The effects of trees and scrub on ecosystem services and biodiversity in the UK uplands: a scoping review (NEER013)

1st Edition – December 2019

www.gov.uk/natural-england

NATURAL ENGLAND

Left blank on purpose

Natural England Evidence Review NEER013

The effects of trees and scrub on ecosystem services and biodiversity in the UK uplands: a scoping review

Susannah Gold, Imperial College London & Institute of Zoology, Zoological Society of London

ISBN 978-1-78354-551-3

Left blank on purpose

Citation

This report should be cited as

GOLD, SUSANNAH[1]. 2019. The effects of trees and scrub on ecosystem services and biodiversity in the UK uplands: a scoping review. Natural England Evidence Review NEER013

[1] – Imperial College London & Institute of Zoology, Zoological Society of London

Natural England contact:

Suzanne Perry

Senior Specialist

Natural England

Suite D, UNEX House

Bourges Boulevard

Peterborough

PE1 1NG

Suzanne.perry@naturalengland.org.uk

Acknowledgements

The author would like to thank Dave Stone and Suzanne Perry for their guidance and work on the editing of this report.

Cover Photograph

Trees in the uplands © Suzanne Perry

ISBN 978-1-78354-551-3

Left blank on purpose

Summary

Woodland expansion is a priority in UK environmental policy. It forms a key focus in the 25 Year Environment Plan and targets for tree planting include a government commitment for 11 million trees by 2022 (180 000ha woodland creation by 2042, Urban Tree Challenge Fund available to plant 130 000 urban trees over the next two years) and the Woodland Trust's Northern Forest initiative aiming for 50 million over 25 years. These initiatives aim to reduce biodiversity loss and improve ecosystem services, for example carbon sequestration, flood control and regulation of water quality. However, all land-use change results in trade-offs and afforestation can negatively impact on some species and ecosystem services. Part of the current demand for tree planting in the UK is likely to be met by increased planting in the uplands, which are the site of a number of sensitive habitats and species. Therefore, there is a need to carefully consider the benefits and costs of woodland expansion in specific contexts.

The ecosystem services provided by trees in the upland are likely to differ depending on the woodland type, for example conifer monocultures provide a high quantity of fibre whereas open canopy broadleaves provide greater opportunities for biodiversity. Historically much of the planting in the uplands has been commercial conifer plantations. However, there has also been growing demand for broadleaved woodlands for recreational and environmental purposes. The specific location of planting will also be influential, as planting on sensitive habitats, such as blanket bog, may have substantial impacts on both ecosystem services and biodiversity. While the majority of afforestation is currently carried out by planting, there is also a growing interest in allowing natural regeneration. Natural regeneration allows woodland to develop without resorting to planting, direct sowing or coppicing, and also allows development of scrub. Scrub is a diverse habitat which is dominated by native or non-native shrubs and tree saplings. It can be a stage in the succession to woodland or a climax community where conditions prevent woodland vegetation developing.

Maximising the benefits of woodland and scrub expansion for biodiversity and ecosystem services in the uplands requires an approach that puts the "right tree in the right place" and using the right method. Given the number of considerations for woodland and scrub expansion in the uplands, this report scopes the available evidence for the effects of upland trees and scrub on the provision of ecosystem services and biodiversity. This report draws on an initial systematic search of the academic literature using Scopus, and on a systematic review by Burton et al. (2018) identified as being highly relevant. We also conducted specific searches for scrub. From this, we draw out general conclusions on the literature available on effects on ecosystem services and biodiversity by uplands trees and scrub and identify knowledge gaps requiring further research.

In this review, we found that the literature on upland trees and ecosystem services is heavily weighted towards studies of conifer plantations. In particular, a number of studies have considered the influence of conifer plantations on regulating and maintenance of ecosystem services, such as carbon sequestration and water quality regulation. There is also a significant evidence base for the effects of upland conifer plantations on biodiversity, although these studies cover a limited number of taxa. The literature is very limited on provisioning or cultural ecosystem services provided by upland trees. This review also found that while there have been several studies looking at the biodiversity benefits of scrub, it is an understudied habitat and there has been little consideration of the effect of this habitat type on other ecosystem services.

To maximise the ecosystem service benefits of tree planting in the uplands, more studies are required to consider the effects of native woodland, including broadleaved trees and scrub. Greater consideration of the effects of trees on provisioning and cultural ecosystem services and studies considering trade-offs between multiple ecosystem services would also be of benefit to inform policy for upland woodland and scrub expansion.

Contents

1 Introduction

Background

1.1 In the UK, 13% of the total land area is currently woodland, although this varies by region with cover of 19% in Scotland, 15% in Wales, 10% in England, and 8% in Northern Ireland (Forest Research, 2018). UK policy objectives aim to significantly increase this area through tree planting. Current targets include a government commitment to plant 11 million trees in England by 2022 (Defra 2018), and the Northern Forest project which is aiming to plant more than 50 million trees over 25 years. Forestry investment zones are also being trialled to increase investment in tree planting for commercial forests.

1.2 To meet current targets for tree planting, the uplands, which cover all land above approximately 250m altitude, are likely to see an increase in tree cover. The UK uplands consist of a diverse range of habitats, such as blanket bog and upland heath, which support a range of specialised species. Currently, the dominant land use in the uplands is farming, in particular livestock production, with other significant uses include field sport management, forestry and recreation.

1.3 Woodland and scrub expansion in the uplands have the potential to provide significant ecosystem benefits, for example carbon sequestration, water quality regulation and soil stabilisation. However, change in land-use to woodland can also have negative effects including impacts on sensitive species and habitats and may result in trade-offs with benefits from current land use. The particular impacts of woodland expansion are context-specific and depend on the location, woodland type, woodland structure and method of expansion.

1.4 In order to inform advice and decision making on tree planting in the uplands, this review was commissioned to scope the evidence available for the effect of trees and scrub in the uplands on ecosystem services and biodiversity.

Aims and objectives

1.5 The aim of this review was to provide an overview of the available evidence on the effects of trees and scrub in the uplands on the provision of ecosystem services and biodiversity. This is to highlight some of the considerations to be taken into account for woodland and scrub expansion in the uplands and to identify the knowledge gaps requiring further research.

2 Method

2.1 To assess the scope of the available literature, we conducted a systematic search of the literature. This search was initially conducted in Scopus. Table 2.-1 shows the full list of search terms used. Exclusion criteria were that the paper was in the English language and UK-focused. The search returned 514 results. From screening of titles 214 papers were found to be relevant.

2.2 The original intention was to conduct further scoping of the grey literature. However, an initial search found a paper, Burton et al. (2018) which conducted a full systematic review on the effects of woodland expansion on biodiversity and ecosystem services in the UK. This review was recent and covered a broad range of grey literature and academic data bases. This review identified 160 relevant papers following full text screening, of which 79 were upland-specific. Rather than repeat this review, here we extract conclusions from this review relevant to the uplands. Additional papers identified from the Scopus search are drawn in to provide additional detail.

2.3 Scrub was not covered by the Burton et al. (2018) paper, therefore we conducted an additional search specific to this habitat type including grey literature. This was done using google and google scholar. The first 50 most relevant results from each search were screened for relevance.

2.4 The results of the Scopus search were divided into categories based on the ecosystem service considered and the type of woodland. Papers looking at effects on biodiversity were divided by taxa considered. We also used the search record from Burton et al. (2018) to identify papers relevant to the uplands and extracted conclusions of general relevance from the review.

Table 2-1 Search terms used to identify relevant evidence

Search	Trees	Area	Ecosystem Services	Country	Date of search
Scopus	tree* OR forest* OR wood* OR plantation OR broadleaf OR parkland OR {natural regeneration} OR afforestation OR conifer OR scrub* OR ffridd OR {shrubby species} OR heather OR juniper OR birch OR blackthorn OR pinus OR willow OR salix	upland* OR mountain* OR subalpine OR montane	"ecosystem service*" OR "provisioning service*" OR food OR livestock OR game OR crops OR water OR fuel OR peat OR timber OR fibre OR "regulating service*" OR "climate regulation" OR "climate control" OR "hazard regulation" OR "hazard control" OR flood* OR wildfire OR fire OR "disease regulation" OR "pest regulation" OR "water quality" OR "erosion control" OR detoxification OR purification OR pollination OR "flood management" OR "flood control" OR "cultural service*" OR recreation OR tourism OR "aesthetic values" OR "cultural heritage" OR "spiritual values" OR education OR "sense of place" OR "health benefits" OR "wild species diversity" OR "biodiversity" OR "environmental settings" OR "maintenance service*" OR "soil formation" OR "nutrient cycling" OR "water cycling" OR "oxygen production"	“United Kingdom" OR UK OR England OR Wales OR Scotland OR Ireland	25/02/2019
Google and Google Scholar	scrub AND ("ecosystem services" OR biodiversity) AND (upland) AND (UK OR England OR Scotland OR Wales OR Ireland)				25/03/2019

3 Effects of upland trees on ecosystem services

3.1 Ecosystem services can be divided into four broad categories: Regulating, Maintenance, Provisioning and Cultural. The uplands provide ecosystem services across all of these categories, which could be enhanced or negatively impacted by woodland expansion. Here, we consider the evidence base for the effects of upland trees on each of these categories.

Regulating and Maintenance Ecosystem Services

3.2 Regulating and maintenance ecosystem services provided by woodlands include climate regulation, erosion control, flood regulation, air and water quality regulation and soil quality regulation (National Ecosystem Assessment, 2011). Of the studies on upland trees identified, regulating and maintenance ecosystem services were the ecosystem services most widely considered. The majority of these studies focused on conifer plantations, in particular non-native Sitka spruce, with very few studies considering broadleaved or mixed habitats. There was strong evidence available on the effects of conifer plantations in the uplands on flood control (e.g. Hornung and Newson, 1986; Heal et al, 2004). A number of studies had also considered carbon sequestration, looking both at soil organic carbon and above-ground biomass (e.g. Reynolds, 2007; Zerva and Mencuccini, 2005). While the impacts on carbon sequestration and floor control were primarily beneficial, negative impacts were also identified, for example there was a strong evidence base relating conifer plantations to acidification (e.g. Neal, 1992; Reynolds, 2004).

3.3 Studies looking at regulating and maintenance ecosystem services by upland broadleaf woodland focused on water quality and quantity (Doake et al. 2001; Gagkas, 2007; Ryan et al, 2012; Zhang and Hiscock, 2010). A few studies also considered natural regeneration, looking at services such as soil quality (Chapman et al, 2003), water quantity (Haria and Price, 2000), methane release (Nazaries et al, 2013) and carbon sequestration (Perks et al, 2010). The majority of these studies compared between other land uses, such as moorland, and afforested land, rather than between different woodland types.

Provisioning Ecosystem Services

3.4 Provisioning ecosystem services provided by woodlands include timber and fuelwood. Mountains, moorland and heath habitats also provide food from upland farming and wild game and fuel from peat (National Ecosystem Assessment, 2011). Considering the importance of forestry for provision of timber, there was little consideration in the academic literature for the benefits of trees on provisioning ecosystem services in the uplands (Burton et al. 2018). The papers identified primarily focused on opportunities to integrate upland farming and forestry. For example, considering the effect of agroforestry on sheep yields and timber production (Doyle, Evans and Rossiter, 1986), comparing profitability of sheep production relative to forestry (Heaton et al, 1999; Hardarker, 2018) and the benefits of agroforestry in provision of shelter for livestock (McArthur, 1991). One study looked at native woodland, and the potential to integrate this with sheep production (Morgan-Davies, 2008). A further area of focus related to provisioning ecosystem services was the effect of afforestation on fish stocks through changes in water quality (e.g. Rees and Ribbens, 1995; Ormerod et al, 2004; Crisp and Beaumont, 1996).

Cultural Ecosystem Services

3.5 Cultural ecosystem services provided by woodland include recreation and tourism, aesthetic values, cultural heritage, education, employment and sense of place (National Ecosystem Assessment, 2011). However, very few studies have considered the potential effects of woodland expansion through planting or natural regeneration on cultural ecosystem services in the uplands. Two studies identified by Burton et al. (2018) suggested conifer plantations may reduce cultural value, although these effects were context specific (Dhubain et al, 2009; Carroll et al, 2011). Change can have long and short term consequences on sense of place. A further study identified found that woodland and forestry was one of the attributes seen as defining a hill system in Scotland by stakeholders (Morgan-Davies and Waterhouse, 2010). However, overall the evidence base for the effects of upland trees on cultural ecosystem services is very limited.

4 Effects of Upland Trees on Biodiversity

4.1 Biodiversity underlies the provision of ecosystem services. The uplands support a number of different habitats and species, including a substantial number covered under the UK Biodiversity Action Plans. Effects on this biodiversity from upland trees was the focus of a substantial number of papers. However, as with the ecosystem services considered, these primarily looked at the effects of commercial conifer plantations. They also only covered the effects on a few groups, notably birds, carabids, and ground flora.

4.2 A number of studies considered the impacts of upland woodland on bird species. Golden eagles were the focus of several studies (Marquiss, Ratcliffe and Roxburgh, 1985; Watson, 1992; Whitfield et al., 2001). Other specific species considered include ravens (Marquiss, Newton and Ratcliffe, 1978), curlew (Douglas et al, 2014) and black grouse (Peare-Higgins et al. 2007; Scridel et al. 2017). Further studies considered the effects of commercial conifer plantations on multiple bird species (Avery et al, 1989; Calladine et al, 2013; Moss et al, 1979; Wilson et al. 2014). Impacts found in these studies varied, although the evidence suggests closed canopy conifer plantation are likely to have negative impacts on species such as golden eagle and raven.

4.3 Further areas of focus in the literature on biodiversity include vegetation and insect diversity. Carabid species have also been the subject of several studies, with clear evidence for change in species composition as a result of conifer establishment, although not for overall change in biodiversity (Day, 1988; Buse and Good, 1993).

4.4 None of the studies identified by Burton et al. (2018) looked at the effect of broadleaf forest in the uplands on biodiversity. Three studies considered natural regeneration of conifer or mixed woodland. These considered woodland expansion in relation to community structure of fungi and microbes and connectivity (Anderson et al. 2003; Hope et al 2006; Nicol et al. 2007).

5 Effects of Scrub on Ecosystem Services and Biodiversity

5.1 Scrub is defined by Mortimer et al. (2000) as 'all stages from the scattered bushes to closed canopy vegetation, dominated by locally native or non-native shrubs and tree saplings, usually less than 5m tall, occasionally with a few scattered trees.' Alternative names include ffridd and coedcae in Wales, and the upland fringe. In the uplands, the term scrub covers several distinct communities including wet scrub forest zones, juniper scrub and dwarf birch scrub (Natural England, 2006).

5.2 We found a significant lack of reference to scrub in the literature. The literature that was available focused primarily on its biodiversity value. Mortimer et al. (2000) provides a review of the importance of scrub for nature conservation. This found that while there has been consideration of the importance of scrub for birds, herbivorous insects and higher plants there has been little consideration of their importance for reptiles, amphibians, mammals, lower plants or non-herbivorous insects. The greatest body of evidence was for the importance of upland scrub for bird communities (Conway and Fuller, 2010; Fuller 2006; Mortimer et al. 2000; Usher and Thompson, 1993; Woodhouse et al., 2005). These papers emphasised the importance of mosaics of habitat for communities, in which scrub is an important component. Calladine et al. (2013) showed a positive relationship between bird species and shrub cover at the interface between conifer plantations and woodlands.

5.3 Of papers focusing on other ecosystem services influenced by scrub, these mainly focused on heather on mountain heath. Of these, one looked at the establishment of conifers in relation to scrub (French et al. 1997). Two looked specifically at heather scrub in relation to carbon sequestration. These found that heather (*Calluna vulgaris*) cover on peat bog causes a net increase in CO2 release (Dixon et al. 2015) however compared to grass-dominated upland, heather results in significant carbon sequestration, with the amount of carbon sequestered comparable to woodland (Quin et al. 2015). One paper, McHugh (2007) looked at factors influencing erosion, finding that vegetation, including scrub, reduced the level of erosion occurring. Reed et al. (2013) considered increasing scrub cover as part of potential scenarios for future change in the uplands. They consider that a scrubby landscape may have negative effects on cultural ecosystem services by blocking views and interrupting the "uninterrupted purple-tinted vistas". By contrast, Scottish Natural Heritage (2010) suggest that scrub on upland farms can play a range of roles including enhancing the landscape, sheltering livestock and acting as a buffer between grazing and water courses.

5.4 Scrub is a diverse habitat and the term covers a number of different more specific habitats. Some of these may be of more importance for biodiversity, for example juniper scrub, which is a BAP habitat. Further study is required to compare between different scrub types and identify the effects on ecosystem services and biodiversity in different contexts.

6 Factors Affecting Ecosystem Service Provision and Biodiversity by Upland Trees

6.1 Woodland type, whether conifer or broadleaved, is one factor which may influence ecosystem service provision by trees and scrub in the uplands. Scoping of the literature also identified several other factors which may influence ecosystem provision and biodiversity by trees and scrub in the uplands. These include woodland structure, land use type prior to afforestation, location of afforestation and natural regeneration.

6.2 The importance of woodland structure in relation to effects on biodiversity was identified in a number of studies (e.g. Wallace et al., 1992; Calladine et al, 2013; Buse & Good, 1993). These suggest that biodiversity benefits from a mix of species, structure and stand age. Mixed woodland containing open areas and trees at different stages, with areas of scrub may be highly beneficial for biodiversity.

6.3 A number of studies identified in Burton et al. (2018) also noted the importance of the land use prior to afforestation. There is strong evidence that woodland expansion is more beneficial for biodiversity on some land use types that are less likely to host sensitive species (Wilson et al, 2012). Location of planting will also affect biodiversity through impacts on connectivity and structure. This was considered by Hope et al. (2006) who modelled how different woodland expansion scenarios would affect focal species and by Douglas et al (2014) who found that planting on open areas may negatively impact open ground moor species due to edge effects.

6.4 Land type is also important for ecosystem provision, for example Brown and Castellazzi (2014) found that planting on agriculturally low quality upland land may be less beneficial for climate mitigation than on high quality lowland areas. A number of studies also looked specifically at the benefits of riparian tree planting. Riparian planting can have greater benefits through factors such as lowering water temperature variability in streams, although effects on the stream ecosystem may also depend on woodland type (Malcolm et al, 2004; Thomas et al, 2016).

6.5 Natural regeneration is the process by which woodlands are restocked by trees that develop from seeds that fall and germinate in situ. Naturally regenerated woodland may differ from planted forest in structure and species composition (Forestry Commission, 1988). From Burton et al. (2018) only six papers were identified which looked at natural regeneration in the uplands. These primarily focused on naturally regenerating conifer woodlands and biodiversity.

7 Knowledge gaps

Broadleaved tree species

7.1 The evidence base on upland trees was heavily biased towards conifer plantations. This is likely a result of the majority of historical planting consisting primarily of commercial conifer plantations. While some evidence suggests that conifer plantations are beneficial for timber provisioning and carbon sequestration, there is other evidence to suggest that they can negatively impact some aspects of biodiversity, cause acidification and may have negative cultural impact. Broadleaved trees may have greater benefits to ecosystem services in some aspects, however the lack of literature makes comparison between the two woodland types difficult. Particular knowledge gaps include the potential effects of broadleaf trees in the uplands on water quality regulation, biodiversity and cultural ecosystem services.

Provisioning ecosystem services

7.2 We identified a limited number of studies considering provisioning ecosystem services. Given that much of the planting is for commercial forestry plantations, greater consideration of the economic and employment benefits of this to upland communities is required. Trade-offs with other economic land-uses, such as sheep farming or tourism should also be considered.

Cultural Ecosystem Services

7.3 Very few studies considered the potential cultural values of woodlands in the uplands. Woodlands may increase recreational activities but could also be seen as changing the local landscape in a negative way. Burton et al (2018) considered that the lack of studies was due to most recreation activities occurring in mature woodland, making it difficult to study these benefits in newly established woodlands. Knowledge gaps include whether afforestation in the uplands is perceived as enhancing or reducing the cultural value, and the potential effects of upland trees on uses such as tourism.

Species groups

7.4 A number of studies have looked at the effects of upland conifers on biodiversity. However, these have been limited to a small number of taxa, in particular birds, vegetation and carabids. This leaves gaps around the effects of upland trees on groups such as mammals, amphibians and insects outside of carabids.

Trade-offs between ecosystem services

7.5 Burton et al. (2018) identified the need for studies covering more than one ecosystem service. Habitats provide multiple ecosystem services and trade-offs will occur between them. This results in conflicts, for example conifer plantations may provide greater benefits in provisioning services from timber but potentially lower recreational value. Maximising the benefits provided by a particular habitat will depend on resolving these conflicts. More studies are required to consider these trade-offs in specific contexts, in order to inform policy decisions on when and where afforestation is appropriate.

8 Recommendations for areas of future study

8.1 A range of evidence gaps have been identified in relation to trees and scrub in uplands. The following are recommended as a focus for future research:

- Effects of broadleaf forest in the uplands on a range of ecosystem services, including comparison to conifer plantations
- Effects of woodland expansion through tree planting or natural regeneration on provisioning ecosystem services, including trade-offs between forestry and other land uses such as sheep farming and tourism, aesthetics and power generation (e.g. Hydroelectric, wind etc.)
- Influence of woodland expansion on cultural ecosystem services such as tourism and recreation
- Impacts of forest expansion on a wider range of taxa, including mammals, reptiles, amphibians and a wider range of insects
- Comparison between naturally regenerated and planted woodland for biodiversity
- Studies looking at trade-offs between multiple ecosystem services, such as recreation and forestry
- The effects of scrub on regulating and maintenance ecosystem services, such as carbon sequestration, flood control and soil quality regulation

References

ANDERSON, I.C., CAMPBELL, C.D. & PROSSER, J.I., 2003. Diversity of fungi in organic soils under a moorland - Scots pine (Pinus sylvestris L.) gradient. Environmental Microbiology 5(11), 1121–1132.

AVERY, M.I., 1989. Effects of Upland Afforestation on Some Birds of the Adjacent Moorlands. Journal of Applied Ecology 26(3), 957–966.

BROWN, I. & CASTELLAZZI, M., 2014. Scenario analysis for regional decision-making on sustainable multifunctional land uses. Regional Environmental Change 14(4), 1357–1371.

BURTON, V., MOSELEY, D., BROWN, C., METZGER, M. J., & BELLAMY, P. 2018. Reviewing the evidence base for the effects of woodland expansion on biodiversity and ecosystem services in the United Kingdom. Forest Ecology and Management 430, 366-379.

BUSE, A. & GOOD, J.E.G., 1993. The effects of conifer forest design and management on abundance and diversity of rove beetles (Coleoptera: Staphylinidae): implications for conservation. Biological Conservation 64, 67–76.

CALLADINE, J., BIELINSKI, A. & SHAW, G., 2013. Effects on bird abundance and species richness of edge restructuring to include shrubs at the interface between conifer plantations and moorland. Bird Study 60(3), 345–356.

CARROLL, M.S. ET AL., 2011. Back Where They Once Belonged? Local Response to Afforestation in County Kerry, Ireland. Sociologia Ruralis 51(1), 35–53.

CONWAY, G., & FULLER, R. J. 2010. Multi-scale relationships between vegetation pattern and breeding birds in the upland margins (ffridd) of North Wales. British Trust for Ornithology.

CRISP, D. T., & BEAUMONT, W. R. C. 1996. The trout (Salmo trutta L.) populations of the headwaters of the Rivers Severn and Wye, mid-Wales, UK. Science of the Total Environment 177(1-3), 113-123.

DAY, K. R., & CARTHY, J. 1988. Changes in carabid beetle communities accompanying a rotation of Sitka spruce. Agriculture, Ecosystems & Environment 24(4), 407-415.

DEFRA. 2018. A Green Future: Our 25 Year Plan to Improve the Environment

DHUBHÁIN, Á.N. ET AL., 2009. Stakeholders' perceptions of forestry in rural areas-Two case studies in Ireland. Land Use Policy 26(3), 695–703.

DIXON, S. D., WORRALL, F., ROWSON, J. G., & EVANS, M. G. 2015. Calluna vulgaris canopy height and blanket peat CO2 flux: Implications for management. Ecological Engineering, 75, 497-505.

DOAKE, F.M. & HEAL, K., 2001. Assessing the impacts of broadleaved forest on stream water quality: A case study of Carrifran Wildwood. Scottish Forestry 55(2), 77–82.

DOUGLAS, D. J., BELLAMY, P. E., STEPHEN, L. S., PEARCE–HIGGINS, J. W. WILSON, J. D., & GRANT, M. C. (2014). Upland land use predicts population decline in a globally near-threatened wader. Journal of Applied Ecology 51(1), 194-203.

DOYLE, C.J., EVANS, J., ROSSITER, J., 1986. Agroforestry: an economic appraisal of the benefits of intercropping trees with grassland in Lowland Britain. Agricultural Systems 21 (1), 1–32.

FOREST RESEARCH 2018. https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/woodland-statistics/. [Accessed March 2019]

FORESTRY COMMISSION.1988. Bulletin 78: Natural Regeneration of Broadleaves.

FRENCH, D. D., MILLER, G. R., & CUMMINS, R. P. 1997. Recent development of high-altitude Pinus sylvestris scrub in the northern Cairngorm Mountains, Scotland. Biological Conservation 79(2-3), 133-144.

FULLER, R. J., ATKINSON, P. W., GARNETT, M. C., CONWAY, G. J., BIBBY, C. J., & JOHNSTONE, I. G. 2006. Breeding bird communities in the upland margins (ffridd) of Wales in the mid-1980s. Bird Study 53(2), 177-186.

GAGKAS, Z., 2007. Effects of broadleaf woodland cover on water chemistry and critical loads exceedance in acid-sensitive catchments in the UK. University of Edinburgh.

HARDAKER, A. 2018. Is forestry really more profitable than upland farming? A historic and present day farm level economic comparison of upland sheep farming and forestry in the UK. Land Use Policy 71, 98-120.

HEAL, K. V. ET AL., 2004. New data for water losses from mature Sitka spruce plantations in temperate upland catchments. Hydrological Sciences Journal 49(3), 477–493.

HEATON, R. J., RANDERSON, P. F., & SLATER, F. M. 1999. The economics of growing short rotation coppice in the uplands of mid-Wales and an economic comparison with sheep production. Biomass and Bioenergy 17(1), 59-71.

HOPE, J.C.E., HUMPHREY, J.W. & STONE, D., 2006. Modelling the effects of forest landscape dynamics on focal species in Glen Affric, northern Scotland. Forestry 79(3), 293–302.

HORNUNG, M. & NEWSON, M.D. 1986. Upland afforestation: influences on stream hydrology and chemistry. Soil Use and Management 2(2), 61–65.

IMHOLT, C., SOULSBY, C., MALCOLM, I. A., & GIBBINS, C. N. 2013. Influence of contrasting riparian forest cover on stream temperature dynamics in salmonid spawning and nursery streams. Ecohydrology 6(3), 380-392.

MALCOLM, I.A., HANNAH, D.M., DONAGHY, M.J., SOULSBY, C. AND YOUNGSON, A.F., 2004. The influence of riparian woodland on the spatial and temporal variability of stream water temperatures in an upland salmon stream. Hydrology and Earth System Sciences Discussions 8(3), 449-459.

MARQUISS, M., NEWTON, I. & RATCLIFFE, D.A., 1978. The Decline of the Raven, Corvus corax, in Relation to Afforestation in Southern Scotland and Northern England. Journal of Applied Ecology 15(1), 129–144.

MARQUISS, M., RATCLIFFE, D.A. & ROXBURGH, R., 1985. The numbers, breeding success and diet of golden eagles in southern Scotland in relation to changes in land use. Biological Conservation 34, 121–140.

MCARTHUR, A. J. 1991. Forestry and shelter for livestock. Forest Ecology and Management 45(1-4), 93-107.

MCHUGH, M. 2007. Short-term changes in upland soil erosion in England and Wales: 1999 to 2002. Geomorphology 86(1-2), 204-213.

MORGAN-DAVIES, C., & WATERHOUSE, T. 2010. Future of the hills of Scotland: Stakeholders' preferences for policy priorities. Land use policy 27(2), 387-398.

MORGAN-DAVIES, C., WATERHOUSE, A., POLLOCK, M. L., & HOLLAND, J. P. 2008. Integrating hill sheep production and newly established native woodland: achieving sustainability through multiple land use in Scotland. International journal of agricultural sustainability 6(2), 133-147.

MORTIMER, S. R., TURNER, A. J., BROWN, V. K., FULLER, R. J., GOOD, J. E. G., BELL, S. A., ... & WARD, L. K. 2000. The nature conservation value of scrub in Britain. Peterborough, JNCC, (JNCC Report 308)

MOSS, D., TAYLOR, P.N. & EASTERBEE, N., 1979. The effects on song-bird populations of upland afforestation with spruce. Forestry 52(2), 129–150.

NATURAL ENGLAND (2001) The Upland Management Handbook. Chapter 8: Woodland and Scrub.

NATURAL ENGLAND. 2006. The Scrub Management Handbook.

NAZARIES, L. ET AL., 2013. Evidence of Microbial Regulation of Biogeochemical Cycles from a Study on Methane Flux and Land Use Change. Applied and Environmental Microbiology 79(13), 4031–4040.

NEAL, C., REYNOLDS, B., SMITH, C. J., HILL, S., NEAL, M., CONWAY, T., ... & FISHER, R. 1992. The impact of conifer harvesting on stream water pH, alkalinity and aluminium concentrations for the British uplands: an example for an acidic and acid sensitive catchment in mid-Wales. Science of the Total Environment 126(1-2), 75-87.

NICOL, G.W. ET AL., 2007. Afforestation of moorland leads to changes in crenarchaeal community structure. FEMS Microbiology Ecology 60(1), 51–59.

ORMEROD, S. J., JONES, M. E., JONES, M. C., & PHILLIPS, D. R. 2004. The effects of riparian forestry on invertebrate drift and brown trout in upland streams of contrasting acidity. Hydrology and Earth System Sciences 8(3), 578-588.

PEARCE-HIGGINS, J.W. ET AL., 2007. The role of forest maturation in causing the decline of Black Grouse Tetrao tetrix. Ibis 149(1), pp.143–155.

PERK, M. P., NAGY, L., MEIR, P., AULD, M., & WOOD, M. (2011). Carbon sequestration benefits of new native woodland expansion in Scotland. Scottish Forest Alliance.

QUIN, S. L., ARTZ, R. R., COUPAR, A. M., & WOODIN, S. J. 2015. Calluna vulgaris-dominated upland heathland sequesters more CO2 annually than grass-dominated upland heathland. Science of the Total Environment 505, 740-747.

REED, M. ET AL. 2013. Anticipating and managing future trade-offs and complementarities between ecosystem services. Ecology and Society, 18(1), 5.

REES, R. M., & RIBBENS, J. C. H. 1995. Relationships between afforestation, water chemistry and fish stocks in an upland catchment in south west Scotland. Water, air, and soil pollution 85(2), 303-308.

REYNOLDS, B. 2004. Continuous cover forestry: possible implications for surface water acidification in the UK uplands. Hydrology and Earth System Sciences 8(3), 306-313.

REYNOLDS, B., 2007. Implications of changing from grazed or semi-natural vegetation to forestry for carbon stores and fluxes in upland organo-mineral soils in the UK. Hydrology and Earth System Sciences 11(1), 61–76.

RYAN, J.L. ET AL., 2012. The effect of broadleaf woodland on aluminium speciation in stream water in an acid-sensitive area in the UK. Science of the Total Environment 439, 321–331.

SCOTTISH NATURAL HERITAGE. 2010. Biodiversity on hill and upland farms.

SCRIDEL, D., GROOM, J.D. & DOUGLAS, D.J.T., 2017. Native woodland creation is associated with increase in a Black Grouse Lyrurus tetrix population. Bird Study 3657(April), 1–14.

THOMAS, S. M., GRIFFITHS, S. W., & ORMEROD, S. J. (2016). Beyond cool: adapting upland streams for climate change using riparian woodlands. Global change biology 22(1), 310-324.

UK NATIONAL ECOSYSTEM ASSESSMENT. 2011. The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge.

USHER, M. B., & THOMPSON, D. B. A. 1993. Variation in the upland heathlands of Great Britain: conservation importance. Biological Conservation 66(1), 69-81.

WALLACE, A.H.L. ET AL., 1992. The Effects of Afforestation on Upland Plant Communities: An Application of the British National Vegetation Classification. Journal of Applied Ecology 29(1), 180–194.

WATSON, J., 1992. Golden Eagle Aquila chrysaetos breeding success and afforestation in Argyll. Bird Study 39(June), 203–206.

WHITFIELD, D.P. ET AL., 2001. The effects of forestry on golden eagles on the island of Mull, western Scotland. Journal of Applied Ecology 38(6), 1208–1220.

WILSON, J.D. ET AL., 2014. Modelling edge effects of mature forest plantations on peatland waders informs landscape-scale conservation. Journal of Applied Ecology 51(1), 204–213.

WILSON, M. W., GITTINGS, T., PITHON, J., KELLY, T. C., IRWIN, S., & O'HALLORAN, J. 2012. Bird diversity of afforestation habitats in Ireland: current trends and likely impacts. Biology and Environment: Proceedings of the Royal Irish Academy. Royal Irish Academy. 55-68

WOODHOUSE, S. P., GOOD, J. E. G., LOVETT, A. A., FULLER, R. J., & DOLMAN, P. M. 2005. Effects of land-use and agricultural management on birds of marginal farmland: a case study in the Llŷn peninsula, Wales. Agriculture, ecosystems & environment 107(4), 331-340.

ZERVA, A. & MENCUCCINI, M., 2005. Carbon stock changes in a peaty gley soil profile after afforestation with Sitka spruce (Picea sitchensis). Annals of Forest Science, 62, pp.873–880.

ZHANG, H. & HISCOCK, K.M., 2010. Modelling the impact of forest cover on groundwater resources: A case study of the Sherwood Sandstone aquifer in the East Midlands, UK. Journal of Hydrology 392(3–4), 136–149.

Natural England is here to secure a healthy natural environment for people to enjoy, where wildlife is protected and England's traditional landscapes are safeguarded for future generations.

Should an alternative format of this publication be required, please contact our enquiries line for more information: 0300 060 3900 or email enquiries@naturalengland.org.uk.

Catalogue Code: NEER013