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Supplement of

Use of spatial embeddings in genosoil identification

Julio César Pachón Maldonado et al.

Correspondence to: Julio César Pachón Maldonado (julio.pachon@sydney.edu.au)

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Supplement

Table S1. Cohesion of the UK candidate genosoil reference populations in 2022. Pixel counts and cohesion describe the full populations. The 95 % confidence intervals were estimated from 2,000 bootstrap resamples of GPM cells, retaining all reference pixels within each resampled cell. For P2932, the intervals describe subsets containing 10,614 AlphaEarth and 11,104 Tessera reference pixels, with cohesion of 0.90 and 0.87, respectively.

Pedogenon	Embedding model	Reference pixels (10 m)	Cohesion	Cohesion 95 % CI	
				Low CI	High CI
P845	AlphaEarth	305	0.93	0.87	0.97
P845	Tessera	294	0.92	0.87	0.96
P1564	AlphaEarth	1,883	0.89	0.89	0.91
P1564	Tessera	2,017	0.82	0.80	0.85
P2932	AlphaEarth	35,195,776	0.89	0.89	0.90
P2932	Tessera	36,136,094	0.87	0.86	0.88

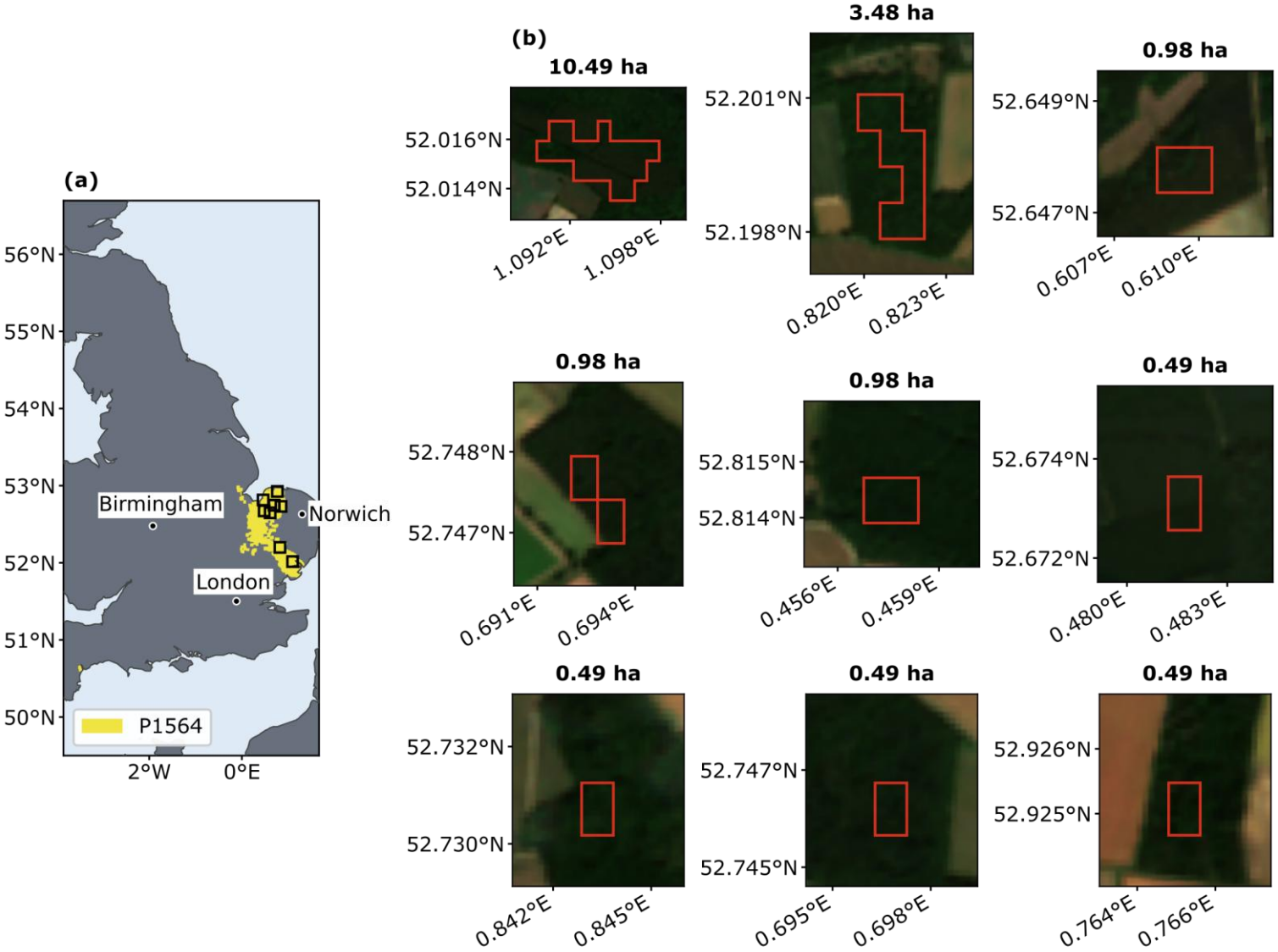


Figure S1. (a) Extent of pedogenon 1564 in the UK, with black squares showing the locations of the all the HMI derived candidate genosoils (18.88 ha) in the pedogenon. (b) Median composites of Sentinel-2 imagery from May–September 2022 using satellites images with less than 15 % cloud coverage (European Space Agency, 2017). Red outlines mark boundaries of HMI derived candidate genosoils.

Table S2. Global geographic distribution of the pedogenons studied, candidate genosoil areas and similarity of reference centroid to the United Kingdom's reference centroid. AlphaEarth uses 2022 data while Tessera uses 2024 data.

Pedogenon	Country	Pedogenon area (km²)	HMI candidate area (km²)	Model	Embedding candidate area (km²)	Reference cohesion	Similarity to UK
P845	United Kingdom	0.89	0.03	AlphaEarth	0.57	0.93	1.00
				Tessera	0.31	0.92	1.00
	Australia	155.91	137.08	AlphaEarth	111.16	0.92	0.07
				Tessera	86.64	0.89	0.37
	Bolivia	0.16	0.16	AlphaEarth	0.16	0.99	0.09
				Tessera	0.16	0.95	0.34
	Brazil	0.13	0.13	AlphaEarth	0.12	0.95	0.04
				Tessera	0.10	0.92	0.38
	Central African Rep.	0.13	0.01	AlphaEarth	0.13	1.00	-0.05
				Tessera	0.10	0.97	0.40
	China	5,619.86	5,035.30	AlphaEarth	369.77	0.84	0.09
				Tessera	260.64	0.82	0.55
	Georgia	0.11	0.11	AlphaEarth	0.07	0.88	0.31
				Tessera	0.05	0.89	0.49
	India	70.32	26.52	AlphaEarth	9.21	0.85	-0.01
				Tessera	8.31	0.85	0.38
	Ireland	28.99	14.94	AlphaEarth	13.11	0.88	0.91
				Tessera	14.12	0.89	0.89
	Japan	1,110.22	442.36	AlphaEarth	98.66	0.82	0.18
				Tessera	76.37	0.81	0.52
	Mexico	165.64	123.55	AlphaEarth	75.26	0.88	-0.02
				Tessera	27.07	0.84	0.38
	Myanmar	14.18	13.87	AlphaEarth	4.65	0.87	-0.04
				Tessera	2.56	0.85	0.37
	Nepal	641.50	542.82	AlphaEarth	191.62	0.86	0.03
				Tessera	177.77	0.86	0.35
	New Caledo-nia	2.81	2.67	AlphaEarth	0.78	0.86	0.11
				Tessera	0.94	0.86	0.45
	New Zealand	902.67	658.69	AlphaEarth	144.03	0.83	0.05
				Tessera	141.91	0.83	0.45
	Peru	1.77	1.63	AlphaEarth	0.80	0.87	0.03
				Tessera	0.37	0.85	0.49

Table S2 (continued)

Pedogenon	Country	Pedogenon area (km²)	HMI candidate area (km²)	Model	Embedding candidate area (km²)	Reference cohesion	Similarity to UK
P845	Thailand	4.00	4.00	AlphaEarth	2.96	0.92	0.01
				Tessera	2.54	0.90	0.36
	United States of America	6,115.74	3,289.08	AlphaEarth	2,296.09	0.84	0.22
				Tessera	1,047.88	0.83	0.50
P1564	United Kingdom	724.14	0.19	AlphaEarth	7.47	0.89	1.00
				Tessera	6.20	0.82	1.00
	Argentina	0.47	0.47	AlphaEarth	0.43	0.95	-0.02
				Tessera	0.30	0.90	0.47
	Australia	27.80	2.47	AlphaEarth	15.18	0.93	-0.03
				Tessera	6.41	0.87	0.41
	Austria	17.77	0.18	AlphaEarth	1.24	0.91	0.73
				Tessera	0.42	0.85	0.87
	Belarus	12.61	1.85	AlphaEarth	3.03	0.89	0.58
				Tessera	0.35	0.82	0.78
	Belgium	45.30	0.00	AlphaEarth	NA	NA	NA
				Tessera	NA	NA	NA
	Bulgaria	280.23	2.34	AlphaEarth	7.79	0.90	0.52
				Tessera	2.93	0.84	0.67
	Canada	17.69	13.92	AlphaEarth	10.56	0.91	0.07
				Tessera	0.00	0.76	0.54
	Chile	1.51	1.48	AlphaEarth	1.22	0.94	-0.02
				Tessera	0.64	0.89	0.46
	China	2,594.95	449.64	AlphaEarth	210.37	0.83	0.11
				Tessera	220.34	0.81	0.47
	Czechia	55.10	0.05	AlphaEarth	2.80	0.94	0.64
				Tessera	0.42	0.86	0.84
	Ecuador	8.04	5.62	AlphaEarth	5.84	0.94	0.12
				Tessera	5.83	0.94	0.43
	Estonia	38.55	16.47	AlphaEarth	15.39	0.92	0.60
				Tessera	6.00	0.84	0.75
	France	33.56	0.00	AlphaEarth	NA	NA	NA
				Tessera	NA	NA	NA
	Germany	187.48	1.30	AlphaEarth	10.67	0.90	0.93
				Tessera	2.46	0.84	0.91

Table S2 (continued)

Pedogenon	Country	Pedogenon area (km²)	HMI candidate area (km²)	Model	Embedding candidate area (km²)	Reference cohesion	Similarity to UK
P1564	Greece	34.62	3.81	AlphaEarth	1.34	0.84	0.28
				Tessera	4.51	0.86	0.58
	Hungary	50.78	4.98	AlphaEarth	4.89	0.85	0.79
				Tessera	2.34	0.83	0.89
	Ireland	101.02	0.14	AlphaEarth	5.36	0.92	0.75
				Tessera	0.62	0.85	0.87
	Lithuania	2.59	0.13	AlphaEarth	0.20	0.92	0.78
				Tessera	0.11	0.86	0.91
	Mexico	12.69	0.71	AlphaEarth	2.35	0.95	0.04
				Tessera	1.53	0.90	0.49
	Morocco	0.42	0.03	AlphaEarth	0.13	0.94	0.26
				Tessera	0.27	0.94	0.49
	New Zealand	13.50	0.19	AlphaEarth	1.66	0.88	-0.06
				Tessera	0.33	0.82	0.57
	North Macedonia	7.17	0.04	AlphaEarth	0.02	0.80	0.20
				Tessera	0.19	0.90	0.44
	Romania	12.72	4.81	AlphaEarth	1.80	0.85	0.45
				Tessera	2.39	0.85	0.76
	Russia	17,797.41	8,306.31	AlphaEarth	5,808.93	0.88	0.32
				Tessera	220.43	0.78	0.60
	Slovakia	0.37	0.27	AlphaEarth	0.35	0.97	0.60
				Tessera	0.29	0.91	0.80
	Spain	168.79	0.53	AlphaEarth	9.85	0.86	0.47
				Tessera	8.14	0.84	0.92
	Sweden	47.13	0.43	AlphaEarth	1.62	0.90	0.75
				Tessera	0.85	0.85	0.86
	Turkey	1.62	0.00	AlphaEarth	NA	NA	NA
				Tessera	NA	NA	NA
	Ukraine	348.99	40.42	AlphaEarth	44.17	0.90	0.66
				Tessera	18.69	0.83	0.84
	United States of America	114.61	87.00	AlphaEarth	42.43	0.86	0.39
				Tessera	21.90	0.84	0.66
P2932	United Kingdom	5,745.96	3,522.66	AlphaEarth	3,456.47	0.89	1.00
				Tessera	2,155.98	0.87	1.00

Table S2 (continued)

Pedogenon	Country	Pedogenon area (km²)	HMI candidate area (km²)	Model	Embedding candidate area (km²)	Reference cohesion	Similarity to UK
P2932	Angola	0.09	0.09	AlphaEarth	0.09	0.99	0.05
				Tessera	0.08	0.96	0.34
	Canada	3.77	3.62	AlphaEarth	3.16	0.94	0.16
				Tessera	0.65	0.83	0.61
	Norway	0.03	0.02	AlphaEarth	0.01	0.91	0.62
				Tessera	0.01	0.91	0.79
	Russia	0.31	0.02	AlphaEarth	0.03	0.97	0.22
				Tessera	0.01	0.90	0.59
	Switzerland	0.92	0.02	AlphaEarth	0.32	0.95	0.16
				Tessera	0.01	0.83	0.65
	United States of America	77.16	12.81	AlphaEarth	0.00	0.66	0.33
				Tessera	0.05	0.77	0.70

Table S3. Tessera UK genosoil temporal stability between 2022 and 2024. Inter-annual silhouette measures the separation between year-specific pixel populations relative to the within-year spread, with values closer to 1 indicating a stronger separation between years, and values closer to 0 indicating greater overlap and thus higher temporal stability. The centroid cosine similarity is calculated between the UK genosoil centroids of 2022 and 2024.

Pedogenon	Number of Candidate Genosoil pixels	Cohesion in 2022	Cohesion in 2024	Inter-annual silhouette	Centroid cosine similarity (2022 vs 2024)
P845	294	0.92	0.92	0.45	0.86
P1564	2,017	0.82	0.82	0.04	0.98
P2932	36,136,094	0.87	0.87	0.06	0.98

Table S4. Global WRB Reference Soil Groups and Shannon diversity H' for the pedogenons studied. Predicted soil classes are from the SoilGrids250m WRB class map (Hengl et al., 2017), sampled at Global Pedogenon Map cell centres. These mapped predictions provide taxonomic context, rather than independent validation.

Pedogenon	Shannon diversity H′	WRB Reference Soil Group	Area (km²)	Classified area (%)
P845	1.36	Acrisols	7,081.60	47.74
		Cambisols	3,924.78	26.46
		Alisols	2,354.53	15.87
		Andosols	759.50	5.12
		Leptosols	384.52	2.59
		Luvisols	125.70	0.85
		Regosols	111.13	0.75
		Nitisols	30.03	0.20
		Fluvisols	24.80	0.17
		Podzols	18.82	0.13
		Gleysols	12.53	0.08
		Ferralsols	3.97	0.03
		Phaeozems	2.25	0.02
		Vertisols	0.25	< 0.01
		Arenosols	0.12	< 0.01
P1564	1.44	Phaeozems	9,270.10	40.73
		Albeluvisols	7,613.24	33.45
		Cambisols	2,667.21	11.72
		Luvisols	2,157.64	9.48
		Chernozems	335.97	1.48
		Fluvisols	229.73	1.01
		Gleysols	208.02	0.91
		Histosols	92.84	0.41
		Podzols	47.93	0.21
		Kastanozems	34.94	0.15
		Vertisols	30.17	0.13
		Alisols	28.35	0.12
		Arenosols	13.66	0.06
		Solonchaks	10.96	0.05
		Cryosols	8.06	0.04
		Ferralsols	5.11	0.02
		Andosols	3.26	0.01
		Calcisols	1.36	0.01
		Solonetz	0.45	< 0.01
		Acrisols	0.25	< 0.01
		Planosols	0.19	< 0.01
		Regosols	0.18	< 0.01
		Lixisols	0.11	< 0.01
		Leptosols	0.09	< 0.01
P2932	0.73	Podzols	4,268.13	73.24
		Cambisols	1,218.17	20.90
		Gleysols	334.51	5.74
		Leptosols	4.19	0.07
		Luvisols	1.75	0.03
		Regosols	0.34	0.01
		Albeluvisols	0.26	< 0.01
		Andosols	0.13	< 0.01
		Kastanozems	0.12	< 0.01
		Ferralsols	0.09	< 0.01

Table S5. USDA Soil Taxonomy Great Groups and associated landforms within the United States for the studied pedogenons covering at least 1 % for each of the pedogenons area, using gSSURGO (Soil Survey Staff, 2026 release). These mapped predictions provide taxonomic context, rather than independent validation.

Pedogenon	Great Group	Classified component area (%)	Major associated landforms (%)
P845	Hapludults	64.70	hillslopes (27); ridges (25); interfluves (24)
	Dystrudepts and legacy Dystrochrepts	26.14	hillslopes (38); ridges (31); mountain slopes (6)
	Paleudults	3.78	escarpments (40); gorges (31); hillslopes (8)
	Udorthents	1.79	hillslopes (73); mountain slopes (15); ridges (8)
	Kanhapludults	1.38	hillslopes (49); hills (38); ridges (9)
P1564	Udipsamments	60.16	deltas (33); stream terraces (28); outwash plains (17)
	Haplosaprists	8.80	depressions (82); swales (5); deltas (3)
	Haplorthods	6.96	moraines (39); deltas (19); outwash plains (17)
	Endoaquods	6.29	stream terraces (23); deltas (22); outwash plains (20)
	Glossudalfs	5.05	moraines (48); lake plains (24); till plains (18)
	Epiaquods	3.42	lake terraces (84); lake plains (8); outwash plains (3)
	Epiaquents	2.87	depressions (94); deltas (2); moraines (1)
	Hapludalfs	1.65	lake plains (56); moraines (16); stream terraces (4)
	Humaquepts	1.57	depressions (65); flood plains (25); deltas (6)
P2932	Quartzipsamments	39.15	moraines (50); outwash plains (48); outwash terraces (1)
	Udipsamments	16.98	outwash plains (51); dikes (23); outwash terraces (11)
	Haplosaprists	13.35	depressions (92); swamps (7); bogs (1)
	Dystrudepts and legacy Dystrochrepts	5.96	kame terraces (27); hills (18); mountain slopes (10)
	Haploxerepts	4.81	mountain slopes (99); flood-plain steps (<1); hills (<1)
	Udorthents	3.65	kame terraces (87); eskers (11); kames (<1)
	Endoaquods	3.60	depressions (55); kettles (34); drainageways (4)
	Dystroxerepts	2.72	mountain valleys (35); alluvial fans (18); mountain slopes (12)
	Psammaquents	1.36	bogs (82); depressions (15); flood plains (2)
	Humaquepts	1.23	depressions (44); drainageways (37); ground moraines (7)
	Duraquods	1.15	depressions (41); drainageways (41); terraces (18)

Note: Legacy Dystrochrepts are pooled with Dystrudepts for presentation. Legacy Xerochrepts series were reassigned to Haploxerepts or Dystroxerepts according to their current USDA Official Series Descriptions. All other names are as recorded in gSSURGO.

Table S6. World Reference Base (WRB) soil profile records located within the global occurrences of the three study pedogenons (Hengl and Gupta, 2025).

Pedogenon	Profile ID	WRB class	Source database	Longitude	Latitude
P845	207839	Endoleptic Luvisols Abruptic	MX-INEGI	-95.501	16.867
	64904	Haplic Alisols	CN-SOTER	118.112	30.145
	64904	Ferric Alisols	CN-SOTER	118.112	30.145
	SIM51744	Haplic Acrisols	HWSDv2	-84.091	35.324
	SIM87807	Dystric Regosols	HWSDv2	118.590	30.383
P1564	2742	Eutric Planosols	BZE_LW	12.560	51.181
	607393	Haplic Chernozems	RU-SPDB	36.300	51.300
	607393	Luvic Chernozems	RU-SPDB	36.300	51.300
	63778	Calcaric Cambisols	WD-ISIS	13.413	55.548
	63778	Eutric Cambisols	WD-ISIS	13.413	55.548
	65099	Dystric Gleysols	CN-SOTER	122.078	41.412
	65099	Eutric Gleysols	CN-SOTER	122.078	41.412
	70364	Eutric Planosols	EU-SOTER,EU-SPADE,WD-WISE	27.200	57.850
	70364	Dystric Planosols	EU-SOTER,EU-SPADE,WD-WISE	27.200	57.850
	SIM13684	Cambic Umbrisols	HWSDv2	-5.195	43.466
	SIM61025	Greyzemic Phaeozems	HWSDv2	49.732	55.945
P2932	612391	Cambic Umbrisols	WD-eSOTER	-4.864	57.994
	612391	Acric Umbrisols	WD-eSOTER	-4.864	57.994
	612393	Rustic Podzols	WD-eSOTER	-3.896	57.206
	612393	Albic Podzols	WD-eSOTER	-3.896	57.206
	612470	Fibric Histosols	WD-eSOTER	-4.750	58.036
	612470	Sapric Histosols	WD-eSOTER	-4.750	58.036
	66794	Rustic Podzols	WD-WISE	-3.625	57.208
	66794	Albic Podzols	WD-WISE	-3.625	57.208
	66798	Rustic Podzols	WD-WISE	-3.678	57.239
	66798	Albic Podzols	WD-WISE	-3.678	57.239
	66799	Rustic Podzols	WD-WISE	-4.104	57.206
	66799	Albic Podzols	WD-WISE	-4.104	57.206

Table S7. Sensitivity of embedding defined candidate genosoil areas to the cosine similarity threshold. IoU is the intersection divided by the union of the HMI defined and embedding defined candidate areas for each model. Both embedding products use UK reference populations from 2022.

Pedogenon	Cosine Similarity Threshold	Candidate Genosoil Area		IoU	
		AlphaEarth (km^2)	Tessera (km^2)	HMI - AlphaEarth	HMI – Tessera
P845	0.85	0.66	0.37	0.04	0.06
	0.90	0.57	0.22	0.04	0.10
	0.95	0.17	0.04	0.11	0.20
P1564	0.85	15.36	28.93	0.01	<0.01
	0.90	7.47	7.49	0.01	0.01
	0.95	1.78	0.03	0.01	<0.01
P2932	0.85	4,512.63	4,156.17	0.56	0.55
	0.90	3,456.47	2,458.86	0.44	0.38
	0.95	468.33	56.16	0.08	0.01

Table S8. Land-cover composition of HMI defined candidate genosoil areas (HMI ≤ 0.10) and areas with higher human modification (HMI > 0.10) within the UK for the pedogenons studied, using ESA WorldCover 2021 v200 (Zanaga et al., 2022) and CORINE Land Cover 2018 (European Environment Agency, 2019).

Pedogenon	Land-cover product	Land-cover class	HMI ≤ 0.10 (km²)	HMI ≤ 0.10 (%)	HMI > 0.10 (km²)	HMI > 0.10 (%)
P845	WorldCover	Grassland	0.03	83.34	0.71	83.53
		Tree cover	0.01	16.66	0.14	16.47
	CORINE	Natural grasslands	0.03	100.00	0.74	85.88
		Coniferous forest	0.00	0.00	0.12	14.12
P1564	WorldCover	Tree cover	0.19	100.00	94.21	13.03
		Cropland	0.00	0.00	474.17	65.61
		Grassland	0.00	0.00	143.81	19.90
		Built-up	0.00	0.00	8.07	1.12
		Permanent water	0.00	0.00	1.69	0.23
		Herbaceous wetland	0.00	0.00	0.70	0.10
		Bare/sparse vegetation	0.00	0.00	0.12	0.02
	CORINE	Mixed forest	0.14	73.98	5.45	0.75
		Coniferous forest	0.02	10.41	7.20	1.00
		Non-irrigated arable land	0.01	5.20	601.65	83.24
		Broad-leaved forest	0.01	5.20	12.96	1.79
		Transitional woodland-shrub	<0.01	2.61	0.54	0.07
		Pastures	<0.01	2.60	68.63	9.50
		Sport and leisure facilities	0.00	0.00	10.60	1.47
		Discontinuous urban fabric	0.00	0.00	5.55	0.77
		Airports	0.00	0.00	2.31	0.32
		Industrial or commercial units	0.00	0.00	2.02	0.28
		Inland marshes	0.00	0.00	1.25	0.17
		Agriculture with natural mix	0.00	0.00	1.09	0.15
		Natural grasslands	0.00	0.00	0.76	0.11
		Mineral extraction sites	0.00	0.00	0.63	0.09
		Construction sites	0.00	0.00	0.56	0.08
		Dump sites	0.00	0.00	0.40	0.06
		Water bodies	0.00	0.00	0.28	0.04
		Agro-forestry areas	0.00	0.00	0.32	0.04
		Fruit trees and berry plantations	0.00	0.00	0.23	0.03
		Green urban areas	0.00	0.00	0.22	0.03
		Moors and heathland	0.00	0.00	0.07	0.01
		Complex cultivation patterns	0.00	0.00	0.03	<0.01
		Road and rail networks	0.00	0.00	0.02	<0.01
		Salt marshes	0.00	0.00	0.01	<0.01
P2932	WorldCover	Grassland	3,246.02	92.15	1,789.81	80.73
		Tree cover	273.05	7.75	409.71	18.48
		Permanent water	1.98	0.06	2.73	0.12
		Bare/sparse vegetation	1.09	0.03	0.56	0.03
		Shrubland	0.45	0.01	0.08	<0.01
		Moss and lichen	0.04	<0.01	0.00	0.00
		Cropland	0.02	<0.01	11.72	0.53
		Built-up	<0.01	<0.01	2.50	0.11

Table S8 (continued)

Pedogenon	Land-cover product	Land-cover class	HMI ≤ 0.10 (km²)	HMI ≤ 0.10 (%)	HMI > 0.10 (km²)	HMI > 0.10 (%)
P2932		Herbaceous wetland	0.00	0.00	0.06	<0.01
	CORINE	Moors and heathland	1,823.40	51.76	743.54	33.54
		Peat bogs	962.40	27.32	627.21	28.29
		Natural grasslands	246.47	7.00	110.17	4.97
		Coniferous forest	222.77	6.32	319.38	14.40
		Sparsely vegetated	195.95	5.56	30.04	1.36
		Transitional woodland-shrub	38.53	1.09	108.10	4.88
		Mixed forest	10.06	0.29	27.63	1.25
		Pastures	8.98	0.25	169.79	7.66
		Broad-leaved forest	8.04	0.23	43.46	1.96
		Bare rocks	2.31	0.07	0.35	0.02
		Industrial or commercial units	1.97	0.06	10.01	0.45
		Water bodies	0.57	0.02	0.55	0.02
		Agriculture with natural mix	0.43	0.01	14.33	0.65
		Inland marshes	0.36	0.01	2.96	0.13
		Watercourses	0.19	0.01	0.20	0.01
		Road and rail networks	0.16	<0.01	0.32	0.01
		Sport and leisure facilities	0.06	<0.01	3.22	0.15
		Discontinuous urban fabric	0.00	0.00	5.09	0.23
		Non-irrigated arable land	0.00	0.00	0.84	0.04

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