

Supplementary data

Bimodal habitat changes and associated changes in ecosystem functions in European Biodiversity Coldspots

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Table S1. Satellite data and regional datasets used for LULC map creation and verification

	Satellite	Date	Path	Row	Reference data
Site A.	Landsat 7	29/07/2000	193	11	CLC 2000 and CLC 2018 - Finnish Environment Institute https://www.syke.fi/fi-FI
	Landsat 8	24/08/2018	193	11	
Site B.	Landsat 7	30/9/2000	186	27	National Ecosystem Map of Hungary ("Ecosystem Map of Hungary," 2019) http://alapterkep.termesztan.hu/
	Landsat 8	08/09/2018	186	27	
Site C.	Landsat 7	14/09/2000	202	30	Land Cover Information System of Spain (SIOSE) – 2005 & 2014 https://datos.gob.es/
	Landsat 8	23/08/2018	202	30	
Site D.	Landsat 7	28/08/2000	195	18	Svenska marktäckedata 2000 & 2018 https://www.dataportal.se/
	Landsat 8	18/05/2018	195	18	

Table S2. Describes the CLC Classes identified in all four sites and their respective CLC codes
Description of LULC classes are as per CORINE technical guidelines (Bossard et al., 2000) along with their latest EUNIS Habitat Class code available.

EUNIS Habitat type (2012 & 2021)	CLC Level 1 code	Description
J Constructed industrial and other artificial habitats	111, 112 Urban	Residential and administrative area
	121 Industrial/Commercial	Land under industrial/commercial units
	131, 132 Mine/dump	Mining sites and man-made dump sites
V1 Vegetated man-made habitats	(211-213) Cropland	Arable (211) and non-irrigated arable land (212), rice fields (213)
V54 Vineyards	221 Agro-forestry	Vineyards
V3 Artificial grasslands and herb dominated habitats	231 Pastures	Land used for fodder production and grazing

T Woodland and forest habitats	311 Broadleaf,	Forest where broad-leaved species predominate
	312 Coniferous	Forest where coniferous species predominate.
	313 Mixed Forest	Forest where neither broad-leaved nor coniferous species predominate.
T4 Lines of trees, small anthropogenic forests, recently felled forest, early-stage forest and coppice	324 Transitional woodlands/scrub	Woodland degradation, forest regeneration / recolonization in managed forests Transitional bushy and herbaceous vegetation with occasional scattered trees
R Grassland habitats	321 Natural grasslands,	areas with herbaceous vegetation covering at least 50 % of the surface
S2 Arctic, alpine and subalpine scrub	322 Heathlands/Moors,	Vegetation with low and closed cover, dominated by bushes, shrubs, dwarf shrubs, forming a climax stage of development.
S5: Maquis, matorral and thermo-Mediterranean scrub	323 Sclerophyllous vegetation,	Maquis, matorral, garrigue and thermo-Mediterranean brushes
U Inland sparsely vegetated or unvegetated habitats	332 bare rocks	non-vegetated areas where at least 90 % of the land surface is covered by rocks
	333 Sparsely vegetated areas	sparse vegetation, covering 10-50% of surface
Q Wetland habitats	411 Inland marshes	Non-forested areas with herbaceous vegetation that is liable to flooding
	412 Peatbogs	Wetlands with accumulation of considerable amount of decomposed moss (mostly Sphagnum) and vegetation matter.
C Freshwater aquatic habitats	511, 512 Inland water bodies	Natural or artificial water bodies with presence of standing water surface during most of the year.

Table S3. Confusion matrix for sites A-D, based on regional LULC map (2018) reclassified based on CLC nomenclature and the map obtained from supervised classification based on CLC nomenclature for 2018.2

[illegible]

Site C.	Class	112	121	211	311	312	313	321	324	511	Total	U_Accuracy	Kappa
	112	10	3	0	1	0	0	0	0	0	14	0.71	0
	121	3	14	0	0	0	0	0	0	0	17	0.82	0
	211	0	0	111	4	0	0	0	0	0	115	0.97	0
	311	0	0	3	112	4	0	2	0	0	121	0.93	0
	312	0	0	0	5	66	0	0	0	0	71	0.93	0
	313	0	0	0	0	2	36	2	1	0	41	0.88	0
	321	0	0	4	4	21	7	93	1	0	130	0.72	0
	324	0	0	0	2	0	1	3	8	0	14	0.57	0
	511	0	0	0	0	0	0	0	0	10	10	1	0
	Total	13	17	118	128	93	44	100	10	10	533	0	0
	P_Accuracy	0.77	0.82	0.94	0.875	0.71	0.82	0.93	0.8	1	0	0.86	0
	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.83
Site D.	Class	112	211	311	312	313	314	324	412	512	Total	U_Accuracy	Kappa
	112	16	0	0	0	0	0	0	0	0	16	1	0
	211	0	7	0	0	0	0	0	0	0	7	1	0
	311	0	0	34	4	0	0	1	1	0	40	0.85	0
	312	0	0	4	150	6	0	4	5	2	171	0.88	0
	313	0	0	2	4	42	0	1	0	1	50	0.84	0
	314	0	0	0	0	0	0	0	0	0	0	0	0
	324	1	0	1	15	3	1	107	1	0	129	0.83	0
	412	0	0	1	0	0	0	0	49	1	51	0.96	0
	512	0	0	0	2	0	0	2	4	47	55	0.85	0
	Total	17	7	42	175	51	1	115	60	51	519	0	0
	P_Accuracy	0.94	1	0.81	0.86	0.82	0	0.93	0.82	0.92	0	0.87	0
	Kappa	0	0	0	0	0	0	0	0	0	0	0	0.84

Table S4. Shows the mean and standard deviation values for the two ecosystem functions in each LULC class in the four sites.

Site, CLC code	AGB (Mg/ha)		WY (ML)	
Site A. (Finland)	Mean	Std. Dev.	Mean	Std. Dev.
112. Urban	24.52	1.47	29.21	0.78
211. Cropland	21.36	1.60	18.87	1.50
311. Broadleaf	48.73	2.71	8.49	0.29
312. Coniferous	34.78	3.52	8.05	0.59
313. Mixed Forest	74.82	5.21	14.98	0.24
322. Heathlands	7.60	0.60	20.66	1.13
324. Transitional	20.80	0.72	49.07	2.12
332. Bare rock	0.02	0.01	0.03	0.00
333. Sparse veg.	23.15	1.04	34.19	1.14
412. Peatbogs	45.83	1.32	4.95	0.92
512. Water body	9.93	0.73	4.42	0.83
Site B. (Hungary)				
112. Urban	2.18	0.47	37.45	1.62

121. Industrial	3.91	0.90	42.23	2.39
211. Cropland	11.36	1.17	42.29	3.83
221. Vineyards	5.33	0.08	34.00	0.88
231. Pastures	1.45	0.83	22.15	0.15
311. Broadleaf	42.90	1.72	7.64	0.92
321. Grassland	4.77	0.65	46.43	4.76
411. Wetland	11.49	0.22	7.36	0.77
512. Water body	12.79	0.12	4.96	0.73
Site C. (Spain)				
112. Urban	1.13	0.66	62.64	3.88
121. Industrial	17.93	0.37	72.25	4.31
211. Cropland	4.47	0.74	54.53	3.38
231. Pastures	0.10	0.01	1.67	0.01
311. Broadleaf	48.76	3.19	8.59	2.04
312. Coniferous	67.79	6.33	5.91	0.92
313. Mixed Forest	93.37	8.77	14.24	0.54
321. Grassland	22.67	1.45	50.29	3.81
323. Sclerophyllous	36.89	3.90	56.91	4.16
324. Transitional	87.12	7.95	53.37	2.88
512. Water body	5.55	0.85	7.70	0.37
Site D. (Sweden)				
112. Urban	37.03	2.83	38.92	2.48
211. Cropland	23.96	0.59	49.24	0.37
231. Pastures	14.01	0.23	27.41	1.56
311. Broadleaf	98.16	7.91	5.55	0.10
312. Coniferous	89.84	5.43	16.93	1.22
313. Mixed Forest	115.67	8.56	6.99	0.57
324. Transitional	76.83	3.12	36.50	1.94
411. Wetland	79.65	2.08	12.99	0.71
512. Water body	9.13	0.91	8.60	0.01

Table S5. Transition matrix showing area (in ha) belonging to different habitat classes in 2000 and 2018. Year code: _00: 2000; _18: 2018. Habitat code - AR: Artificial; CR: Croplands; PS: Pastures; BR: Broadleaf; CF: Coniferous; MX: Mixed Forest; GR: Grassland; HT: Heathlands; SC: Sclerophyllous scrub; TR: Transitional; OA: Open areas with little/no vegetation; WT: Wetland; AQ: inland aquatic.

Table 3(a) Transition matrix for Site A (Finland).

Site A	AR_18	CR_18	BR_18	CF_18	MX_18	HT_18	TR_18	OA_18	WT_18	AQ_18
AR_00	81.2	1.6	49.5	3.4	5.3	6.0	27.6	0.4	2.3	4.6
CR_00	0.8	9.7	3.7	0.1	0.1		1.2		0.1	1.0
BR_00	17.6	0.9	2415.2	108.7	43.6	1025.7	114.5	33.1	540.7	41.8
CF_00	7.2	0.3	119.2	51.3	27.6	84.2	20.5	6.7	4.7	25.7
MX_00	11.5	0.4	500.7	117.7	77.5	158.7	41.8	15.4	8.7	29.6
HT_00	17.7	4.8	41.9	1.8	1.9	14720.0	107.7	1141.9	121.2	29.0
TR_00	42.9	2.5	631.3	38.1	31.2	9247.2	487.9	213.6	1358.3	113.0
OA_00	3.2		0.9		0.2	131.2	2.0	3104.0	2.0	3.7

WT_00			8.1	0.2	0.1	348.1	102.5	7.5	948.0	
AQ_00	3.7	0.4	31.4	2.8	7.2	17.8	10.9	10.4	17.6	1032.2

Table 1(b) Transition matrix for Site B (Hungary)

Site B	AR_18	CR_18	PS_18	BR_18	GR_18	WT_18	AQ_18
AR_00	1269.7	123.8	29.9	73.3	12.9		0.4
CR_00	206.4	25631.6	1531.8	1688.2	433.5	91.8	73.7
PS_00	7.0	345.8	1064.9	7.5	557.2	2.0	
BR_00	9.2	518.7	14.6	1656.1	9.4	6.9	3.6
GR_00	125.7	1360.0	1601.7	43.9	1002.8	2.2	0.3
WT_00	15.7	37.5	0.9	40.8		37.6	15.3
AQ_00	1.7	10.2	0.3	48.2	0.3	74.1	210.8

Table 1(c) Transition matrix for Site C (Spain)

Site C. (Spain)	AR_18	CR_18	PS_18	BR_18	CF_18	MX_18	GR_18	SC_18	TR_18	AQ_18
AR_00	856.8	0.2	90.9	35.1		0.1	45.7			8.1
CR_00	70.6	9273.5		240.0	2.8	116.6	280.7	0.3	54.9	
PS_00		3.6	34.6					3.4		
BR_00	27.5	4.3	19.1	8227.5	54.8	207.7	227.3	0.9	240.1	
CF_00	2.6	0.4	0.9	72.2	4750.9	10.9	108.5	7.7	17.0	1.8
MX_00	28.7	0.2	5.5	412.5	1809.7	2084.7	31.6		13.5	
GR_00	26.0	189.0	1789.4	191.1	144.4	146.0	2432.3	362.4	133.4	0.1
SC_00		2.6	2.2	177.3	134.4	17.4	545.2	280.6	97.3	
TR_00	1.6	12.3	286.4	605.4	1259.7	819.5	397.4	86.5	210.9	
AQ_00										94.4

Table 1(d). Transition matrix for Site D (Sweden)

Site D. (Sweden)	AR_18	CR_18	PS_18	BR_18	CF_18	MX_18	TR_18	WT_18	AQ_18
AR_00	12.8		0.6	5.2	1.3	0.7	0.5		
CR_00	1.1	10.9	3.5	11.2	1.8	0.6	1.5		1.4
PS_00	7.8	10.4	28.3	66.4	18.6	21.5	15.2	1.5	5.2
BR_00	0.6	2.8	0.4	156.7	200.8	50.0	62.0	3.2	4.5
CF_00	4.5	0.7	3.2	766.0	12350.8	2624.9	7476.4	147.8	172.5
MX_00	1.1	0.3	1.7	234.0	734.4	114.5	155.9	4.4	10.3
TR_00	1.1	0.9	7.6	239.6	1959.7	401.1	4506.3	20.2	19.1
WT_00	3.1		9.0	20.5	396.2	1589.6	174.2	1337.6	122.0
AQ_00			0.1	12.3	170.2	46.6	47.0	24.3	3469.8

Table S6. Comparison of different pressure categories under the BIOPRESS methodology (Cole et al., 2022; Gerard et al., 2006; Hazeu & Mächer, 2005), and the ones used in this study.

Pressure category	BIOPRESS definition	Updated category/definition
Urbanisation	Transformation of land cover to urban covers (built-up, road	Conversion (CV): the use of natural or semi-natural areas

	systems, leisure areas, construction sites, etc.)	for anthropogenic activities such as agriculture, building commercial units, industries, etc leading to their conversion to a Habitat type J or V under EUNIS classification of 100 and 200 under CORINE classification. Including conversion of “wet” classes into artificial (urban and agricultural) habitat classes.
Intensification	Conversion of land or transformations toward more intensive land uses (e.g. more intensive agriculture)	
Afforestation	Conversion of open or more or less natural habitats into forests or scrub/woody cover	Regrowth (RG): the growth of vegetation on formerly bare land or abandoned agricultural land, regrowth of vegetation after natural or anthropogenic stressors (fire, clearcutting, etc.), natural change (or succession) in vegetation from non-woody to woody vegetation.
Abandonment	Cessation of agricultural or managed land use, leading to conversion into early successional, herbaceous habitats. Woody later-successional conversion is sometimes considered under afforestation in certain Mediterranean contexts.	
Deforestation	Conversion of forest to non-forest land cover classes (i.e. loss of forest)	Deforestation (DF): cutting of forests for timber production or extraction of other forest products. i.e conversion of forest land to habitat types T4 or U in the EUNIS habitat classification.
Drainage	Transformation of aquatic or wet habitats toward more terrestrial ones. Includes loss of peatlands (when drained), changes from intertidal or wetlands to drained land for agriculture/forest, etc	Encroachment (EN): the advancement of woody vegetation into inland marshes, inland water bodies, and peatbogs.
Rewetting	Conversion of “dry” habitat classes back into wetlands or intertidal/water types (partial or full reversal of drainage effects)	Wetting (WT): the conversion of natural/ semi-natural classes into wetlands and/or water bodies.
Degradation		Degradation (DE): the degeneration of vegetation via decrease in species richness, diversity, and/or biomass.
Range-Shift		

		Range shift (RS): the spatio-temporal change in distribution limits of habitat types along altitudinal or latitudinal gradients. This pressure excludes changes in and around inland aquatic habitat (wetting, encroachment) and any changes resulting directly from land conversion for human use (conversion).
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