A summary of ECN Cairngorm vegetation monitoring 1998-2020

Data & Methods Summary Report

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Summary

This report details core vegetation recording carried out at the Cairngorm Environmental Change Network (ECN) field site since establishment in 1998. It is designed to be of use to researchers wanting to understand and make use of ECN Cairngorm vegetation datasets.

Three core systematic species presence surveys have been undertaken since:

(i) a systematic gridded baseline survey with a spacing of 166.5 m resulting in 353 2 m x 2 m plots (VB),

(ii) a coarse grain (VC) re-survey of a random subset (40) of the baseline plots every 9 years; with species presence recorded for twenty-five 40 cm x 40 cm cells within each 2 m x 2 m plot.

(iii) a fine grain (VF) survey of key habitat types within the catchment (14) every 3 years; with species presence recorded for ten 40 cm x 40 cm cells within each 10 m x 10 m plot.

For VF surveys, plots were accurately relocated >99 % of the time, whilst 85 % of sub-plots were accurately re-located. By contrast, 82 % of VC plots were accurately relocated across all surveys.

In total 223 unique species of vascular plants, lichen and bryophyte (including liverworts) have been recorded across the three surveys. The species assemblage varied greatly depending on habitat type, with Bryophytes featuring prominently in woodland and montane habitats, and Cladonia lichens and Ericaceous species more common in moorland habitats. *Calluna vulgaris* was the most frequently encountered vascular species, occurring in >75 % of all plots surveyed.

In addition to the core repeated surveys other vegetation surveys have taken place in the catchment either as part of one off research projects or as additional long-term monitoring. Notably the Global Observation Research Initiative in Alpine Environments (GLORIA) a repeat survey of four mountain tops (2002, 2008 and 2015) involving quadrats, and broader summit area surveys to identify all species occupying the top 10 m of four mountain summits within the catchment.

1 How to use this report

This report details core vegetation recording carried out at the ECN Cairngorm field site since the site was established in 1998. There is a general introduction to long-term vegetation monitoring and background to the Environmental Change Network. The following chapter focuses on the land-use history and bio-geographical aspects of the study area. The field methods, data, and data quality are then detailed for each survey type, along with a summary of some of the species and habitats of the Catchment. Information on additional surveys carried out is also provided.

2 Introduction

2.1 Why monitor vegetation?

Vegetation is a key part of most terrestrial ecosystems, underpinning biogeochemical and ecological functioning, as well as frequently providing a basis for ecosystem classification (Rose et al., 2016). Having a systematic, accurate and repeatable survey method to monitor changes in vegetation over time is therefore essential for understanding both changes the biodiversity of the ecosystem, as well as its function (Baxendale et al., 2016).

2.2 Environmental Change network (ECN)

The ECN is the UK's long-term, integrated environmental monitoring and research programme. They collect, analyse and interpret a wide range of long-term data from a network of sites across the UK. ECN's current mission is: "To develop and maintain a multi-agency network and early-warning system to detect, present, interpret and predict long-term ecosystem change and help society mitigate and adapt to global change."

ECN summary data can be accessed through the ECN website (http://www.ecn.ac.uk/data), and on request from the ECN Central Coordination Unit. Complete datasets and supporting documentation covering the years 1993 – 2015 are freely available from the NERC Environmental Information Data Centre under the terms of the Open Government Licence (Rennie et al, 2020).

2.3 Aim of this report

The aim of this report is to provide a summary of the ECN vegetation monitoring carried out in the Allt a'Mharcaidh. It is designed to be of use to researchers wanting to understand and make use of ECN Cairngorm vegetation datasets.

The report is one of a series of reports detailing interim analyses of trends in environmental and ecological variables in the ECN Cairngorm long-term monitoring site (Allt a'Mharcaidh catchment). A report on temporal trends in spider communities

(Andrews et al., 2020) and phenological and environmental change (Andrews & Dick, 2020) is available from the NERC open access archive.

3 Study site

3.1 Study area

Long-term monitoring of physical, chemical and biological processes has taken place in the Allt a'Mharcaidh catchment in the Cairngorms National Park (57° 6' 28"N, 3° 50' 6"W) as part of the UK Environmental Change Network (ECN, www.ecn.ac.uk) since 1998. The catchment takes the form of a hanging valley, and extends to 10 km^2 forming a large part of the wider Invereshie and Inshriach National Nature Reserve, owned and managed by Nature Scot (fig 1).

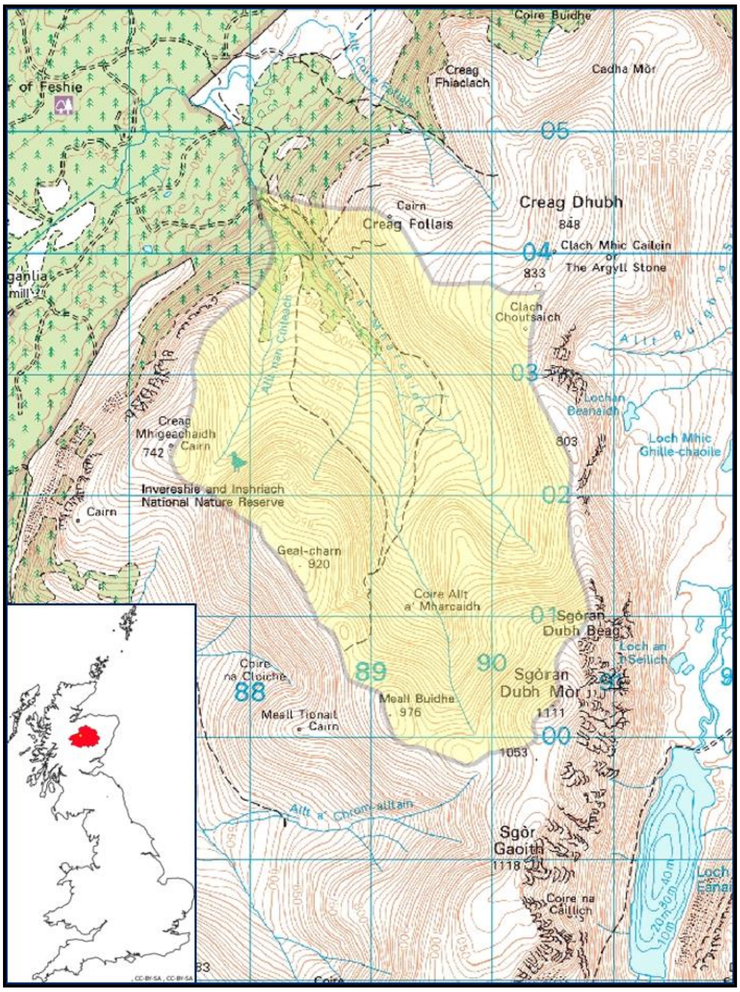

Figure 1 *The Allt a'Mharcaidh catchment and co-located ECN field site (yellow) in the Cairngorms National Park (red, inset), Scotland.*

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The catchment is predominantly north facing, rising from 320 m to 1111 m above sea level at the summit of Sgoran Dubh Mor. The lower ground surrounding the catchment is predominantly commercial pine (*Pinus sylvestris*) forest, interspersed with small areas of mainly improved pasture. Within the catchment the landscape is largely semi-natural, having been managed for nature conservation since 1954. The lower slopes are largely covered by mature *P. sylvestris* woodland, with regenerating pine on dry and wet heaths above this (fig 2). Above 750-800 m sub-montane and montane plant communities dominate.

3.2 Land-use history

From the late 18th century the catchment was principally used as a sporting estate, with timber extraction on the lower slopes, and deer and game-bird shooting above this. After purchase by the Nature Conservancy in 1954 the catchment became part of the Cairngorms National Nature Reserve, with the mature forest ring-fenced from deer in 1972. Since 1976 there has been a policy of reducing deer numbers to a level that allows for tree regeneration (Matthew 1990), with fences being removed in the 1990s (Cox & Philips, https://www.nature.scot/invereshie-and-inshriach-nnr-management-planning-documents). The site has been extensively used for research since the 1950s.

3.3 Vegetation and soils

The catchment consists of mature pine woodland on the lower and steeper slopes to around 500 m (fig 2). Above this, where dry heaths exist on steeper ground there are areas of extensive regeneration of *Pinus sylvestris*. Where slopes are less steep on the lower and middle altitudes, areas of wet heath and mire are extensive. From around 700 – 900 m alpine heaths dominate, consisting primarily of wind-clipped *Calluna-Cladonia* heath. Above this, montane moss heaths can be found on the higher summits, with *Nardus stricta-Carex bigelowii* grasslands more common in areas of late laying snow.

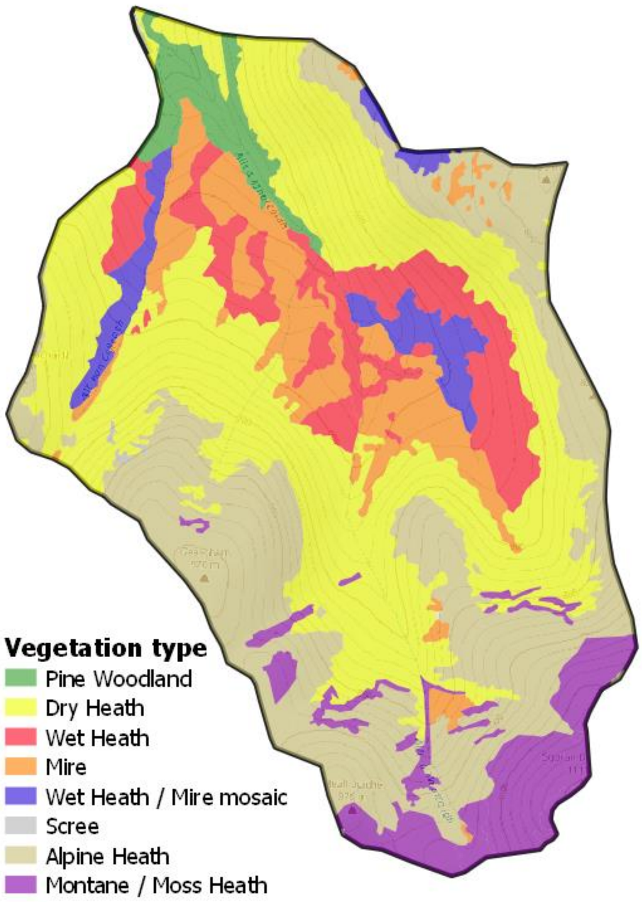

Figure 2 *Distribution of broad vegetation classifications in the Allt a'Mharcaidh catchment, based on the British National Vegetation Classification (NVC). Contains Crown copyright and database rights 2019, and SNH information licensed under the Open Government Licence v3.0.*

Soils in the catchment were assessed by Nolan & Lilly (1985), and can be simplified into three broad categories that map quite closely to that of the vegetation shown in figure 2. Alpine soils consisting mainly of alpine and subalpine podzols underlay the alpine and montane heaths in the upper parts of the catchment. Peats underlay the gentler slopes, with shallower peat (< 1m) in the wet heath areas, and deeper peat (>1 m), sometimes forming eroded peat hags, can be found in the mire areas. Finally, peaty podzols are largely characteristic of the dry heath and woodland areas.

3.4 Climate

Climate data for the site was extracted from the ECN Cairngorm weather station, located on an exposed ridge at 700 m.a.s.l within the catchment. The data represents the climate of a typical year at the site. For reliability, only complete data years were utilised to create the 'typical' year, and includes 11 years of data between 2008 and 2018 for all measurements except precipitation. Data for precipitation covers seven years between 2009 and 2015.

Annual precipitation at the site is 1024 mm (SD = 172), with highest accumulations occurring during the summer months of July and August (Figure 3). Prevailing wind is from the south-southwest, averaging 7.95 ms (SD = 0.67), peaking in January (10.23 ms (SD = 2.11)) and lowest during June (5.67 ms (SD = 1.06)) (Figure 3).

Mean annual temperature is 4.77 °C (SD = 0.52), with a mean minimum of -8.68 °C (SD = 0.1.36) and mean maximum temperature of 24.15 °C (SD = 2). January is the coldest month with a mean temperature of -0.12 °C (SD = 0.91), whilst July is the warmest at 10.69 °C (SD = 1.69). June, July, August and September are the only months where the mean minimum temperature remains above freezing. Soil temperatures at both 10 and 30 cm depth follow a similar pattern to air temperature across the year (Figure 3). Only a single cold day (where mean daily soil temperature was <0 °C) was recorded at 30 cm soil depth (16/02/2009, -0.01 °C). At 10 cm depth, the soil is more prone to freeze-thaw cycles. This is exacerbated by the monitoring location being exposed to scouring winds, preventing the accumulation of protective snow cover during winter. The number of cold days at 10 cm soil depth were therefore highly variable between winters (1 – 77 days), averaging at 24 days (SD = 23.82) per winter.

Accumulated solar radiation is 851.02 Kw/m² (SD = 53.76) per year. Tracking day length, it follows an expected bell shape pattern (Figure 3), although it peaks in May (142.37 Kw/m² (SD = 18.81)) rather than June. This fits with anecdotal information from fieldworkers that May is the 'best' weather month in the catchment, with extensive periods of sunshine and weather coming more from the south and south-east. In winter, accumulated solar radiation drops to its lowest during December as would be expected as it has the shortest day lengths (9.44 Kw/m² (SD = 2.59)).

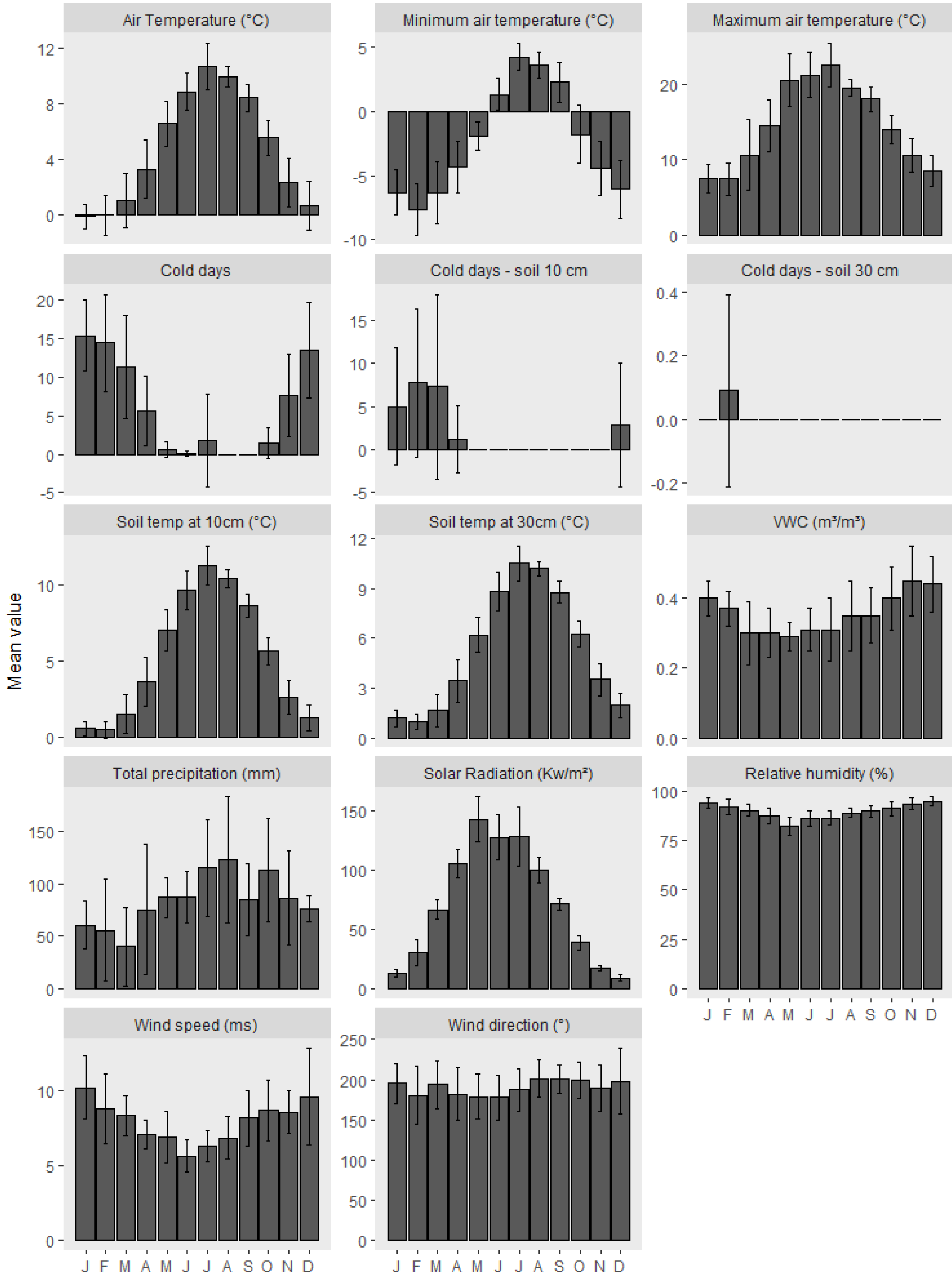

Figure 3 *Mean monthly climate data recorded at 700 m.a.s.l in the Allt a'Mharcaidh catchment for 11 years between 2008 and 2018, except for total precipitation which was between 2009 and 2015 due to incomplete data in remaining years. Error bars represent SD. 'Cold days' represents days where mean temperature was <0 °C. VWC = volumetric water content of soil*

4 Methods

Systematic vegetation recording in the catchment began in 1998, with three different core ECN vegetation protocols taking place since. These are, the initial baseline survey, which was an in-depth survey of the entire catchment, and two surveys of varying frequency, scale and detail known as the 'coarse-' and 'fine-' grain surveys. Methods for each survey are summarised below, with detailed descriptions available in Sykes & Lane (1996) or from http://www.ecn.ac.uk/measurements/terrestrial.

Overall, the methods used for ECN vegetation monitoring were selected to be sensitive enough to detect changes in the vegetation, whilst also being repeatable into the future. As such, only objective measures of vegetation were used (presence, absence), rather than more difficult subjective measures such as cover estimation (Sykes & Lane, 1996) which are more liable to error.

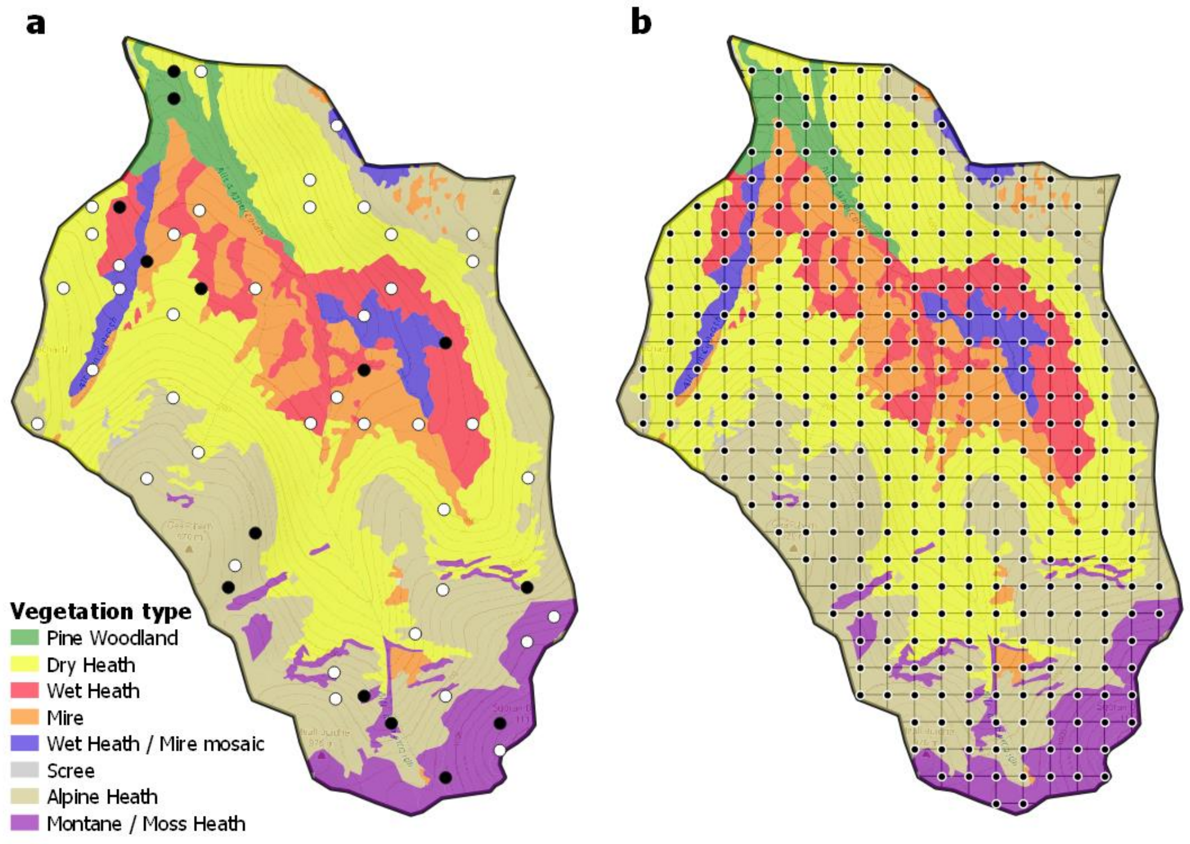

Figure 4 *National Vegetation Classification (NVC) community types and vegetation recording plots for three different vegetation surveys in the Allt a'Mharcaidh catchment, Cairngorms National Park, Scotland. (a) the 3-yearly fine grain (black circles) and 9-yearly coarse grain (white circles) surveys; and (b) the initial baseline survey. Contains Crown copyright and database rights 2019, and SNH information licensed under the Open Government Licence v3.0.*

4.1 Baseline survey (VB)

The VB survey was designed as a one-off survey at the start of ECN monitoring to establish a vegetation map and the plots for continuous monitoring (Rennie et al., 2020). A scaled grid was generated for the catchment with a spacing of 166.5 m. The grid intersections provided 353 un-biased plot locations that were re-locatable for baseline and future vegetation sampling (Table 1; Figure 4b).

Table 1 *NVC community type of 353 baseline (VB) vegetation plots surveyed at the Cairngorms ECN site between 1998 and 2000.*

Broad Habitat	Number of Plots
Dry Heath	135
Alpine Heath	95
Mire	42
Wet Heath	31
Montane Heath	26
Mosaic	15
Pine Woodland	9

The baseline survey took place over three summers between 1998 and 2000; plots consisting of 2 m x 2 m were centred on the grid intersections, and orientated to compass cardinal points. Species presence was recorded for all vascular plant, bryophyte and lichens (except where growing on wood or rock). Plots were permanently marked by a pair of wooden corner posts arranged in a North-South orientation across the diagonal of the plot.

4.2 Coarse-grain survey (VC)

The coarse-grain survey aims to record broad changes in vegetation at the site (Sykes & Lane, 1996), and takes place every 9 years from 2002. It involves re-surveying 40 of the 2 m x 2 m baseline plots (figure 4a, table 2), which were randomly selected from the completed baseline plots.

Table 2 *Summary of 40 coarse-grain (VC) vegetation plots surveyed at the Cairngorms ECN site every nine years since 2002 including their NVC code and community type.*

Plot	Habitat (NVC)	Broad Habitat	Elevation (m)
3	H10 H12	Dry Heath	458
13	M19b H13	Mosaic	700

34	H10 H12	Dry Heath	595
40	H10 H12	Dry Heath	550
44	M19b	Mire	500
48	H10 H12	Dry Heath	577
50	H10 H12	Dry Heath	708
56	H10 H12	Dry Heath	569
59	M19b	Mire	518
67	H10 H12	Dry Heath	702
70	H13	Alpine Heath	795
73	M19b H22A	Mosaic	544
86	H13	Alpine Heath	769
87	H10 H12	Dry Heath	653
89	M19b H22A	Mosaic	565
94	M19b	Mire	530
99	M16	Wet Heath	616
107	H10 H12	Dry Heath	595
114	M19b H22A	Mosaic	559
139	M19b H22A	Mosaic	621
161	H13	Alpine Heath	745
167	M19b	Mire	573
175	H13 (H13)	Alpine Heath	714
185	M15b	Wet Heath	590
187	M15b	Wet Heath	614
189	M19b	Mire	635
191	M16	Wet Heath	666
198	H10 H12	Dry Heath	796
212	H13	Alpine Heath	876
226	H10 H12	Dry Heath	768
238	H10 H12	Dry Heath	698
257	H13	Alpine Heath	857
277	H13 (H19)	Alpine Heath	833
294	U10b	Montane Heath	958
301	H13 (H13)	Alpine Heath	812
305	U10b	Montane Heath	990
309	H13	Alpine Heath	849

A frequency of taxa in each plot is recorded by sub-dividing each 2 m x 2 m plot into twenty-five 40 cm x 40 cm cells (figure 5). In each cell the presence of all rooted vascular species are recorded, whilst non-vascular species are recorded in three broad groups, sphagna, other bryophyte and lichens. Additional data is recorded for presence of bare soil, bare rock, litter, dead wood or open water, whilst bio-physical data is recorded at the overall plot level (habitat type, slope, aspect, altitude).

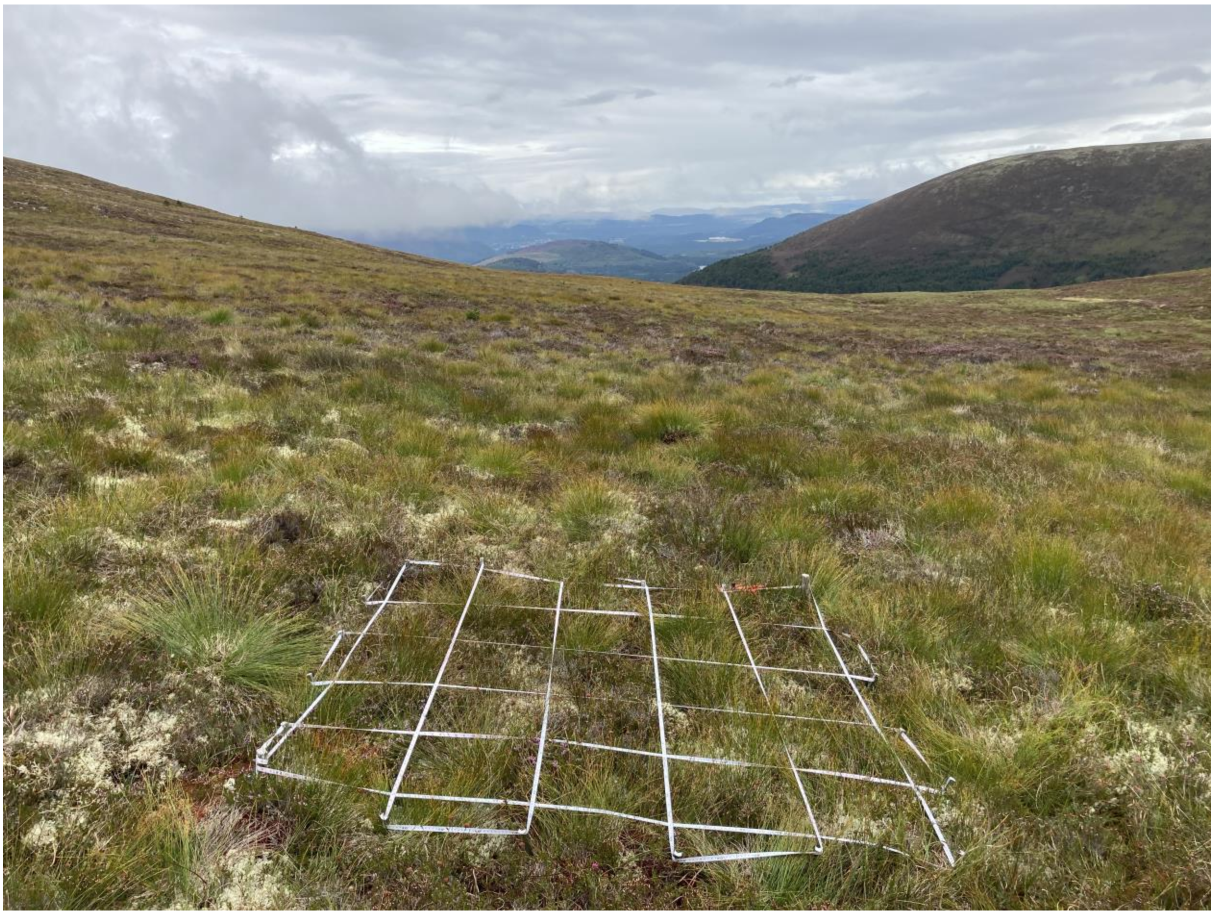

Figure 5 *An example 2 m x 2 m coarse-grain (VC) vegetation monitoring plot, showing the twenty-five 40 cm x 40 cm sub divisions in which the presence of all vascular species is recorded. Allt a'Mharcaidh, Cairngorms National Park.*

4.3 Fine-grain survey (VF)

The fine-grain survey was established primarily to be able to detect changes in relation to the UK's National Vegetation Classification (NVC). It takes place every three years from 2002 onwards, and provides a more in-depth monitoring of the vegetation than the coarse-grain survey. For each major habitat type identified in the catchment, two 10 m x 10 m plots were established for fine-grain monitoring purposes (figure 4a, table 3). Plots were randomly located, but coinciding with the original baseline grid. The survey takes place every three years.

Table 3 *Summary of 14 fine-grain (VF) vegetation plots surveyed at the Cairngorms ECN site at least every three years since 2002.*

Plot	Habitat (NVC)	Broad Habitat	Elevation (m)

2	W18	Pine Woodland	398
7	W18	Pine Woodland	392
41	M15b	Wet Heath	511
74	M19b	Mire	526
92	H10 H12	Dry Heath	556
134	M16	Wet Heath	651
149	H22A	Wet Heath	579
245	H13	Alpine Heath	805
269	H13	Alpine Heath	865
280	H18 H22b	Alpine Heath	856
321	U7	Montane Heath	856
331	H19	Alpine Heath	864
335	U10b	Montane Heath	1064
349	U10b	Montane Heath	980

Within each 10 m x 10 m plot, ten 40 cm x 40 cm cells were randomly assigned based on a possible 100 grid (1 m x 1 m) locations. The presence of all of vascular plants (if rooted), bryophytes and lichens (except those growing on rock or wood) are recorded to species level in each cell. Presence of bare soil, bare rock, litter, dead wood or open water are also recorded, whilst bio-physical data is recorded at the overall plot level (habitat type, slope, aspect, altitude). Plots were permanently marked by a pair of wooden corner posts arranged in a N-S orientation across the diagonal of the plot, allowing for simple orientation of the internal 10 m x 10 m grid used to located cells. Cells were permanently marked using short sections of wooden or metal rod (figure 6).

Figure 6 *An example 10 m x 10 m fine-grain (VF) vegetation monitoring plot viewed from the North (L) and South (R). Canes within the plot mark the ten 40 cm x 40 cm sub-plots in which the presence of all vascular plants, bryophytes and lichens is recorded. Allt a'Mharcaidh catchment, Cairngorms National Park.*

5 Results

5.1 Summary of surveys

As of 2020 there have been three VC survey's and nine VF surveys completed in the catchment (table 4). Additional VF surveys also took place in 2006 and 2007 to increase temporal resolution of data at that time. At the base 40 cm x 40 cm recording unit (cell) used in the VC and VF surveys, 4200 cells have been surveyed since 2002.

With the exception of VF surveys in 2002 and 2008, all plots, whether found or requiring re-establishment, were surveyed as required. In 2002 five of the 14 VF plots are missing from the data records, and presumably were not recorded, whilst in 2008 one plot was not recorded.

Table 4 *Summary of baseline (VB), coarse-grain (VC) and fine-grain (VF) vegetation monitoring protocols undertaken at the Cairngorms ECN site.*

Survey	Survey frequency	Survey years completed	Total number of plots (cells) per survey
VB	Once (but over 3 year period)	1998, 1999, 2000	353
VC	9-yearly	2002, 2011, 2020	40 (1000)
VF	3-yearly (+ *additional*)	2002, 2005, (*2006*), (*2007*), 2008, 2011, 2014, 2017, 2020	14 (140)

One of the biggest obstacles to the methodology has been accurately re-locating plots and cells. Although both VF and VC plots are marked by wooden corner posts, many of these are removed between sampling years primarily by deer chewing on them. The same applies to cell markers in the VF survey. In most cases the plot can be accurately re-located if a single post survives, however in some years precise re-location of cells in the VF survey dropped below 50% (table 5).

Table 5 *Summary of plot and cell re-location, by year, for coarse-grain (VC) and fine-grain (VF) vegetation monitoring protocols at the Cairngorms ECN site.*

Survey	Survey year	Plots surveyed	Plots		Cells	
			Relocated / not relocated	Successful re-location (%)	Relocated / not relocated	Successful re-location (%)
VF	2002	9	9 / 0	100	90 / 0	100
	2005	14	13 / 1	93	120 / 20	86
	2006	14	14 / 0	100	62 / 78	44
	2007	14	14 / 0	100	130 / 10	93
	2008	13	13 / 0	100	130 / 0	100

	2011	14	14 / 0	100	108 / 32	77
	2014	14	14 / 0	100	140 / 0	100
	2017	14	14 / 0	100	116 / 24	83
	2020	14	14 / 0	100	131 / 9	94
VC	2002	40	40 / 0	100	n/a	n/a
	2011	40	31 / 9	78	n/a	n/a
	2020	40	28 / 12	70	n/a	n/a

Unfound plots are re-established at the expected GPS coordinates, or, where the GPS location appeared to be in a different habitat than expected, then in the closest correct habitat/species assemblage type to the GPS coordinates. Occurrences of the latter are very low, as it can only occur where plots were located immediately adjacent habitat boundaries. As such, plots are usually re-established either atop of, or within a few meters of the expected plot location. The re-location of the larger plots in the VF survey has been very successful in most years, with only one plot (#280) being incorrectly identified in 2005, and not surveyed in 2008. The accurate re-location of 40 cm x 40 cm cells in the VF survey has however proved more difficult. However, where the plot has been located, then cells can be re-established within a 1 m x 1 m grid area, and are almost certain to partially overlap earlier cells.

Despite problems with the re-location of plots and/or cells, depending on intended analyses, a low re-location rate in some years is not necessarily a problem to long-term data analyses. The design of the surveys, using absolute presence/absence in numerous sub-plots rather than cover indices, and the very close re-location of lost plots/cells within habitat/assemblage types, means species assemblage and species frequency can still be calculated at the plot level, and be used to assess overall change in the plot or broader habitat.

5.2 Species

To date, across all three surveys, 87 species of vascular plant, 56 species of lichen and 80 species of bryophyte (of which 27 are liverworts) have been recorded in the catchment (table 6, and supplementary table 1 for a full species list). Well-represented genera include the Cladonia lichens with 41 species recorded and Sphagnum mosses with 14 species present. For both genera this equates to around 50% of known UK species.

Table 6 *Total number of species recorded using three different core ECN vegetation monitoring methods (baseline (VB), coarse-grain (VC) and fine-grain (VF)), and the total number of unique species, as recorded at the Cairngorms ECN site between 1998 and 2020.*

Survey	Bryophytes	Liverworts	Lichens	Vascular plants	*Total*
VB	35	42	15	76	***168***

VC	N/A	N/A	N/A	46	***46***
VF	46	39	26	60	***171***
Total unique species	***53***	***27***	***56***	***87***	***223***

Although notable lichen species such as *Cladonia botrytis* and *C. cenotea* are recorded within the dataset, a validation exercise suggests this may be a result of recorder error, rather than actual presence. Both species are associated wood; either cut pine wood in the case of *C. botrytis*, or on dead/rotting wood in deep shade for *C. cenotea*. Here, they were recorded as part of the VF survey, but only in high altitude plots situated in either alpine or montane heaths. As such, considerable caution would need to be applied when considering the presence of these two species.

Table 7 *Ten commonest species recorded during the ECN Cairngorm baseline (VB) survey between 1998 and 2000. Represented by the number and percent of plots (n = 353) in which a species was present.*

Species	**Total # plots present**	**% of plots present**
Calluna vulgaris	266	75.35
Cladonia arbuscula	209	59.21
Cladonia uncialis	209	59.21
Cladonia portentosa	196	55.52
Racomitrium lanuginosum	191	54.11
Trichophorum cespitosum	163	46.18
Vaccinium myrtillus	163	46.18
Empetrum nigrum nigrum	156	44.19
Deschampsia flexuosa	142	40.23
Hypnum sp	142	40.23

Across all three surveys, *Calluna vulgaris* was the most commonly recorded species, occurring in 75 % of the 353 baseline survey plots (table 7). For vascular species, this was followed *Tricophorum cespitosum* (46 %), *Vaccinium myrtillus* (46 %), *Empetrum nigrum* (44 %) and *Deschampsia flexuosa* (40 %). The high presence of ericaceae species, cladonia lichens and *Racomitrium* amongst in the top five vascular species underlines the heathland nature of the catchment. However, the species and their assemblage vary greatly depending on habitat type (table 8).

Table 8 *Five most frequently recorded species in each NVC community as recorded during the ECN Cairngorm baseline (VB) survey between 1998 and 2000.*

Habitat	Species	Group	% Occurrence
Pine Woodland	*Hylocomium splendens*	Bryophyte	66.7
	Vaccinium vitis-idaea	Vascular	55.6
	Vaccinium myrtillus	Vascular	55.6
	Calluna vulgaris	Vascular	55.6
	Rhytidiadelphus loreus	Bryophyte	55.6
Dry Heath	*Calluna vulgaris*	Vascular	88.1
	Cladonia portentosa	Lichen	68.1
	Cladonia arbuscula	Lichen	59.3
	Trichophorum cespitosum	Vascular	56.3
	Cladonia uncialis	Lichen	54.8
Wet Heath	*Calluna vulgaris*	Vascular	87.1
	Erica tetralix	Vascular	80.6
	Cladonia portentosa	Lichen	74.2
	Trichophorum cespitosum	Vascular	74.2
	Racomitrium lanuginosum	Bryophyte	74.2
Mire	*Calluna vulgaris*	Vascular	97.6
	Cladonia portentosa	Lichen	85.7
	Erica tetralix	Vascular	73.8
	Trichophorum cespitosum	Vascular	73.8
	Cladonia uncialis	Lichen	71.4
Wet Heath / Mire mosaic	*Calluna vulgaris*	Vascular	100
	Cladonia portentosa	Lichen	93.3
	Erica tetralix	Vascular	80
	Trichophorum cespitosum	Vascular	66.7
	Racomitrium lanuginosum	Bryophyte	66.7
Alpine Heath	*Cladonia arbuscula*	Lichen	78.9
	Empetrum nigrum nigrum	Vascular	67.4
	Cladonia uncialis	Lichen	66.3
	Deschampsia flexuosa	Vascular	65.3
	Racomitrium lanuginosum	Bryophyte	61.1
Montane Heath	*Deschampsia flexuosa*	Vascular	80.8
	Racomitrium lanuginosum	Bryophyte	76.9
	Vaccinium myrtillus	Vascular	73.1
	Carex bigelowii	Vascular	65.4
	Empetrum nigrum nigrum	Vascular	65.4

5.3 Limitations

Despite the wide range of surveys taking place, fixed-point methods mean that some species undoubtedly get missed in the wider landscape. As such, the species recorded here will not be a complete species list for the Allt a'Mharcaidh catchment. Additional searches, particularly along river channels and in wet flushes, would certainly add further species. However, the range of surveys was specifically designed to identify changes over time, and publications such as Rose et al. (2016) show the methods are applicable to time-series analysis.

5.4 Other vegetation surveys

Beyond the routine ECN vegetation monitoring, several other vegetation surveys have taken place in the catchment either as part of one off research projects or as additional long-term monitoring.

The most important of these is our contribution to the Global Observation Research Initiative in Alpine Environments (GLORIA, www.gloria.ac.at). This monitoring programme involves a combination of high precision quadrat, and broader summit area surveys to identify all species occupying the top 10 m of four mountain summits within the catchment. The method allows for the identification of small-scale changes in summit flora cover and assemblage. Taking place every seven years, three rounds of sampling have occurred to date, in 2002, 2008 and 2015. The next scheduled survey is 2022.

The GLORIA monitoring has proved highly successful, and has significantly contributed to the understanding of climate driven changes in mountain flora at regional and global scales; providing evidence of upward shifts in species (Pauli et al., 2012), and an increase in generalist species at the expense of specialist mountain species in a warming climate (Gottfried et al., 2012). The GLORIA monitoring has also led to wider research, contributing data and research plots to global studies on litter decomposition (Djukic et al., 2018) and soil temperatures (Lembrechts et al., 2020).

A key feature of the catchment is the natural regeneration of Scots Pine (*Pinus sylvestris*) on the lower and middle slopes. Baseline monitoring of this regeneration was carried out between 1996-97 to calculate the density and height of tree saplings in a systematic way across the catchment. MSc students undertook partial resurveys in 2011 and 2012, with results indicating that sapling density were both in excess and to a greater altitude then predicted by Thurlow et al. (1998). Given the current interest in increasing upland tree cover, often on moorland habitats, this baseline data has great research potential. Options for undertaking a full re-survey of the plots and associated co-variates are currently being explored.

Phenological change of pine and heather have been studied annually since 2010 within the catchment (Andrews & Dick, 2020). This survey data is taken from a single fixed-point camera taking daily photographs, and has shown pine needle flushing to be occurring earlier in the year. Although heather flowering showed no temporal trend, both it and pine leaf flushing were strongly correlated to spring/summer temperature.

Between 2009 and 2016 bud-break data was also collected for Scots Pine along an altitudinal gradient. This was recorded weekly April and August to collect data on key phenological stages. The survey was labour intensive and although beginning to produce some interesting data by 2016, was dropped from weekly monitoring due to reduced funding.

Further surveys have been carried out as part of other research questions. These tend to be one-off surveys, but could potentially be revisited in the future to look at changes over time within the confines of the original research questions. Surveys include:

(i) the vegetation occupying areas of long snow-lie. This researched focused on above and below ground ecosystem resilience in and near to snow patches;

(ii) vegetation effecting beetle assemblages. This research involved undertaking 2 m x 2 m quadrates of vegetation around the 30 ECN Cairngorm beetle traps. It was done using photography of plots.

(iii) functional traits of alpine species along an altitudinal gradient. The Research on Alpine Plant Traits and Functionality in the Context of Climate Change (RAPT) project was funded in part by INTERACT TA (see Valles et al., 2017).

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7 References

Andrews, C., Dick, J. (2020). Utilising repeat photography for long-term monitoring at the Cairngorm Environmental Change Network site: data analysis report. Wallingford, UK Centre for Ecology & Hydrology, 31pp. (UKCEH Project no. 04404, 06953) (Unpublished). http://nora.nerc.ac.uk/id/eprint/529051/

Andrews, C., Snazell, R., Dick, J. (2020). Temporal trends in spider communities at the UK Environmental Change Network Cairngorm field station, 2007-2019: data analysis report. Wallingford, UK Centre for Ecology & Hydrology, 31pp. (UKCEH Project no. 04404, 06953) (Unpublished). http://nora.nerc.ac.uk/id/eprint/528208/

Baxendale, C.L., Ostle, N.J., Wood, C.M., Oakley, S., Ward, S.E. (2016). Can digital image classification be used as a standardised method for surveying peatland vegetation cover?. Ecological Indicators, 68, 150-156. https://doi.org/10.1016/j.ecolind.2015.11.035

Bayfield, N., Brooker, R. and Milne, L. (2003). Cairngorms ECN Site handbook. ECN report.

Djukic, I., et al. (2018). Early stage litter decomposition across biomes. STOTEN, 628: 1369-1394.

Gottfried, M., Pauli, H., Futschik, A. et al. (2012). Continent-wide response of mountain vegetation to climate change. Nature Climate Change, 2: 111–115. https://doi.org/10.1038/nclimate1329

Lembrechts, J.J., Aalto, J., Ashcroft, M.B., et al. (2020). SoilTemp: A global database of near-surface temperature. Global Change Biology, 26: 6616– 6629. https://doi.org/10.1111/gcb.15123

Matthew, E.M. (1990). The role of the Nature Conservancy Council in protecting the Cairngorms. In: Caring for the High Mountains. Conservation of the Cairngorms. Proceedings of the Conference on Conservation of the Cairngorms, Aberdeen, 1988. Eds. J.W.H. Conroy, A.Watson & A.R.Gunson. Centre for Scottish Studies and Natural Environment Research Council, Aberdeen. pp 30-49.

Nolan, A.J. & Lilly, A. (1985). The Soils of the Allt a' Mharcaidh Catchment. Macaulay Institute for Soil Research, Aberdeen.

Pauli, H. et al. (2012). Recent Plant Diversity Changes on Europe's Mountain Summits. Science, 336: 353-355.

Rennie, S., Andrews, C., Atkinson, S., Beaumont, D., Benham, S., Bowmaker, V., Dick, J., Dodd, B., McKenna, C., Pallett, D., Rose, R., Schafer, S., Scott, T., Taylor, C. and Watson, H. (2020). The UK Environmental Change Network datasets – integrated and co-located data for long-term environmental research (1993–2015). Earth System Science Data, 12: 87-107. DOI: https://doi.org/10.5194/essd-12-87-2020.

Rose, R., Monteith, D.T., Henrys, P., Smart, S., Wood, C., Morecroft, M., Andrews, C., Beaumont, D., Benham, S., Bowmaker, V., Corbett, S., Dick, J., Dodd, B., Dodd, N., Flexen, M., McKenna, C., McMillan, S., Pallett, D., Rennie, S., Schafer, S., Scott, T., Sherrin, L., Turner, A., Watson, H. (2016). Evidence for increases in vegetation species richness across the UK Environmental Change Network sites linked to changes in air pollution and weather patterns. Ecological Indicators, 68, 52-62. https://doi.org/10.1016/j.ecolind.2016.01.005.

Sykes J.M., Lane A.M.J. (Eds.), The United Kingdom Environmental Change Network: Protocols for Standard Measurements at Terrestrial Sites, HMSO, London (1996).

The British Lichen Society. https://www.britishlichensociety.org.uk/resources/lichen-taxon-database/. Accessed 23/12/2020.

Thurlow, M., French, D.D., Bayfield, N.G. (1999). Colonisation by Pinus sylvestris. In: Land-use changes in European mountain ecosystems, Cernusca, A., Tappeiner, U., and Bayfield, N (eds). Blackwell, Berlin. pp 305-310.

Valles, D., Apple, M. E., Andrews, C. (2017). Visual Simulations Correlate Plant Functional Trait Distribution with Elevation and Temperature in the Cairngorm Mountains of Scotland. 2017 International Conference on Computational Science and Computational Intelligence (CSCI), pp. 1252-1258, https://doi.org/10.1109/CSCI.2017.220

8 Supplementary materials

8.1 Species list

Group	Species
Bryophyte	*Aulacolmium Paulistre*
Bryophyte	*Breutelia chrysocoma*
Bryophyte	*Bryum sp*
Bryophyte	*Calliergon cuspidatum*
Bryophyte	*Campylopus introflexus*
Bryophyte	*Campylopus pyriformis*
Bryophyte	*Cratoneuron commutatum*
Bryophyte	*Dicranum majus*
Bryophyte	*Dicranum scoparium*
Bryophyte	*Eurhynchium praelongum*
Bryophyte	*Eurhynchium striatum*
Bryophyte	*Grimmia donniana*
Bryophyte	*Hylocomium splendens*
Bryophyte	*Hypnum cupressiforme var cupressiforme*
Bryophyte	*Hypnum jutlandicum*
Bryophyte	*Isopterygium elegans*
Bryophyte	*Kiaeria starkei*
Bryophyte	*Leucobryum glaucum*
Bryophyte	*Mnium hornum*
Bryophyte	*Oligotrichum hercynicum*
Bryophyte	*Plagiomnium ellipticum*
Bryophyte	*Plagiothecium sp*
Bryophyte	*Pleurozia purpurea*
Bryophyte	*Pleurozium schreberi*
Bryophyte	*Pohlia nutans*
Bryophyte	*Polytrichum alpestre*
Bryophyte	*Polytrichum alpinum*
Bryophyte	*Polytrichum commune*
Bryophyte	*Polytrichum juniperinum*
Bryophyte	*Polytrichum piliferum*
Bryophyte	*Pseudoscleropodium purum*
Bryophyte	*Ptilidium ciliare*
Bryophyte	*Ptilium crista-castrensis*
Bryophyte	*Racomitrium lanuginosum*
Bryophyte	*Ranunculus repens*
Bryophyte	*Rhytidiadelphus loreus*
Bryophyte	*Rhytidiadelphus squarrosus*
Bryophyte	*Rhytidiadelphus triquetrus*
Bryophyte	*sphagnum angustifolium*
Bryophyte	*Sphagnum auriculatum var auriculatum*
Bryophyte	*Sphagnum capillifolium*
Bryophyte	*Sphagnum compactum*
Bryophyte	*Sphagnum cuspidatum*
Bryophyte	*Sphagnum fimbriatum*
Bryophyte	*Sphagnum magellanicum*
Bryophyte	*Sphagnum palustre*
Bryophyte	*Sphagnum papillosum*
Bryophyte	*Sphagnum quinquefarium*
Bryophyte	*Sphagnum recurvum*
Bryophyte	*Sphagnum russowii*
Bryophyte	*Sphagnum subnitens*
Bryophyte	*Sphagnum tenellum*
Bryophyte	*Thuidium tamariscinum*
Liverwort	*Anastrophyllum donianum*
Liverwort	*Anthelia julacea*
Liverwort	*Barbilophozia atlantica*
Liverwort	*Barbilophozia attenuata*
Liverwort	*Barbilophozia sp*
Liverwort	*Calypogeia muelleriana*
Liverwort	*Calypogeia sphagnicola*
Liverwort	*Calypogeia trichomanis*
Liverwort	*Cephalozia bicuspidata*
Liverwort	*Cephaloziella sp*
Liverwort	*Diplophyllum albicans*
Liverwort	*Frullania tamarisci*
Liverwort	*Jungermannia atrovirens*
Liverwort	*Lepidozia reptans*
Liverwort	*Leptoscyphus cuneifolius*
Liverwort	*Lophocolea bidentata*
Liverwort	*Lophozia bicrenata*
Liverwort	*Lophozia ventricosa*
Liverwort	*Mylia taylorii*
Liverwort	*Odontoschisma sphagni*
Liverwort	*Pellia sp*
Liverwort	*Plagiochila asplenioides*
Liverwort	*Plagiochila porelloides*
Liverwort	*Pleurocladula albescens*
Liverwort	*Scapania gracilis*
Liverwort	*Scapania undulata*

Liverwort	*Tritomaria quinquedentata*
Lichen	*Alectoria nigricans*
Lichen	*Bryoria bicolor*
Lichen	*Cetraria islandica*
Lichen	*Cetraria nivalis*
Lichen	*Cladonia arbuscula*
Lichen	*Cladonia bellidiflora*
Lichen	*Cladonia botrytes*
Lichen	*Cladonia carneola*
Lichen	*Cladonia cenotea*
Lichen	*Cladonia cervicornis*
Lichen	*Cladonia chlorophaea*
Lichen	*Cladonia ciliata*
Lichen	*Cladonia ciliata var ciliata*
Lichen	*Cladonia ciliata var tenuis*
Lichen	*Cladonia coccifera*
Lichen	*Cladonia coniocraea*
Lichen	*Cladonia crispata*
Lichen	*Cladonia crispata var cetrariiformis*
Lichen	*Cladonia crispata var crispata*
Lichen	*Cladonia deformis*
Lichen	*Cladonia digitata*
Lichen	*Cladonia fimbriata*
Lichen	*Cladonia floerkeana*
Lichen	*Cladonia fragilissima*
Lichen	*Cladonia furcata*
Lichen	*Cladonia glauca*
Lichen	*Cladonia gracilis*
Lichen	*Cladonia macilenta*
Lichen	*Cladonia macrophylla*
Lichen	*Cladonia metacorallifera*
Lichen	*Cladonia ochrochlora*
Lichen	*Cladonia pleurota*
Lichen	*Cladonia polydactyla*
Lichen	*Cladonia portentosa*
Lichen	*Cladonia pyxidata*
Lichen	*Cladonia ramulosa*
Lichen	*Cladonia rangiferina*
Lichen	*Cladonia rangiformis*
Lichen	*Cladonia scabriuscula*
Lichen	*Cladonia squamosa*
Lichen	*Cladonia stricta*
Lichen	*Cladonia subulata*
Lichen	*Cladonia sulphurina*
Lichen	*Cladonia uncialis*
Lichen	*Cladonia zopfii*
Lichen	*Coelocaulon aculeata*
Lichen	*Cornicularia sp*
Lichen	*Hypogymnia physodes*
Lichen	*Icmadophila ericetorum*
Lichen	*Ochrolechia frigida*
Lichen	*Ochrolechia pallescens*
Lichen	*Ochrolechia tartarea*
Lichen	*Sphaerophorus fragilis*
Lichen	*Sphaerophorus globosus*
Lichen	*Stereocaulon vesuvianum*
Lichen	*Thamnolia vermicularis*
Vascular	*Agrostis canina*
Vascular	*Agrostis capillaris*
Vascular	*Alchemilla alpina*
Vascular	*Antennaria dioica*
Vascular	*Anthoxanthum odoratum*
Vascular	*Arctostaphylos uva-ursi*
Vascular	*Athyrium filix-femina*
Vascular	*Betula nana*
Vascular	*Betula pendula*
Vascular	*Betula pubescens*
Vascular	*Blechnum spicant*
Vascular	*Calluna vulgaris*
Vascular	*Carex bigelowii*
Vascular	*Carex binervis*
Vascular	*Carex dioica*
Vascular	*Carex flacca*
Vascular	*Carex nigra*
Vascular	*Carex panicea*
Vascular	*Carex pilulifera*
Vascular	*Carex viridula ssp oedocarpa*
Vascular	*Chamerion angustifolium*
Vascular	*Dactylorhiza maculata*
Vascular	*Dactylorhiza maculata ericetorum*
Vascular	*Deschampsia cespitosa cespitosa*
Vascular	*Deschampsia flexuosa*
Vascular	*Digitalis purpurea*
Vascular	*Diphasiastrum alpinum*
Vascular	*Drosera rotundifolia*
Vascular	*Dryopteris filix-mas*
Vascular	*Empetrum nigrum*
Vascular	*Erica cinerea*
Vascular	*Erica tetralix*
Vascular	*Eriophorum angustifolium*

Vascular	*Eriophorum vaginatum*
Vascular	*Euphrasia officinalis agg*
Vascular	*Festuca ovina*
Vascular	*Festuca vivipara*
Vascular	*Galium saxatile*
Vascular	*Genista anglica*
Vascular	*Geranium robertianum*
Vascular	*Gymnocarpium dryopteris*
Vascular	*Holcus lanatus*
Vascular	*Holcus mollis*
Vascular	*Huperzia selago*
Vascular	*Juncus effusus*
Vascular	*Juncus squarrosus*
Vascular	*Juncus trifidus*
Vascular	*Juniperus communis communis*
Vascular	*Leontodon sp*
Vascular	*Listera cordata*
Vascular	*Listera ovata*
Vascular	*Loiseleuria procumbens*
Vascular	*Lotus corniculatus*
Vascular	*Luzula campestris*
Vascular	*Luzula multiflora*
Vascular	*Luzula sylvatica*
Vascular	*Lycopodium annotinum*
Vascular	*Lycopodium clavatum*
Vascular	*Melampyrum pratense*
Vascular	*Molinia caerulea*
Vascular	*Montia fontana*
Vascular	*Nardus stricta*
Vascular	*Narthecium ossifragum*
Vascular	*Oxalis acetosella*
Vascular	*Pinguicula vulgaris*
Vascular	*Pinus sylvestris*
Vascular	*Plagiomnium undulatum*
Vascular	*Plagiothecium undulatum*
Vascular	*Polygala serpyllifolia*
Vascular	*Polygala vulgaris*
Vascular	*Polygonum sp*
Vascular	*Potentilla erecta*
Vascular	*Pteridium aquilinum*
Vascular	*Rubus chamaemorus*
Vascular	*Rumex acetosa*
Vascular	*Sagina sp*
Vascular	*Salix herbacea*
Vascular	*Sorbus aucuparia*
Vascular	*Stellaria media*
Vascular	*Succisa pratensis*
Vascular	*Trichophorum cespitosum*
Vascular	*Vaccinium myrtillus*
Vascular	*Vaccinium uliginosum*
Vascular	*Vaccinium vitis-idaea*
Vascular	*Veronica fruticans*
Vascular	*Viola palustris*
Vascular	*Viola riviniana/reichenbachiana*