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Moorland ecology and conservation of the Kinder Scout plateau: An integrated assessment of an upland peatland ecosystem

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Abstract
Kinder Scout is the highest point in the Peak District National Park and supports one of the United Kingdom's most important blanket bog ecosystems. This study examines the geology, ecology, floral diversity and conservation significance of the plateau, with particular emphasis on the relationship between vegetation composition and ecosystem function. The Carboniferous Millstone Grit geology provides the foundation for acidic, waterlogged peat soils that support characteristic blanket bog vegetation. Field observations identified a diverse assemblage of dwarf shrubs, bryophytes, liverworts, graminoids, ferns and flowering plants, including Calluna vulgaris, Vaccinium myrtillus, Sphagnum fallax and Eriophorum vaginatum. These species play essential roles in peat formation, carbon sequestration, water retention, soil stabilisation and habitat provision. The presence of diverse bryophytes and liverworts indicates relatively stable hydrological conditions, while a limited number of non-characteristic species reflects localised disturbance and transitional habitats. The findings demonstrate that, despite historical degradation caused by grazing, erosion and land-use change, extensive restoration programmes have significantly improved vegetation cover and ecological function. Kinder Scout now serves as an important example of successful peatland restoration, illustrating the benefits of science-based conservation management. Continued protection and monitoring are essential to preserve biodiversity, maintain ecosystem services, regulate downstream hydrology and enhance long-term carbon storage in response to future environmental and climatic change.

Keywords: Mosses, upland, peat, moorlands, Peak District

Introduction
Kinder Scout is an extensive upland moorland plateau situated within the Dark Peak region of the Peak District National Park (Anderson *et al*.,1994) [1]. Rising to an elevation of 636 m above mean sea level, it represents the highest topographic point within the Peak District, the county of Derbyshire, and the East Midlands (Tebbutt *et al*,2006) [2]. The plateau is recognised as a National Nature Reserve because of its internationally significant blanket bog habitats, distinctive geomorphology, and ecological importance (Gordon *et al*.,2002) [3].
The geological framework of Kinder Scout and the surrounding Edale Basin was established during the Carboniferous Period, approximately 320 million years ago, when the region occupied a near-equatorial position as part of the supercontinent Euramerica (Tebbutt *et al*,2006) [2]. At that time, tropical climatic conditions prevailed, and repeated fluctuations in relative sea level strongly influenced sediment deposition across the Pennine Basin (Tebbutt *et al*,2006) [2]. This basin functioned as a major depositional environment bordered by elevated landmasses undergoing prolonged erosion (Tebbutt *et al*,2006) [2]. Sediments generated from these surrounding uplands were transported into the basin through river systems, where they accumulated over millions of years to produce the alternating sandstone, siltstone, and mudstone successions that today constitute the Millstone Grit Group (Tebbutt *et al*,2006) [2].
Sedimentary deposition varied in response to cyclic changes in sea level (Anderson *et al*.,1994) [1]. During periods of marine regression, extensive fluvial-deltaic systems advanced into the basin, depositing thick sequences of coarse-grained sandstone that now form the resistant gritstone escarpments characteristic of Kinder Scout (Siddiqui *et al*.,2017) [4]. Conversely, marine transgressions promoted the accumulation of finer-grained silts and muds within shallow marine environments, producing laterally extensive mudstone units (Morad *et al*,2010) [5]. Certain stratigraphic intervals also preserve deposits associated with sediment gravity flows, indicating episodic downslope transport of unconsolidated sediments beneath the water surface (Morad *et al*,2010) [5]. These alternating depositional environments collectively record the dynamic interaction between tectonic subsidence, sediment supply, and sea-level oscillations that characterised the evolution of the Pennine Basin during the Late Carboniferous (Morad *et al*,2010) [5].
The resulting lithological succession has exerted a fundamental control on the present-day landscape (Yanites *et al*,2017) [6]. The resistant Millstone Grit forms the elevated plateau and dramatic cliff edges of Kinder Scout, whereas less resistant mudstones are more readily weathered and eroded (Al-Dabbagh,1986). Together with Quaternary climatic processes, these geological materials have influenced soil development, peat accumulation, drainage patterns, and the establishment of the characteristic upland moorland ecosystems that define Kinder Scout today (Al-Dabbagh,1986).

Results
Blanket bog ecology on Kinder Scout is defined by a cold, high-rainfall upland climate that maintains permanently waterlogged, acidic soils, enabling the long-term accumulation of peat and the development of ombrotrophic vegetation dominated by peat-forming *Sphagnum* species and specialised upland plants (Alderson, *et al*.,2019) [8]. The plateau's hydrology is controlled almost entirely by rainfall, producing saturated, oxygen-poor conditions that slow decomposition and allow *Sphagnum* mosses to engineer the

ecosystem by retaining water, acidifying the substrate and creating the anaerobic environment required for peat formation (Alderson, *et al.*,2019) [8]. Structural vegetation such as heather (*Calluna vulgaris*) and bilberry (*Vaccinium myrtillus*) stabilises the peat surface, reduces erosion and supports diverse invertebrate and bird communities, while cotton grasses (*Eriophorum vaginatum*) contribute fibrous organic matter and root networks that reinforce peat integrity (Ritson *et al*,2023) [9]. Bryophytes and liverworts regulate moisture and microclimate, indicating stable hydrological conditions across intact areas of the plateau (Ritson *et al*,2023) [9]. Together, these plant assemblages sustain key ecosystem functions—including carbon sequestration, water regulation, nutrient cycling and habitat provision—demonstrating that Kinder Scout remains an active, ecologically functional blanket bog system despite historical disturbance (Ritson *et al*,2023) [9].

Table 1: List of selected floral species found in Kinder Scout

Name	Scientific name
Cloudberry	*Rubus chamaemorus*
Common Bilberry	*Vaccinium myrtillus*
Common Heather	*Calluna vulgaris*
Purple Foxglove	*Digitalis purpurea*
Lingonberry	*Vaccinium vitis-idaea*
Deer Fern	*Struthiopteris spicant*
Cross-leaved Heath	*Erica tetralix*
Waved Silk-Moss	*Plagiothecium undulatum*
Tufted Vetch	*Vicia cracca*
Green Alkanet	*Pentaglottis sempervirens*
Meadow Pea	*Lathyrus pratensis*
Dwarf Flapwort	*Jungermannia pumila*
Creeping Thistle	*Cirsium arvense*
Rufous Forklet-Moss	*Ruficaulis rufescens*
Floerke's Pawwort	*Neoorthocaulis floerkei*
Common Spotted Orchid	*Dactylorhiza fuchsii*
Flat-top Bogmoss	*Sphagnum fallax*
Juniper Haircap Moss	*Polytrichum juniperinum*
Capillary Thread-Moss	*Ptychostomum capillare*
Recurved Bristle Moss	*Blindiadelphus recurvatus*
Purple Moor-grass	*Molinia caerulea*
Tail Cotton Grass	*Eriophorum vaginatum*

Discussion

Significance of floral species in Kinder Scout

The recorded flora of the Kinder Scout plateau demonstrates the ecological complexity of one of the United Kingdom's most significant upland blanket bog ecosystems (Table 1). The observed plant assemblage comprises dwarf shrubs, graminoids, bryophytes, liverworts, ferns and herbaceous flowering plants, each occupying distinct ecological niches determined by peat depth, hydrology, soil acidity and microtopography (Ritson *et al*,2023) [9]. The predominance of acidophilic species such as heather (*Calluna vulgaris*), bilberry (*Vaccinium myrtillus*), cross-leaved heath (*Erica tetralix*), purple moor-grass (*Molinia caerulea*), hare's-tail cotton grass (*Eriophorum vaginatum*) and flat-top bog-moss (*Sphagnum fallax*) reflects the nutrient-poor, waterlogged and acidic conditions characteristic of upland blanket bogs (Chatters,2021) [10]. The coexistence of vascular plants with a diverse bryophyte and liverwort community indicates that ecological processes such as peat formation, nutrient cycling and water retention remain active across much of the plateau, despite historical degradation (Ritson *et al*,2023) [9]. Collectively, these species provide evidence of a heterogeneous landscape containing both relatively intact peat-forming habitats and areas undergoing ecological recovery through natural succession and conservation management (Ritson *et al*,2023) [9].

The dominance of heather (*Calluna vulgaris*) and bilberry (*Vaccinium myrtillus*) is particularly significant because these species form the structural foundation of Kinder Scout's dry heath communities (Ritson *et al*,2023) [9]. Heather creates a dense evergreen canopy that protects the peat surface from erosion by wind and rainfall, while simultaneously reducing moisture loss and stabilising surface soils (Ritson *et al*,2023) [9]. Bilberry contributes additional vegetation cover and provides an important food resource for birds and mammals, including red grouse, field voles and numerous invertebrates (Ritson *et al*,2023) [9]. Together these dwarf shrubs create habitat heterogeneity that supports a wide range of insects, spiders and ground-nesting birds (Ritson *et al*,2023) [9]. The presence of cross-leaved heath (*Erica tetralix*) further indicates persistently wet and acidic conditions, marking transitional zones between dry heath and blanket bog where water availability remains high throughout the year (Ritson *et al*,2023) [9].

Fig 1: Landscape of Kinder Scout showing different nature of moorland ecosystems

The occurrence of peat-forming species, particularly flat-top bog-moss (*Sphagnum fallax*) and hare's-tail cotton grass (*Eriophorum vaginatum*), is of exceptional ecological importance (Ritson *et al*,2023) [9] Species of *Sphagnum* are recognised as ecosystem engineers because of their remarkable capacity to retain water, acidify their surroundings and promote the accumulation of partially decomposed organic matter (Palozzi *et al*,2017) [11]. Through continuous growth and slow decomposition under anaerobic conditions, these mosses actively contribute to peat formation, enabling long-term sequestration of atmospheric carbon (Palozzi *et al*,2017) [11]. Cotton grasses complement this process by producing large quantities of organic biomass that become incorporated into the developing peat profile (Kaštovská *et al*.,2018) [12]. Their extensive root systems also improve peat stability, reduce erosion and facilitate colonisation by additional bog species (Kaštovská *et al*.,2018) [12]. Consequently, the abundance of these taxa provides strong evidence that sections of Kinder Scout continue to function as active carbon-accumulating blanket bog, an ecosystem of international conservation significance (Kaštovská *et al*.,2018) [12].

Bryophytes and liverworts recorded from the plateau, including waved silk-moss (*Plagiothecium undulatum*), juniper haircap moss (*Polytrichum juniperinum*), capillary thread-moss (*Ptychostomum capillare*), recurved bristle moss (*Blindiadelphus recurvatus*), rufous forklet-moss (*Ruficaulis rufescens*), dwarf flapwort (*Jungermannia pumila*) and Floerke's pawwort (*Neoorthocaulis floerkei*), perform essential ecological functions that are often overlooked despite their importance(Ritson *et al*,2023) [9]. These non-vascular plants intercept precipitation, retain moisture within the upper peat layers and regulate microclimatic conditions by reducing evaporation from the soil surface (Ritson *et al*,2023) [9]. Bryophyte mats also provide habitat for numerous microorganisms and microinvertebrates that contribute to decomposition and nutrient cycling (Ritson *et al*,2023) [9]. Liverworts are particularly sensitive to changes in humidity, atmospheric pollution and hydrological disturbance, making their continued presence valuable indicators of environmental quality and habitat stability within upland ecosystems (Ritson *et al*,2023) [9].

Purple moor-grass (*Molinia caerulea*) represents an important structural component of wet heath and blanket bog vegetation, although its ecological role depends upon its abundance (Taylor *et al*,2001) [13]. Under natural conditions it contributes to plant diversity, provides nesting material for birds and increases habitat complexity (Taylor *et al*,2001) [13]. However, excessive dominance of *Molinia* may indicate altered hydrological conditions, increased nitrogen deposition or historical management practices, potentially suppressing the regeneration of dwarf shrubs and *Sphagnum* species (Taylor *et al*,2001) [13]. Consequently, monitoring its abundance can provide valuable information regarding ecological change and restoration success on Kinder Scout (Taylor *et al*,2001) [13].

Several fewer dominant species, including cloudberry (*Rubus chamaemorus*), lingonberry (*Vaccinium vitis-idaea*), hard fern (*Blechnum spicant*, formerly *Struthiopteris spicant*), common spotted orchid (*Dactylorhiza fuchsii*) and foxglove (*Digitalis purpurea*), further enrich the botanical diversity of the landscape (Ritson *et al*,2023) [9]. Cloudberry is particularly noteworthy because it is considered a scarce upland species in England and is strongly associated with cool, acidic peatlands (Ritson *et al*,2023) [9]. Its presence reflects the persistence of high-quality bog habitat and relatively undisturbed microclimatic conditions (Ritson *et al*,2023) [9]. Lingonberry similarly indicates nutrient-poor acidic substrates, while hard fern occupies moist, shaded habitats along streams and rocky outcrops, illustrating the ecological variability that exists within the plateau (Page ,2004) [14]. The occurrence of orchids and foxglove demonstrates the presence of localised disturbances, flushes or better-drained microsites that increase habitat heterogeneity and contribute to overall biodiversity (Ritson *et al*,2023) [9].

Conversely, species such as tufted vetch (*Vicia cracca*), meadow pea (*Lathyrus pratensis*), creeping thistle (*Cirsium arvense*) and green alkanet (*Pentaglottis sempervirens*) are not typical components of intact blanket bog communities (Wilson, 2019) [15]. Their occurrence is more likely to reflect marginal habitats, disturbed ground, footpath edges or lower-altitude transitional zones surrounding the moorland (Wilson,2019) [15]. Although they contribute to local floral diversity and provide nectar resources for pollinating insects, they should not be regarded as indicator species of the core Kinder Scout peatland ecosystem (Wilson,2019) [15]. Their abundance should therefore be interpreted within the broader landscape context rather than as evidence of bog condition (Wilson,2019) [15].

Overall, the observed floral assemblage highlights the ecological resilience and conservation value of Kinder Scout (Wilson,2019) [15]. The coexistence of peat-forming mosses, dwarf shrubs, sedges, cotton grasses, liverworts and specialised upland species indicates that the plateau continues to support many of the biological community's characteristic of healthy blanket bog ecosystems (Wilson,2019) [15]. These plant communities underpin a wide range of ecosystem functions, including carbon sequestration, water storage, regulation of downstream hydrology, soil stabilisation, nutrient cycling and the provision of habitat for birds, mammals, amphibians and invertebrates (Wilson,2019) [15]. Consequently, conserving this diverse flora is fundamental not only for maintaining the biodiversity of Kinder Scout but also for sustaining the wider ecosystem services that these internationally important upland peatlands provide (Wilson,2019) [15].

Importance of conservation

Since the mid-twentieth century, upland heather moorlands in England and Wales have undergone substantial decline and degradation as a result of multiple interacting land-use pressures (Ramchunder *et al*.,2009) [16]. Approximately one-fifth of the heather moorland present during the 1940s has been converted or significantly altered through commercial forestry, agricultural improvement, intensive livestock grazing, and the expansion of bracken (*Pteridium aquilinum*) (Ramchunder *et al*,2009) [16]. Among the remaining moorland habitats, a large proportion is considered vulnerable to further ecological deterioration, with many sites exhibiting degraded vegetation structure or reduced ecological function (Ramchunder *et al*.,2009) [16]. High stocking densities of domestic sheep (*Ovis aries*), particularly where grazing exceeds approximately two ewes per hectare, have been identified as a major driver of continued habitat degradation by limiting heather regeneration, reducing plant diversity, and increasing soil exposure (Ramchunder *et al*.,2009) [16].

Kinder Scout – the highest plateau in the Peak District – exemplifies the importance of upland moorlands (Anderson *et al*.,1994) [1]. Its vast blanket bog is a Site of Special Scientific Interest and National Nature Reserve due to intact peat and rare upland habitats (Anderson *et al*.,1994) [1]. Decades of monitoring and restoration have demonstrated its value. Before interventions, much of Kinder Scout was a "barren moonscape" of eroding peat (Anderson *et al*.,1994) [1]. National Trust and research teams have since revegetated thousands of square meters of bare peat, planted millions of Sphagnum plugs, and built dams in gully systems (Evans, *et al*.,2005) [17]. The result is a dramatic recovery of vegetation: the moor now hosts extensive carpets of Sphagnum and cotton grass, along with thicker heather and cranberry carpets (Evans, *et al*.,2005) [17]. These plants form the physical structure for a healthy bog and feed invertebrate communities that in turn sustain higher trophic levels (Evans, *et al*.,2005) [17]. Upland bird surveys on Kinder Scout report increases in key species (e.g. golden plover, lapwing) as habitat improves (Evans, *et al*.,2005) [17].

Crucially, Kinder Scout has become an outdoor laboratory for understanding ecosystem responses (Shuttleworth *et al*,2019) [18]. Installed dipwells, weirs and flux towers have quantified how restoration alters hydrology and carbon balanc (Evans, *et al*.,2005) [17]. For instance, data show that the restored sections hold water longer and lower downstream peak flows, validating the hypothesis that intact peatland attenuates floods (Shuttleworth *et al*,2019) [18]. Carbon measurements indicate that the regenerating mosses significantly sequester CO_2, helping to convert what was once a net carbon source (due to erosion) into a sink (Shuttleworth *et al*,2019) [18]. In practice, the Kinder Scout case underscores the multifaceted role of moorlands: they are not just scenic landscapes but dynamic ecosystems that clean water, store carbon, support wildlife and human culture in tandem (Shuttleworth *et al*,2019) [18].

Overall, moorlands like those on Kinder Scout are of global conservation significance. In the UK and beyond, peat-forming uplands cover only a tiny fraction of land area – far less, for example, than tropical rainforests – but they preserve unique biota and disproportionate ecosystem services (Tebbutt *et al*,2006) [2]. Protecting and enhancing these landscapes thus yields outsized benefits: stabilising atmospheric carbon, reducing flood damage downstream, and providing critical habitat for endangered upland species (Shuttleworth *et al*,2019) [18]. The evidence makes it clear that the future health of Kinder Scout's plateau (and similar moors) depends on maintaining the balance of *traditional stewardship informed by science*, thereby securing both biodiversity and human livelihoods (Shuttleworth *et al*,2019) [18].

Conclusion

The vegetation recorded across the Kinder Scout plateau demonstrates that this internationally important blanket bog continues to function as a complex and ecologically valuable upland ecosystem (Wilson,2019) [15]. The dominance of characteristic peatland species, including heather (*Calluna vulgaris*), bilberry (*Vaccinium myrtillus*), cotton grass (*Eriophorum vaginatum*) and *Sphagnum* mosses, indicates the persistence of acidic, waterlogged conditions necessary for active peat formation, carbon sequestration and long-term ecosystem stability (Kaštovská *et al*.,2018) [12]. At the same time, the diversity of bryophytes, liverworts, ferns and flowering plants reflects the presence of varied microhabitats that support high levels of biodiversity and ecological resilience (Ritson *et al*,2023) [9].

Although the occurrence of a small number of non-characteristic species suggests areas of disturbance or transitional habitats, the overall floristic composition provides strong evidence that extensive restoration efforts have significantly improved ecosystem condition (Wilson,2019) [15]. The recovery of peat-forming vegetation has enhanced hydrological regulation, reduced peat erosion, increased carbon storage and created habitat for a wide range of upland wildlife (Shuttleworth *et al*,2019) [18]. These findings highlight the success of long-term conservation management and demonstrate the importance of science-based restoration in reversing historical degradation (Shuttleworth *et al*,2019) [18].

Ultimately, Kinder Scout represents far more than a botanical assemblage; it is a functioning ecosystem that delivers essential ecosystem services at both local and global scales (Ritson *et al*,2023) [9]. Continued protection, monitoring and restoration are therefore essential to maintain its biodiversity, safeguard its role as a major carbon sink, regulate water resources and ensure that this iconic upland landscape remains resilient in the face of future environmental change, including climate change and increasing human pressures (Shuttleworth *et al*,2019) [18].

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