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The benefits of mountain woodland restoration

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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.

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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.