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High mountain trees: altitudinal records recently broken for eleven different tree species in Britain

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Abstract
In 2022 a project was initiated utilising citizen science to document observations of trees growing in Britain above 900 m. This focused recording effort contributed to eleven new altitudinal records for tree species in this country, including *Sorbus aucuparia* at 1150 m and *Picea sitchensis* at 1125 m (both East Inverness-shire, v.c.96). Some of these observations involved increases of at least 200 m above previous known altitudinal limits. The new records were a mix of small, stunted plants not expected to reach maturity in these extreme environments, as well as arctic-alpine *Salix* shrubs adapted to low temperatures and exposed conditions. Although these findings are currently too restricted to draw broad conclusions on the impacts of climate warming and land management on tree colonisation in mountain environments, long-term data collection may allow an analysis of drivers of change in the future. Out of a total of 72 tree records above 900 m collated by the author in 2022, 56% were *Picea sitchensis*, highlighting the ability of this neophyte to spread into high elevation habitats. The project has been useful for generating public interest in biological recording at and above the altitudinal treeline, and the continuation of such work will assist with mountain woodland restoration projects for a variety of ecologically important taxa and plant communities.

Keywords: biological recording; elevation; altitude; mountain woodland; montane scrub; uplands

Introduction

Quantifying the altitudinal ranges of plants is important for understanding distributional patterns of biodiversity (Grytnes & McCain, 2007). Such information, gathered from broad to local scales, strengthens our comprehension of plant biogeography, invasion ecology, evolutionary adaptation and ecophysiology; particularly by expanding knowledge of the limits of species' environmental tolerances (Becker *et al.*, 2005). Variations in elevation are characterised by steep gradients in linked abiotic factors - most notably temperature, but also precipitation, soil moisture, wind speed, air pressure and solar radiation (Körner, 2003, 2007). These physical conditions accordingly influence vegetation phenology, growing season length and biological interactions. Altitudinal data are therefore key to

documenting elevational range shifts or contractions driven by climate change or other anthropogenic causes (Jump *et al.*, 2012; Watts *et al.*, 2022a), and can consequently assist with conservation and land management decisions.

The collection of altitudinal data became popular in Victorian times, and was first published for British and Irish plants by Wilson (1931), and then revised by Wilson (1956), posthumously, from a compilation of records dating from 1848 to 1949. Updated altitudinal ranges were provided by Preston *et al.* (2002) using material from more recent sources including Stewart *et al.* (1994), Preston & Croft (1997), Preston & Pearman (1998) and Wigginton (1999). The Botanical Society of Britain & Ireland (BSBI) regularly revises current information with new records gathered by botanists (Pearman & Corner, 2021) and through the Vascular Plant Distribution Database (Botanical Society of Britain & Ireland, 2023). These data have been used again in the most recent Plant Atlas 2020 (Stroh *et al.*, 2023); a significant achievement given that elevational ranges are often omitted from regional or national floras, despite being such important ecological attributes (Birks, 2021).

Recording the distribution of trees informs woodland management and creation, with applications in upland areas where conservation efforts are focused. Mountain woodland habitats in Britain have been subjected to centuries of degradation and loss due to overgrazing by large herbivores, burning and exploitation (Hester, 1995; Scott, 2000; Gilbert, 2016). The Scottish Highlands have been compared to south-west Norway, which has a similar climate but has undergone extensive regeneration of woodland and scrub to higher altitudes as a consequence of significant divergences in land management beginning in the 18th and 19th centuries (Halley, 2017; Wilson, 2017). In contrast, habitat remnants in the British uplands largely persist on cliff ledges and steep slopes inaccessible to sheep and deer. These sites are fragments of a formerly more widespread altitudinal treeline, functioning as the transition zone from continuous cover forests on lower slopes through to a mosaic of stunted trees and shrubs at upper elevations (Armstrong *et al.*, 2014; Wilson, 2015). Montane scrub is typically found at altitudes of 600-900 m and is characterised by low bushes with a decurrent (many branched) growth form (Averis *et al.*, 2004; Scottish Montane Willow Research Group, 2005).

In recent decades there has been burgeoning interest and action in reinstating mountain woodland habitats in Britain, through planting schemes for scarce and ecologically important species, and by encouraging natural colonisation (Gilbert & Di Cosmo, 2003; Mardon, 2003; Rao, 2020; Mardon & Cole, 2022; Watts & Jump, 2022). Mapping relict populations and incidents of regeneration is useful for locating propagation sources for restoration projects and examining the range of environmental conditions suitable for tree establishment (Montane Scrub Action Group, 2016). The full extent of existing and potential habitat may still be under-represented across the Scottish Highlands, because new records of montane trees and sub-arctic willows continue to be made, particularly at sites where grazing pressures are reduced (Wilson, 2015; Watts *et al.*, 2022b; Botanical Society of Britain & Ireland, 2023).

In fact, tree species have been recorded at elevations well above the fragmented remnant treeline ecotone in Scotland, as isolated occurrences on crags and in montane grasslands and heaths. Notable observations include an individual *Sorbus aucuparia* on Ben Macdui (v.c.92) at 1093 m (Shaila Rao, pers. obs.). These records provide an opportunity to investigate the most extreme thresholds for tree

persistence near mountain summits by exploring the question "What are the very upmost elevational limits of tree growth in Britain?" This paper documents recent efforts to add to current knowledge of the altitudinal ranges of tree species in this country through biological recording and citizen science.

Methods

In order to build on the excellent resource of altitudinal records already compiled by the BSBI (Pearman & Corner, 2021; Stroh *et al.*, 2023), from 2021 onwards the author began logging any occurrences of tree taxa[1] above 900 m during the course of other montane fieldwork. Exceptional records close to or surpassing current altitudinal records were also noted. The focus was on recording sites where plants (including non-native taxa) had colonised without direct human intervention, rather than atypical locations where they had been deliberately sown or dumped, and are classed as "alien" by Pearman & Corner (2021). Altitude was determined using two handheld Garmin 65s devices with GLONASS used simultaneously; either by waiting until they converged on the same value, or by taking the mean if direct agreement was not met after 10 minutes. Tree height was measured or estimated, while photographs were taken close-up and of the plant within its wider surroundings.

Citizen science was also utilised by encouraging the public to share observations and photographs of high-altitude trees above 900 m on social media (via the hashtag #highmountaintrees) or through the Mountain Woodland Action Group website (https://www.msag.org.uk/). Exceptional discoveries supplied without a GPS reading were subsequently relocated and verified by the author using the procedure outlined above. Other notable records were also kindly sent direct to the author by colleagues, upland ecologists and BSBI members. All new altitudinal records were verified by David Pearman.

Results

New GB altitudinal records

GB altitudinal records were broken for eleven different tree species during the period of 15 months between July 2021 and October 2022 (Table 1). The highest new altitude was achieved by *Sorbus aucuparia* (Fig. 2) at 1150 m asl near the summit of Sgurr nan Ceathreamhnan in West Affric (v.c.96). Several willows are now known to occur above 1000 m, and two new altitudinal records were made for non-native taxa (*Picea sitchensis* and *Pinus contorta*). Increases of at least 100 m and 200 m between the previously listed and new altitudinal record were documented for seven and four species respectively.

In fact, some records were broken several times in quick succession. *Betula pubescens* was recorded sequentially by the author on Corrour Estate at 924 m (Watts *et al.*, 2022b), 928 m and 949 m on Stob Coire Sgriodain, and then at 968m on Beinn Eibhinn, before the current record of 1026 m was achieved on nearby Ben Nevis (v.c.97). In 2022, *P. sitchensis* was found at 1030 m on Schiehallion (v.c.88) and Beinn a'Chaorainn (v.c.97), and at 1120 m on Ben Macdui (v.c.92), before being discovered at 1125 m on Braeriach (v.c.92).

[1]Including *Salix* spp. shrubs, with the exception of *Salix herbacea* which functions as a dwarf-shrub of exposed mountain ridges and plateaus.

The individual plants listed in Table 1 displayed a variety of growth forms, although no browsing was noted on any. The *Salix lanata* (Fig. 3), *Salix myrsinites* and *Salix phylicifolia* were mature multi-stemmed bushes typical of these species and were recorded within remnant patches of sub-arctic montane willow scrub. All other observations were relatively isolated, rather than occurring as part of existing treeline habitat. The *S. aucuparia*, *Salix caprea* (Fig. 3) and *P. sitchensis* were small, stunted specimens, and the tiny *B. pubescens* seedling on Ben Nevis was the least developed of all. The only large upright mature tree record listed in Table 1 is for *Populus tremula*.

Summary of records above 900 m

During 2022, a total of 72 observations of tree species growing above 900 m asl were made or received by the author as part of the #HighMountainTrees ad-hoc citizen science campaign (Fig. 1). Data were collected from 33 different mountains. The most common tree species recorded was *P. sitchensis* (56% of all records), while *S. aucuparia* was the second most frequent (19%). Nearly all observations were from the Scottish Highlands, concentrated particularly in the Cairngorms (v.c.92) and Westerness (v.c.97). One *S. aucuparia* record above 900 m was also submitted from each of England (Helvellyn; v.c.69) and Wales (Y Gribin; v.c.49).

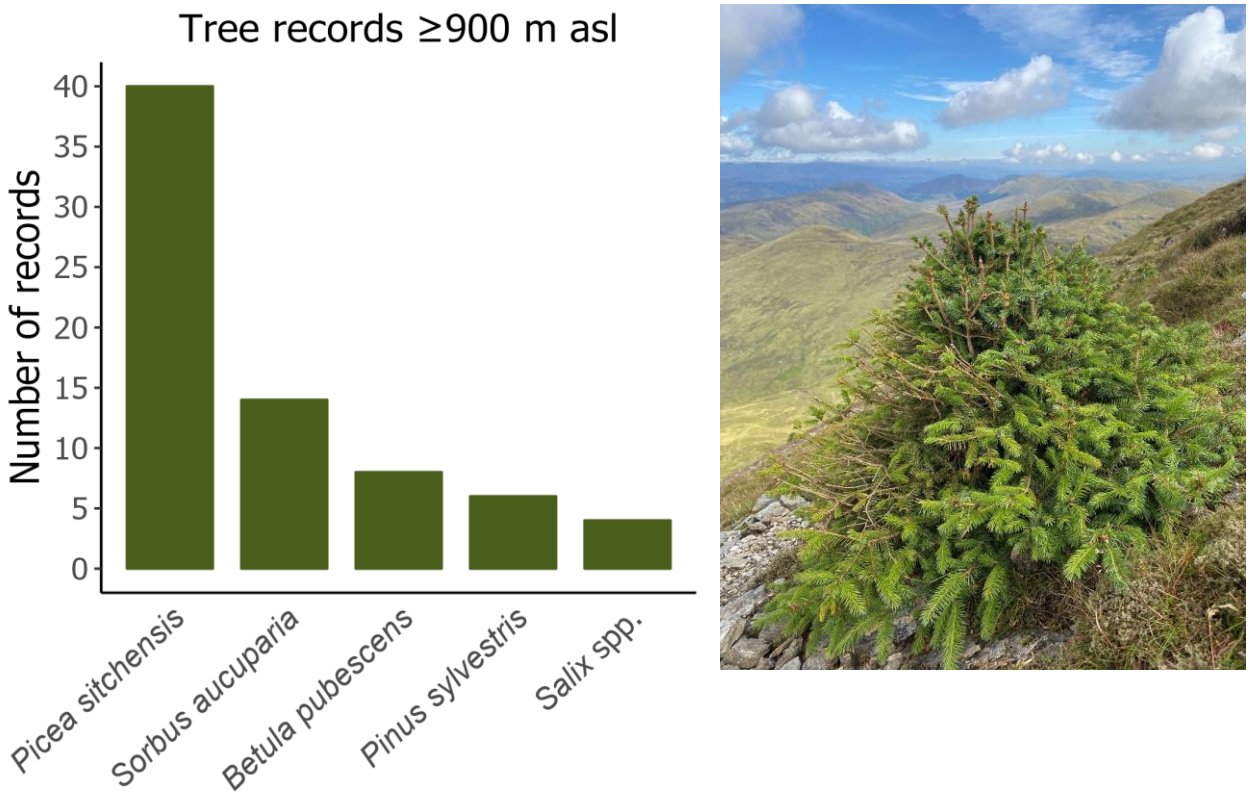

Figure 1. Left: The number of tree records at ≥900 m above sea level in Britain compiled and received by the author during 2022 as part of the #HighMountainTrees citizen science campaign. Right: *Picea sitchensis* recorded at 951 m on Ben Vorlich (v.c.88) in 2022. Image: Sarah Watts

Table 1. New GB altitudinal records documented since May 2021 for eleven different tree species. Previous records refer to those listed by Pearman and Corner (2021), or otherwise known to the author (indicated by †). Diff. = the difference between the new and previous altitudinal records; * = non-native/neophyte; v.c. = vice-county. NR = Nationally Rare; NS = Nationally Scarce. Nomenclature follows Stace (2019).

Species name	Common name	Altitudinal record pre 2021	New altitudinal record	Diff.	v.c.	Grid ref.	Location	Date	Recorder(s)	Notes
Sorbus aucuparia	Rowan	1093 m†	1150 m	57 m	96	NH 0564 2286	Sgurr nan Ceathreamhnan	18/07/22	Will Gilbertson Sarah Watts	Stunted plant 30 cm high with several stems; at least 7 years old
*Picea sitchensis**	Sitka Spruce	1015 m	1125 m	110 m	96	NH 9401 0025	Braeriach	13/08/22	Iain Cameron	Small, stunted plant
Salix lanata (NR)	Woolly Willow	1035 m	1044 m	9 m	97	NN 4717 7542	Sron Gharbh, Geal-Chàrn	10/08/22	Sarah Watts	Mature plant with catkins; prostrate growth form typical of this species
Salix aurita	Eared Willow	790 m	1031 m	241 m	92	NO 0036 9903	Coire Sputan Dearg, Ben Macdui	25/06/22	Andrew Painting	Small bush with several stems; upright leader shoot
Betula pubescens	Downy Birch	795 m	1026 m	231 m	97	NN 1534 7163	Ben Nevis	22/09/22	Steph McKenna	Tiny seedling, with two leaves
Salix myrsinites (NS)	Whortle-leaved Willow	1000 m	1020 m	20 m	92	NN 9568 9790	Coire an Lochain Uaine, Cairn Toul	31/07/21	Lewis Donaghy	Large bush growing with *S. phylicifolia*
Salix phylicifolia	Tea-leaved Willow	720 m	1020 m	300 m	92	NN 9568 9790	Coire an Lochain Uaine, Cairn Toul	31/07/21	Lewis Donaghy	Large bush growing with *S. myrsinites*
Salix caprea	Goat Willow	760 m	984 m	224 m	97	NN 4447 7391	Coire Gorm, Beinn Eibhinn	23/07/22	Allan McLeod Sarah Watts	Seedling 15 cm high
Populus tremula	Aspen	640 m	706 m	66 m	96	NJ 0173 0882	Stac na h-Iolaire	08/03/22	Gus Routledge	Mature tree with suckers growing on rocky ledge
Betula pendula	Silver Birch	510 m	665 m	155 m	92	NO 0289 9973	Coire Etchachan	03/10/22	Shaila Rao	Multi-stemmed bush
*Pinus contorta**	Lodgepole Pine	520 m	620 m	100 m	97	NN 3621 7581	Fersit, Corrour	16/10/22	Sarah Watts	Sapling 50 cm high

Figure 2. *Sorbus aucuparia* at 1150 m on Sgurr nan Ceathreamhnan, West Affric (v.c.96). Images: Sarah Watts

Figure 3. *Salix lanata* (top image) at 1044 m on Geal-Chàrn, and *Salix caprea* (bottom image) at 984 m on Beinn Eibhinn; both v.c.97.
Images: Sarah Watts

Discussion

Within a relatively short space of time, ad hoc biological recording focused on high altitude trees in the Scottish Highlands has led to new altitudinal records for eleven different species. As well as featuring arctic-alpine specialists (*Salix lanata* and *S. myrsinites*), the list also includes taxa which are common at lower elevations but can grow in sub-montane and montane situations. The new records highlight that trees and shrubs can colonise even at extremely high altitudes, demonstrating wider potential for woodland and scrub species in Britain's mountain areas than is perhaps generally perceived after centuries of habitat loss and degradation. These observations are creating a useful mechanism for media engagement with biological recording, and generating wider public interest in the restoration of habitats at the altitudinal treeline and the benefits they can provide to people and wildlife (BBC News, 2022; Watts & Jump, 2022).

Trees are likely to have arrived in these extreme high-altitude locations by long distance seed dispersal mechanisms, particularly wind (for *Salix* and *Betula* spp.), but also animal vectors in the case of *Sorbus aucuparia* (e.g. Fieldfare *Turdus pilaris* or other winter thrushes). However, it is important to note that several of the new records were of very stunted individuals, and these observations do not equate to the altitudes at which contiguous mountain woodland is expected to develop. Above 900 m there may be isolated opportunities for small saplings to establish in sheltered niches amongst mountain rocks, but these plants are unlikely to become mature seed-producing trees due to the severe climatic pressures imposed by such elevations. The exceptions are the arctic-alpine willows, adapted to thrive in low temperatures and exposed conditions and forming montane willow scrub, one of the rarest and most threatened habitats in the country (Horsfield & Thompson, 1997; Mortimer *et al.*, 2000). The population of *S. lanata* above 1000 m on Geal-Chàrn is the largest in Britain; its continued viability owing to late snow lie in an area otherwise accessible to large herbivores (Mardon & Moore, 2008; Marriott *et al.*, 2015).

Excluding *Salix herbacea*, only two other tree species have been observed in Britain at altitudes higher than the *Sorbus aucuparia* we discovered at 1150 m. *Juniperus communis* was recorded at 1200 m on Ben Macdui by Jim McIntosh in 2010, and *Pinus sylvestris* was recorded at 1160 m on Cairn Lochan by David Welch in 2003 (Pearman & Corner, 2021).

Drivers of new altitudinal records and tree establishment in upland areas

The primary reason for the upsurge in altitudinal records described here is most likely to be a concentration of recording interest and effort, facilitated by social media and technological advancements such as handheld GPS devices and georeferenced photography. Substantial new results can be yielded by even relatively few days of systematic data collection targeted at known elevational limits (Preston & Pearman, 1998).

In the global context, accelerating climate change is driving montane plants and treelines to higher latitudes and altitudes (Jump *et al.*, 2012; Lenoir & Svenning, 2015; Coals *et al.*, 2018; Watts *et al.*, 2022a), albeit with variability in the responses of individual species (O' Sullivan *et al.*, 2020). Nevertheless, the observations presented here are certainly too few to offer evidence of uphill movement in the distribution of British trees. Yet if such biological recording continues, it may be

possible to document a shift in the altitudinal limits to tree growth in our upland areas in the future, particularly for lowland taxa that are currently restricted to altitudes below 400 m. At the same time, it would be important to track any changes in the lower altitudinal limits of arctic-alpine specialists listed by Pearman & Corner (2021), including the montane willows *S. lapponum*, *S. lanata* and *S. myrsinites* which may be particularly vulnerable to the effects of climate warming (Coals *et al.*, 2018; Watts *et al.*, 2022a).

Changes in land-use and grazing management are also increasingly facilitating the expansion of trees and shrubs in mountain areas via natural regeneration. For example, *P. sylvestris*, *S. aucuparia* and *B. pubescens* are emerging above vegetation height at high altitudes on Mar Lodge in the Cairngorms due to a reduction of deer densities on a landscape scale (Rao, 2020). With other Highland estates also lessening pressures from overgrazing (Watts *et al.*, 2022b), further expansion of treeline habitats is anticipated where there are suitable conditions for tree growth and a viable seed source. It is therefore important to account for historical land use legacies, management practices and their interaction with climate change when considering upslope colonisation by trees in the future.

Non-native tree records

Two neophytes feature in the new altitudinal records displayed in Table 1, and over 50 % of all observations of tree species above 900 m compiled by the author during 2022 were of *P. sitchensis*. This non-native conifer is the principal plantation species in Britain (Forestry Commission, 2022), with high economic importance and productivity as a forestry crop. On the national scale, it showed the greatest estimated increase in range of any species covered by the Plant Atlas 2020 project (Stroh *et al.*, 2023; Walker *et al.*, 2023). As well as having low palatability to large herbivores, *P. sitchensis* can exhibit fast growth rates in upland areas through tolerance of wind exposure and wet, nutrient-poor soils (Malcolm, 1987; Stokes *et al.*, 2022). A relatively high propagule pressure offered by plantations could also allow this conifer to colonise more rapidly at altitude in comparison to grazing-sensitive native tree species with restricted seed sources. Upslope *P. sitchensis* regeneration may need to be managed to limit negative impacts on biodiversity and carbon cycling in fragile mountain habitats.

Data precision

Progression in GPS technology has facilitated more accurate mapping abilities, but individual devices can nonetheless sometimes vary in their readings by as much as 10 m. Two handheld Garmin units were used by the author to record the observations listed here with as much precision as possible. A statistical comparison of altitudinal data collected at the same location using a variety of different methods (e.g. Garmin GPS, sub-1m accuracy GPS, georeferenced photographs and altitudes generated from mapping software) would be valuable for determining confidence limits to these spatial observations.

Future recording work

The data for records above 900 m presented here are a summary of an initial ad hoc recording effort. However, if this work continues on the long-term, then a more comprehensive dataset could be built up across Britain's mountains, allowing a

geographical analysis of the factors contributing to tree regeneration at high altitude (e.g. land management, localised sheltering and climate, or topography). As well as documenting the tree species listed in Table 1, it will be valuable to record other nationally scarce or notable taxa that can form a component of mountain woodland and scrub, such as *Salix lapponum*, *Salix arbuscula*, *Salix reticulata*, *Betula nana, Sorbus rupicola* and *Salix caprea* subsp. *sphacelata* (high-altitude goat willow). This information will help identify priority areas for habitat restoration and key sites for collecting propagation material to supplement and connect small relict populations at risk of extirpation. For example, the Mountain Birch Project organised by Reforesting Scotland is providing an avenue for citizen science to contribute records of *Betula pubescens, Sorbus aucuparia*, *Prunus padus* and *Populus tremula* above 650 m to assist with efforts to reinstate a largely absent mountain "birch-belt" (Reforesting Scotland, 2021). These biological recording projects encourage the combination of mountaineering with data collection and thus foster an awareness of vegetation science, the threats to biodiversity and opportunities for restoration ecology (Dentant, 2018).

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