Evaluation of understory LAI estimation methodologies over forest ecosystem ICOS sites across Europe

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The forest understory (LAI_u): still a poorly investigated research realm

◦ Direct assessments of LAI_u are costly and difficult due to the obscure character of the forest understory (especially true when mosses & lichens are part of LAI_u)

◦ Sattellite-based approaches of LAI_u assessment are limited to areas where the influence of forest overstory is small (e.g. sparse forests, savannas, etc.)

◦ Only very few attempts have been made to produce separate retrievals for over- and understory LAI from vegetation index information (e.g. Deng et al. 2006; Liu et al. 2017; Kobayashi et al. 2018)

Why could accurate and cost-effective LAI_u retrieval assist ecological research?

- Carbon fixed through net primary productivity has different residence times for over- and understory in forest vegetation
- Overstory and understory can possess asynchronous phenology, which complicates remotely-sensed determination of start and end of the growing season
- LAI_u is currently not well treated in carbon-balance modelling….

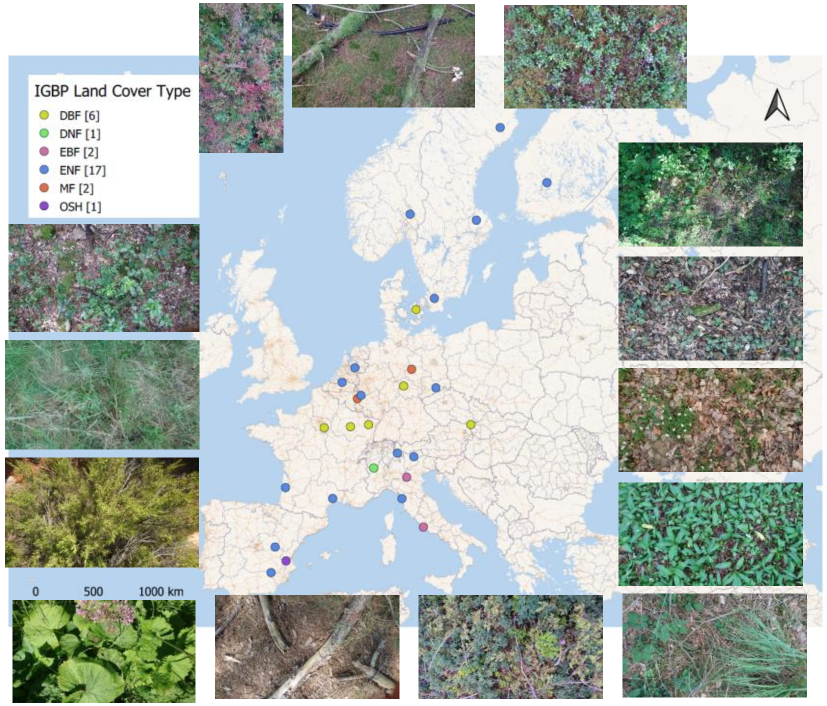
$$\mathrm{NPP} = \underbrace{\mathrm{fNPP}}_{\boxed{\text{foliage}}} + \underbrace{\mathrm{wNPP}}_{\boxed{\text{wood}}} + \underbrace{\mathrm{rNPP}}_{\boxed{\text{root}}} + \boxed{\mathrm{mNPP}}.$$

mNPP-> all components that are difficult to measure (flowers, seeds, fruits and understory) are often pooled, because they can only roughly be approximated!

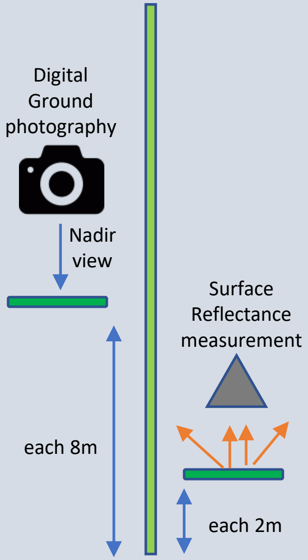
Luyssaert et al. (2007)

…although the contribution of LAI_u can be substantial (e.g. in boreal forests at high latitudes)!

29 ICOS and GHG forest ecosystem sites with diverse understory types and LAI_u



Two 50m long transects at each site



Digital Ground photography

Surface Reflectance measurement

LAI_{FC}

Analyze particles with *imageJ*

Determination of Fractional vegetation cover (FC)

$$LAI_{FC}=-2\ln(1-FC)$$

Beer-Lambert-Bouguer law
Of light absorption

LAI_{NDVI}

Canopy radiative transfer model **FLiES** (Kobayashi and Iwabuchi, 2008).

LUT with simulated LAI and RED, NIR reflectances for VZA=0, SZA=45, VAA=40

Finding LAI from LUT for corresponding NDVI from field measurement

LAI_{SR}

Four Scale model simulations (Chen & Leblanc 1997) and Chebyshev polynomials with land cover type-specific algorithm coeffcients taken from look-up tables (Deng et al. 2006)

$$LAI = f_{LE\_VI}\,[f_{biome}(VI_{obs}) \cdot f_{BRDF}(\theta v,\theta s,\varphi)]$$

simple ratio (SR) and biome-specific functions designed for 3 non-forest cover types

Task A

Method Comparison

How do the three methods correlate?

Where are limits of agreements among the three methods?

Which method to choose in which situation?

Task B

Relationship of LAI_u with biogeography & vegetation diversity

Is LAI_u variation related to differences in site-climate?

Is there a relationship between species richness and LAI_u

Task A

Method Comparison

How do the three methods correlate?

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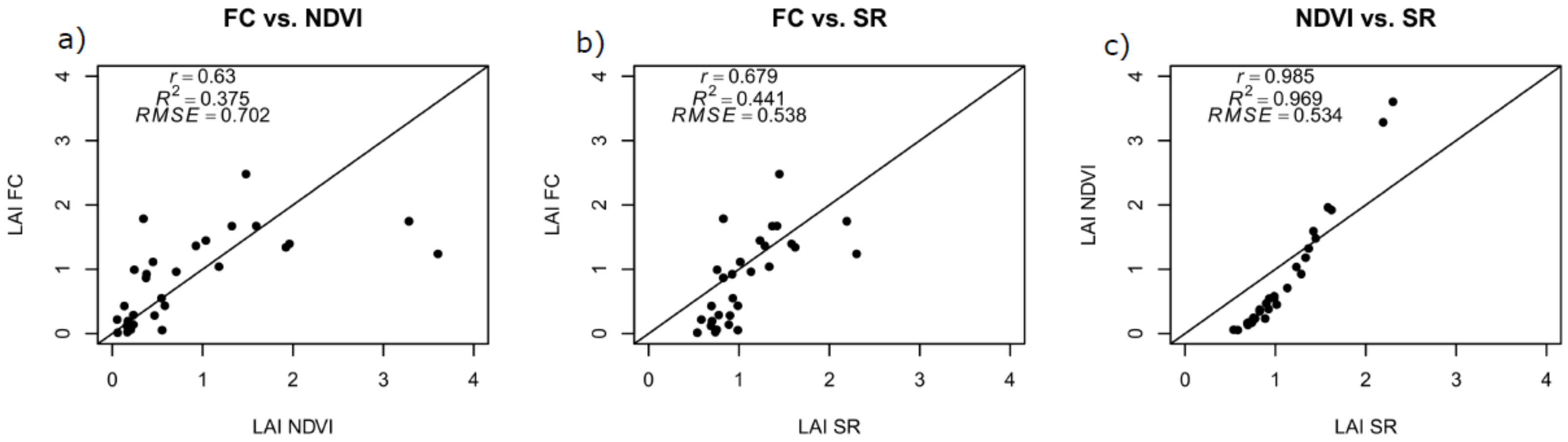
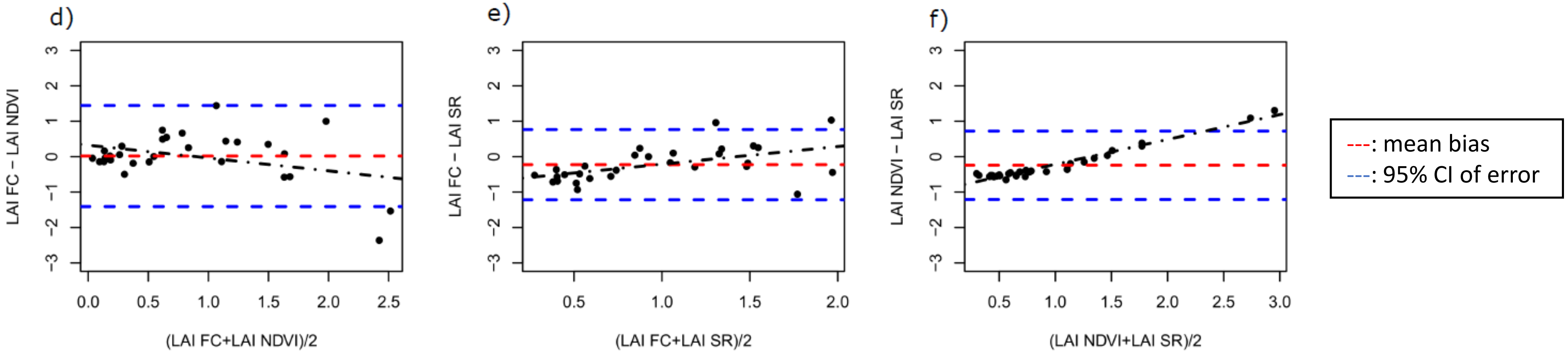
Which method to choose in which situation?

Pairwise correlation plots



Pairwise Bland-Altmann diagrams (limits of agreement)



LAI_{NDVI} systematically overestimates at LAI>2; LAI_{SR} systematically overestimates at LAI<0.5

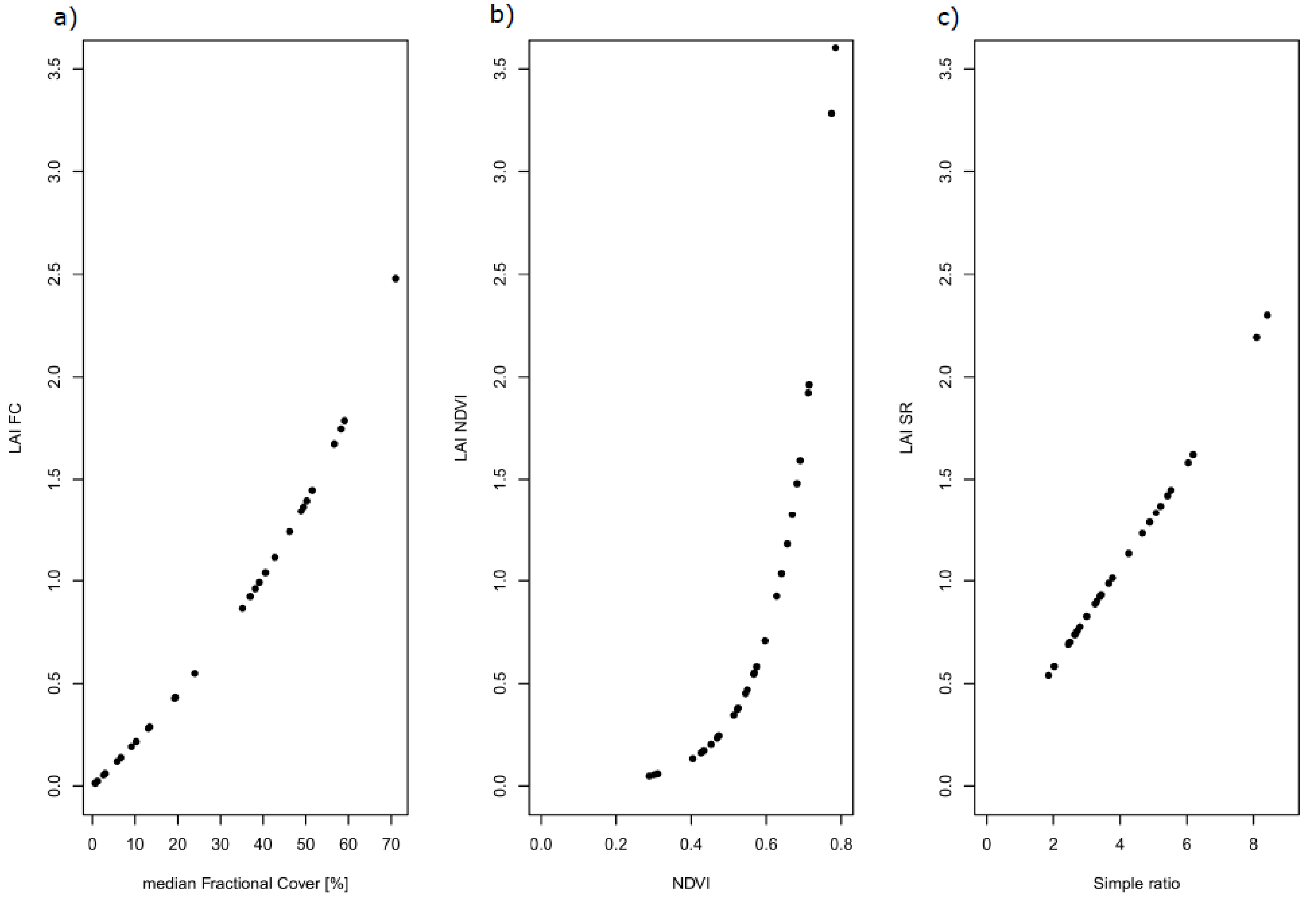
Task A
Method Comparison

How do the three methods correlate?

Where are limits of agreements among the three methods?

Which method to choose in which situation?

Relationship between retrieved LAI_u and its main parameter in the models



LAI_{NDVI} shows strong exponential character leading to unrealistically high values at productive sites

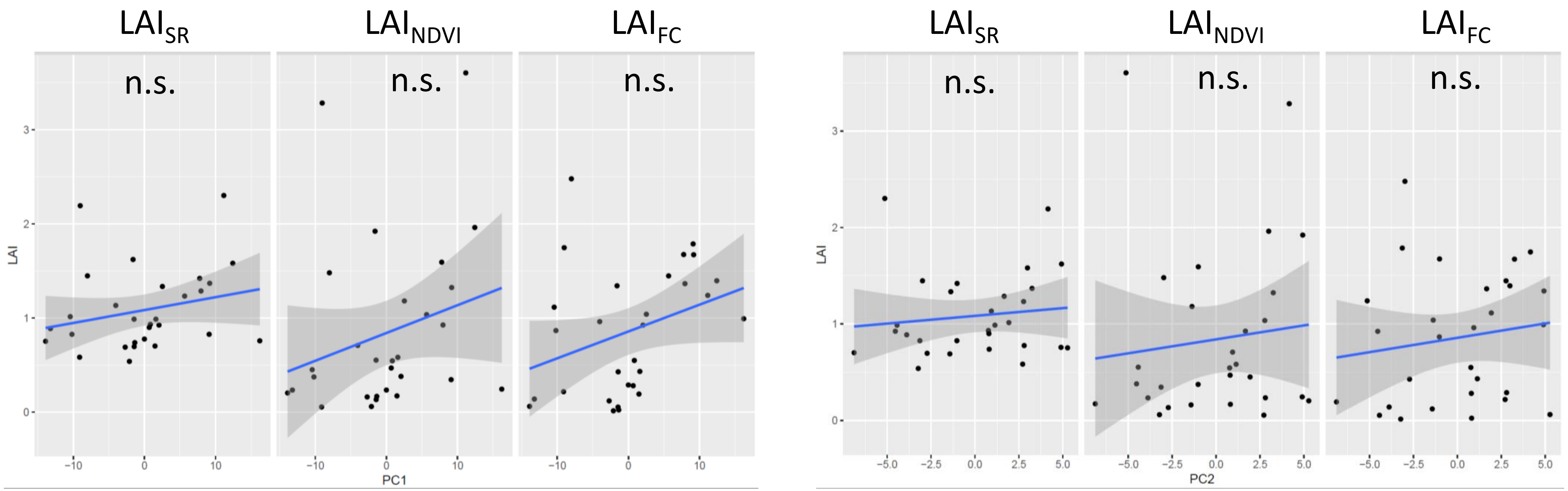
Task B

Relationship of LAI_u with biogeography & vegetation diversity

Is LAI_u variation related to differences in site-climate?

Is there a relationship between species richness and LAI_u

Linear model between LAI_u and first two principal components of 83 long-term climatic variables with $1km^2$ spatial resolution (climate dataset from Chakraborty et al. 2019)



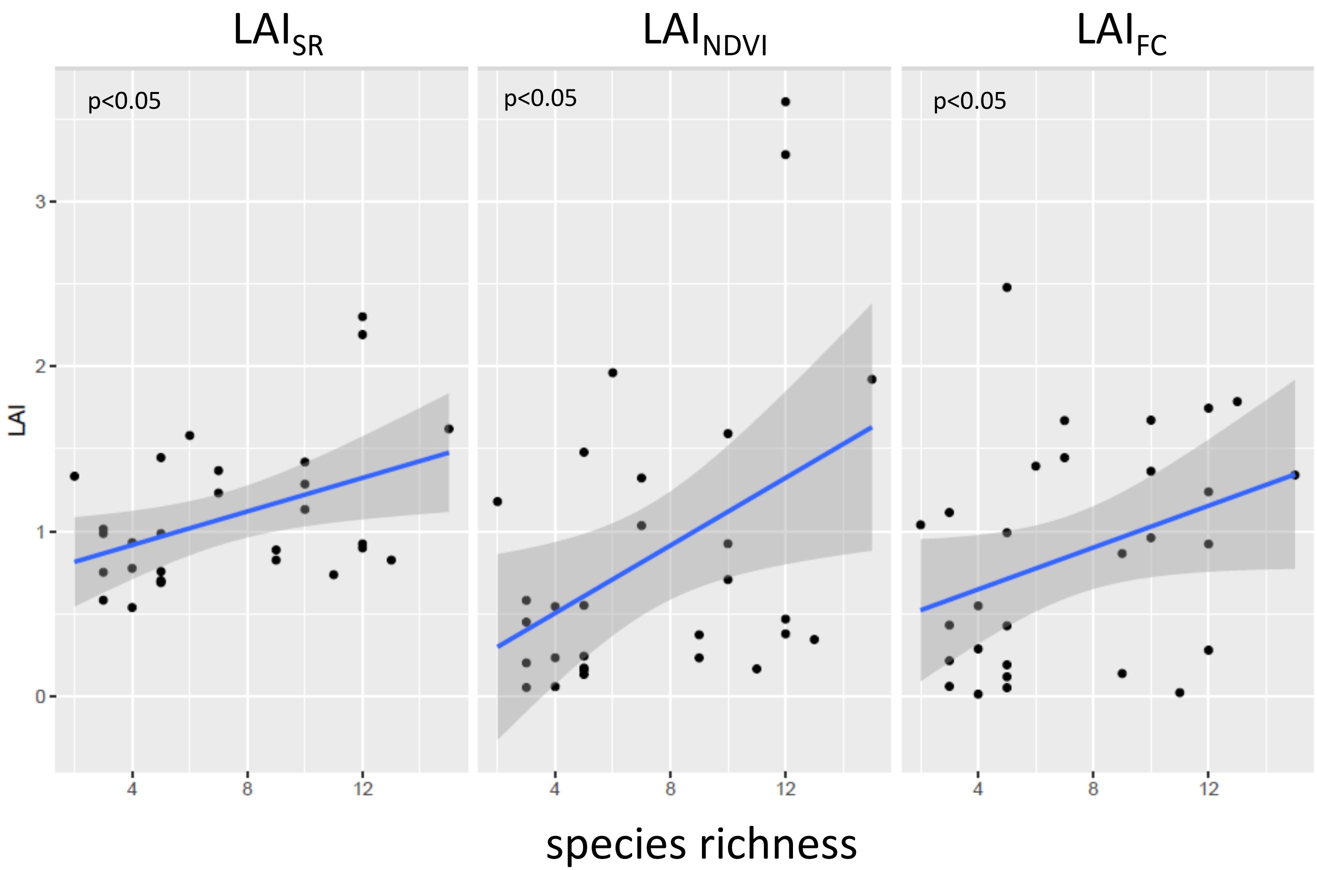
Higher LAI_u values were generally found at higher latitudes, but LAI_u variation in space seems to be largely decoupled from bioclimatic clines!

Task B

Relationship of LAI_u with biogeography & vegetation diversity

Is LAI_u variation related to differences in site-climate?

Is there a relationship between species richness and LAI_u



All three methods show a significant increase of LAI_u with increasing species richness!

◦ Retrievals obtained from the three methods were **significantly correlated** with each other, but performed differently at specific LAI ranges

◦ LAI_{NDVI} gives **larger LAI** values at productive sites (**LAI>2**), whereas LAI_{SR} seems to be **insensitive** to low LAI values (**0.0-0.5**)

◦ LAI_u derived from **fractional vegetation cover** seems to be a **good compromise** for indirect in situ LAI_u estimation given that it was capable of retrieving LAI_u at both low and high LAI ranges without constraints of reflectivity issues related to presence of bare soil or dense vegetation and saturation.

◦ LAI_u variation in space that can be attributed to differences in vegetation diversity, but not to variation in climate among sites.

Acknowledgements

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Eesti Teadusagentuur
Estonian Research Council

Appendix 1: cited literature

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Appendix 2: site & instrument information

Site name	Country	Side code	Lat	Lon	IGBP land cover type	Sampling date	dominant species in understory	Spectrometer model
Fontainebleau-Barbeau (ICOS)	FR	FR-Fon	48.476	2.780	DBF	2018/06	hornbeam	Ocean Optics FLAME-S-VIS-NIR-ES
Bilos-Salles (ICOS)	FR	FR-Bil	44.494	-0.956	ENF	2018/06	Molinia coerulea Moench., Pteridium aquilineum , Ulex europaeus	Ocean Optics FLAME-S-VIS-NIR-ES
Bosco Fontana (ICOS)	IT	IT-BFt	45.202	10.743	EBF	2018/07	Hedera helix, Corylus spec., Ruscus aculeatus	Ocean Optics FLAME-S-VIS-NIR-ES
Braschaat (ICOS)	BE	BE-Bra	51.300	4.517	ENF	2019/01	Betula spec, Quercus robur, Sorbus aucuparia	Ocean Optics FLAME-S-VIS-NIR-ES
Castelporziano2 (ICOS)	IT	IT-Cp2	41.704	12.357	EBF	2019/01	Phyllirea latifolia, Pistacia lentiscus	Ocean Optics FLAME-S-VIS-NIR-ES
Cuenca de Las Majadas	ESP	ES-CMu	40.252	-1.965	ENF	2018/07	Juniperus communis, Juniperus oxycedrus, Crataegus monogyna	Ocean Optics FLAME-S-VIS-NIR-ES
Cortes de Pallas	ESP	ES-CPa	39.224	-0.903	OSH	2018/07	Rosmarinus officinalis, Ulex parviflorus, Brachypodium retusum	Ocean Optics FLAME-S-VIS-NIR-ES
Davos (ICOS)	CH	CH-Dav	46.817	9.850	ENF	2018/07	dwarf shrubs, blueberry, mosses	Ocean Optics FLAME-S-VIS-NIR-ES
Hainich (ICOS)	DE	DE-Hai	51.079	10.453	DBF	2018/04	Anemone nemorosa, Allium ursinum	Ocean Optics FLAME-S-VIS-NIR-ES
Hesse (ICOS)	FR	FR-Hes	48.674	7.066	DBF	2018/08	beech (Fagus sylvatica), Blackberry	Ocean Optics FLAME-S-VIS-NIR-ES
Hohes Holz (ICOS)	DE	DE-HoH	52.083	11.217	MF	2018/04	Anemone nemorosa	Ocean Optics FLAME-S-VIS-NIR-ES
Hurdal (ICOS)	NO	NO-Hur	60.372	11.078	ENF	2018/09	Vaccinium spec., Norway spruce seedlings	Ocean Optics FLAME-S-VIS-NIR-ES
Hyltemossa (ICOS)	SE	SE-Htm	56.098	13.419	ENF	2018/09	continuous moss cover	Ocean Optics FLAME-S-VIS-NIR-ES
Hyytiälä (ICOS)	FI	FI-Hyy	61.847	24.295	ENF	2018/06	Vaccinium spec., Norway spruce seedlings	Ocean Optics FLAME-S-VIS-NIR-ES
Lanžhot (ICOS)	CZ	CZ-Lnz	48.682	16.948	DBF	2017/04	Allium ursinum, Asarum europeum	ASD FieldSpec 4
Loobos (ICOS)	NL	NL-Loo	52.167	5.744	ENF	2018/08	Prunus serotina , Vaccinium Myrtilus, Deschampsia felexuosa, mosses	Ocean Optics FLAME-S-VIS-NIR-ES
Montiers sur Saulx (ICOS)	FR	FR-MsS	48.538	5.312	DBF	2019/01	sparse Sphagnum spec. vegetation	Ocean Optics FLAME-S-VIS-NIR-ES
Norunda (ICOS)	SE	SE-Nor	60.086	17.480	ENF	2018/10	bilberry, lingonberry, moss	ASD FieldSpec Pro
Puechabon (ICOS)	FR	FR-Pue	43.741	3.596	ENF	2018/06	Buxus sempervirens	Ocean Optics FLAME-S-VIS-NIR-ES
Renon (ICOS)	IT	IT-Ren	46.587	11.434	ENF	2018/07	Deschampsia flexuosa L. , Vaccinium myrtillus L. , Rhododendron ferrugineum L.	Ocean Optics FLAME-S-VIS-NIR-ES
San Rossore 2 (ICOS)	IT	IT-SR2	43.732	10.291	ENF	2018/07	Ligustrum vulgare	Ocean Optics FLAME-S-VIS-NIR-ES
Sodankylä (ICOS)	FI	FI-Sod	67.362	26.638	ENF	2017/06	lingonberry, Calluna vulgaris, lichens	ASD FieldSpec Pro
Soroe (ICOS)	DK	DK-Sor	55.486	11.645	DBF	2018/09	beech saplings and seedlings, Pteridium Aquilinum	Ocean Optics FLAME-S-VIS-NIR-ES
Svartberget (ICOS)	SE	SE-Svb	64.256	19.775	ENF	2019/08	bilberry, lingonberry and moss	ASD FieldSpec Pro
Tharandt (ICOS)	DE	DE-Tha	50.967	13.567	ENF	2018/04	Fagus sylvatica, Abies alba, Deschampsia flexuosa	Ocean Optics FLAME-S-VIS-NIR-ES
Torgnon-LD	IT	IT-Tor	45.833	7.567	DNF	2018/07	Juniperus communis, Rhododendron ferrugineum, Festuca varia	Ocean Optics FLAME-S-VIS-NIR-ES
Vielsalm (ICOS)	BE	BE-Vie	50.300	5.983	MF	2018/08	sparse fern and moss cover	Ocean Optics FLAME-S-VIS-NIR-ES
Wustebach (ICOS)	DE	DE-RuW	50.505	6.331	ENF	2018/08	sparse Deschampsia flexuosa, Deschampsia cespitosa and Molinia caerulea	Ocean Optics FLAME-S-VIS-NIR-ES
Yeste	ESP	ES-Yst	38.339	-2.351	ENF	2018/07	Rosmarinus officinalis L., Thymus vulgaris L., Cistus clusii Dunal	Ocean Optics FLAME-S-VIS-NIR-ES