

Supplementary Information for the article *Higher levels of multiple ecosystem services are found in forests with more tree species*

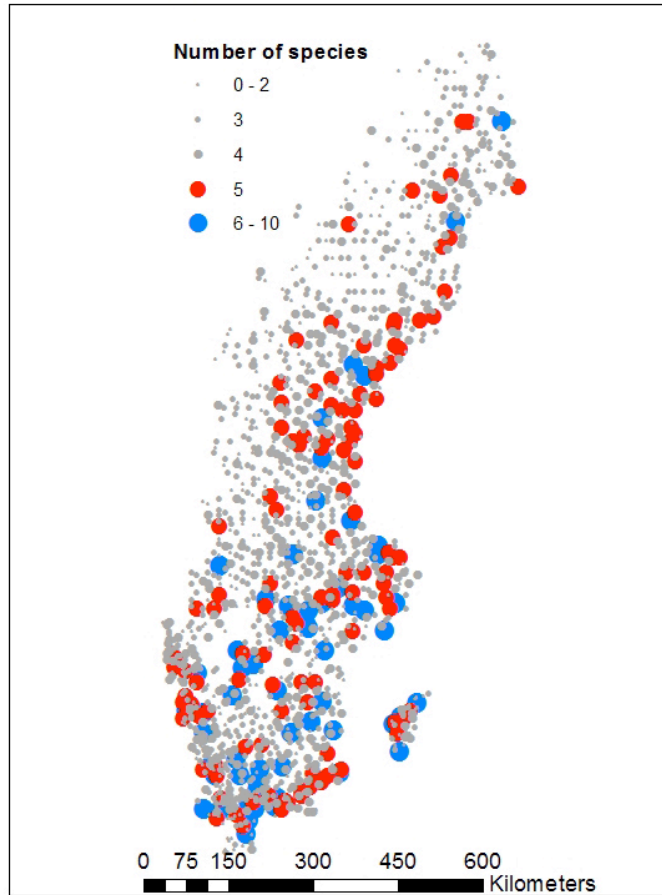
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The Supplementary Information contains:

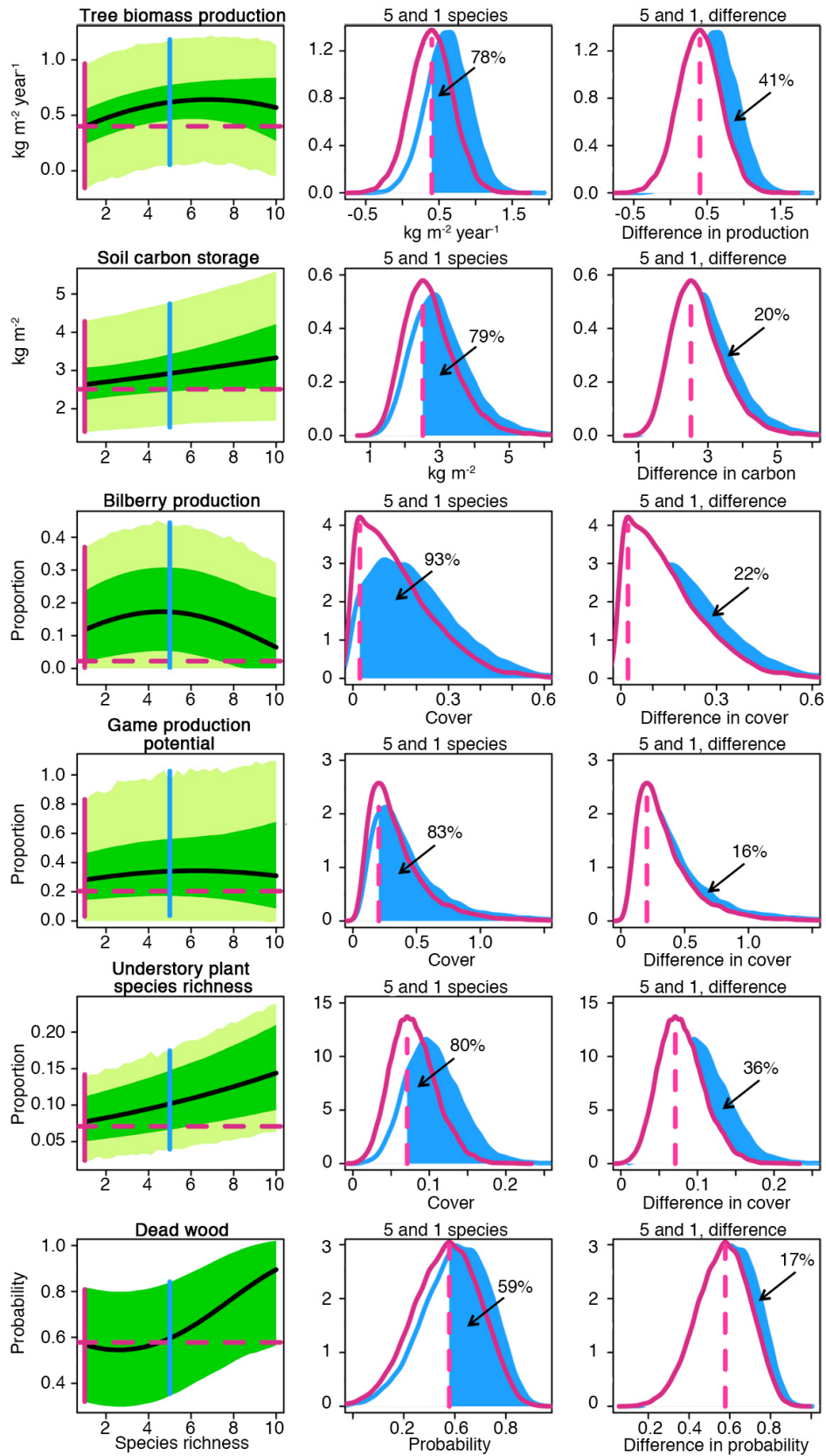
Supplementary Figures S1 to S3

Supplementary Tables S1 to S6

Supplementary Figures S1-S3



Supplementary Figure S1 | Maximum number of species per tract in the sampled region (Sweden). Scale in kilometres. The sampling region covers 13.7 degrees of latitude.

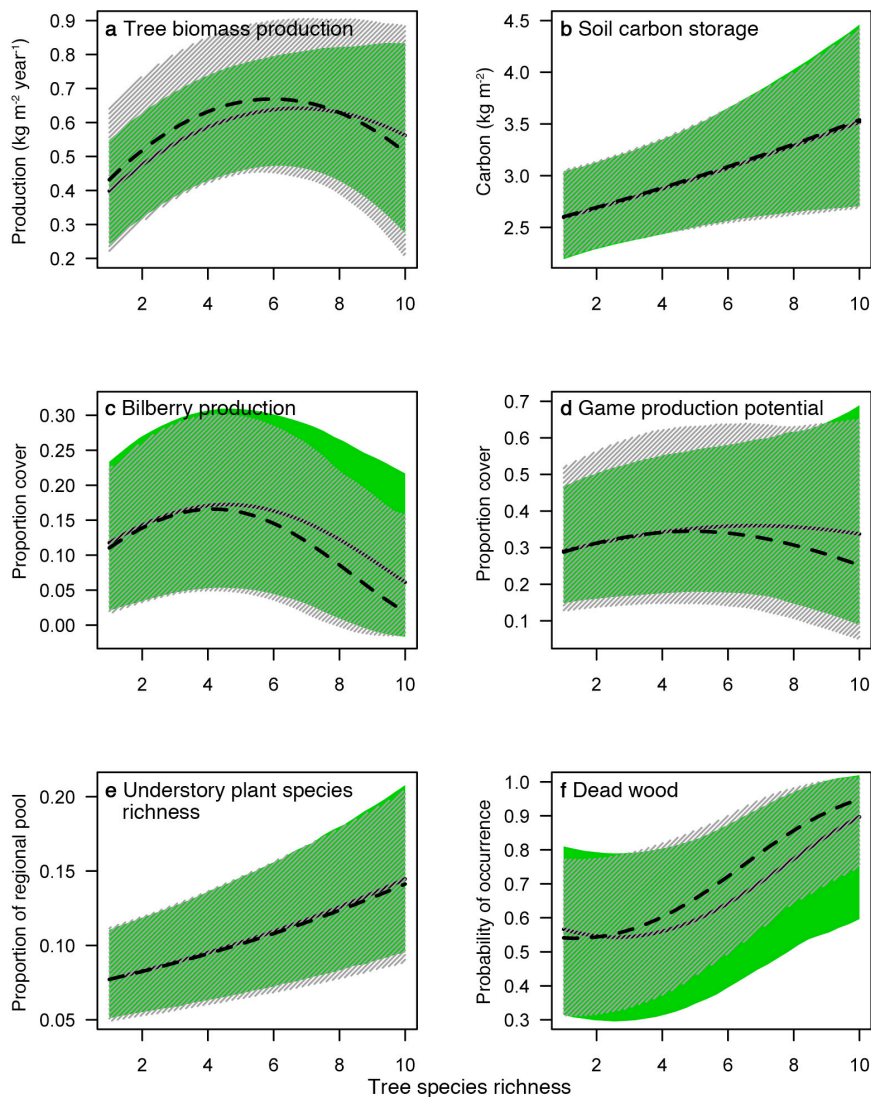


Supplementary Figure S2 | Legend on next page

Supplementary Figure S2 | Details on relationships between tree species richness and the six ecosystem services. The left column shows the relationship between tree species richness and the six ecosystem services, conditional of mean levels for all other explanatory variables and non-peat soil. The effects of the other explanatory variables have been accounted for. We show mean relationships (black) and 95% Bayesian confidence intervals for the relationships excluding (dark green) and including (light green) the residual variation (the variance among $\varepsilon_{p,t}$ in Eq.1). Both intervals reflect the uncertainties in parameter estimates. In the model for understory vegetation, the dark green area is based on Eq. 1, while the light green area also accounts for the variance given by the overdispersed Poisson distribution. The vertical lines show the Bayesian 95% confidence interval for the prediction of the response variable assuming one (red) and five (blue) tree species. These lines are based on the posterior distribution of the predictions. The dashed horizontal line shows the most likely value (the mode) of the response variable assuming one tree species.

The percentages in the middle column shows how likely it is that the value of the response variable assuming five tree species is greater than the mode assuming one species. For example, the support is 78% for tree biomass production being greater than $0.40 \text{ kg m}^{-2} \text{ year}^{-1}$, which is the most likely production assuming one species. Specifically, the middle column shows the posterior distribution of the predictions (summarized in the left column) assuming one (red) and five (blue) tree species. The dashed vertical line shows the mode of the response variable assuming one tree species. The blue area shows the prediction distribution assuming five species that is greater than the mode given by assuming one species. The percentage shows the proportion of the prediction distribution assuming five species that is greater than the mode (78% for tree biomass production).

The percentages in the right column shows how likely it is that the value of the response variable assuming five tree species is greater than when assuming one tree species. For example, tree biomass production is 41% more likely to be higher on plots with five species than on plots with one species. Specifically, the blue area shows the proportion of the prediction distribution for five species which is greater than the prediction distribution for one species.



Supplementary Figure S3 | Graphical comparison between the main model (solid line, 95% Bayesian confidence interval in green) and the model in which the tree biomass terms have been excluded (dashed line, 95% Bayesian confidence interval in grey). Excluding the effect of tree species biomass from the main model did not change the relationships between tree species richness and the response variables. Confidence intervals do not include the residual variation. **a**, *Tree biomass production*; **b**, *Soil carbon storage*; **c**, *Bilberry production*; **d**, *Game production potential*; **e**, *Understory plant species richness*; **f**, *Occurrence of dead wood*.

Supplementary Tables S1-S6

Supplementary Table S1 | Plot- and tract-level explanatory variables. Their units, means, ranges, standard deviations (Stdev), and the number of plots or tracts in which they were recorded or estimated. N deposition refers to nitrogen deposition, Richness to tree species richness, Age to forest stand age, C:N to carbon:nitrogen ratio, and Moisture to soil moisture. Also listed are the squared variables (e.g. Richness²), and the interactions between variables (e.g. Richness*Age) that were included in the models.

Explanatory variable	Scale	Unit	Mean	Range	Stdev	Tracts/Plots
Temperature	Tract	°C	1087	420–1690	276	1401
Humidity	Tract	mm	43.0	-60–225	59.5	1401
N deposition	Tract	kg ha ⁻¹ year ⁻¹	6.6	2.0–18.5	3.8	1401
Temp*N dep	Tract					1401
Humid*N dep	Tract					1401
Richness	Plot	number	2.5	0–10	1.1	1401/4335
Richness ²	Plot					1401/4335
Age	Plot	year	64.5	1–315	45.6	1401/4335
Age ²	Plot					1401/4335
Richness*Age	Plot					1401/4335
pH	Plot	pH units	4.0	3.1–7.9	0.63	1098/1953
pH ²	Plot					1098/1953
C:N	Plot	ratio	30.8	11–90.0	9.7	1098/1953
Moisture	Plot	%	0.22	0.15–0.35	0.03	1393/4326
Moisture ²	Plot					1393/4326
Peat	Plot	0, 1	0.08	–	0.27	1393/4326
Richness*pH	Plot					1098/1953
Richness*C:N	Plot					1098/1953
Richness*Moisture	Plot					1393/4326
Spruce	Plot	kg m ⁻² year ⁻¹	4.5	0–59.4	6.7	1401/4335
Pine	Plot	kg m ⁻² year ⁻¹	3.6	0–33.6	4.6	1401/4335
Birch	Plot	kg m ⁻² year ⁻¹	0.97	0–21.0	2.0	1401/4335
Oak	Plot	kg m ⁻² year ⁻¹	0.14	0–27.2	1.2	1401/4335
Aspen	Plot	kg m ⁻² year ⁻¹	0.12	0–24.6	0.9	1401/4335
Beech	Plot	kg m ⁻² year ⁻¹	0.11	0–33.8	1.3	1401/4335
Spruce*Age	Plot					1401/4335
Pine*Age	Plot					1401/4335
Birch*Age	Plot					1401/4335

Supplementary Table S2 | Modelled ecosystem services. Their units, statistical distributions assumed, link functions used, transformations, observed means and ranges, and the number of tracts and plots in which they were recorded or estimated.

Service	Unit	Distribution	Link function	Transformation	Mean	Range of values	Tracts/Plots
Tree biomass production ^a	kg m ⁻² year ⁻¹	Normal	identity	-	0.43	-0.30–2.65 ^b	1401/4335
Soil carbon storage	g m ⁻²	Normal	identity	ln	3977	140–41973	1098/1953
Bilberry production	Proportion of cover ^c	Normal	identity	arcsine	0.14	0–0.77	1176/2127
Game production	Proportion of cover ^d	Normal	identity	ln ^e	0.42	0–1.61	1176/2127
Understory plant richness	Number of species ^f	Poisson	ln	-	12.4 ^g	1–39 ^h	1394/4327
Dead wood	Occurrence (1) or not (0)	Bernoulli	logit	-	0.57	0 or 1	1401/4335

^a Negative production results from a biomass growth smaller than biomass loss due to tree mortality.

^b Corresponds to around -1 to 30 m³ ha⁻¹.

^c Proportion of the cover of the field layer of vascular plants (Supplementary Table S6).

^d Proportion can exceed 1 in single plots due to multiple layers of vegetation (Supplementary Table S5).

^e ln(data +0.01)

^f Note that the proportion of the regional species pool is modelled (Eq. 1).

^g The mean regional species pool was 127.

^h The range of values for the regional species pool was 83–136.

Supplementary Table S3 | Estimates of parameters (γ in Eq. 3; σ ; σ_α in Eq. 2) not presented in Fig. 4. Modes and limits of the 95% Bayesian confidence intervals (in parenthesis) are shown.

Tree biomass production	Estimates	Soil carbon storage	Estimates
γ	0.51 (0.49, 0.53)	γ	7.9 (7.8, 8.1)
σ	0.28 (0.27, 0.29)	σ	0.60 (0.58, 0.63)
σ_α	0.079 (0.061, 0.095)	σ_α	0.26 (0.21, 0.31)
Bilberry production	Estimates	Game production potential	Estimates
γ	0.40 (0.36, 0.45)	γ	-1.14 (-1.18, -1.10)
σ	0.16 (0.15, 0.17)	σ	0.58 (0.56, 0.61)
σ_α	0.086 (0.073, 0.099)	σ_α	0.28 (0.23, 0.33)
Understory plant species richness	Estimates	Dead wood occurrence	Estimates
γ	-2.44 (-2.51, -2.38)	γ	0.18 (0.072, 0.28)
–	–	–	–
σ_α	0.19 (0.18, 0.21)	σ_α	0.55 (0.39, 0.70)

Supplementary Table S4 | Prior distributions for the parameters of the models (Eqs. 1–3).

Parameter	Response variable: Prior distribution	Description	Equation
σ	Tree biomass production: Uniform(0, 1) ^a Soil carbon storage: Uniform(0, 1) ^a Bilberry production: Uniform(0, 25) ^a Game production potential: Uniform(0, 20) ^a Understory plant species richness ^b : Gamma(0.00001,0.00001) ^c	Standard deviation of the plot-level residual variation ^b	1
β_n	Normal(0, 1000) ^d	Effects-size (‘slope’) parameters for the plot-level explanatory variables ^e	1
σ_α	Tree biomass production: Uniform(0, 1) Soil carbon storage: Uniform(0, 1) Bilberry production: Uniform(0, 25) Game production potential: Uniform(0, 20) Understory plant species richness: Uniform(0, 1) Dead wood occurrence: Uniform(0, 1)	Standard deviation of the tract-level residual variation	2
ρ_m	Normal(0, 1000) ^d	Effects-size (‘slope’) parameters for the tract-level explanatory variables ^e	3
γ	Normal(0, 1000) ^d	‘Intercept’ parameter	3

^a Uniform distribution with minimum 0 and maximum 1.

^b For understory plant species richness, σ denotes the standard deviation of the plot-level overdispersion contributions.

^c The precision ($= \sigma^{-2}$) followed a Gamma distribution with shape and scale equal to 0.00001.

^d Normal distribution with mean 0 and variance 1000.

^e For explanatory variables, see Supplementary Table S1.

Supplementary Table S5 | Species and plant groups constituting the food for the herbivores. The estimate of ‘Game production potential’ is based on the occurrence of these plants. Listed are the groups, species, the layer in which they were measured (field, coppice), and the weighting.

Groups	Species	Layer	Weight
Broad leaved grasses	<i>Poaceae</i> , mainly: <i>Milium effusum</i> , <i>Melica nutans</i> , <i>Deschampsia cespitosa</i> , <i>Poa</i> spp., <i>Calamagrostis</i> spp.	Field	0.66
Narrow leaved grasses	<i>Poaceae</i> , mainly: <i>Deschampsia flexuosa</i> , <i>Festuca ovina</i>	Field	0.66
Herbs	<i>Anemone nemorosa</i>	Field	0.66
	<i>Anthriscus sylvestris</i>	Field	0.66
	<i>Epilobium angustifolium</i>	Field	0.66
	<i>Geum rivale</i>	Field	0.66
	<i>Melampyrum pratense</i>	Field	0.66
	<i>Oxalis acetosella</i>	Field	0.66
	<i>Rumex acetosa</i>	Field	0.66
	<i>Stellaria holostea</i>	Field	0.66
	<i>S. nemorum</i>	Field	0.66
	<i>Rubus idaeus</i>	Field	1
	<i>Calluna vulgaris</i>	Field	1
	<i>Erica tetralix</i>	Field	1
	<i>Vaccinium myrtillus</i>	Field	1
	<i>V. vitis-idaea</i>	Field	1
Trees	<i>Pinus sylvestris</i>	Coppice	1
	<i>Betula pubescens</i> , <i>B. pendula</i>	Coppice	1
	<i>Populus tremula</i> , <i>Quercus robur</i> , <i>Fraxinus excelsior</i> , <i>Pinus contorta</i> , <i>Sorbus aucuparia</i> , <i>Salix</i> spp., <i>Juniperus communis</i>	Coppice	1

Supplementary Table S6 | Understory plant species richness was based on a count of these 141 forest-associated species. They are a subset of the species recorded in the Swedish National Forest Inventory.

<i>Achillea millefolium</i>	<i>Dryopteris filix-mas</i>	<i>Lysimachia thyrsiflora</i>	<i>Rhytidadelphus triquetrus</i>
<i>A. ptarmica</i>	<i>Empetrum nigrum</i>	<i>L. vulgaris</i>	<i>Ribes alpinum</i>
<i>Aconitum lycoctonum</i>	<i>Epilobium angustifolium</i>	<i>Maianthemum bifolium</i>	<i>R. arcticus</i>
<i>Agrostis capillaris</i>	<i>Equisetum hyemale</i>	<i>Matteuccia struthiopteris</i>	<i>R. idaeus</i>
<i>Allium ursinum</i>	<i>E. pratense</i>	<i>Melampyrum pratense</i>	<i>R. nigrum</i>
<i>Andromeda polifolia</i>	<i>E. sylvaticum</i>	<i>M. sylvaticum</i>	<i>Rubus chamaemorus</i>
<i>Anemone nemorosa</i>	<i>Erica tetralix</i>	<i>Melica nutans</i>	<i>R. saxatilis</i>
<i>Angelica sylvestris</i>	<i>Eriophorum angustifolium</i>	<i>Menyanthes trifoliata</i>	<i>Rumex acetosa</i>
<i>Antennaria dioica</i>	<i>E. vaginatum</i>	<i>Mercurialis perennis</i>	<i>R. acetosella</i>
<i>Anthoxanthum odoratum</i>	<i>Filipendula ulmaria</i>	<i>Milium effusum</i>	<i>Sanicula europaea</i>
<i>Anthriscus sylvestris</i>	<i>F. vulgaris</i>	<i>Moehringia trinervia</i>	<i>Saussurea alpina</i>
<i>Arctostaphylos uva-ursi</i>	<i>Galium boreale</i>	<i>Molinia caerulea</i>	<i>Saxifraga granulata</i>
<i>Aulacomnium palustre</i>	<i>G. odoratum</i>	<i>Moneses uniflora</i>	<i>Scirpus sylvaticus</i>
<i>Betula pendula</i>	<i>Geranium robertianum</i>	<i>Mycelis muralis</i>	<i>Scrophularia nodosa</i>
<i>Calamagrostis arundinacea</i>	<i>G. sylvaticum</i>	<i>Myrica gale</i>	<i>Selaginella selaginoides</i>
<i>Calluna vulgaris</i>	<i>Geum rivale</i>	<i>Nardus stricta</i>	<i>Silene dioica</i>
<i>Caltha palustris</i>	<i>G. urbanum</i>	<i>Nephroma arcticum</i>	<i>Solidago virgaurea</i>
<i>Cardamine bulbifera</i>	<i>Goodyera repens</i>	<i>Orthilia secunda</i>	<i>Stellaria graminea</i>
<i>Carex chordorrhiza</i>	<i>Gymnocarpium dryopteris</i>	<i>Oxalis acetosella</i>	<i>S. holostea</i>
<i>C. digitata</i>	<i>Hepatica nobilis</i>	<i>Paris quadrifolia</i>	<i>S. nemorum</i>
<i>C. echinata</i>	<i>Huperzia selago</i>	<i>Parnassia palustris</i>	<i>Succisa pratensis</i>
<i>C. globularis</i>	<i>Hylocomium splendens</i>	<i>Pedicularis palustris</i>	<i>Thelypteris palustris</i>
<i>C. lasiocarpa</i>	<i>Hypochaeris maculata</i>	<i>Petasites frigidus</i>	<i>Trientalis europaea</i>
<i>Cicerbita alpina</i>	<i>Juncus filiformis</i>	<i>Phegopteris connectilis</i>	<i>Trifolium medium</i>
<i>Cirsium helenioides</i>	<i>Lamiastrum galeobdolon</i>	<i>Phragmites australis</i>	<i>Trollius europaeus</i>
<i>C. palustre</i>	<i>Lathyrus linifolius</i>	<i>Plagiochila asplenioides</i>	<i>Tussilago farfara</i>
<i>Cladonia stellaris</i>	<i>L. vernus</i>	<i>Pleurozium schreberi</i>	<i>Urtica dioica</i>
<i>Climacium dendroides</i>	<i>Linnaea borealis</i>	<i>Poa nemoralis</i>	<i>Vaccinium myrtillus</i>
<i>Convallaria majalis</i>	<i>Listera cordata</i>	<i>Polypodium vulgare</i>	<i>V. uliginosum</i>
<i>Corallorrhiza trifida</i>	<i>L. ovata</i>	<i>Potentilla erecta</i>	<i>V. vitis-idaea</i>
<i>Cornus suecica</i>	<i>Lotus corniculatus</i>	<i>Potentilla palustris</i>	<i>Veronica chamaedrys</i>
<i>Crepis paludosa</i>	<i>Luzula multiflora</i>	<i>Pteridium aquilinum</i>	<i>V. officinalis</i>
<i>Dactylorhiza maculata</i>	<i>L. pilosa</i>	<i>Ptilium crista-castrensis</i>	<i>Viola mirabilis</i>
<i>Daphne mezereum</i>	<i>Lycopodium annotinum</i>	<i>Ranunculus ficaria</i>	
<i>Deschampsia cespitosa</i>	<i>L. clavatum</i>	<i>Rhodobryum roseum</i>	
<i>D. flexuosa</i>	<i>L. complanatum</i>	<i>Rhododendron tomentosum</i>	