

SUPPLEMENTS

Epixylic diversity in an old-growth boreal forest is influenced by dynamic substrate attributes

Helena Kushnevskaia, Eugene Borovichev, and Ekaterina Shorohova

Table S1. Characteristics of the sampled logs

Tree species	#	Diameter	Decomposition (knife penetration, mm)	Time since tree death	Bark cover, %	Bark moisture, %	Bark pH	Bark specific mass	Height above ground, cm	Litter, %
Spruce	16	35 (31–47)	6.4 (0.1–19.3)	19 (3–40)	50 (3–100)	131 (27–289)	5.0 (4.1–6.1)	0.13 (0.03–0.26)	12 (0–53)	22 (5–63)
Birch	8	29 (24–37)	3.5 (0.2–9.2)	17 (9–21)	84 (5–100)	107 (60–157)	5.1 (4.5–5.7)	0.31 (0.12–0.45)	6 (1–12)	21 (11–28)
Aspen	14	54 (30–79)	3.1 (0.3–21.3)	14 (4–38)	80 (25–100)	149 (46–241)	5.6 (5.1–6.3)	0.42 (0.15–0.76)	9 (0–27)	17 (3–39)
Pine	14	32 (20–49)	5.9 (0.2–19.9)	14 (6–66)	18 (5–50)	94 (19–273)	4.6 (4.1–5.1)	0.10 (0.02–0.23)	9 (0–28)	17 (3–43)

Table S2. Specialization of epixylic species

Species	Abbreviation	Log (tree) species identity	Specialization index d'	Indicator and/or red-listed
<i>Lichens</i>				
<i>Bacidia subincompta</i> (Nyl.) Arnold	BaciSubi	A	0.20	
<i>Biatora helvola</i> Korb. ex Hellb.	BiatHelv	B	0.24	
<i>Bryoria capillaris</i> (Ach.) Brodo & D. Hawksw.	BryoCapi	A; B; P; S	0.06	
<i>Catinaria atropurpurea</i> (Schaer.) Vezda & Poelt	CatiAtro	A	0.20	
<i>Cladonia arbuscula</i> (Wallr.) Flot.	CladArbu	P	0.09	
<i>Cladonia botrytes</i> (K. G. Hagen) Willd.	CladBotr	P; S	0.10	
<i>Cladonia caespiticia</i> (Pers.) Flörke	CladCaes	P	0.16	
<i>Cladonia cenotea</i> (Ach.) Schaer.	CladCeno	B; P; S	0.04	
<i>Cladonia coniocraea</i> (Flörke) Spreng.	CladConi	A; B; P; S	0.04	
<i>Cladonia cornuta</i> (L.) Hoffm.	CladCorn	B	0.24	
<i>Cladonia digitata</i> (L.) Hoffm.	CladDigi	B; P	0.05	
<i>Cladonia gracilis</i> (L.) Willd.	CladGrac	P	0.16	
<i>Cladonia mitis</i> Sandst.	CladMiti	P; S	0.00	
<i>Cladonia norvegica</i> Tønsberget et Holien	CladNorv	B; P; S	0.09	!
<i>Cladonia rangiferina</i> (L.) F. H. Wigg.	CladRang	P	0.00	
<i>Cladonia</i> sp.	Cladsp	A; B; P; S	0.01	
<i>Hypogymnia physodes</i> (L.) Nyl.	HypoPhys	B; P; S	0.10	
<i>Lepraria incana</i> (L.) Ach.	LeprInca	S	0.16	
<i>Leptogium saturninum</i> (Dicks.) Nyl.	LeptSatu	A	0.20	!
<i>Lobaria pulmonaria</i> (L.) Hoffm.	LobaPulm	A	0.31	3 (VU)
<i>Micarea</i> sp.	MicaSp	B; S	0.13	
<i>Mycobilimbia carnealbida</i> (Mull. Arg.) Printzen	MycoSang	A	0.20	
<i>Mycoblastus sanguinarius</i> (L.) Norman	MycoSang	B	0.24	
<i>Nephroma parile</i> (Ach.) Ach.	NephPari	A; B	0.35	!
<i>Opegrapha varia</i> Pers.	OpegVari	S	0.16	
<i>Parmelia sulcata</i> Taylor	ParmSulc	S	0.16	
<i>Parmeliopsis ambigua</i> (Wulfen) Nyl.	ParmAmbi	B; P; S	0.10	
<i>Parmeliopsis hyperopta</i> (Ach.) Arnold	ParmHype	B; P	0.12	
<i>Peltigera canina</i> (L.) Willd.	PeltCani	A	0.20	
<i>Peltigera neopolydactyla</i> (Gyeln.) Gyeln.	PeltNeop	B; P; S	0.11	
<i>Peltigera praetextata</i> (Florke ex Sommerf.) Zopf	PeltPrae	A	0.53	
<i>Pertusaria amara</i> (Ach.) Nyl.	PertAmar	A	0.20	
<i>Phlyctis argena</i> (Spreng.) Flot.	PhlyArge	A	0.31	
<i>Placynthiella dasaea</i> (Stirt.) Tonsberg	PlacDasa	P; S	0.11	
<i>Placynthiella icmalea</i> (Ach.) Coppins & P. James	PlacIcma	P	0.00	
<i>Platismatia glauca</i> (L.) W. L. Culb. & C. F. Culb.	PlatGlau	P; S	0.14	

Species	Abbreviation	Log (tree) species identity	Specialization index d'	Indicator and/or red-listed
<i>Tuckermannopsis chlorophylla</i> (Willd.) Hale	TuckChlo	P; S	0.00	
<i>Usnea</i> sp.		A	0.20	
<i>Vulpicida pinastri</i> (Scop.) J.-E.Mattsson & M. J. Lai	VulpPina	P	0.09	
Mosses				
<i>Brachythecium erythrorrhizon</i> Bruch et al.	BracEryt	A	0.05	
<i>Brachythecium salebrosum</i> (F. Weber & D.Mohr) Bruch et al.	BracSale	A; B	0.20	
<i>Campylidium sommerfeltii</i> (Myrin) Ochyra	CampSomm	S	0.00	
<i>Cirriphyllum piliferum</i> (Hedw.) Grout	CirrPili	B; P; S	0.13	
<i>Dicranum fuscescens</i> Turner	DicrFusc	B; P; S	0.23	
<i>Dicranum majus</i> Turner	DicrMaju	S	0.19	
<i>Dicranum montanum</i> Hedw.	DicrMont	A; B; S	0.05	
<i>Dicranum polysetum</i> Sw.	DicrPoly	A; B; P; S	0.09	
<i>Dicranum scoparium</i> Hedw.	DicrScop	A	0.03	
<i>Eurhynchiastrum pulchellum</i> (Hedw.) Ignatov & Huttunen	EurhPulc	A	0.05	!
<i>Hylocomiastrum umbratum</i> (Hedw.) M. Fleisch.	HyloUmbr	S	0.00	!
<i>Hylocomium splendens</i> (Hedw.) Bruch et al.	HyloSple	A; B; P; S	0.00	
<i>Orthotrichum obtusifolium</i> Brid.	OrthObtu	A; B	0.20	!
<i>Orthotrichum speciosum</i> Nees	OrthSpec	A	0.18	
<i>Plagiomnium cuspidatum</i> (Hedw.) T. J. Kop	PlagCusp	A; B; S	0.11	
<i>Plagiomnium ellipticum</i> (Brid.) T. J. Kop	PlagElly	S	0.00	
<i>Plagiomnium medium</i> (Bruch et al.) T. J. Kop	PlagMedi	S	0.00	
<i>Plagiothecium denticulatum</i> (Hedw.) Bruch et al.	PlagDent	S	0.00	
<i>Plagiothecium laetum</i> Bruch et al.	PlagLaet	S; B	0.15	
<i>Pleurozium schreberi</i> (Brid.) Mitt.	PleuSchr	A; B; P; S	0.14	
<i>Pohlia nutans</i> (Hedw.) Lindb.	PohlNuta	S; P	0.07	
<i>Ptilium crista-castrensis</i> (Hedw.) De Not.	PtilCris	A; B; P; S	0.01	
<i>Pylaisia polyantha</i> (Hedw.) Bruch et al.	PylaPoly	A	0.33	
<i>Rhizomnium pseudopunctatum</i> (Bruch & Schimp.) T. J. Kop	RhizPseu	B	0.00	
<i>Rhizomnium punctatum</i> (Hedw.) T. J. Kop	RhizPunc	A; B; S	0.06	
<i>Rhodobryum roseum</i> (Hedw.) Limpr.	RhodRose	A	0.07	
<i>Rhytidiadelphus subpinnatus</i> (Lindb.) T. Kop	RhytSubp	S	0.13	
<i>Rhytidiadelphus triquetrus</i> (Hedw.) Warnst.	RhytTriq	A; B; S	0.08	
<i>Sanionia uncinata</i> (Hedw.) Loeske	SaniUnci	A; B; S	0.09	
<i>Sciuro-hypnum oedipodium</i> (Mitt.) Ignatov & Huttunen	SciuOedi	A; B; S	0.11	
<i>Sciuro-hypnum reflexum</i> (Starke) Ignatov & Huttunen	SciuRefl	A; B	0.07	
<i>Sciuro-hypnum starkei</i> (Brid.) Ignatov & Huttunen	SciuStar	A; B; S	0.11	
<i>Serpoleskea subtilis</i> (Hedw.) Loeske	SerpSubt	S	0.00	
<i>Tetraphis pellucida</i> Hedw.	TetrPell	S	0.13	

Species	Abbreviation	Log (tree) species identity	Specialization index d'	Indicator and/or red-listed
<i>Liverworts</i>				
<i>Aneura pinguis</i> (L.) Dumort.	AneuPing	S; A	0.17	
<i>Blepharostoma trichophyllum</i> (L.) Dumort.	BlepTrich	A; B; P; S	0.03	
<i>Calypogeia integristipula</i> Steph.	CalyInte	B; P; S	0.09	
<i>Calypogeia muelleriana</i> (Schiffn.) Müll. Frib.	CalyMuel	A; B; P; S	0.01	
<i>Cephalozia bicuspidata</i> (L.) Dumort.	CephBicu	B; S	0.15	
<i>Cephalozia macounii</i> (Austin) Austin	CephMaco	S	0.00	2 (EN)
<i>Chiloscyphus pallescens</i> (Ehrh. ex Hoffm.) Dumort.	ChilPall	S	0.05	
<i>Crossocalyx hellerianus</i> (Nees ex Lindenb.) Meyl.	CrosHell	A; P; S	0.21	!
<i>Fuscocephalozia lunulifolia</i> (Dumort.) Váňa et L. Söderstr.	FuscLunu	A; P; S	0.04	
<i>Lepidozia reptans</i> (L.) Dumort.	LepiRept	B; S	0.11	
<i>Lophocolea heterophylla</i> (Schrad.) Dumort.	LophHete	A; B; S	0.09	
<i>Lophozia ascendens</i> (Warnst.) R. M. Schust	LophAsce	A; S	0.21	3 (NT)
<i>Lophozia guttulata</i> (Lindb. et Arnell) A. Evans	LophGutt	B; P; S	0.12	
<i>Lophozia silvicola</i> H. Buch	LophSilv	A; S	0.10	
<i>Lophozia ventricosa</i> (Dicks.) Dumort.	LophVent	A; S	0.11	
<i>Lophozia longidens</i> (Lindb.) Konstant. et Vilnet	LophLong	A; S	0.11	
<i>Neoorthocaulis attenuatus</i> (Mart.) L. Söderstr., De Roo et Hedd.	NeoAtte	S	0.16	!
<i>Plagiochila porelloides</i> (Torrey ex Nees) Lindenb.	PlagPore	A	0.27	
<i>Ptilidium ciliare</i> (L.) Hampe	PtilCili	S	0.00	
<i>Ptilidium pulcherrimum</i> (Weber) Vain.	PtilPulc	A; B; P; S	0.07	
<i>Radula complanata</i> (L.) Dumort.	RaduComp	A	0.46	
<i>Riccardia latifrons</i> (Lindb.) Lindb.	RiccLati	A; P; S	0.04	!
<i>Riccardia palmata</i> (Hedw.) Carruth.	RiccPalm	A	0.20	!
<i>Scapania apiculata</i> Spruce	ScapApic	A; S	0.01	!; 3 (NT)
<i>Schistochilopsis incisa</i> (Schrad.) Konstant.	SchiInci	S	0.13	
<i>Syzygiella autumnalis</i> (DC.) K. Feldberg, Váňa, Hentschel et Heinrichs.	SyzyAutu	S	0.16	!; 3 (NT)
<i>Tritomaria exsecta</i> (Schmidel) Schiffn. ex Loeske	TritExec	S	0.05	2 (EN)
<i>Vascular plants</i>				
<i>Actaea spicata</i> L.		S	0.00	
<i>Avenella flexuosa</i> (L.) Drejer	AvenFlex	A; B	0.17	
<i>Circaea alpina</i> L.	CircAlpi	A; B; S	0.11	
<i>Convallaria majalis</i> L.	ConvMaja	S; B	0.05	
<i>Fragaria vesca</i> L.	FragVesc	S	0.00	
<i>Galium triflorum</i> Michx.	GaliTrif	A; S	0.00	!
<i>Gymnocarpium dryopteris</i> (L.) Newman	GymnDryo	S	0.00	
<i>Linnaea borealis</i> L.	LinnBore	A; B; P; S	0.05	

Species	Abbreviation	Log (tree) species identity	Specialization index d'	Indicator and/or red-listed
<i>Lycopodium annotinum</i> L.	LycoAnno	P; S	0.16	
<i>Maianthemum bifolium</i> (L.) F. W. Schmidt	MajaBifo	S	0.08	
<i>Oxalis acetosella</i> L.	OxalAcet	A; B; P; S	0.03	
<i>Paris quadrifolia</i> L.	PariQuad	S	0.00	
<i>Picea abies</i> (L.) H. Karst juv.	PiceAbie	A; B; S	0.10	
<i>Rubus saxatilis</i> L.	RubuSaxa	S	0.08	
<i>Trientalis europaea</i> L.	TrieEuro	A; B; S	0.04	
<i>Vaccinium myrtillus</i> L.	VaccMyrt	A; B; P; S	0.09	
<i>Vaccinium vitis-idaea</i> L.	VaccViti	B; P; S	0.11	

Log species identity: A — aspen, B — birch, P — pine, S — spruce. ! — the indicators of old-growth forests (Konechnaya et al., 2009). Categories of the red-listed species in the Republic of Karelia (2020) are following: EN — Endangered; VU — Vulnerable; NT — Near Threatened.

Table S3. Results of generalized linear models of factors affecting the occurrence of species by taxonomic and substrate groups. Only the factors included in the final models are listed. Values in parentheses are SE. Tree species identity: A aspen, B birch, P pine, S spruce. Significance codes: 0 '*' 0.001 '**' 0.01 '*'**

Dependent variable	Family, link function		Intercept	Species	Time	Decomposition	Bark specific mass	Position	Litter
All species	Gaussian, identity	χ^2 Wald	27.65 (0.00)	14.60 (0.00)				8.60 (0.00)	8.00 (0.01)
		Coefficients	11.12 (2.11)	S = 7.10 (2.00)				-0.26 (0.09)	0.18 (0.06)
<i>Taxonomic groups</i>									
Lichens	Poisson, Log	χ^2 Wald	193.44 (0.00)	26.66 (0.00)		15.77 (0.00)			
		Coefficients	1.98 (0.14)	S = -0.75 (0.20) B = -0.57 (0.23) A = -0.98 (0.22)		-0.07 (0.02)			
Liverworts	Tweedie, identity	χ^2 Wald	31.36 (0.00)	18.60 (0.00)				20.70	
		Coefficients	3.93 (0.70)	S = 4.30 (1.20)				-0.12	
Mosses	Poisson, log	χ^2 Wald	34.31 (0.00)	20.90 (0.00)				8.3 (0.00)	8.40 (0.00)
		Coefficients	1.15 (0.20)	S = 0.63 (0.2) B = 0.86 (0.2) A = 0.61 (0.2)				-0.03 (0.01)	0.01 (0.00)
Vascular	Poisson, log	χ^2 Wald	4.98 (0.26)						54.91 (0.00)
		Coefficients	-0.45 (0.20)						0.04 (0.01)
<i>Substrate groups</i>									
Epiphytes	Poisson log	χ^2 Wald	9.54 (0.00)				32.14 (0.00)		16.93 (0.00)
		Coefficients	0.68 (0.22)				2.37 (0.40)		-0.05(0.01)
Facultative epixylics	Poisson log	χ^2 Wald	26.56 (0.00)	8.13 (0.04)			8.70 (0.00)		
		Coefficients	1.03 (0.20)	S = 0.46 (0.20)			-0.03 (0.12)		
True epixylics	Tweedie identity	χ^2 Wald	14.66 (0.00)	19.69 (0.00)				12.24 (0.00)	
		Coefficients	0.98 (0.26)	S = 0.74 (0.30)				-0.06 (0.17)	
Generalists	Poisson log	χ^2 Wald	58.44 (0.00)					5.79 (0.02)	4.51 (0.03)
		Coefficients	1.37 (0.18)					-0.03 (0.01)	0.01 (0.01)
Epigeous	Poisson log	χ^2 Wald	1.09 (0.21)					6.48 (0.01)	4.82 (0.03)
		Coefficients	27.54 (0.00)					-0.03 (0.01)	0.01(0.01)

Table S4. Correlations between substrate attributes. Values in parentheses are SE

	Diameter	Decomposition	Time	Bark cover	Bark moisture	Log position	Bark pH	Litter	Bark specific mass
Diameter	1.0	0.0 (0.9)	0.0 (0.8)	0.2 (0.3)	0.5 (0.0)	-0.1 (0.7)	0.3 (0.0)	0.1 (0.4)	0.2 (0.1)
Decomposition		1.0	0.8 (0.0)	-0.5(0.0)	0.3 (0.0)	-0.7 (0.0)	-0.1 (0.3)	0.7 (0.0)	-0.5 (0.0)
Time			1.0	-0.3 (0.0)	0.4 (0.0)	-0.6 (0.0)	-0.1 (0.5)	0.7 (0.0)	-0.4 (0.3)
Bark cover				1.0	0.2 (0.2)	0.2 (0.2)	0.3 (0.0)	-0.2 (0.1)	0.6 (0.0)
Bark moisture					1.0	-0.5 (0.0)	0.1 (0.4)	0.4 (0.0)	0.0 (0.8)
Log position						1.0	-0.1 (0.7)	-0.6 (0.0)	0.3 (0.1)
Bark pH							1.0	0.0 (0.9)	0.4 (0.0)
Litter								1.0	-0.2 (0.1)
Bark specific mass									1.0

Table S5. Determination coefficients (r^2) and significance (p) of fitted vectors with ordination configurations for species occurrence on Fig. 3. r^2 values significant at the $p < 0.05$ level are denoted by bold font

Variable	r^2	p
Log (tree) species identity	0.463	0.001
Litter cover	0.429	0.001
Wood softness (Decomposition)	0.373	0.001
Time since tree death	0.326	0.001
Log diameter	0.325	0.001
Bark mass	0.298	0.001
Bark moisture	0.286	0.001
Surface area	0.293	0.001
Bark pH	0.241	0.001
Log position	0.221	0.001
Bark cover	0.194	0.007