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The benefits of mountain woodland restoration

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Key words: Biodiversity, Climate change, Conservation policy, Ecosystem services, Environmental management, Montane scrub, Natural capital, Nature-based solutions

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Author contributions: SW conceived the idea; SW, AJ elaborated the concept; SW wrote the first draft; SW, AJ revised subsequent drafts.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/rec.13701

Abstract

Mountain woodland ecotones require urgent action to reverse long-term habitat degradation and biodiversity loss. There is growing interest in restoring high-elevation woodland and scrub communities, harnessing planting and natural regeneration. Emissions offsetting has been a key driver, yet mountain systems offer slower mechanisms for biomass accumulation due to their typically smaller size, lower density and slower growth than forests at lower elevations. We argue that the natural capital afforded by mountain woodland restoration is far more comprehensive than carbon sequestration alone and encompasses an important array of ecosystem services and biodiversity gains. Improved opportunities for wildlife and people include natural hazard protection, sheltering, structural variability, vegetation diversity and recreation. Furthermore, mountain woodland restoration provides critically needed nature-based solutions for reducing threats from escalating climate change such as soil erosion, flooding, warming temperatures and extreme weather. It is imperative that these benefits are embedded within conservation policy and environmental incentives.

Conceptual implications

- Mountain woodland restoration offers a broader suite of benefits to people and biodiversity than carbon sequestration potential alone.
- Concerted action for mountain woodland restoration will provide fundamental nature-based solutions which are urgently needed to alleviate the risks to infrastructure, rural livelihoods, food production, wildlife and recreation during the escalating climate crisis.
- Mountain woodland restoration should be recognised as fundamentally important in conservation policy, economic incentives and land management decisions for high-elevation regions across the globe.

Introduction

Mountain woodland ecotones across the globe have undergone significant anthropogenic degradation and contraction which has accelerated during the last few hundred years. Driving factors include overstocking and consequent overgrazing by large herbivores, agricultural expansion, burning, infrastructure development and nutrient loading via atmospheric deposition (Scott 2000; Verheyen et al. 2009). Mountain forest and scrub communities are now highly fragmented and depleted in many areas, with negative implications for the ecosystem functions they once performed and thus the ecological and socioeconomic systems which depend on them. Governmental bodies, charities, land managers and local communities are expressing growing interest in facilitating restoration of these habitats. Yet there can be a hesitancy to act without tangible rewards, given the high resource effort and time required to repair slow-growing upland vegetation in remote locations. Policymakers and conservation practitioners have therefore communicated the need for a clear evidence base outlining the suite of environmental and human benefits provided by mountain woodland restoration.

There is an increasing focus on tree planting and woodland regeneration for promoting carbon sequestration during the escalating climate change crisis (Bastin et al. 2019; Fletcher et al. 2021). However, sequestering carbon emissions using woody species is less definitive in high-latitude and high-attitude mountain ecosystems. Forest and treeline expansion in these regions can aid soil formation, but also alter soil mineralization, respiration and decomposition rates; potentially counteracting any increased aboveground biomass storage which will nonetheless be slow (Hartley et al. 2012; Friggens et al. 2020).

Despite this uncertainty, we argue that mountain woodland restoration should be incorporated more widely into conservation policy because there is significant restoration value through nature-based solutions, ecosystem service provision and biodiversity gains. Here we outline the opportunities for natural hazard mitigation, soil stabilization, flood risk management, habitat sheltering and associated flora and fauna. This evidence indicates that

mountain woodland restoration offers enhanced natural capital within a diverse environment capable of supporting a variety of land-uses.

In the context of our review, mountain woodland is broadly defined as communities of tree species in high-elevation and arctic-alpine regions. It includes the ecotone between the timberline (where trees have an upright form) and montane scrub (Fig. 1) at the uppermost altitudinal limit of tree growth (the treeline). Restoration of these habitats can be achieved through tree planting or management to facilitate natural regeneration, although the outputs will differ somewhat depending on the approach used. The narrative below has a wide biogeographical focus, but specific examples of mountain woodland restoration benefits from across the globe are given in Table 1.

Defence against soil erosion and flooding

Mountain forests protect built infrastructure, farmland and environmental assets against a range of natural hazards including avalanches, landslides, and rockfalls (Bebi et al. 2001; Brang et al. 2001; Stoffel et al. 2006). The likelihood and severity of these destructive events is reduced by management to improve the structural complexity, condition and regeneration of treeline habitats (Dorren et al. 2005; Wehrli et al. 2006). Such restoration actions are thus important nature-based solutions for alleviating the impacts of more extreme weather caused by global climate change.

For example, afforestation and scrub establishment in mountain regions moderates soil erosion risks. Colonisation by trees and shrubs can create deeper, more organic and variable soils on areas previously covered by very thin, eroded soil and scree (Pawlik 2013; Valtera et al. 2013). The presence of tree roots stabilizes steep slopes and ameliorates soil structure, filtration and permeability (Podrázský et al. 2015; Scarciglia et al. 2020). These belowground modifications increase the water absorption rates of upland soils, while the tree canopy above intercepts rainfall and controls evapotranspiration (Dirnböck & Grabherr 2000; He et al. 2012). Downslope hydrological functioning and river discharge is subsequently regulated by reduced surface runoff and streamflow (Wei et al. 2005; McVicar et al. 2007).

The management benefits for alleviating downstream flooding are particularly noticeable when woodland is restored to over-compacted and degraded soils in upland river catchments (Murphy et al. 2021). Moreover, the improved water retention capacity of treeline communities compared to alpine grasslands can also act as moisture reservoir during periods of drought (Dirnböck & Grabherr 2000).

Shelter and vegetation facilitation

As well as buffering the effects of precipitation variability, the presence of mountain woodland and scrub has an important sheltering influence against high wind speeds, intense sunlight and extreme temperature fluctuations. This reduction in exposure can assist the survival and development of other flora in the otherwise harsh arctic-alpine environment, including dwarf shrubs and palatable eutrophic tall herbs (Jonasson 1992; Dona & Galen 2007). Clumps of montane trees and arctic-alpine shrubs accumulate snowdrifts on their leeward side which offers further insulation against frost damage, abrasion or winter desiccation (Hadley & Smith 1986; Holtmeier & Broll 2017).

Positive feedbacks, facilitation and succession can result when these treeline sheltering effects create more favourable microclimatic conditions for forest recruitment via the establishment of new seedlings (Smith et al. 2003; Bekker 2005; Baumeister & Callaway 2006). Enhanced vegetation growth within the ecotone is also supported by leaf litter, root exudates and diverse mycorrhizal associations with woody species which increase rates of mineralization, nitrogen availability and soil organic matter accumulation (Jumpponen et al. 1998; Sjögersten & Wookey 2005; Mitchell et al. 2010; Friggens et al. 2020)

Animal biodiversity

The structural variability of treeline habitats offers a range of ecological niches for numerous pollinators and generalist insects groups, including diptera, beetles, lepidoptera and bumblebees (Scottish Montane Willow Research Group 2005). Populations of specialist phytophagous taxa and locally endemic invertebrates are also sustained, often through host-

specific relationships with individual tree species, particularly montane willows (Pryke & Samways 2010; Liston et al. 2012). The high diversity of fungi, plants and invertebrates in mountain woodland subsequently provides opportunities for mycophagous, herbivorous and insectivorous small mammals, as well as predators higher up the food chain including raptors (Scott 2000; Schickmann et al. 2012). Avian species richness and biomass are much greater in re-established upland forests in comparison to unforested areas (Barri et al. 2021; Warner et al. 2021), with the benefits of treeline creation extending to birds of woodland edge and open scrub (Klaus et al. 2020). Livestock, reindeer, deer and other game animals such as grouse take advantage of the shelter and nutritious forage provided by the ecotone, especially alpine willow-dominated communities (García-González et al. 2016; Denryter et al. 2022). Riparian woodland restoration in upland catchments also mediates water temperature fluctuations through shading (Garner et al. 2015), thereby enriching habitat quality for freshwater invertebrates and fish such as salmonids and buffering them from harmful warming due to climate change.

Benefits to human experience

Restoration of mountain woodland and treeline scrub removes abrupt forest edges at the timberline and allows for a visual and ecological gradation into montane grassland and heaths (Scott 2000). This mosaic structure offers aesthetic landscape improvements beyond uniform plantation boundaries and overgrazed vegetation on bare slopes. It also creates an environment with a variety of opportunities for a range of land users, including tourism, birdwatching, botanizing, an enhanced hunting experience, sport and other recreational activities. With visitor numbers to many upland regions increasing (Tsiaras 2017), the noise attenuation effect provided by woodland could dampen unwanted anthropogenic sound and reduce acoustic disturbance for both wildlife and people (Attenborough & Taherzadeh 2016). Access to a holistic mountain adventure which involves healthy, biodiverse treeline habitats has a positive influence on physical and mental well-being (Bell & Thompson 2014). Mountain

woodlands are also an intrinsic feature of indigenous culture and food production across the globe (Msuya et al. 2010; Svensson et al. 2020).

Conclusion

The ecosystem service and biodiversity benefits delivered by mountain woodland restoration are much greater than carbon sequestration alone. Moreover, the escalating climate crisis gives an increasingly urgent need to implement restoration programmes now to protect the essential resources, rural livelihoods and recreational value offered by high-elevation systems. Mountain woodland will be critical for reducing the impacts of more frequent storms and other natural hazards, creating shelter and allowing temperature sensitive species to persist even as extreme weather becomes more common. We recommend that the natural capital and nature-based solutions afforded by mountain woodland restoration are integrated into conservation policy incentives and environmental management decision making as key tools for combatting climate breakdown and averting biodiversity loss.

Acknowledgements

Inspiration and ideas for this paper were developed from discussions with Diana Gilbert, Mick Drury, David Mardon and the Mountain Woodland Action Group. SW acknowledges funding from Corrour Estate, Woodland Trust, Scottish Forestry Trust, Macaulay Development Trust, National Trust for Scotland, Forest Research and Future Woodlands Scotland. AJ is supported by the Natural Environment Research Council (NERC) under grants NE/S010041/1 and NE/V00929X/1.

LITERATURE CITED

Attenborough K, Taherzadeh S (2016) Sound propagation through forests and tree belts. *Proceedings of the Institute of Acoustics* **38**:114-125

Barri F, Toledo M, Herzog P, Bellis L, Renison D (2021) Avifaunal responses after two decades of Polylepis forest restoration in central Argentina. *Neotropical Biodiversity* **7**:205-212

Bastin J-F, Finegold Y, Garcia C, Mollicone D, Rezende M, Routh D, Zohner CM, Crowther TW (2019) The global tree restoration potential. *Science* **365**:76-79

Batllori E, Camarero JJ, Ninot JM, Gutiérrez E (2009) Seedling recruitment, survival and facilitation in alpine Pinus uncinata tree line ecotones. Implications and potential responses to climate warming. *Global Ecology and Biogeography* **18**:460-472

Baumeister D, Callaway RM (2006) Facilitation by Pinus flexilis during succession: a hierarchy of mechanisms benefits other plant species. *Ecology* **87**:1816-1830

Bebi P, Kienast F, Schönenberger W (2001) Assessing structures in mountain forests as a basis for investigating the forests' dynamics and protective function. *Forest Ecology and Management* **145**:3-14

Bekker MF (2005) Positive feedback between tree establishment and patterns of subalpine forest advancement, Glacier National Park, Montana, USA. *Arctic, Antarctic, and Alpine Research* **37**:97-107

Bell S, Thompson CW (2014) Human engagement with forest environments: implications for physical and mental health and wellbeing. Pages 71-92 In: Fenning T, (ed) Challenges and Opportunities for the World's Forests in the 21st Century. Springer, Dordrecht

Bennell AP, Millar CS (1984) Fungal pathogens of birch in Britain. *Proceedings of the Royal Society of Edinburgh, Section B: Biological Sciences* **85**:153-167

Bland KP, Entwistle PF, Horsfield D (1997) The invertebrate fauna of montane scrub. Pages 35-40 In: Gilbert D, Horsfield D and Thompson DBA, (eds) The ecology and restoration of montane and subalpine habitats in Scotland. Highland Birchwoods, Munlochy

Brang P, Schönenberger W, Ott E, Gardner B (2001) Forests as protection from natural hazards. *The forests handbook* **2**:53-81

Denryter K, Cook RC, Cook JG, Parker KL (2022) Animal-defined resources reveal nutritional inadequacies for woodland caribou during summer–autumn. *The Journal of Wildlife Management*

Dirnböck T, Grabherr G (2000) GIS assessment of vegetation and hydrological change in a high mountain catchment of the Northern Limestone Alps. *Mountain Research and Development* **20**:172-179

Dona AJ, Galen C (2007) Nurse effects of alpine willows (Salix) enhance over-winter survival at the upper range limit of fireweed, Chamerion angustifolium. *Arctic, Antarctic, and Alpine Research* **39**:57-64

Dorren L, Berger F, Mermin E, Tardif P (2006) Results of real size rockfall experiments on forested and non-forested slopes. Pages 223-228 In: Disaster mitigation of debris flows, slope failures and landslides. Universal Academy Press, Inc., Tokyo, Japan

Dorren LK, Berger F, Le Hir C, Mermin E, Tardif P (2005) Mechanisms, effects and management implications of rockfall in forests. *Forest Ecology and Management* **215**:183-195

Fletcher TI, Scott CE, Hall J, Spracklen DV (2021) The carbon sequestration potential of Scottish native woodland. *Environmental Research Communications* **3**:041003

Friggens NL, Aspray TJ, Parker TC, Subke J-A, Wookey PA (2020) Spatial patterns in soil organic matter dynamics are shaped by mycorrhizosphere interactions in a treeline forest. *Plant and Soil* **447**:521-535

García-González R, Aldezabal A, Laskurain NA, Margalida A, Novoa C (2016) Factors affecting diet variation in the Pyrenean rock ptarmigan (Lagopus muta pyrenaica): conservation implications. *PloS one* **11**:e0148614

Garner G, Malcolm IA, Sadler JP, Millar CP, Hannah DM (2015) Inter-annual variability in the effects of riparian woodland on micro-climate, energy exchanges and water temperature of an upland Scottish stream. *Hydrological Processes* **29**:1080-1095

Gu C, Mu X, Gao P, Zhao G, Sun W, Tatarko J, Tan X (2019) Influence of vegetation restoration on soil physical properties in the Loess Plateau, China. *Journal of Soils and Sediments* **19**:716-728

Hadley JL, Smith WK (1986) Wind effects on needles of timberline conifers: seasonal influence on mortality. *Ecology* **67**:12-19

Halley D (2011) Common birds of montane scrub and their potential to recolonise restored habitat in Scotland. *Scrubbers' Bulletin* **9**:22-34

Hartley IP, Garnett MH, Sommerkorn M, Hopkins DW, Fletcher BJ, Sloan VL, Phoenix GK, Wookey PA (2012) A potential loss of carbon associated with greater plant growth in the European Arctic. *Nature Climate Change* **2**:875-879

Hättenschwiler S, Smith WK (1999) Seedling occurrence in alpine treeline conifers: a case study from the central Rocky Mountains, USA. *Acta Oecologica* **20**:219-224

He Z, Zhao W, Liu H, Tang Z (2012) Effect of forest on annual water yield in the mountains of an arid inland river basin: a case study in the Pailugou catchment on northwestern China's Qilian Mountains. *Hydrological Processes* **26**:613-621

Hesling E, Taylor A (2015) Mountain woodlands in Scotland found to support a treasure trove of fungal diversity. *Scrubbers' Bulletin* **11**:22-27

Holtmeier F-K, Broll G (2017) Feedback effects of clonal groups and tree clusters on site conditions at the treeline: implications for treeline dynamics. *Climate Research* **73**:85-96

Jiao J, Zhang Z, Bai W, Jia Y, Wang N (2012) Assessing the ecological success of restoration by afforestation on the Chinese Loess Plateau. *Restoration Ecology* **20**:240-249

Jonasson S (1992) Plant responses to fertilization and species removal in tundra related to community structure and clonality. *Oikos* **63**:420-429

Jumpponen A, Mattson K, Trappe JM, Ohtonen R (1998) Effects of established willows on primary succession on Lyman Glacier forefront, North Cascade Range, Washington, USA: evidence for simultaneous canopy inhibition and soil facilitation. *Arctic and Alpine Research* **30**:31-39

Kelly CN, Mcguire KJ, Miniat CF, Vose JM (2016) Streamflow response to increasing precipitation extremes altered by forest management. *Geophysical Research Letters* **43**:3727-3736

Klaus NA, Rush SA, Weitzel SL, Holdrege MC (2020) Changes in tree canopy, groundcover, and avian community following restoration of a Montane longleaf pine woodland. *The American Midland Naturalist* **184**:163-176

Liston AD, Knight G, Heibo E, Bland K, Barstad T-E, Blank SM, Boevé J-L, Fiedler C, Grearson K, Halstead A (2012) On Scottish sawflies, with results of the 14th International Sawfly Workshop, in the southern Highlands, 2010 (Hymenoptera, Symphyta). *Beiträge zur Entomologie= Contributions to Entomology* **62**:1-68

Mardon D (2003) Conserving montane willow scrub on Ben Lawers NNR. *Botanical Journal of Scotland* **55**:189-203

Mcvicar TR, Li L, Van Niel TG, Zhang L, Li R, Yang Q, Zhang X, Mu X, Wen Z, Liu W (2007) Developing a decision support tool for China's re-vegetation program: Simulating regional impacts of afforestation on average annual streamflow in the Loess Plateau. *Forest Ecology and Management* **251**:65-81

Milne JM, Helfer S, Kirk C, Hollingsworth PM, Ennos RA (2012) Molecular evidence indicates that subarctic willow communities in Scotland support a diversity of host-associated Melampsora rust taxa. *Fungal biology* **116**:603-612

Mitchell RJ, Campbell CD, Chapman SJ, Cameron CM (2010) The ecological engineering impact of a single tree species on the soil microbial community. *Journal of Ecology* **98**:50-61

Monger F, V Spracklen D, J Kirkby M, Schofield L (2022) The impact of semi-natural broadleaf woodland and pasture on soil properties and flood discharge. *Hydrological Processes* **36**:e14453

Msuya TS, Kideghesho JR, Mosha TC (2010) Availability, preference, and consumption of indigenous forest foods in the Eastern Arc Mountains, Tanzania. *Ecology of food and nutrition* **49**:208-227

Murphy TR, Hanley ME, Ellis JS, Lunt PH (2021) Native woodland establishment improves soil hydrological functioning in UK upland pastoral catchments. *Land Degradation & Development* **32**:1034-1045

Pawlik Ł (2013) The role of trees in the geomorphic system of forested hillslopes - a review. *Earth-Science Reviews* **126**:250-265

Podrázský V, Holubík O, Vopravil J, Khel T, Moser W, Prknová H (2015) Effects of afforestation on soil structure formation in two climatic regions of the Czech Republic. *Journal of Forest Science* **61**:225-234

Pryke J, Samways M (2010) Significant variables for the conservation of mountain invertebrates. *Journal of insect conservation* **14**:247-256

Scarciglia F, Nicolaci A, Del Bianco S, Pelle T, Soligo M, Tuccimei P, Marzaioli F, Passariello I, Iovino F (2020) Reforestation and soil recovery in a Mediterranean mountain environment: Insights

into historical geomorphic and vegetation dynamics in the Sila Massif, Calabria, southern Italy. *Catena* **194**:104707

Schickmann S, Urban A, Kräutler K, Nopp-Mayr U, Hackländer K (2012) The interrelationship of mycophagous small mammals and ectomycorrhizal fungi in primeval, disturbed and managed Central European mountainous forests. *Oecologia* **170**:395-409

Scott M (2000) Natural Heritage Management Series: Montane Scrub. Scottish Natural Heritage, Battleby

Scottish Montane Willow Research Group. (2005) Biodiversity: taxonomy, genetics and ecology of sub-arctic willow scrub. Summary Booklet. Royal Botanic Garden Edinburgh, Edinburgh

Sjögersten S, Wookey PA (2005) The role of soil organic matter quality and physical environment for nitrogen mineralization at the forest-tundra ecotone in Fennoscandia. *Arctic, Antarctic, and Alpine Research* **37**:118-126

Smith JA, Blanchette RA, Newcombe G (2004) Molecular and morphological characterization of the willow rust fungus, Melampsora epitea, from arctic and temperate hosts in North America. *Mycologia* **96**:1330-1338

Smith WK, Germino MJ, Hancock TE, Johnson DM (2003) Another perspective on altitudinal limits of alpine timberlines. *Tree Physiology* **23**:1101-1112

Stoffel M, Wehrli A, Kühne R, Dorren LK, Perret S, Kienholz H (2006) Assessing the protective effect of mountain forests against rockfall using a 3D simulation model. *Forest Ecology and Management* **225**:113-122

Svensson J, Bubnicki JW, Jonsson BG, Andersson J, Mikusiński G (2020) Conservation significance of intact forest landscapes in the Scandinavian Mountains Green Belt. *Landscape Ecology* **35**:2113-2131

Teich M, Bebi P (2009) Evaluating the benefit of avalanche protection forest with GIS-based risk analyses—A case study in Switzerland. *Forest Ecology and Management* **257**:1910-1919

Totland Ø, Esaete J (2002) Effects of willow canopies on plant species performance in a low-alpine community. *Plant Ecology* **161**:157-166

Tsiaras S (2017) Exploring the impact of tourism to the sustainable development of mountain regions: Implications of the climatic conditions. *International Journal of Agricultural and Environmental Information Systems* **8**:14-28

Valtera M, Šamonil P, Boublik K (2013) Soil variability in naturally disturbed Norway spruce forests in the Carpathians: Bridging spatial scales. *Forest Ecology and Management* **310**:134-146

Verheyen K, Adriaenssens S, Gruwez R, Michalczyk IM, Ward LK, Rosseel Y, Van Den Broeck A, Garcia D (2009) Juniperus communis: victim of the combined action of climate warming and nitrogen deposition? *Plant Biology* **11**:49-59

Warner E, Hector A, Brown N, Green R, Savory A, Gilbert D, Mcdonnell A, Lewis OT (2021) The response of plants, carabid beetles and birds to 30 years of native reforestation in the Scottish Highlands. *Journal of Applied Ecology* **58**:2185-2194

Watts SH, Griffith A, Mackinlay L (2019) Grazing exclusion and vegetation change in an upland grassland with patches of tall herbs. *Applied Vegetation Science* **22**:383-393

Wehrli A, Dorren LK, Berger F, Zingg A, Schönenberger W, Brang P (2006) Modelling long-term effects of forest dynamics on the protective effect against rockfall. *For. Snow Landsc. Res* **80**:57-76

Wei X, Liu S, Zhou G, Wang C (2005) Hydrological processes in major types of Chinese forest. *Hydrological Processes: An International Journal* **19**:63-7

Figure 1. Restored montane willow scrub at Ben Lawers NNR, Scotland, featuring *Salix lapponum* (downy willow) planted 15 years previously in an area where large herbivores are excluded by fencing. The site is rich in invertebrate and bird biodiversity, as well as associated upland eutrophic tall herb vegetation which has regenerated when freed from overgrazing.

Benefit	Examples	References
Protection from extreme events	• GIS-based analysis for a 300-year snow avalanche event in the Swiss Alps showed that deforestation significantly increased the collective risk to people and infrastructure • Rockfall experiments in the French Alps demonstrated that forested slopes provide protection against rockfall by decreasing velocity and rebound height	Teich & Bebi (2009) Dorren et al. (2006)
Control of soil erosion	• Afforestation and replanted scrubland on the Loess Plateau, China, significantly enhanced soil anti-erodibility indexes compared to pre-planted sites	Jiao et al. (2012) & Gu et al. (2019)
Flood mitigation	• A comparison of paired watersheds at Coweeta, southeastern United States, found that reforestation at riverbasin headwaters significantly reduced peak stream flows and protected against flooding during spring snow melt • Upland broad-leaved woodland in the Lake District, England, increased topsoil permeability and reduced peak flood discharge and run-off by up to 60% in comparison to livestock pasture	Kelly et al. (2016) Monger et al. (2022)
Sheltering & vegetation facilitation	• Arctic-alpine willow canopies in Finse, western Norway, promote aboveground mass of associated herbs such as *Potentilla crantzii* (Alpine cinquefoil), *Ranunculus acris* (Meadow buttercup), *Bartsia alpina* (Alpine bartsia), *Geum rivale* (Water avens), *Geranium sylvaticum* (Wood cranesbill) and *Scorzoneroides autumnalis* (Autumn hawkbit) • Snow holding in the treeline ecotone facilitates greater conifer seedling survival rates of *Picea engelmannii* (Engelmann spruce) and *Abies lasiocarpa* (Subalpine fir) in the Rocky Mountains, and *Pinus uncinata* (Swiss mountain pine) in the Catalan Pyrenees • Management interventions to protect montane willow scrub in Scotland from large herbivores have also promoted restoration of the associated grazing-sensitive hydrophilous tall herb fringe community (Fig. 1)	Totland & Esaete (2002) Hättenschwiler & Smith (1999) & Batllori et al. (2009) Watts et al. (2019)
Fungal diversity	• Analysis of root samples collected from montane woodland in Scotland discovered exceptionally high diversity of ectomycorrhizal fungi, including 34 species new to the country and 23 considered new to science • *Salix* and *Betula* subarctic scrub supports commensal relationships with tar spot fungi and leaf rusts (e.g. *Rhytisma*, *Melampsora* & *Melampsoridium)*	Hesling & Taylor (2015) Bennell & Millar (1984), Smith et al. (2004), & Milne et al. (2012)
Invertebrate diversity	• Restored *Salix lapponum-luzula sylvatica* scrub in the Scottish Highlands (Fig. 1) has high associated invertebrate diversity, attracting a wide range species including *Bombus monticola* (Blaeberry bumblebee), *Cerura vinula* (Puss moth), *Lasiocampa quercus callunae* (Northern eggar), *Orgyia antiqua* (Vapourer moth) and *Furcula furcula* (Sallow kitten) • Montane willows support rare and endangered host specific willow-galling sawflies in the genera *Pontania*, *Phyllocolpe* and *Euura*	Mardon (2003) Bland et al. (1997) & Liston et al. (2012)
Bird diversity	• Restoration of montane longleaf pine forests in Georgia, United States, increased bird species richness and abundance, particularly for shrub and woodland dependents of high conservation value, including *Melanerpes erythrocephalus* (Red-headed Woodpecker), *Setophaga discolor* (Prairie Warbler) and *Hylocichla mustelina* (Wood Thrush) • Treeline restoration in Britain is anticipated to encourage the breeding of bird species that are declining, nest sporadically or have potential for colonisation from Scandinavia, such as *Tetrao tetrix* (Black Grouse), *Turdus torquatus* (Ring Ouzel) *Turdus iliacus* (Redwing), *Motacilla flava* (Yellow Wagtail), *Tringa nebularia* (Greenshank), *Luscinia svecica* (Bluethroat) and *Calcarius lapponicus* (Lapland Bunting).	Klaus et al. (2020) Halley (2011)

Table 1: Selected examples of mountain woodland restoration benefits from a range of geographical locations.