. Plant clippings may also help to increase organic material in the soil.

Related interventions: Sow seeds (section 13.18).

A randomized, controlled study in 1988–1993 in Dorset, UK (1) found that the addition of shoots and seeds of heathland plants increased the number of seedlings for two of seven species, increased the abundance of mature plants for one of six species, but did not increase abundance of mature plants for three of six species. For two of seven heathland species the number of seedlings in plots where the shoots and seeds of heathland species were spread (14–30 seedlings/m^2) was higher than in plots where the shoots and seeds of heathland species were not spread (0 seedlings/m^2). The abundance of one of six heathland plant species was higher where shoots and seeds of heathland species had been spread (8.5 shoots/m^2) compared to plots where shoots and seeds were not spread (0.2 shoots/m^2). However, there was no significant difference in the abundance of four of six heathland plant species where heathland shoots and seeds had been spread (0–3.9 shoots/m^2) when compared to areas where they were not spread (0–3.9 shoots/m^2). In December 1988 shoots of heathland species were harvested from a mature heathland. In three 500 m^2 plots soil was disturbed using a rotary cultivator and shoots spread at a rate of 3 kg/m^2, three other plots were disturbed but had no shoots spread. In 1990–1991 the number of seedlings was recorded in seven 0.5 m x 1 m quadrats in each plot. In 1993 the number of plant shoots was recorded in three 1 m^2 quadrats which were randomly placed in each plot.

A replicated, randomized, controlled study in 1989–1991 in one abandoned mineral quarry and one abandoned farmland site in Dorset, UK (2) found that spreading clippings from intact heathlands increased the density of heather *Calluna vulgaris* and *Erica* spp. seedlings, but did not increase the density of other heathland species. After two years, there were more heather seedlings in plots where clippings were spread (38–224 seedlings/m^2) than in plots where no clippings were spread (0–2 seedlings/m^2). The density of other heathland species (*Ulex minor*, *Molinia caerulea*, and *Agrostis curtisii*) did not differ significantly between plots were clippings were spread (31 seedlings/m^2) and plots where no clippings were spread (1 seedling/m^2). In 1990 at the quarry site nine 30 m^2 plots were rotovated and clippings spread on the soil surface, while four plots were left unrotovated and no clippings were spread. At the abandoned farmland site in 1990 three 500 m^2 plots were rotovated and clippings spread, while three plots were left unrotovated and no clippings spread. In 1991 the density of plants was recorded in twenty 0.3 m^2 quadrats/plot at the quarry site and in seven 0.25 m^2 quadrats/plot in the farmland site.

A randomized, controlled study between 1991 and 2004 in a former pine plantation in Kent, UK (3) found that 12 years after spreading heather *Calluna vulgaris* clippings the frequency of heather plants was the same as in areas where clippings were not spread. After 12 years there was no significant difference in the frequency of heather between areas where heather clippings were added (heather present in 95% of plots) and areas where clippings were not added (heather present in 99% of plots). Four blocks consisting of two 25 m^2 plots were established. In one plot leaf litter was removed and in the other leaf litter was removed and heather clippings added. In each plot ten 0.25 m^2 quadrats were placed and used to record frequency of heather plants.

A replicated, randomized, controlled study between 2007 and 2011 in a karoo shrubland in Richtersveld, South Africa (4) found that spreading branches of the shrub *Brownanthus pseudoschlichtianus* on overgrazed plots did not increase plant cover or the number of plant species. After three years, plant cover of areas where shrub branches were spread (3%) did not differ significantly from areas where branches were not spread (4%). Similarly, the number of plant species in areas where shrub branches were spread (6 species) did not differ significantly from areas where branches were not spread (7 species). Five 1 ha blocks were divided using a fence to exclude cattle. In each block branches from *B. pseudoschlichtianus* were spread in one 10 m x 10 m plot while another plot was left with no branches spread. Vegetation in each 10 m x 10 m plot was assessed annually between 2008 and 2011.

(1) Pywell, R.F., Webb, N.R. & Putwain, P.D. (1995) A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32, 400-411.
(2) Pywell, R.F., Webb, N.R. & Putwain, P.D. (1996) Harvested heather shoots as a resource for heathland restoration. *Biological Conservation*, 75, 247-254.
(3) Allison, M. & Ausden, M. (2006) Effects of removing the litter and humic layers on heathland establishment following plantation removal. *Biological Conservation*, 127, 177-182.
(4) Hanke, W., Wesuls, D., Münchberger, W. & Schmiedel, U. (2015) Tradeoffs in the Rehabilitation of a Succulent Karoo Rangeland. *Land Degradation and Development*, 26, 833-842.

13.21 Build bird perches to encourage colonisation by plants

- One replicated, controlled study in South Africa[1] found that building artificial bird perches increased the number of seeds at two sites, but no shrubs became established at either of these sites.

Background
Building bird perches in degraded shrublands may help to encourage birds to perch on them. As a result the number of droppings deposited by birds at the site may increase, increasing the probability that the site will be colonized by plants.

A replicated, controlled study in two renosterveld shrubland sites in Western Cape province, South Africa (1) found that building artificial bird perches increased the number of seeds, but no shrubs became established at any of two sites. Two areas where artificial bird perches were built received more seeds (18–202 seeds/seed trap) than areas without artificial bird perches (0 seeds/seed trap). However, no shrubs became established at any of the sites with bird perches or those without bird perches. At both sites artificial bird perches made of dead branches of *Eucalyptus* sp. were erected in 10 abandoned agricultural areas, whereas in another 10 areas no perches were erected. Netted seed traps were placed below each perch or in the areas without perches.

(1) Heelemann, S., Krug, C.B., Esler, K.J., Reisch, C. & Poschlod, P. (2012) Pioneers and Perches—Promising Restoration Methods for Degraded Renosterveld Habitats? *Restoration Ecology*, 20, 18-23.

13.22 Plant turf

- Two randomized, controlled studies in the UK[1,2], found that planting turf from intact heathland sites increased the abundance or cover of heathland species. One of these studies[1] also found that planting turf increased the seedling abundance for a majority of heathland plant species.
- One randomized, controlled study in the UK[2] found that planting turf increased forb cover, and reduced grass cover.

- One randomized, replicated, controlled study in Iceland[3] found that planting large turves from intact heathland sites increased the number of plant species, but smaller turves did not.

Background

Cutting turf from an intact shrubland and planting it at a degraded site effectively transplants part of one shrubland to another one. This intervention may almost instantly restore shrubland habitat in some areas of a site, and over time may allow for the colonization of a site by shrubland plants.

Related interventions: Plant individual plants (section 13.17).

A randomized, controlled study in 1988–1993 in a former heathland in Dorset, UK (1) found that planting turf from intact heathland sites increased the number of seedlings for four of seven heathland species after one year, and increased the abundance of five of six heathland species after three years. For four of seven heathland species the number of seedlings in plots where turves were planted was (8–538 seedlings/m^2) was higher than in plots turves were not planted (0 seedlings/m^2). The abundance of five of six heathland plant species was higher in plots where turves were planted (3–90 shoots/m^2) compared to plots no turves were planted (0–4 shoots/m^2). In 1989 turves measuring 1.2 m x 2.3 m x 0.15 m were excavated from a nearby mature heathland site and transported to the restoration site. In three 500 m^2 plots soil was stripped to a depth of 15 cm and turves planted and in three plots no turves were planted. In 1990–1991 the number of seedlings was recorded in seven 0.5 m x 1 m quadrats which were placed in each plot. In 1993 the number of plant shoots was recorded in three 1 m^2 quadrats which were randomly placed in each plot.

A randomized, controlled study in 1988–2005 in a former heathland in Dorset, UK (2) found that planting turf from intact heathland sites increased the cover of heathland species and forbs, and reduced grass cover. After 17 years, cover of heathland species and forbs was higher in plots where turf was planted (heathland: 100%; forbs: 92%) than in plots where it was not (heathland: 16%; forbs: 27%). Grass cover was lower in plots where turf was added (10%) than in plots where it was not (59%). In 1989 turves were excavated from a nearby mature heathland site. Topsoil of three 500 m^2 plots was removed and turves planted, while in three plots no turves were planted. In 2005 the cover of plants was recorded in four 1 m^2 quadrats which were randomly placed in each plot.

A randomized, replicated, controlled study from 2007 to 2009 at two sites in southern Iceland (3) found that transplanting turf from heathland sites to unvegetated sites had a mixed effect on number of plant species, and the cover of shrubs and grass. After two years, when transplanted turf sizes were larger than 20 cm x 20 cm, the number of plant species was higher in areas with transplanted turf (7 species/plot) than in untreated areas (2 species/plot), but not when turf sizes were smaller (3 species/plot). The cover of shrubs increased when turf was larger than 30 cm x 30 cm (to 1% cover) relative to untreated controls (0%), but not when turf sizes were smaller (0%). Grass cover increased when turf was larger than 30 cm x 30 cm (to 2%) compared to untreated controls (0–1%), but not when turf were smaller than 20 cm x 20 cm. Two unvegetated sites were established in 2007. At one site all vegetation had been removed, while the other site was a roadside verge covered with gravel. At each site turf from a nearby dwarf shrub heathland was planted in 40 randomly located 2 m^2 plots using different sizes of turf (8 plots for each turf size), with eight further plots left untreated. Vegetation cover of all plant species was recorded yearly between June and August in each 2 m^2 plot.

(1) Pywell, R.F., Webb, N.R. & Putwain, P.D. (1995) A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32, 400-411.
(2) Pywell, R.F., Meek, W.R., Webb, N.R., Putwain, P.D. & Bullock, J.M. (2011) Long-term heathland restoration on former grassland: The results of a 17-year experiment. *Biological Conservation*, 144, 1602-1609.
(3) Aradottir, A.L. (2012) Turf transplants for restoration of alpine vegetation: does size matter? *Journal of Applied Ecology*, 49, 439-446.

14. Actions to benefit introduced vegetation

Background

This chapter focuses on interventions that may help to increase the survival or growth of introduced plants. Use of these methods may help to improve the success of shrubland restoration.

Although the inventions in this section target plants that have been introduced during habitat restoration, these interventions may affect plants other than those that have been introduced. However, it is likely that the main beneficiaries of the interventions included in this section are introduced plants.

Related threats: interventions in this chapter apply to the majority of threats in Chapters 2-11.

Key messages

14.1 Add fertilizer to soil (alongside planting/seeding)

- A replicated, controlled study in Iceland found that adding fertilizer and sowing seeds increased cover of shrubs and trees in a majority of cases. The same study showed an increase in vegetation cover in two of three cases.
- One controlled study in the USA found that adding fertilizer increased the biomass of four-wing saltbush in a majority of cases.

14.2 Add peat to soil (alongside planting/seeding)

- A replicated, randomized, controlled study in the UK found that adding peat to soil and sowing seed increased the cover of common heather in the majority of cases, compared to seeding alone. One replicate, randomized, controlled study in the UK found that adding peat to soil and sowing seed increased the density of heather seedlings, and led to larger heather plants than seeding alone, but that no seedlings survived after two years.

14.3 Add mulch to soil (alongside planting/seeding)

- A replicated, randomized, controlled study in the USA found that using mulch did not increase the number of shrubs, or the height of California sagebrush. A randomized, controlled study in South Africa found that applying mulch and sowing seeds increased the number of seedlings, but not their survival.

14.4 Add mulch and fertilizer to soil (alongside planting/seeding)

- A randomized, controlled study in the USA found that adding mulch and fertilizer, followed by sowing of seeds increased the abundance of seedlings for a minority of shrub species. The same study found that adding mulch and fertilizer, followed by sowing seeds had no significant effect on grass cover.

14.5 Add gypsum to soil (alongside planting/seeding)

- One randomized, controlled study in South Africa found that adding gypsum to soils and sowing seeds increased survival of seedlings for one of two species.

14.6 Add sulphur to soil (alongside planting/seeding)

- A randomized, replicated, controlled study in the UK found that adding sulphur to soil alongside sowing seeds did not increase heather cover in a majority of cases. One replicated, controlled study in the UK found that adding sulphur and spreading heathland clippings had mixed effects on cover of common heather, perennial rye-grass, and common bent. One randomized, controlled study in the UK found that adding sulphur to soil alongside planting of heather seedlings increased their survival, though after two years survival was very low.

14.7 Strip/disturb topsoil (alongside planting/seeding)

- Two replicated, controlled studies in the UK found that removal of topsoil and addition seed/clippings increased cover of heathland plants or cover of heather and gorse. One controlled study in the UK found that soil disturbance using a rotovator and spreading clippings of heathland plants (alongside mowing) increased the number of heathland plants.
- One replicated, controlled study in the UK found that stripping the surface layers of soil and adding seed reduced the cover of perennial rye-grass. One randomized, replicated, paired, controlled study in the UK found that removal of topsoil and addition of the clippings of heathland plants did not alter the cover of annual grasses but led to a decrease in cover of perennial grasses.

14.8 Add topsoil (alongside planting/seeding)

- One randomized, replicated, paired, controlled study in the USA found that addition of topsoil alongside sowing of seed increased the biomass of grasses but reduced the biomass of forbs in comparison to addition of topsoil alone.

14.9 Plant seed balls

- A randomized, replicated, controlled study in the USA found that planting seeds balls resulted in lower seedling numbers than sowing seeds.

14.10 Plant/sow seeds of nurse plants alongside focal plants

- A randomized, replicated, controlled study in the UK found that sowing seeds of nurse plants and heathland plants did not increase the cover of common heather. One replicated, randomized, controlled study in the USA found a reduction in the survival of California sagebrush shrubs in more than half of cases. The same study also found that California sagebrush biomass was reduced when its seeds were sown with those of nurse plants.

14.11 Plant/seed under established vegetation

- A randomized, replicated, controlled study in the USA found that sowing seeds under established shrubs had mixed effects on blackbrush seedling emergence.

14.12 Plant shrubs in clusters

- A randomized, controlled study in South Africa found that when shrubs were planted in clumps more of them died than when they were planted alone.

14.13 Add root associated bacteria/fungi to introduced plants

- Two controlled studies in Spain (one of which was randomized) found that adding rhizobacteria to soil increased the biomass of shrubs. One of these studies also found an increase in shrub height.

Interventions

14.1 Add fertilizer to soil (alongside planting/seeding)

- A replicated, controlled study in Iceland[2] found that adding fertilizer and sowing seeds increased cover of shrubs and trees in a majority of cases. The same study showed an increase in vegetation cover in two of three cases.

- One controlled study in the USA[1] found that adding fertilizer increased the biomass of four-wing saltbush in a majority of cases.

Background
Adding fertilizer to the soil of restoration sites alongside planting/seeding may help to encourage germination and growth of introduced shrubland plants.

Related interventions: Add mulch and fertilizer to soil (section 13.14); add manure (section 13.15); plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19); add mulch and fertilizer to soil (alongside planting/seeding) (section 14.4).

A controlled study in 1972 in a greenhouse in New Mexico, USA (1) found that adding fertilizer increased the biomass of four-wing saltbush *Atriplex canescens* in two of three cases. In two of three cases when fertilizer was added the biomass of four-wing saltbush was higher (149–175 mg) than when fertilizer was not added (73–86 mg). Soil was collected from nearby shrublands and local gardens. Soil from shrublands was used to fill 24 pots and soil from gardens was used in 12 pots. Fertilizer was added to half of the pots while the other half were left unfertilized. One hundred four-wing saltbush seeds/plot were added and these were later thinned so that there were nine plants/pot. After 97 days plants were harvested, dried, and biomass calculated.

A replicated, controlled study in 1954–1999 in three unvegetated areas in Iceland (2) found that sowing of seeds followed by fertilization increased vegetation cover in two of three cases, increased cover of shrubs and trees in two of three cases, and did not increase the number of plant species. Plant cover was higher in two of three sites where seeds had been sown and fertilizer applied (7–100% cover) than in sites where no seeds were sown or fertilizer applied (1–5% cover). Shrub cover was higher in two of three sites where seeds had been sown and fertilizer applied (0–8% cover) than in sites where no seeds were sown or fertilizer applied (0–1% cover). The number of plant species was significantly lower in one of three sites where seeds had been sown and fertilizer applied (4–8 species) compared to sites where no seeds were sown or fertilizer applied (3–9 species). At one site seeds were sown from airplanes, followed by application of fertilizer between 1954 and 1979 while at the other site this occurred between 1960 and 1975. In 1999 five 100 m^2 plots were placed at each site and at nearby areas where no seed was sown and no fertilizer was applied. Ten 0.25 m^2 quadrats were placed randomly in each plot and vegetation cover assessed.

(1) Williams, S.E. & Oconnor, G.A. (1973) Chemical Fertilization of Fourwing Saltbush. *Journal of Range Management*, 26, 379-380.
(2) Gretarsdottir, J., Aradottir, A.L., Vandvik, V., Heegaard, E. & Birks H. J, B. (2004) Long-term effects of reclamation treatments on plant succession in Iceland. *Restoration Ecology*, 12, 268-278.

14.2 Add peat to soil (alongside planting/seeding)

- A replicated, randomized, controlled study in the UK[2] found that adding peat to soil and sowing seed increased the cover of common heather in the majority of cases, compared to seeding alone. One replicated, randomized, controlled study in the UK[1] found that adding peat to soil and sowing seed increased the density of heather seedlings, and led to larger heather plants than seeding alone, but that no seedlings survived after two years.

Background
Adding peat to soil may increase its acidity. If combination with the addition of seed or plants that favour acid conditions this may help to promote the growth of shrubland plants.

Related interventions: Add peat to soil (section 13.9); plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19)

A replicated, randomized, controlled study in 1991–1993 in former agricultural fields in Norfolk, UK (1) found that addition of peat to agricultural soils alongside sowing of seed increased the density of heather *Calluna vulgaris* seedlings in seven of eight trials, and led to larger heather plants, but no heather seedlings survived after two years. After one year, in seven of eight trials, the density of heather seedlings was higher in areas where peat had been added to agricultural soils and heather seed sown (30–66 seedlings/plot) than in areas where heather seed was sown but no peat had been added (5–16 seedlings/plot). However, after two years no seedlings survived in any plots. After one year heather plants were larger in six of eight trials in areas where peat had been added to soils along with seed (5–58 whorls/plant) than in areas where seed had been sown but no peat had been added to soils (1–15 whorls/plant). Thirty-six water tanks were inserted into the ground in September 1991, twenty-four of which contained a mixture of peat and agricultural soil and 12 of which contained only agricultural soil. All tanks were sown with heather shoots that had been harvested in autumn. 10 cm x 10 cm quadrats were placed in each tank and used to monitor the abundance of heather seedlings between June and September 1992.

A replicated, randomized, controlled study in 1992–1997 in an agricultural field that was previously heathland in Suffolk, UK (2) found that in two of three cases adding peat to soil, followed by sowing of seed of shrubland plants increased cover of common heather *Calluna vulgaris* compared to seeding alone. In two of three cases common heather cover was higher in areas where peat was added to soil and seed sown (40–49%) than areas where only seed was sown (8%). In 1992 peat was added to 18 randomly located 4 m x 8 m plots and seeds were sown, while only seeds were sown in 6 other plots. Thirty-two 1 m^2 quadrats placed in each plot which were used to record the cover of common heather in August 1994 and September 1997.

(1) Davy, A.J., Dunsford, S.J. & Free, A.J. (1998) Acidifying peat as an aid to the reconstruction of lowland heath on arable soil: lysimeter experiments. *Journal of Applied Ecology*, 35, 649-659.
(2) Dunsford, S.J., Free, A.J. & Davy, A.J. (1998) Acidifying peat as an aid to the reconstruction of lowland heath on arable soil: a field experiment. *Journal of Applied Ecology*, 35, 660-672.

14.3 Add mulch to soil (alongside planting/seeding)

- A replicated, randomized, controlled study in the USA[2] found that using mulch did not increase the number of shrubs, or the height of California sagebrush. A randomized, controlled study in South Africa[1] found that applying mulch and sowing seeds increased the number of seedlings, but not their survival.

Background
Adding mulch to soil alongside planting and seeding may help to increase survival of shrubland plants by increasing the amount of moisture in the soil.

Related interventions: Add mulch and fertilizer to soil (section 13.14); plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19); add mulch and fertilizer to soil (alongside planting/seeding) (section 14.4).

A randomised, controlled study in 1994–1998 in a succulent karoo shrubland in Western Cape, South Africa (1) found that applying mulch, followed by sowing seeds of shrubland species increased the number of seedlings of these species, but did not increase seedling survival. Applying mulch followed by seeding with the seeds of the species Karoo bietou *Tripteris sinuata*, Spiny ruschia *Ruschia spinosa* and Gha grass *Chaetobromus dregeanus* increased the number of seedlings of these species compared with unmulched, unseeded plots (data not provided). However, applying mulch followed by seeding did not increase the survival of seedlings relative to unmulched, unseeded plots (data not provided). In 1994 eight 12.5 m^2 plots were established. In four plots mulch was applied, followed by sowing with the seeds of shrubland species. In the other four plots no mulch was applied, and no seeds were sown. Seedlings in each plots were counted annually between 1994 and 1998.

A replicated, randomized, controlled study in 2008–2009 in sagebrush scrub shrubland that had been burnt in wildfires in California, USA (2) found that using a hydromulch did not increase the number of shrubs, forb cover, or the height of California sagebrush *Artemisia californica* and common deerweed *Lotus scoparius* and did not reduce the cover of non-native forbs and grasses. After one year, California sagebrush (32-37 cm) and common deerweed (50-51 cm) were not significantly taller in areas where hydromulch had been used than areas where it had not (California sagebrush: 33 cm; common deerweed: 48 cm). In January 2008 in eight 8 m x 20 m plots hydromulch was applied, while in four other plots no hydromulch was applied. In July 2009 vegetation was surveyed by placing three 20 m transects in each plot and recording vegetation every 1 m.

(1) Beukes, P.C. & Cowling, R.M. (2003) Evaluation of restoration techniques for the Succulent Karoo, South Africa. *Restoration Ecology*, 11, 308-316.
(2) McCullough, S.A. & Endress, B.A. (2012) Do Postfire Mulching Treatments Affect Plant Community Recovery in California Coastal Sage Scrub Lands? *Environmental Management*, 49, 142-150.

14.4 Add mulch and fertilizer to soil (alongside planting/seeding)

- A randomized, controlled study in the USA[1] found that adding mulch and fertilizer, followed by sowing of seeds increased the abundance of seedlings for a minority of shrub species. The same study found that adding mulch and fertilizer, followed by sowing seeds had no significant effect on grass cover.

Background
Adding mulch to soil may help to increase the amount of moisture it contains, while adding fertilizer may help to promote the growth and survival of introduced plants.

Related interventions: Add mulch and fertilizer to soil (section 13.14); add manure (section 13.15); plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19); add mulch to soil (alongside planting/seeding) (section 14.3).

A randomized, controlled study in 1997–1999 in a sagebrush scrub shrubland that had been invaded by grass and burnt by wildfires in California, USA (1) found that adding mulch, followed by addition of nitrogen fertilizer, and seeding with shrub seeds increased the seedling abundance of two of seven shrub species but did not reduce grass cover after one year. Areas where mulch, fertilizer and shrub seeds were added had more shrub seedlings for two of seven species (1–2 seedlings/m^2) than areas where mulch, fertilizer and seed were not added (0 seedlings/m^2). There was no difference in grass cover between areas where mulch, fertilizer and seed had been added (84%) and areas where mulch, fertilizer and seed were not added (84%). In 1997 mulch and fertilizer were added to five randomly located 5 m x 5 m plots which were subsequently sown with seeds from native shrubs, while in five other plots no mulch or fertilizer were added. In spring 1997 plots were surveyed for grasses using two 0.25 m x 0.5 m quadrats/plot and two 0.5 m x 1 m quadrats/plot for shrubs.

(1) Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.

14.5 Add gypsum to soil (alongside planting/seeding)

- One randomized, controlled study in South Africa[1] found that adding gypsum to soils and sowing seeds increased survival of seedlings for one of two species.

Background
Addition of gypsum to soil can help to increase water infiltration into soils. Combining this with the addition of plants or seeds may help to increase the survival and growth of introduced plants.

Related interventions: Plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19)

A randomised, controlled study in 1994–1998 in a succulent karoo shrubland in Western Cape, South Africa (1) found that applying gypsum, followed by sowing the seeds of shrubland species increased the number of seedlings of these species, and increased seedling survival of one of two species. Applying gypsum followed by sowing the seeds of the species Karoo bietou *Tripteris sinuata*, Spiny ruschia *Ruschia spinosa* and Gha grass *Chaetobromus dregeanus* increased the number of seedlings of these species compared plots where unmulched, unseeded plots (data not provided). Applying gypsum followed by seeding increased the survival of seedlings of Karoo bietou relative to areas that where gypsum had not been applied and that were not seeded (data not provided), but there was no difference in the survival of Gha grass. In 1994 eight 12.5 m^2 plots were established. In four plots gypsum ($CaSO_4$) was applied at a rate of 5 tonnes/ha, followed by sowing of the seeds of shrubland species. In the other four plots no mulch was applied, and no seeds were sown. Seedlings in each plots were counted annually between 1994 and 1998.

(1) Beukes, P.C. & Cowling, R.M. (2003) Evaluation of restoration techniques for the Succulent Karoo, South Africa. *Restoration Ecology*, 11, 308-316.

14.6 Add sulphur to soil (alongside planting/seeding)

- A randomized, replicated, controlled study in the UK[3] found that adding sulphur to soil alongside sowing seeds did not increase heather cover in a majority of cases. One replicated, controlled study in the UK[2] found that adding sulphur and spreading heathland clippings had mixed effects on cover of common heather, perennial rye-grass, and common bent. One randomized, controlled study in the UK[1] found that adding sulphur to soil alongside planting of heather seedlings increased their survival, though after two years survival was very low.

Background

Adding sulphur to soils can increase their acidity and when done alongside planting or sowing of seed may help to increase the survival and growth of plants that favour acid conditions.

Related interventions: Plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19)

A randomized, controlled study in 1994–1996 in an arable field near Aberdeen, UK (1) found that the addition of sulphur to arable soil increased the survival of heather *Calluna vulgaris* seedlings after six months, but after two years almost all seedlings had died. In plots where sulphur was added survival of heather seedlings (26% survival) was higher than in plots where no sulphur was added (12% survival). After two years survival in plots where sulphur had been added (2% survival) was higher than in plots where no sulphur was added (0% survival). Sulphur was applied in eight 2.6 m x 2.6 m plots, while in eight other plots sulphur was not applied. All plots were sprayed with glyphosate to kill weeds in May 1995. One hundred seedlings were planted in each plot and survival was recorded after six, 12 and 22 months.

A replicated, controlled study in 2000–2006 in ten improved grasslands in Dorset, UK (2) found that application of sulphur, followed by spreading of heather *Calluna vulgaris* clippings increased cover of heather in one of two cases and decreased the cover of perennial rye-grass *Lolium perenne* in one of two cases, but increased the cover of common bent *Agrostis capillaris* in one of two cases. In one of two cases, after five years, areas where sulphur had been applied and heather clippings spread had a higher cover of heather (heather: 24%) than areas where sulphur was not applied and heather clippings were not spread (heather: 0%). In one of two cases plots where sulphur was applied and clipping spread had lower cover of perennial rye-grass (0%) than areas where sulphur had not been applied and heather clippings were not spread (24%). However, in one of two cases cover of common bent was higher in areas where sulphur had been applied and clippings spread (34%) than areas where sulphur had not been applied and heather clippings were not spread (24%). In May 2000 and March 2001 sulphur was applied in twenty 2500 m^2 plots. Heather clippings were spread on these plots in November 2001. Sulphur was not applied and heather clippings were not spread in ten 2500 m^2 plots. In June 2006 plant cover was assessed using ten 4 m^2 quadrats randomly located in each plot.

A randomized, replicated, controlled study in 1994–2003 in two agricultural fields in Suffolk, UK (3) found that application of sulphur, followed by sowing seeds of heathland species did not increase the cover of common heather *Calluna vulgaris* in four of six comparisons. After nine years and in four of six comparisons, cover of common heather in areas where sulphur had been applied and heathlands seed sown (0–13%) was not significantly different to that in areas where it had not been sown (0%). At both sites in 1994 sulphur was applied in twelve 80 m^2 plots following which seeds of heathland species were sown. Italian ryegrass seeds were sown in eight of these plots. At each site in four other plots no seeds were sown. In April 2003 five 2500 cm^2 quadrats were placed in each plot and the cover of all plant species recorded.

(1) Lawson, C.S., Ford, M.A., Mitchley, J. & Warren, J.M. (2004) The establishment of heathland vegetation on ex-arable land: the response of Calluna vulgaris to soil acidification. *Biological Conservation*, 116, 409-416.
(2) Diaz, A., Green, I. & Tibbett, M. (2007) Re-creation of heathland on improved pasture using top soil removal and sulphur amendments: Edaphic drivers and impacts on ericoid mycorrhizas. *Biological Conservation*, 141, 1628-1635.
(3) Walker, K.J., Warman, E.A., Bhogal, A., Cross, R.B., Pywell, R.F., Meek, B.R., Chambers, B.J. & Pakeman, R. (2007) Recreation of lowland heathland on ex-arable land: assessing the limiting processes on two sites with contrasting soil fertility and pH. *Journal of Applied Ecology*, 44, 573-582.

14.7 Strip/disturb topsoil (alongside planting/seeding)

- Two replicated, controlled studies in the UK[2,3] found that removal of topsoil and addition seed/clippings increased cover of heathland plants[2] or cover of heather and gorse[3]. One controlled study in the UK[1] found that soil disturbance using a rotovator and spreading clippings of heathland plants (alongside mowing) increased the number of heathland plants.
- One replicated, controlled study in the UK[3] found that stripping the surface layers of soil and adding seed reduced the cover of perennial rye-grass. One randomized, replicated, paired, controlled study in the UK[2] found that removal of topsoil and addition of the clippings of heathland plants did not alter the cover of annual grasses but led to a decrease in cover of perennial grasses.

Background
Stripping or disturbing topsoil can remove vegetation as well as any seeds present in the soil, thereby reducing the abundance unwanted plant species and reducing the potential for their regeneration. Combining this with planting and sowing seed may help to increase the survival and growth of introduced plants.

Related interventions: Disturb topsoil (section 13.6); strip topsoil (section 13.7); plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19)

A controlled study in 1983-1989 in two grasslands in Dorset, UK (1) found that mowing followed by rotovating, and the spreading of clippings of heathland plants increased the number of heathland plant species in two of two cases, and increased the presence of heathland plant species in 3 of 16 comparisons, but increased the presence of non-heathland plant species for 2 of 22 comparisons after six years. In two of two cases areas that had been mowed, rotovated and spread with heathland clippings had a higher number of heathland plant species (4-7 species) than areas that had not been mowed, rotovated, and spread with clippings (1-5 species). Presence of heathland plant species was higher in areas that had been mowed, rotovated and spread with heathland clippings than in areas that had not been mowed, rotovated, and spread with clippings in 3 of 16 comparisons (cut: present in 1-16% of plots, uncut: present in 0% of plots). Presence of non-heathland plant species was higher in areas that had been mowed, rotovated and spread with heathland clippings than in areas that had not been mowed, rotovated, and spread with clippings in 1 of 22 comparisons (cut: present in 12% of plots, uncut: present in 4% of plots). In 1983 five 25 m^2 plots were mowed and rotovated and subsequently spread with clippings harvested from a mature heathland and five plots were left unmowed and unrotovated, and were not spread with clippings. In 1989 four 1 m^2 quadrats divided into twenty-five 20 x 20 cm squares were placed in each plot and the presence of plant species in each square recorded.

A randomized, replicated, paired, controlled study in 1993–2002 in three former grassland sites in the UK (2) found that removal of topsoil and addition of heathland clippings increased cover of heathland species, did not alter cover of annual grasses, but led to a decrease in perennial grass cover. After nine years, cover of heathland species was higher in areas where topsoil was removed and clippings were added (58%) than in areas where topsoil was not removed and clippings were not added (0%). Cover of annual grasses was not significantly different in areas where topsoil was removed and clippings added (2%) and areas where topsoil was not removed or clippings added (1%). However, the cover of perennial grasses was lower in areas where topsoil was removed and clippings were added (6%) than in areas where topsoil was not removed and clippings were not added (83%). Heathland clippings were collected from an intact heathland in September 1996. In 1993 topsoil was removed from twelve 3 x 3 m plots while in another twelve plots topsoil was not removed. Clippings were spread on the plots where topsoil was removed in November 1996. The cover of plant species in each plot was estimated in July and August 2002 using a point quadrat.

A replicated, controlled study in 2001–2006 in ten improved grasslands in Dorset, UK (3) found that stripping the surface layers of soil, followed by spreading of heather *Calluna vulgaris* clippings increased cover of heather and gorse *Ulex europaeus*, and decreased the cover of perennial rye-grass *Lolium perenne*. After five years, areas where the soil surface had been stripped and heather clippings spread had higher cover of both heather and gorse (heather: 6%; gorse: 21%) than areas where soil was not stripped and heather clippings were not spread (heather: 0%; gorse: 0%). Plots where the soil surface had been stripped and heather clippings spread also had lower cover of perennial rye-grass (1%) than areas where soil had not been stripped and heather clippings were not spread (24%). In April 2001 soil was stripped to a depth of 10 cm in ten 400 m^2 plots after which heather clippings were spread over the plots. Soil was not stripped and heather clippings were not spread in ten 2500 m^2 plots. In June 2006 plant cover was assessed using ten 4 m^2 quadrats randomly located in each plot.

(1) Smith, R.E.N., Webb, N.R. & Clarke, R.T. (1991) The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57, 221-234.
(2) Allison, M. & Ausden, M. (2004) Successful use of topsoil removal and soil amelioration to create heathland vegetation. *Biological Conservation*, 120, 221-228.
(3) Diaz, A., Green, I. & Tibbett, M. (2007) Re-creation of heathland on improved pasture using top soil removal and sulphur amendments: Edaphic drivers and impacts on ericoid mycorrhizas. *Biological Conservation*, 141, 1628-1635.

14.8 Add topsoil (alongside planting/seeding)

- One randomized, replicated, paired, controlled study in the USA[1] found that addition of topsoil alongside sowing of seed increased the biomass of grasses but reduced the biomass of forbs in comparison to addition of topsoil alone.

Background
Adding topsoil from shrublands to degraded shrubland sites may help to increase the number of seeds in the soil, thereby increasing the probability of shrubland plants becoming established. The addition of topsoil may also help to increase soil fertility or reduce the effects of processes that dramatically alter soil structure, such as mining or quarrying. Combined with planting or seeding addition of topsoil may help to increase germination and survival of shrubland plants.

Related interventions: Add topsoil (section 13.8); plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19)

A randomized, replicated, paired, controlled study in 1997–2000 in a former coal mine in Wyoming, USA (1) found that addition of topsoil alongside sowing of seed increased the biomass of grasses but reduced the biomass of forbs in comparison to addition of topsoil alone. Areas where topsoil was added and seed sown had higher grass biomass (51-93 g/m^2) than areas where topsoil alone was added (14 g/m^2). However, in areas where topsoil was added and seed sown, forb biomass was lower (12-37 g/m^2) than in areas where topsoil was added alone (76 g/m^2). Topsoil was spread to a depth of 56 cm over the entire site in December 1997. In spring 1998 the entire site was seeded with barley *Hordeum vulgare* which was later cut to provide a mulch. In December 1998 grass seed was sown in twenty 6.5 x 27 m plots, while in four plots no seed was sown. Wyoming big sagebrush *Artemisia tridentata wyomingensis* seeds were also sown in all plots. In July 2000 clippings of vegetation were taken in four 0.18 m^2 quadrats within each plot to determine biomass.

(1) Williams, M.I., Schuman, G.E., Hild, A.L. & Vicklund, L.E. (2002) Wyoming Big Sagebrush Density: Effects of Seeding Rates and Grass Competition. *Restoration Ecology*, 10, 385-391.

14.9 Plant seed balls

- A randomized, replicated, controlled study in the USA[1] found that planting seed balls resulted in lower seedling numbers than sowing seed.

Background

Seed balls are made of a mixture of soil and seed. These balls can be planted, thrown or scattered over wide areas from aircraft. Use of the seed balls may reduce seed predation and desiccation, thereby increasing germination of the seeds in seed balls.

Related interventions: Plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19)

A randomized, replicated, controlled study in three blackbrush shrubland sites in California, USA (1) found that planting seed balls containing shrubland species resulted in lower seedling numbers than sowing seeds. Seedling emergence was lower in areas where seed balls containing shrubland species were planted (0–5% of seeds) than in areas where seeds were sown (17–22% of seed). Plots measuring 70 cm x 70 cm were established and in January 2010 seed balls planted in some plots and seeds sown in the other plots (number of plots unclear). Seedling emergence was assessed in between March 2010 and May 2012.

(1) Jones, L.C., Schwinning, S. & Esque, T.C. (2014) Seedling Ecology and Restoration of Blackbrush (Coleogyne ramosissima) in the Mojave Desert, United States. *Restoration Ecology*, 22, 692-700.

14.10 Plant/sow seeds of nurse plants alongside focal plants

- A randomized, replicated, controlled study in the UK[2] found that sowing seeds of nurse plants and heathland plants did not increase the cover of common heather. One replicated, randomized, controlled study in the USA[1] found that sowing seeds of nurse plants and California sagebrush seeds together reduced survival of shrubs in more than half of cases. The same study found that California sagebrush biomass was also reduced when its seeds were sown with those of nurse plants.

Background

Nurse plants are plants which are thought to aid the growth of other species by providing relatively benign conditions below their canopy. Examples of these altered conditions may include increases in moisture and nutrients, and decreases in temperature and damage from herbivores (de Toledo Castanho & Prado 2014). Combining the planting or sowing of seeds of nurse plants with that of focal plants may help to increase focal plant survival and growth.

Related interventions: Plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19); plant/sow seeds under established vegetation (section 14.10).

de Toledo Castanho, C. and P. I. Prado (2014). "Benefit of shading by nurse plant does not change along a stress gradient in a coastal dune." PLOS ONE 9(8): e105082.

A replicated, randomized, controlled study in 1993–1994 in former shrubland in California, USA (1) found that sowing California sagebrush *Artemisia californica* seeds with the seeds of nurse plants reduced its survival in four of seven comparisons and reduced its biomass in seven of seven comparisons. In four of seven comparisons, California sagebrush seedlings showed lower survival where they were sown with seeds of nurse plants (5–75% survival) than when they were sown without seeds of nurse plants (100% survival). In seven of seven comparisons California sagebrush biomass was lower when sown with seeds of nurse plants (0-1 g/m^2) than when sown without seeds of nurse plants (5 g/m^2). In three 0.75 m^2 plots California sagebrush seeds were sown, while in 18 plots a mixture of California sagebrush and succulent lupine *Lupinus succulentus* or rose clover *Trifolium hirtum* seeds were sown. Plant survival was recorded in May 1994 following which all plants were harvested and dried to calculate their biomass.

A randomized, replicated, controlled study in 1994–2003 in two agricultural fields in Suffolk, UK (2) found that sowing seeds of a nurse plant, followed by seeds of heathland species did not increase the cover of common heather *Calluna vulgaris* . After nine years, cover of common heather in areas where seeds of a nurse plant and heathland species were sown (0%) was not significantly different to that in areas where no seeds had been sown (0%). In 1994 seeds of the nurse plant Italian ryegrass *Lolium multiflorum* were sown, followed in 1995 by seeds of common heather, grasses, and herbs in four 80 m^2 plots. In four other plots no seeds were sown. In April 2003 five 2500 cm^2 quadrats were placed in each plot and the cover of all plant species was recorded.

(1) Marquez, V.J. & Allen, E.B. (1996) Ineffectiveness of Two Annual Legumes as Nurse Plants for Establishment of Artemisia californica in Coastal Sage Scrub*. Restoration Ecology*, 4, 42-50.
(2) Walker, K.J., Warman, E.A., Bhogal, A., Cross, R.B., Pywell, R.F., Meek, B.R., Chambers, B.J. & Pakeman, R. (2007) Recreation of lowland heathland on ex-arable land: assessing the limiting processes on two sites with contrasting soil fertility and pH*. Journal of Applied Ecology*, 44, 573-582.

14.11 Plant/seed under established vegetation

- A replicated, randomized, controlled study in the USA[1] found that sowing seed under established shrubs had mixed effects on blackbrush seedling emergence.

Background
Planting or sowing seeds under established vegetation may expose focal plants to less extreme conditions than planting them in unvegetated areas and therefore may result in higher survival and growth.

Related interventions: Plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19); plant/sow seeds of nurse plants alongside focal plants (section 14.9).

A randomized, replicated, controlled study in three blackbrush shrubland sites in California, USA (1) found that sowing seeds under established shrubs had mixed effects on blackbrush *Coleogyne ramosissima* seedling emergence. In one of three cases seedling emergence was higher under shrubs (28 seedlings/plot) than in open areas (21 seedlings/plot), but did not significantly differ under shrubs (25 seedlings/plot) from open areas (31 seedlings/plot) in one of three cases, and was lower under shrubs (15 seedlings/plot) than in open areas (25 seedlings/plot) in one of three cases. Plots measuring 70 cm x 70 cm were placed close to mature shrubs or at least 1 m away from shrubs (number of plots unclear). In January 2010 150 blackbrush seeds were sown in each plot. Seedling emergence was assessed in between March 2010 and May 2012.

(1) Jones, L.C., Schwinning, S. & Esque, T.C. (2014) Seedling Ecology and Restoration of Blackbrush (Coleogyne ramosissima) in the Mojave Desert, United States. *Restoration Ecology*, 22, 692-700.

14.12 Plant shrubs in clusters

- A randomized, controlled study in South Africa[1] found that when shrubs were planted in clumps more of them died than when they were planted alone.

Background
Planting shrubs in clusters may result in an alteration of microclimatic conditions which favour their survival and growth.

Plant individual plants (section 13.17); sow seeds (section 13.18); sow seeds and plant individual plants (section 13.19); plant/sow seeds of nurse plants alongside focal plants (section 14.9); plant/sow seeds under established vegetation (section 14.10).

A randomized, controlled study in 2000–2001 in a formerly mined karoo shrubland in Cape Province, South Africa (1) found that planting shrub species in clumps led to an increase in their mortality. After one year the percentage of shrubs planted in clumps that died (39%) was higher than the percentage of shrubs planted on their own that died (25%). In 2000 adult shrubs of three species (*Aridaria noctiflora*, *Drosanthemum deciduum*, and *Psilocaulon dinteri*) were removed from a shrubland and translocated to a formerly mined area. Ninety-six clumps each consisting of three shrubs of different species were planted with one clump per 25 m^2 plot, while 288 shrubs of the three species used were planted alone in each plot. Survival of plants was recorded in 2001.

(1) Blignaut, A. & Milton S, J. (2005) Effects of multispecies clumping on survival of three succulent plant species translocated onto mine spoil in the Succulent Karoo Desert, South Africa. *Restoration Ecology*, 13, 15-19.

14.13 Add root associated bacteria/fungi to introduced plants

- Two controlled studies (one of which was randomized) in Spain[1,2] found that adding rhizobacteria to soil increased the biomass of shrubs. One of these studies[2] also found an increase in shrub height.

Background
Many plants have symbiotic relationships with bacteria and fungi associated with their roots. These fungi can help to reduce the effects of plant pathogens as well helping to fix atmospheric nitrogen, thereby potentially increasing plant survival and growth.

A randomized, controlled study in 2011–2012 in experimental fields in southern Spain (1) found that inoculating soils with rhizobacteria increased the shoot and root biomass of French lavender *Lavandula dentata*. Lavender plants where soil was inoculated had higher shoot (2–9 g) and root biomass (0–3 g) than where soil was not inoculated (shoot: 1 g, root: 1 g). In March 2011 rhizobacteria cultures were added to the soil of 20 pots where lavender seedlings were growing, but not five others. The seedlings were planted in a field in May 2011. In June 2012 plants were harvested and their dry weight was estimated.

A controlled study in 2008–2011 in a field in southern Spain (2) found that inoculating shrubs with rhizobial bacteria increased their height and biomass. *Cytisus balansae* plants that had been inoculated were taller (2–8 m) than those that had not been inoculated (1 m) and the same was true for *Cytisus multiflorus* (inoculated: 2–6 m, non-inoculated: 1 m), *Cytisus striatus* (inoculated: 5–6 m, non-inoculated: 1 m), and *Genista florida* plants (inoculated: 1–7 m, non-inoculated: 1 m). All four shrub species also had higher biomass when inoculated (60–530 mg/plant) than when they were not inoculated (30–110 mg/plant). In 2008 forty seedlings of each plant species were grown in a greenhouse in soil inoculated with rhizobial bacteria, and another 40 in soil that was not inoculated. In 2009 plants were transplanted to a field. In 2011 the height of plants was measured and plants were harvested and dried to allow biomass to be calculated.

(1) Mengual, C., Schoebitz, M., Azcón, R. & Roldán, A. (2014) Microbial inoculants and organic amendment improves plant establishment and soil rehabilitation under semiarid conditions. *Journal of Environmental Management*, 134, 1-7.

(2) Pérez-Fernández, M.A., Calvo-Magro, E. & Valentine, A. (2016) Benefits of the Symbiotic Association of Shrubby Legumes for the Rehabilitation of Degraded Soils under Mediterranean Climatic Conditions. *Land Degradation and Development*, 27, 395-405.

15. Education and awareness

Background

The importance of raising awareness and educating people about biodiversity is recognised by the Convention of Biological Diversity in its 2020 targets (CBD 2010). From the perspective of shrublands, education and awareness campaigns can help to change people's attitudes to these habitats and the biodiversity contained within them.

Studies of education programmes or awareness campaigns would ideally measure their effect on the condition of shrubland habitat. However, studies of education or awareness campaigns rarely measure this and more often studies assess changes in attitudes, knowledge, or behaviour (Ferraro and Pattanayak 2006). In this section we also include information on the number of people who were engaged by campaigns or measures of the spatial distribution of those involved in the campaign, where it is available.

CBD. (2010) Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its Tenth Meeting: the Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets. See http://www.cbd.int/decisions/cop.

Ferraro PJ, Pattanayak SK (2006) Money for nothing? a call for empirical evaluation of biodiversity conservation investments. *PLoS Biol* 4(4): e105.

Key messages

15.1 Raise awareness amongst the general public

We captured no information on the effect on shrublands of raising awareness amongst the general public.

15.2 Provide education campaigns about shrublands

We captured no information on the effect on shrublands of providing education campaigns.

Interventions

15.1 Raise awareness amongst the general public

We captured no information on the effect on shrublands of raising awareness amongst the general public.

Background

Raising awareness about shrublands, the threats they face, and their conservation can help to change perceptions about shrublands and therefore indirectly affect their conservation. This intervention involves the provision of information and campaigns to raise awareness.

For information relating to 'Use signs and access restrictions to reduce disturbance' see chapter 7 and for information on educational programmes see 15.2 'Provide education programmes about shrublands'

15.2 Provide education programmes about shrublands

We captured no information on the effect on shrublands of providing education programmes.

Background
Providing education campaigns to the general public may help to raise awareness of the biodiversity found in shrublands and its importance, the threats they face, and the steps people can take to protect them. This education may also help change the perception of shrubland habitats, thereby can potentially contribute for their conservation.

Appendix: Complete reference list

This appendix lists all references summarized as evidence within the Shrubland and Heathland Conservation synopsis. It does not include references used only in background sections.

Abella, S.R., O'Brien, K.L. & Weesner, M.W. (2015) Revegetating Disturbance in National Parks: Reestablishing Native Plants in Saguaro National Park, Sonoran Desert. *Natural Areas Journal*, 35, 18-25.

Ahlstrand, G.M. (1982) Response of Chihuahuan Desert Mountain Shrub Vegetation to Burning. *Journal of Range Management*, 35, 62-65.

Alday, J.G., Cox, E.S., Pakeman, R.J., Harris, M.P., LeDuc, M.G. & Marrs, R.H. (2013) Overcoming resistance and resilience of an invaded community is necessary for effective restoration: a multi-site bracken control study. *Journal of Applied Ecology*, 50, 156-167.

Alday, J.G., Marrs, R.H. & Martínez Ruiz, C. (2011) Vegetation succession on reclaimed coal wastes in Spain: The influence of soil and environmental factors. *Applied Vegetation Science*, 14, 84-94.

Aldezabal, A., Mandaluniz, N. & Laskurain, N. (2013) Gorse (Ulex spp.) use by ponies in winter: Is the spatial pattern of browsing independent of the neighbouring vegetation? *Grass and Forage Science*, 68, 49-58.

Allison, M. & Ausden, M. (2004) Successful use of topsoil removal and soil amelioration to create heathland vegetation. *Biological Conservation*, 120, 221-228.

Allison, M. & Ausden, M. (2006) Effects of removing the litter and humic layers on heathland establishment following plantation removal. *Biological Conservation*, 127, 177-182.

Allison, M. & Ausden, M. (2006) Effects of removing the litter and humic layers on heathland establishment following plantation removal. *Biological Conservation*, 127, 177-182.

Anderson, P. & Radford, E. (1994) Changes in vegetation following reduction in grazing pressure on the National Trust's Kinder Estate, Peak District, Derbyshire, England. *Biological Conservation*, 69, 55-63.

Aradottir, A.L. (2012) Turf transplants for restoration of alpine vegetation: does size matter? *Journal of Applied Ecology*, 49, 439-446.

Ascoli, D., Lonati, M., Marzano, R., Bovio, G., Cavallero, A. & Lombardi, G. (2013) Prescribed burning and browsing to control tree encroachment in southern European heathlands. *Forest Ecology and Management*, 289, 69-77.

Bakker, J., De Bie, S., Dallinga, J., Tjaden, P. & De Vries, Y. (1983) Sheep-grazing as a management tool for heathland conservation and regeneration in the Netherlands. *Journal of Applied Ecology*, 541-560.

Barker, C.G., Power, S.A., Bell, J.N.B. & Orme, C.D.L. (2004) Effects of habitat management on heathland response to atmospheric nitrogen deposition. *Biological Conservation*, 120, 41-52.

Bates, J.D. & Svejcar, T.J. (2009) Herbaceous Succession After Burning of Cut Western Juniper Trees. *Western North American Naturalist*, 69, 9-25.

Bates, J.D., Davies, K.W. & Sharp, R.N. (2011) Shrub-Steppe Early Succession Following Juniper Cutting and Prescribed Fire. *Environmental Management*, 47, 468-481.

Beltran, R.S., Kreidler, N., Van Vuren, D.H., Morrison, S.A., Zavaleta, E.S., Newton, K., Tershy, B.R. & Croll, D.A. (2014) Passive Recovery of Vegetation after Herbivore Eradication on Santa Cruz Island, California. *Restoration Ecology*, 22, 790-797.

Bermejo, L.A., de Nascimento, L., Mata, J., Fernández-Lugo, S., Camacho, A. & Arévalo, J.R. (2012) Responses of plant functional groups in grazed and abandoned areas of a Natural Protected Area. *Basic and Applied Ecology*, 13, 312-318.

Beukes, P.C. & Cowling, R.M. (2003) Evaluation of restoration techniques for the Succulent Karoo, South Africa. *Restoration Ecology*, 11, 308-316.

Blignaut, A. & Milton S, J. (2005) Effects of multispecies clumping on survival of three succulent plant species translocated onto mine spoil in the Succulent Karoo Desert, South Africa. *Restoration Ecology*, 13, 15-19.

Bokdam, J. & Gleichman, J.M. (2000) Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. *Journal of Applied Ecology*, 37, 415-431.

Bokdam, J. & Gleichman, J.M. (2000) Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. *Journal of Applied ecology*, 37, 415-431.

Borghesio, L. (2014) Can fire avoid massive and rapid habitat change in Italian heathlands? *Journal for Nature Conservation*, 22, 68-74.

Bork, E.W., West, N.E. & Walker, J.W. (1998) Cover components on long-term seasonal sheep grazing treatments in three-tip sagebrush steppe. *Journal of Range Management*, 293-300.
Boyd, C.S. & Svejcar, T.J. (2011) The influence of plant removal on succession in Wyoming big sagebrush. *Journal of Arid Environments*, 75, 734-741.
Brian, M.V., Mountford, M.D., Abbott, A. & Vincent, S. (1976) The Changes in Ant Species Distribution During Ten Years Post-Fire Regeneration of a Heath. *Journal of Animal Ecology*, 45, 115-133.
Britton, A.J., Carey, P.D., Pakeman, R.J. & Marrs, R.H. (2000) A comparison of regeneration dynamics following gap creation at two geographically contrasting heathland sites. *Journal of Applied Ecology*, 37, 832-844.
Britton, A.J., Marrs, R.H., Carey, P.D. & Pakeman, R.J. (2000) Comparison of techniques to increase Calluna vulgaris cover on heathland invaded by grasses in Breckland, south east England. *Biological Conservation*, 95, 227-232.
Brook, S., McCracken, M. & Bulman, C.R. (2007) Post-burn bracken Pteridium aquilinum control to manage habitat for the heath fritillary butterfly Mellicta athalia on Exmoor, Somerset, England. *Conservation Evidence*, 4, 81-87.
Bullock, J.M. & Pakeman, R.J. (1997) Grazing of lowland heath in England: management methods and their effects on healthland vegetation. *Biological Conservation*, 79, 1-13.
Bülow-Olsen, A. (1980) Changes in the species composition in an area dominated by Deschampsia flexuosa (L.) trin. as a result of cattle grazing. *Biological Conservation*, 18, 257-270.
Burke, A. (2008) The effect of topsoil treatment on the recovery of rocky plain and outcrop plant communities in Namibia. *Journal of Arid Environments*, 72, 1531-1536.
Calvo, L., Alonso, I., Frenandez, A.J. & De Luis, E. (2005) Short-term study of effects of fertilisation and cutting treatments on the vegetation dynamics of mountain heathlands. *Plant Ecology*, 179, 181-191.
Calvo, L., Alonso, I., Marcos, E. & De Luis, E. (2007) Effects of cutting and nitrogen deposition on biodiversity in Cantabrian heathlands. *Applied Vegetation Science*, 10, 43-52.
Celaya, R., Jáuregui, B.M., García, R.R., Benavides, R., García, U. & Osoro, K. (2010) Changes in heathland vegetation under goat grazing: Effects of breed and stocking rate. *Applied Vegetation Science*, 13, 125-134.
Celaya, R., Jáuregui, B.M., Rosa García, R., Benavides, R., García, U. & Osoro, K. (2010) Changes in heathland vegetation under goat grazing: effects of breed and stocking rate. *Applied Vegetation Science*, 13, 125-134.
Céspedes, B., Luna, B., Pérez, B., Urbieta, I.R. & Moreno, J.M. (2014) Burning season effects on the short-term post-fire vegetation dynamics of a Mediterranean heathland. *Applied Vegetation Science*, 17, 86-96.
Céspedes, B., Torres, I., Pérez, B., Luna, B. & Moreno, J.M. (2014) Burning season does not affect post-fire regeneration but fire alters the balance of the dominant species in a seeder-dominated Mediterranean shrubland. *Applied Vegetation Science*, 17, 711-725.
Cione, N.K., Padgett, P.E. & Allen, E.B. (2002) Restoration of a Native Shrubland Impacted by Exotic Grasses, Frequent Fire, and Nitrogen Deposition in Southern California. *Restoration Ecology*, 10, 376-384.
Cox, R.D. & Allen, E.B. (2008) Stability of exotic annual grasses following restoration efforts in southern California coastal sage scrub. *Journal of Applied Ecology*, 45, 495-504.
Critchley, C., Adamson, H., McLean, B. & Davies, O. (2008) Vegetation dynamics and livestock performance in system-scale studies of sheep and cattle grazing on degraded upland wet heath. *Agriculture, ecosystems & environment*, 128, 59-67.
Critchley, C.N.R., Mitchell, R.J., Rose, R.J., Griffiths, J.B., Jackson, E., Scott, H. & Davies, O.D. (2013) Re-establishment of Calluna vulgaris (L.) Hull in an eight-year grazing experiment on upland acid grassland. *Journal for Nature Conservation*, 21, 22-30.
Damgaard, C., Thomsen, M.P., Borchsenius, F., Nielsen, K.E. & Strandberg, M. (2013) The effect of grazing on biodiversity in coastal dune heathlands. *Journal of coastal conservation*, 17, 663-670.
Davies, K., Bates, J., Madsen, M. & Nafus, A. (2014) Restoration of mountain big sagebrush steppe following prescribed burning to control western juniper. *Environmental Management*, 53, 1015-1022.
Davies, K.W., Bates, J.D., Madsen, M.D. & Nafus, A.M. (2014) Restoration of mountain big sagebrush steppe following prescribed burning to control Western Juniper. *Environmental Management*, 53, 1015-1022.
Davy, A.J., Dunsford, S.J. & Free, A.J. (1998) Acidifying peat as an aid to the reconstruction of lowland heath on arable soil: lysimeter experiments. *Journal of Applied Ecology*, 35, 649-659.
de Bie, K. & Vesk, P.A. (2014) Ecological indicators for assessing management effectiveness: A case study of horse riding in an Alpine National Park. *Ecological Management and Restoration*.
DeGabriel, J.L., Albon, S.D., Fielding, D.A., Riach, D.J., Westaway, S. & Irvine, R.J. (2011) The presence of sheep leads to increases in plant diversity and reductions in the impact of deer on heather. *Journal of Applied Ecology*, 48, 1269-1277.

DeGabriel, J.L., Albon, S.D., Fielding, D.A., Riach, D.J., Westaway, S. & Irvine, R.J. (2011) The presence of sheep leads to increases in plant diversity and reductions in the impact of deer on heather. *Journal of Applied Ecology*, 48, 1269-1277.

Denyer, J.L., Hartley, S.E. & John, E.A. (2010) Both bottom-up and top-down processes contribute to plant diversity maintenance in an edaphically heterogeneous ecosystem. *Journal of ecology*, 98, 498-508.

DeSimone, S.A. (2011) Balancing Active and Passive Restoration in a Nonchemical, Research-Based Approach to Coastal Sage Scrub Restoration in Southern California. *Ecological Restoration*, 29, 45-51.

Diaz, A., Green, I. & Tibbett, M. (2007) Re-creation of heathland on improved pasture using top soil removal and sulphur amendments: Edaphic drivers and impacts on ericoid mycorrhizas. *Biological Conservation*, 141, 1628-1635.

Diaz, A., Green, I. & Tibbett, M. (2008) Re-creation of heathland on improved pasture using top soil removal and sulphur amendments: Edaphic drivers and impacts on ericoid mycorrhizas. *Biological Conservation*, 141, 1628-1635.

Eiswerth, M.E., Krauter, K., Swanson, S.R. & Zielinski, M. (2009) Post-fire seeding on Wyoming big sagebrush ecological sites: regression analyses of seeded nonnative and native species densities. *Journal of Environmental Management*, 90, 1320-1325.

Ellsworth, L.M. & Kauffman, J.B. (2010) Native Bunchgrass Response to Prescribed Fire in Ungrazed Mountain Big Sagebrush Ecosystems. *The Journal of the Association for Fire Ecology*, 6, 86-96.

Fottner, S., Härdtle, W., Niemeyer, M., Niemeyer, T., Von Oheimb, G., Meyer, H. & Mockenhaupt, M. (2007) Impact of sheep grazing on nutrient budgets of dry heathlands. *Applied Vegetation Science*, 10, 391-398.

Gachet, S., Sarthou, C., Bardat, J. & Ponge, J.-F. (2009) The state of change of Erica scoparia L. heathland through cattle grazing and oak colonization. *Revue d'Ecologie, Terre et Vie*, 64, 3-17.

Gallet, S. & Roze, F. (2001) Conservation of heathland by sheep grazing in Brittany (France): Importance of grazing period on dry and mesophilous heathlands. *Ecological Engineering*, 17, 333-344.

Gardiner, T. & Vaughan, A. (2008) Responses of ground flora and insect assemblages to tree felling and soil scraping as an initial step to heathland restoration at Norton Heath Common, Essex, England. *Conservation Evidence*, 5, 95-100.

Gardner, E.T., Anderson, V.J. & Johnson, R.L. (2009) Arthropod and Plant Communities as Indicators of Land Rehabilitation Effectiveness in a Semiarid Shrubsteppe. *Western North American Naturalist*, 69, 521-536.

Grant, S., Milne, J., Barthram, G. & Souter, W. (1982) Effects of season and level of grazing on the utilization of heather by sheep. 3. Longer-term responses and sward recovery. *Grass and Forage Science*, 37, 311-320.

Gretarsdottir, J., Aradottir, A.L., Vandvik, V., Heegaard, E. & Birks H. J, B. (2004) Long-term effects of reclamation treatments on plant succession in Iceland. *Restoration Ecology*, 12, 268-278.

Groome, G.M. & Shaw, P. (2015) Vegetation response to the reintroduction of cattle grazing on an English lowland valley mire and wet heath. *Conservation Evidence*, 12, 33-39.

Hanke, W., Wesuls, D., Münchberger, W. & Schmiedel, U. (2015) Tradeoffs in the Rehabilitation of a Succulent Karoo Rangeland. *Land Degradation and Development*, 26, 833-842.

Harniss, R.O. & Murray, R.B. (1973) 30 years of vegetal change following burning of sagebrush-grass range. *Journal of Range Management*, 26, 322-325.

Hartley, S.E. & Mitchell, R.J. (2005) Manipulation of nutrients and grazing levels on heather moorland: changes in Calluna dominance and consequences for community composition. *Journal of Ecology*, 93, 990-1004.

Hobbs, R.J. & Gimingham, C. (1984) Studies on fire in Scottish heathland communities II. Post-fire vegetation development. *The Journal of Ecology*, 585-610.

Hoelzle, T.B., Jonas, J.L. & Paschke, M.W. (2012) Twenty-five years of sagebrush steppe plant community development following seed addition. *Journal of Applied Ecology*, 49, 911-918.

Holmes, P.M. & Foden, W. (2001) The effectiveness of post-fire soil disturbance in restoring fynbos after alien clearance. *South African Journal of Botany*, 67, 533-539.

Hope, D., Picozzi, N., Catt, D.C. & Moss, R. (1996) Effects of reducing sheep grazing in the Scottish Highlands. *Journal of Range Management*, 301-310.

Hulme, P., Merrell, B., Torvell, L., Fisher, J., Small, J. & Pakeman, R. (2002) Rehabilitation of degraded Calluna vulgaris (L.) Hull-dominated wet heath by controlled sheep grazing. *Biological Conservation*, 107, 351-363.

Hulme, P.D., Merrell, B.G., Torvell, L., Fisher, J.M., Small, J.L. & Pakeman, R.J. (2002) Rehabilitation of degraded Calluna vulgaris (L.) Hull-dominated wet heath by controlled sheep grazing. *Biological Conservation*, 107, 351-363.

Jansen, A.J.M., de Graaf, M.C.C. & Roelofs, J.G.M. (1996) The restoration of species-rich heathland communities in the Netherlands. *Vegetatio*, 126, 73-88.

Jáuregui, B., Celaya, R., García, U. & Osoro, K. (2007) Vegetation dynamics in burnt heather-gorse shrublands under different grazing management with sheep and goats. *Agroforestry Systems*, 70, 103-111.

Jáuregui, B.M., Celaya, R., Garcia, U. & Osoro, K. (2007) Vegetation dynamics in burnt heather-gorse shrublands under different grazing management with sheep and goats. *Agroforestry Systems*, 70, 103-111.

Kerr, T.F. & Ruwanza, S. (2016) Does Eucalyptus grandis invasion and removal affect soils and vegetation in the Eastern Cape Province, South Africa? *Austral Ecology*, 41, 328-338.

Kimball, S., Lulow, M.E., Mooney, K.A. & Sorenson, Q.M. (2014) Establishment and Management of Native Functional Groups in Restoration. *Restoration Ecology*, 22, 81-88.

Kraaij, T., Cowling, R.M., Wilgen, B.W. & Schutte-Vlok, A. (2013) Proteaceae juvenile periods and post-fire recruitment as indicators of minimum fire return interval in eastern coastal fynbos. *Applied Vegetation Science*, 16, 84-94.

Krueper, D., Bart, J. & Rich, T.D. (2003) Response of vegetation and breeding birds to the removal of cattle on the San Pedro River, Arizona, USA. *Conservation Biology*, 17, 607-615.

Krupek, A., Gaertner, M., Holmes, P.M. & Esler, K.J. (2016) Assessment of post-burn removal methods for Acacia saligna in Cape Flats Sand Fynbos, with consideration of indigenous plant recovery. *South African Journal of Botany*, 105, 211-217.

Kyser, G.B., Wilson, R.G., Zhang, J. & DiTomaso, J.M. (2013) Herbicide-assisted restoration of Great Basin sagebrush steppe infested with medusahead and downy brome. *Rangeland Ecology and Management*, 66, 588-596.

Lawson, C.S., Ford, M.A., Mitchley, J. & Warren, J.M. (2004) The establishment of heathland vegetation on ex-arable land: the response of Calluna vulgaris to soil acidification. *Biological Conservation*, 116, 409-416.

Lawson, C.S., Ford, M.A., Mitchley, J. & Warren, J.M. (2004) The establishment of heathland vegetation on ex-arable land: the response of Calluna vulgaris to soil acidification. *Biological Conservation*, 116, 409-416.

Le Duc, M.G., Pakeman, R.J. & Marrs, R.H. (2003) Changes in the rhizome system of bracken subjected to long-term experimental treatment. *Journal of Applied Ecology*, 40.

Leu, S., Mussery, A. & Budovsky, A. (2014) The Effects of Long Time Conservation of Heavily Grazed Shrubland: A Case Study in the Northern Negev, Israel. *Environmental Management*, 54, 309-319.

Liepert, C., Gardner, S. & Rees, S. (1993) Managing heather moorland: impacts of burning and cutting on Calluna regeneration. *Journal of Environmental Planning and Management*, 36, 283-293.

Liu, H., Tao, Y.E., Qiu, D., Zhang, D. & Zhang, Y. (2013) Effects of Artificial Sand Fixing on Community Characteristics of a Rare Desert Shrub. *Conservation Biology*, 27, 1011-1019.

Lowday, J. & Marrs, R. (1992) Control of bracken and the restoration of heathland. III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*, 212-217.

Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and restoration of heathland.III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*, 29, 212-217.

Lowday, J.E. & Marrs, R.H. (1992) Control of bracken and the restoration of heathland. I. Control of bracken. *Journal of Applied Ecology*, 29, 195-203.

Maren, I.E., Vandvik, V. & Ekelund, K. (2008) Restoration of bracken-invaded Calluna vulgaris heathlands: Effects on vegetation dynamics and non-target species. *Biological Conservation*, 141, 1032-1042.

Marrs, R. (1984) Birch control on lowland heaths: mechanical control and the application of selective herbicides by foliar spray. *Journal of applied ecology*, 703-716.

Marrs, R. (1985) The effects of potential bracken and scrub control herbicides on lowland Calluna and grass heath communities in East Anglia, UK. *Biological Conservation*, 32, 13-32.

Marrs, R. (1987) Studies on the conservation of lowland Calluna heaths. I. Control of birch and bracken and its effect on heath vegetation. *Journal of applied ecology*, 163-175.

Marrs, R., Phillips, J., Todd, P., Ghorbani, J. & Le Duc, M. (2004) Control of Molinia caerulea on upland moors. *Journal of Applied Ecology*, 41, 398-411.

Marrs, R.H. (1984) Birch control on lowland heaths: mechanical control and the application of selective herbicides by foliar spray. *Journal of Applied Ecology*, 21, 703-716.

Marrs, R.H. (1985) The use of Krenite to control birch on lowland heaths. *Biological Conservation*, 32, 149-164.

Marrs, R.H. (1987) Studies on the Conservation of Lowland Calluna Heaths. I. Control of Birch and Bracken and Its Effect on Heath Vegetation. *Journal of Applied Ecology*, 24, 163-175.

Marrs, R.H. (1987) Studies on the conservation of lowland Calluna heaths. II. Regeneration of Calluna, and its relation to bracken infestation. *Journal of Applied Ecology*, 24, 177-189.

Marrs, R.H., Johnson, S.W. & Duc, M.G.L. (1998) Control of bracken and restoration of heathland. VIII. The regeneration of the heathland community after 18 years of continued bracken control or 6 years of control followed by recovery. *Journal of Applied Ecology*, 35, 857-870.

Mengual, C., Schoebitz, M., Azcón, R. & Roldán, A. (2014) Microbial inoculants and organic amendment improves plant establishment and soil rehabilitation under semiarid conditions. *Journal of Environmental Management*, 134, 1-7.

Milligan, A.L., Putwain, P.D. & Marrs, R.H. (2003) A field assessment of the role of selective herbicides in the restoration of British moorland dominated by Molinia. *Biological Conservation*, 109, 369-379.

Milligan, G., Cox, E., Alday, J., Santana, V., McAllister, H., Pakeman, R., Le Duc, M. & Marrs, R. (2016) The effectiveness of old and new strategies for the long-term control of Pteridium aquilinum, an 8-year test. *Weed Research*, 56, 247-257.

Mitchell, R.J., Rose, R.J. & Palmer, S.C.F. (2008) Restoration of Calluna vulgaris on grass-dominated moorlands: The importance of disturbance, grazing and seeding. *Biological Conservation*, 141, 2100-2111.

Mitchell, R.J., Rose, R.J. & Palmer, S.C.F. (2009) The effect of restoration techniques on non-target species: Case studies in moorland ecosystems. *Applied Vegetation Science*, 12, 81-91.

Ndou, E. & Ruwanza, S. (2016) Soil and vegetation recovery following alien tree clearing in the Eastern Cape Province of South Africa. *African Journal of Ecology*.

Newton, A., Stewart, G.B., Myers, G., Lake, S., Bullock, J. & Pullin, A.S., *How does the impact of grazing on heathland compare with other management methods?* 2009, Collaboration for Environmental Evidence: CEE Review.

Newton, A.C., Stewart, G.B., Myers, G., Diaz, A., Lake, S., Bullock, J.M. & Pullin, A.S. (2009) Impacts of grazing on lowland heathland in north-west Europe. *Biological Conservation*, 142, 935-947.

Nilsen, L.S., Johansen, L. & Velle, L.G. (2005) Early stages of Calluna vulgaris regeneration after burning of coastal heath in central Norway. *Applied Vegetation Science*, 8, 57-64.

Ojeda, F., Marañón, T. & Arroyo, J. (1996) Postfire regeneration of a mediterranean heathland in Southern Spain. *International Journal of Wildland Fire*, 6, 191-198.

Pakeman, R.J. & Nolan, A.J. (2009) Setting sustainable grazing levels for heather moorland: a multi-site analysis. *Journal of Applied Ecology*, 46, 363-368.

Papanikolaou, A.D., Fyllas, N.M., Mazaris, A.D., Dimitrakopoulos, P.G., Kallimanis, A.S. & Pantis, J.D. (2011) Grazing effects on plant functional group diversity in Mediterranean shrublands. *Biodiversity and Conservation*, 20, 2831.

Paterson, S., Pakeman, R. & Marrs, R. (2000) Describing vegetation succession after bracken control: Evaluation of the REBRA model. *Journal of Environmental management*, 59, 31-45.

Pedley, S.M., Franco, A.M., Pankhurst, T. & Dolman, P.M. (2013) Physical disturbance enhances ecological networks for heathland biota: a multiple taxa experiment. *Biological conservation*, 160, 173-182.

Pérez-Fernández, M.A., Calvo-Magro, E. & Valentine, A. (2016) Benefits of the Symbiotic Association of Shrubby Legumes for the Rehabilitation of Degraded Soils under Mediterranean Climatic Conditions. *Land Degradation and Development*, 27, 395-405.

Piessens, K., Aerts, N. & Hermy, M. (2006) Long-term (1978-2003) effects of an extensive grazing regime on plant species composition of a heathland reserve. *Belgian Journal of Botany*, 49-64.

Potts, J.B., Marino, E. & Stephens, S.L. (2010) Chaparral shrub recovery after fuel reduction: a comparison of prescribed fire and mastication techniques. *Plant Ecology*, 210, 303-315.

Power, S.A., Barker, C.G., Allchin, A.E., Ashmore, M.R. & Bell, J.N.B. (2001) Habitat management: a tool to modify ecosystem impacts of nitrogen deposition? *The Scientific World*, 1, 714-721.

Pretorius, M.R., Esler, K.J., Holmes, P.M. & Prins, N. (2008) The effectiveness of active restoration following alien clearance in fynbos riparian zones and resilience of treatments to fire. *South African Journal of Botany*, 74, 517-525.

Pywell, R.F., Meek, W.R., Webb, N.R., Putwain, P.D. & Bullock, J.M. (2011) Long-term heathland restoration on former grassland: The results of a 17-year experiment. *Biological Conservation*, 144, 1602-1609.

Pywell, R.F., Webb, N.R. & Putwain, P.D. (1995) A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32, 400-411.

Pywell, R.F., Webb, N.R. & Putwain, P.D. (1996) Harvested heather shoots as a resource for heathland restoration. *Biological Conservation*, 75, 247-254.

Rahlao, S.J., Hoffman, M.T., Todd, S.W. & McGrath, K. (2008) Long-term vegetation change in the Succulent Karoo, South Africa following 67 years of rest from grazing. *Journal of Arid Environments*, 72, 808-819.

Reemts, C.M. & Cimprich, D.A. (2014) Restoring early-successional shrubland habitat for black-capped vireos using mechanical mastication. *Natural areas journal*, 34, 400-407.

Reinecke, M.K., Pigot, A.L. & King, J.M. (2008) Spontaneous succession of riparian fynbos: Is unassisted recovery a viable restoration strategy? *South African Journal of Botany*, 74, 412-420.

Richardson, G.R., Lubke, R.A. & Guilarmod, A.J. (1984) Regeneration of grassy fynbos near Grahamstown (eastern Cape) after fire. *South African Journal of Botany*, 3, 153-162.

Rickart, E.A., Bienek, K.G. & Rowe, R.J. (2013) Impact of Livestock Grazing on Plant and Small Mammal Communities in the Ruby Mountains, Northeastern Nevada. *Western North American Naturalist*, 73, 505-515.

Roselle, L., Seefeldt, S.S. & Launchbaugh, K. (2010) Delaying sheep grazing after wildfire in sagebrush steppe may not affect vegetation recovery. *International Journal of Wildland Fire*, 19, 115-122.

Ross, S., Adamson, H. & Moon, A. (2003) Evaluating management techniques for controlling Molinia caerulea and enhancing Calluna vulgaris on upland wet heathland in northern England, UK. *Agriculture, ecosystems & environment*, 97, 39-49.

Ruwanza, S., Gaertner, M., Esler, K.J. & Richardson, D.M. (2013) The effectiveness of active and passive restoration on recovery of indigenous vegetation in riparian zones in the Western Cape, South Africa: A preliminary assessment. *South African Journal of Botany*, 88, 132-141.

Smith, R.E.N., Webb, N.R. & Clarke, R.T. (1991) The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57, 221-234.

Snow, C. & Marrs, R. (1997) Restoration of Calluna heathland on a bracken Pteridium-infested site in north west England. *Biological Conservation*, 81, 35-42.

Snow, C.S.R. & Marrs, R.H. (1997) Restoration of Calluna heathland on a bracken Pteridium-infested site in north west England. *Biological Conservation*, 81, 35-42.

Stevens, M.T., Holland, D.L. & Tanner, N.V. (2016) Netleaf hackberry seeds planted near boulders in the foothills of the Wasatch Mountains: germination, survival, and patterns of establishment. *Western North American Naturalist*, 76, 452-458.

Stewart, G.B., Coles, C.F. & Pullin, A.S. (2004) Does burning of UK sub-montane, dry dwarf-shrub heath maintain vegetation diversity? Systematic Review No. 2. *Centre for Evidence-Based Conservation*.

Tárrega, R., Luis-Calabuig, E. & Alonso, I. (1995) Comparison of the regeneration after burning, cutting and ploughing in a Cistus ladanifer shrubland. *Plant Ecology*, 59-67.

Todd, P., Phillips, J., Putwain, P. & Marrs, R. (2000) Control of Molinia caerulea on moorland. *Grass and forage science*, 55, 181.

Virtanen, R. (1998) Impact of grazing and neighbour removal on a heath plant community transplanted onto a snowbed site, NW Finnish Lapland. *Oikos*, 81, 359-367.

Walker, K.J., Warman, E.A., Bhogal, A., Cross, R.B., Pywell, R.F., Meek, B.R., Chambers, B.J. & Pakeman, R. (2007) Recreation of lowland heathland on ex-arable land: assessing the limiting processes on two sites with contrasting soil fertility and pH. *Journal of Applied Ecology*, 44, 573-582.

Welch, D. & Scott, D. (1995) Studies in the grazing of heather moorland in northeast Scotland. VI. 20-year trends in botanical composition. *Journal of Applied Ecology*, 596-611.

Welch, D. (1998) Response of bilberry Vaccinium myrtillus L. stands in the Derbyshire Peak District to sheep grazing, and implications for moorland conservation. *Biological Conservation*, 83, 155-164.

Welch, D., Scott, D., Mitchell, R. & Elston, D.A. (2006) Slow recovery of heather (Calluna vulgaris L.(Hull)) in Scottish moorland after easing of heavy grazing pressure from red deer (Cervus elaphus L.). *Botanical Journal of Scotland*, 58, 1-17.

West, N.E. & Hassan, M.A. (1985) Recovery of Sagebrush-Grass Vegetation Following Wildfire. *Journal of Range Management*, 38, 131-134.

Wilkie, M., *Mixed herbivore grazing on a lowland heath system: quantifying the collective impacts for conservation management*. 2013, University of Southampton.

Williams, M.I., Schuman, G.E., Hild, A.L. & Vicklund, L.E. (2002) Wyoming big sagebrush density: effects of seeding rates and grass competition. *Restoration Ecology*, 10, 385-391.

Williams, S.E. & Oconnor, G.A. (1973) Chemical Fertilization of Fourwing Saltbush. *Journal of Range Management*, 26, 379-380.

Wilton-Jones, G. & Ausden, M. (2005) Restoring heathland by removing birch Betula woodland and adding heather Calluna vulgaris seed at The Lodge RSPB Reserve, Bedfordshire, England. *Conservation Evidence*, 2, 68-69.