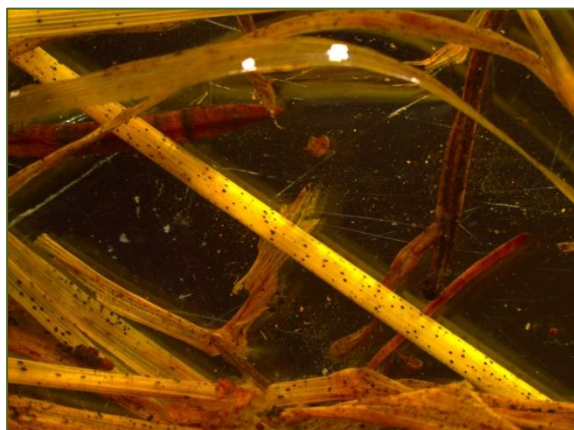


Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Stems fragm.



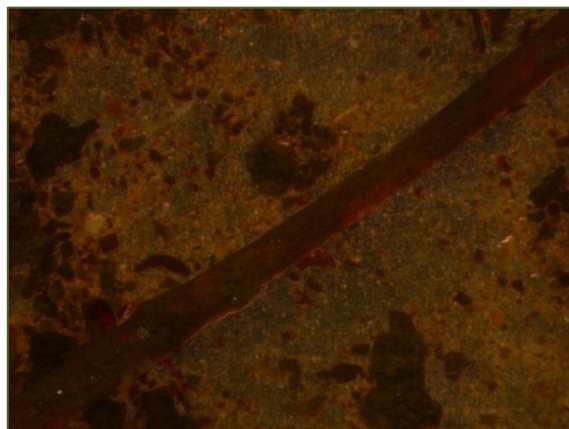
Fragment of stem from N03G3,
size: 22.43 x 16.82 mm.



Fragment of stem from N03G3,
size: 22.43 x 16.82 mm.



Fragment of stem from N01M2,
size: 18.21 x 13.66 mm.



Fragment of stem from N03G3,
size: 11.54 x 8.66 mm.



Fragment of stem from N03M2,
size: 13.52 x 10.14 mm.



Fragment of stem from N03G2,
size: 22.49 x 16.87 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Twigs / 0 – 2 mm



Twig from S06L3,
size: 22.55 x 16.91 mm.



Twig from N01M2,
size: 16.74 x 12.55 mm.



Twig from N03G3,
size: 22.43 x 16.82 mm.



Twig from N03M1,
size: 18.56 x 13.92 mm.



Twig from N03M2,
size: 17.41 x 13.06 mm.



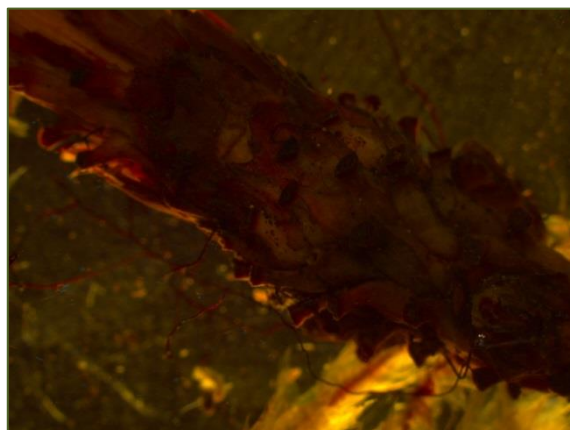
Twig from N01F3,
size: 22.38 x 16.78 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Twigs /]2[- 5 mm



Twig from N03G2,
size: 22.49 x 16.87 mm.

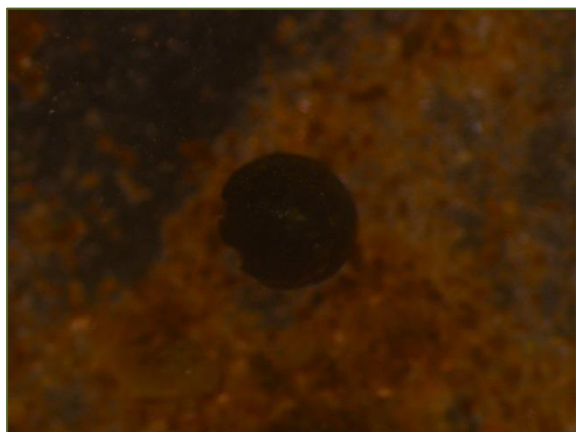


Twig from N03M3,
size: 17.58 x 13.19 mm.

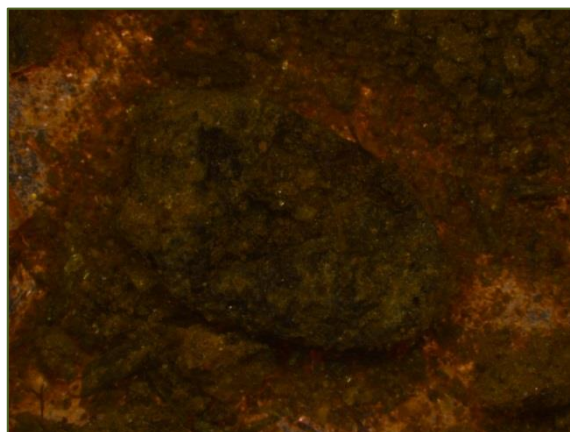


Twig from N03M1,
size: 18.29 x 13.71 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Undet. holorg. mat.

Undetermined holorganic material from N01F3,
size: 3.93 x 2.95 mm.



Undetermined holorganic material from N03G3,
size: 14.43 x 10.83 mm.



Undetermined holorganic material from N01F3,
size: 5.89 x 4.41 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Undetermin.

Undetermined component from S08L2,
size: 8.90 x 6.67 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Various vgt mat / coal



Piece of coal from N03G1,
size: 15.11 x 11.33 mm.



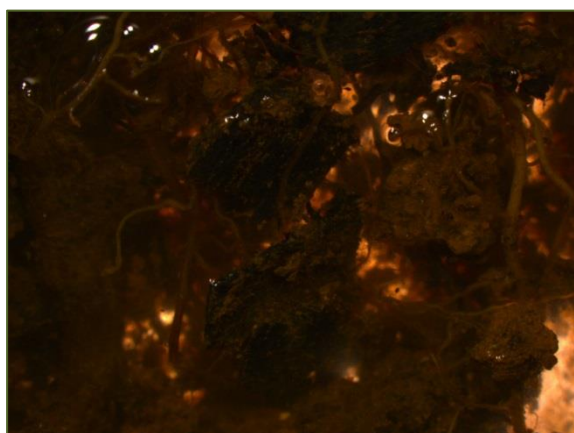
Piece of coal from N03G1,
size: 12.65 x 9.49 mm.



Piece of coal from N03G2,
size: 18.64 x 13.98 mm.



Piece of coal from N03G2,
size: 9.06 x 6.79 mm.



Piece of coal from N03G2,
size: 18.29 x 13.71 mm.



Piece of coal from N03G2,
size: 18.17 x 13.63 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

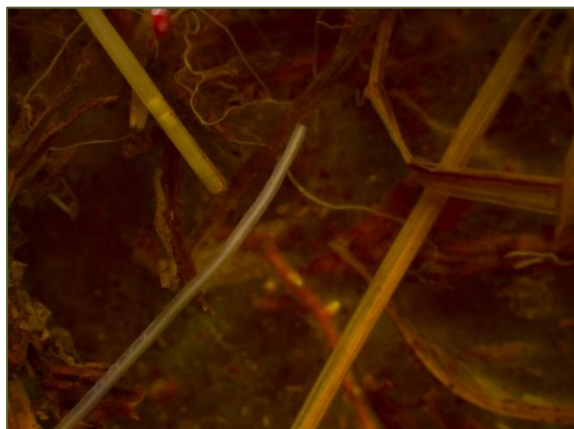
Various vgt mat / germs



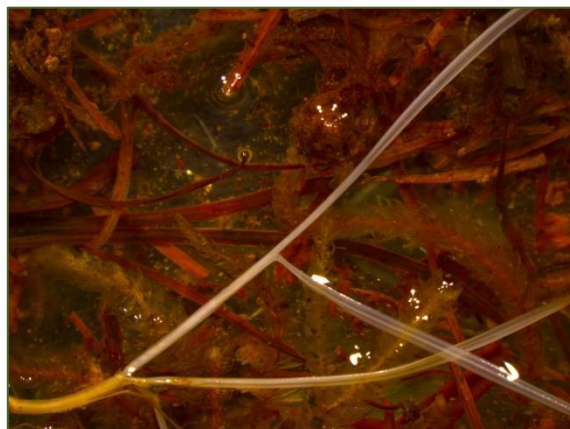
Plant shoot from N03M1,
size: 13.47 x 10.11 mm.



Plant shoot from N03G2,
size: 11.48 x 8.61 mm.



Plant shoot from N03G2,
size: 22.49 x 16.87 mm.



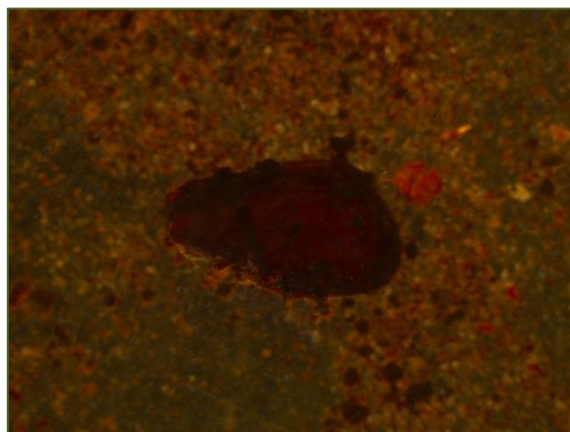
Plant shoot from N01M2,
size: 22.49 x 16.87 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Various vgt mat / seeds



Seed from N01F3,
size: 6.23 x 4.67 mm.



Seed from N03M3,
size: 10.04 x 7.53 mm.



Seed from S06L1,
size: 9.10 x 6.82 mm.



Seed from N03G2,
size: 10.72 x 8.04 mm.



Seed from N03M1,
size: 9.41 x 7.06 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Woody material / bark fragment / 0 – 2 mm

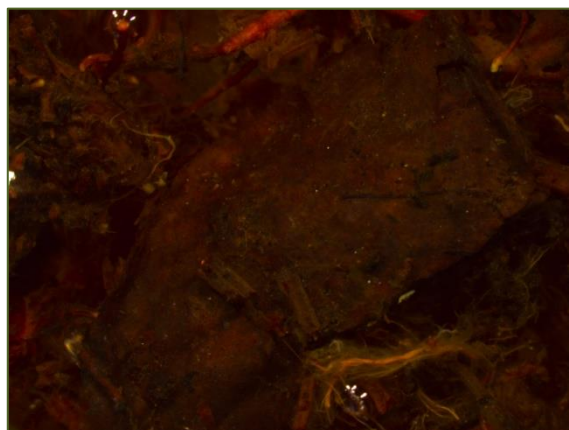
Piece of bark from N01F2,
size: 4.97 x 3.72 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

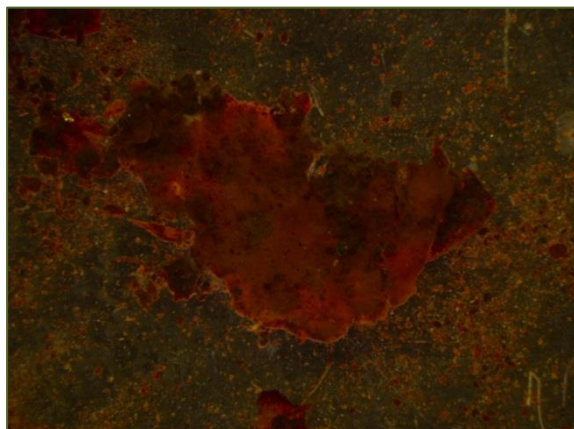
Woody material / bark fragment /]2[– 20 mm



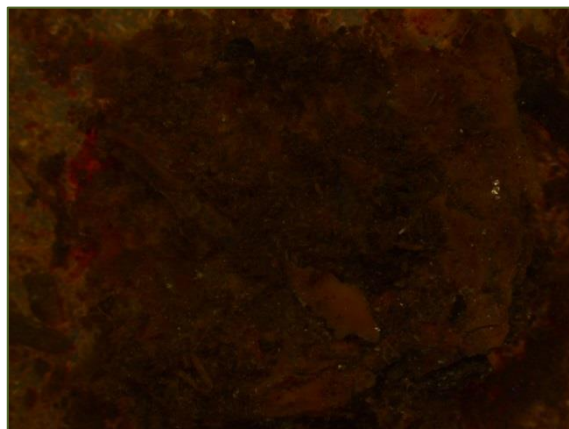
Piece of bark from N03M3,
size: 13.11 x 9.83 mm.



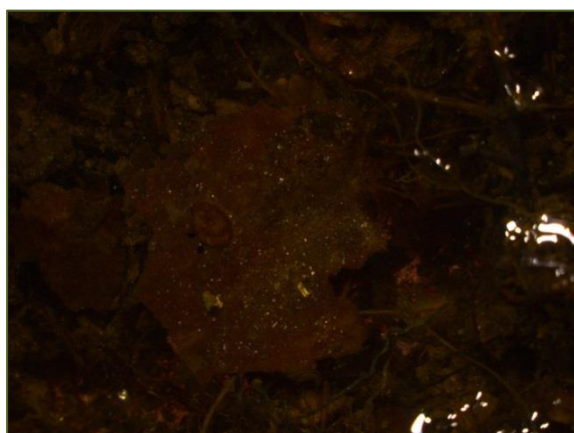
Piece of bark from N03M3,
size: 20.48 x 15.36 mm.



Piece of bark from S06L2,
size: 22.38 x 16.78 mm.



Piece of bark from S06L2,
size: 22.55 x 16.91 mm.



Piece of bark from N01F2,
size: 22.38 x 16.78 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Woody material / bark fragment /]20[– 50 mm

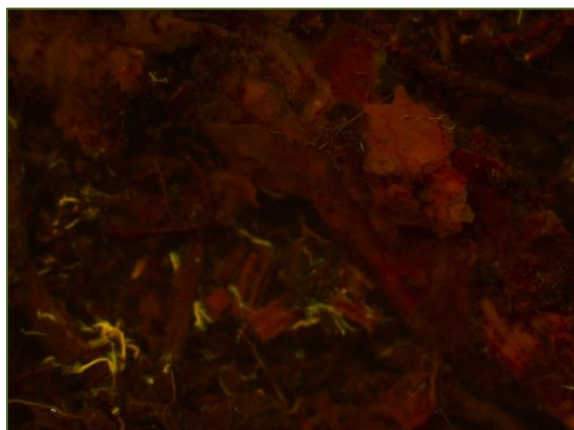


Piece of bark from N03M3,
size: 18.84 x 14.13 mm.

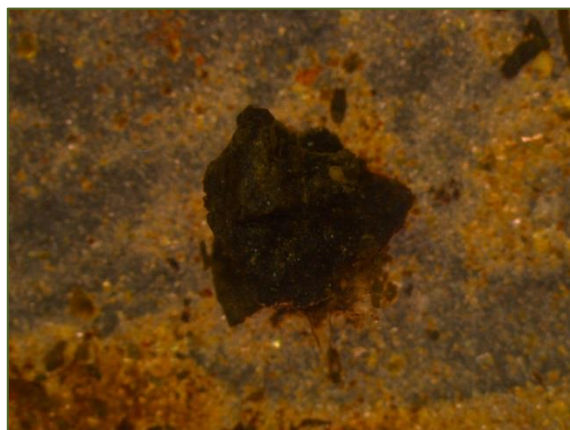


Piece of bark from N03M2,
size: 22.49 x 16.87 mm.

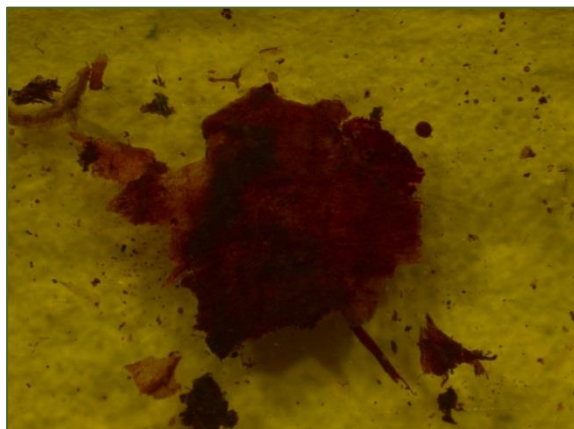
Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Woody material / undet. / 0 – 2 mm

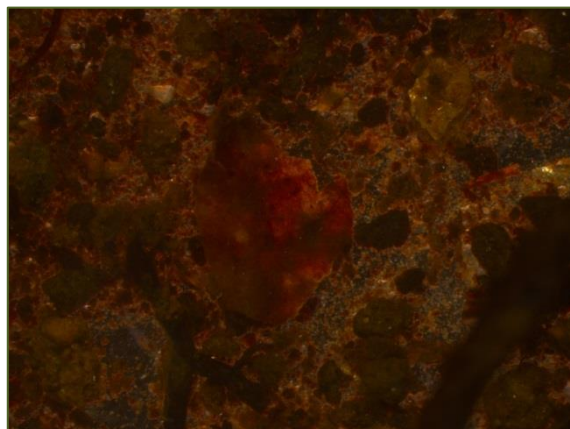
Woody material from N03M2,
size: 22.55 x 16.91 mm.



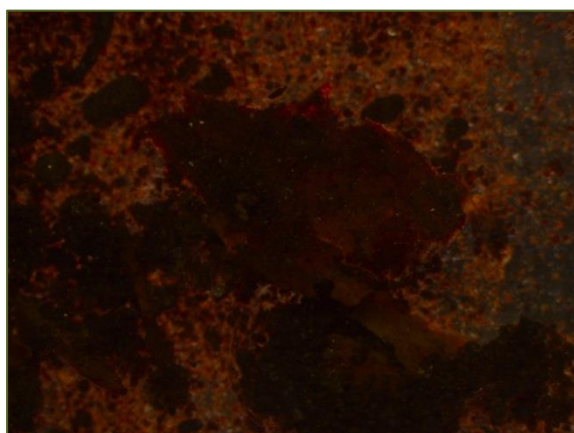
Woody material from S06G1,
size: 11.33 x 8.50 mm.



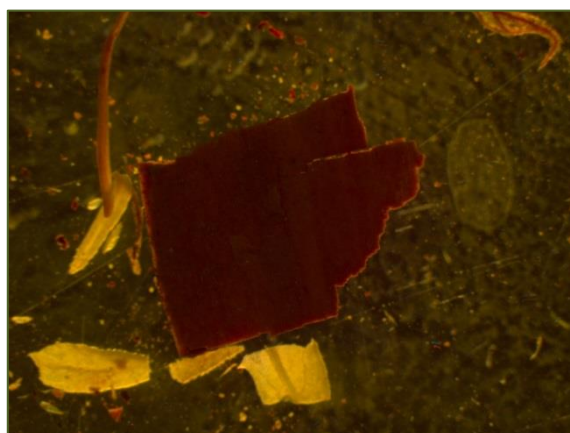
Woody material from N03M2,
size: 10.20 x 7.65 mm.



Woody material from N01F2,
size: 10.00 x 7.50 mm.



Woody material from S06G2,
size: 10.84 x 8.13 mm.



Woody material from N03M3,
size: 12.99 x 9.74 mm.

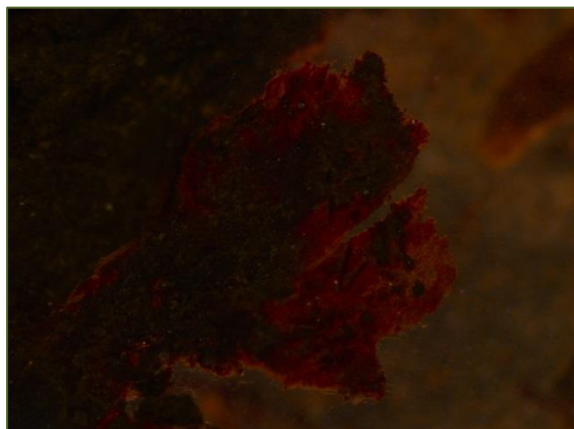
Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Woody material / undet. /]2[- 20 mm

Woody material from S06L2,
size: 18.40 x 13.80 mm.



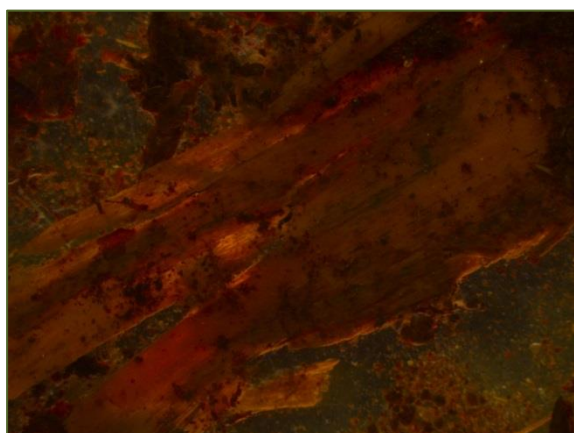
Woody material from N03M2,
size: 19.05 x 14.28 mm.



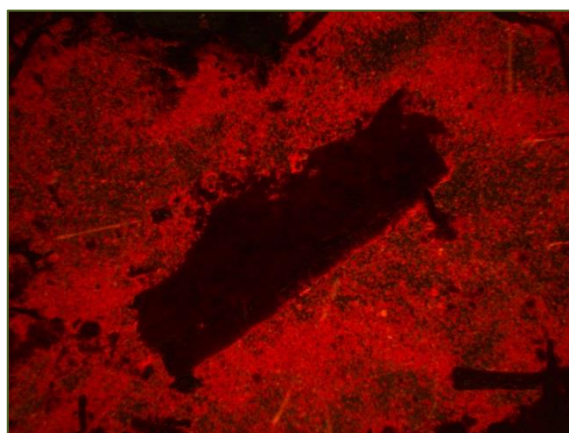
Woody material from N03G3,
size: 8.49 x 6.37 mm.



Woody material from N03M1,
size: 15.03 x 11.27 mm.

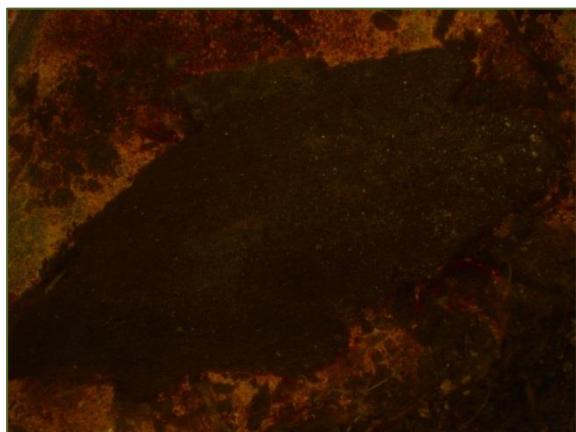


Woody material from S06L2,
size: 19.83 x 14.87 mm.



Woody material from N03M2,
size: 22.43 x 16.82 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

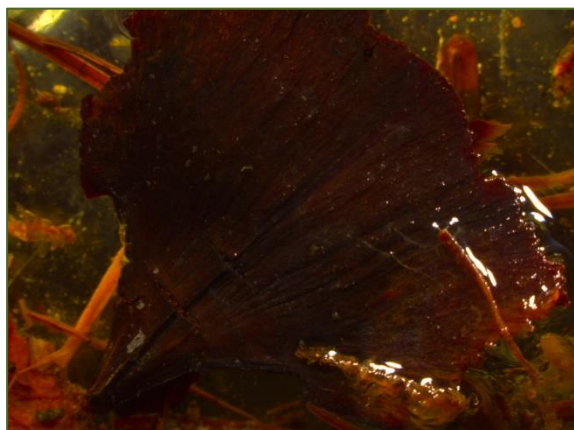
Woody material / undet. /]20[- 50 mm

Woody material from N01M2,
size: 22.55 x 16.91 mm.

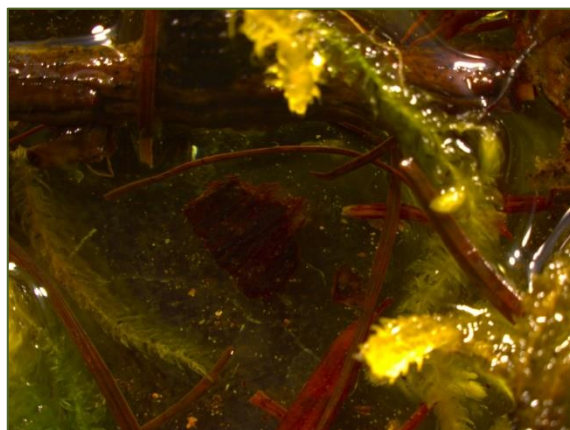


Woody material from N01F3,
size: 22.55 x 16.91 mm.

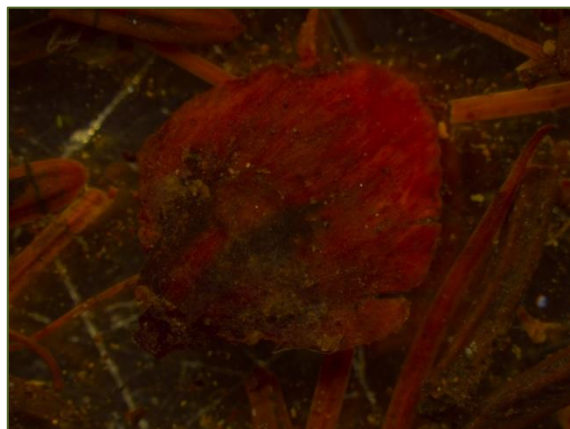
Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Woody material / cones / fragm.

Fragment of cone from N01M2,
size: 22.49 x 16.87 mm.



Fragment of cone from N01M2,
size: 22.49 x 16.87 mm.



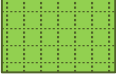
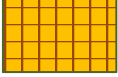
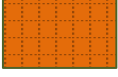
Fragment of cone from S08L3,
size: 13.77 x 10.33 mm.

Méthode des petits volumes – photographies des principaux types d'éléments identifiés

Woody material / cones / intact

Intact cone from N03G2,
size: 22.49 x 16.87 mm.

Légendes

	lea_dic_bg1 dicotyledonous leave > 1 cm ²		fau_org animal organism
	lea_dic_st1 dicotyledonous leave, < 1 cm ²		myc_und mycelium
	lea_mon_bt1 monocotyledonous leaf, > 1 cm ²		roo_uII root, diameter 0-2 mm
	lea_mon_st1 monocotyledonous leaf, < 1 cm ²		roo_utV root, diameter]2[-5 mm
	lea_und_bt1 undetermined leaf, > 1cm ²		roo_btV root, diameter > 5 mm
	lea_und_st1 undetermined leaf, < 1cm ²		ste_fra fragment of stem
	nee_int intact needle		twi_uII twig, diameter 0-2 mm
	nee_fra fragmented needle		twi_utV twig, diameter]2[-5 mm
	flo_und flower or fragment of flower		twi_mtV twig, diameter > 5 mm
	fru_und fruit or fragment of fruit		bra_VtX fragment of branch
	vvm_see seed or fragment of seed		vvm_coa coal or fragment of coal
	vvm_bul bulb or fragment of bulb		woo_uII undetermined woody material, diameter 0-2 mm
	vvm_ger plant sprout		woo_uXX undet. woody material, diameter]2[-20 mm
	vvm_sto stolon		woo_utL undet. woody material, diameter]20[-50 mm
	bud_int intact bud		woo_con_fra fragment of conifere cone
	bud_fra fragmented bud		woo_con_int intact conifere cone
	lic_fra fragment of lichen		omi_und organomineral
	mos_int intact moss		min_uII mineral, 0-2 mm
	mos_fra fragment of moss		min_uXX mineral,]2[-20 mm
	fau_fec fauna feces		min_utL mineral,]20[-50 mm
			min_uCC mineral, > 50 mm

Graphiques obtenus par l’application de la méthode des petits volumes.

En abscisse figurent les pourcentages des différents macrorestes identifiés, en ordonnée la profondeur en millimètres.

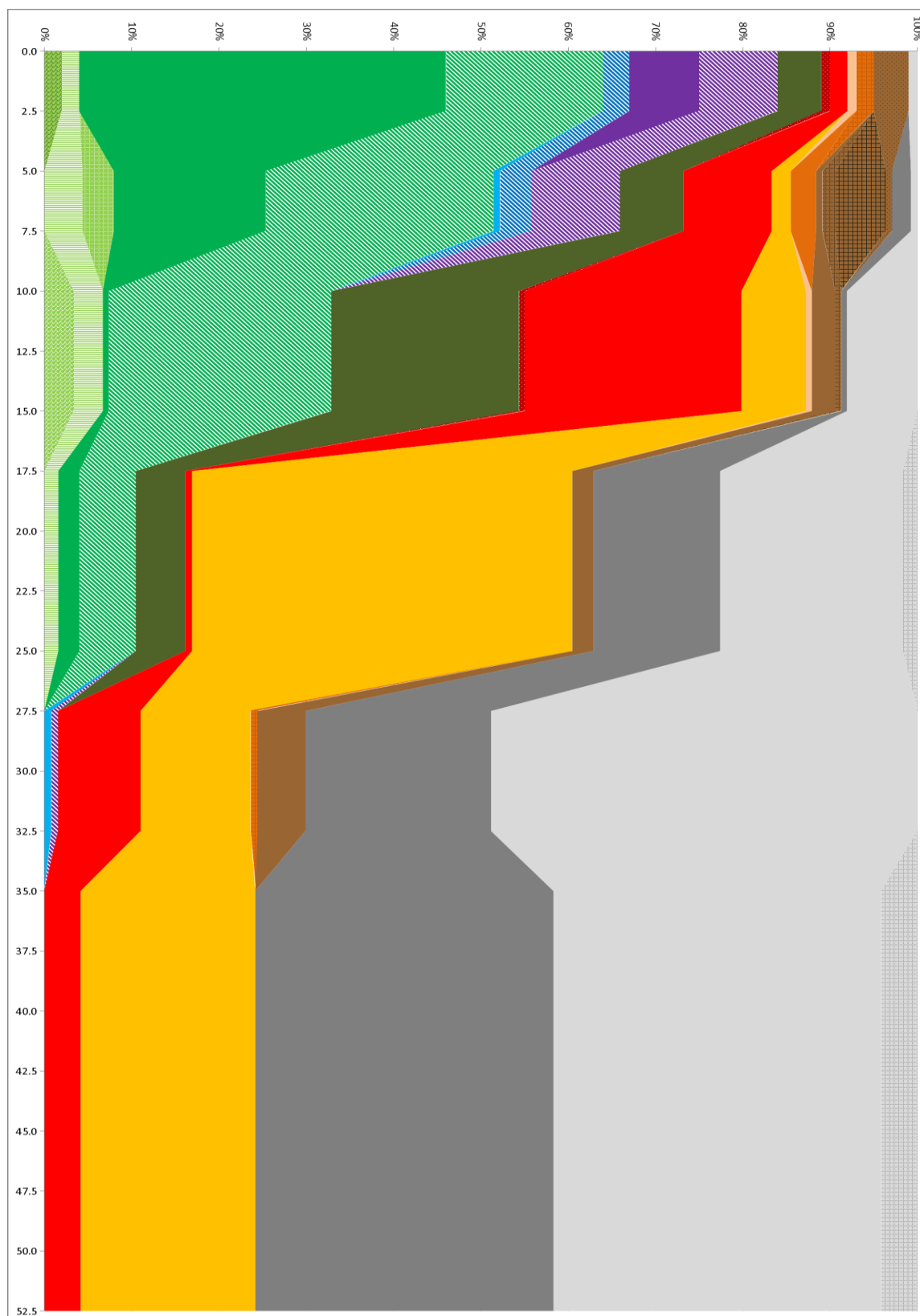
N01F1

0-3 : OL

3-7 : OF

7-14 : OH

14-52.5 : A



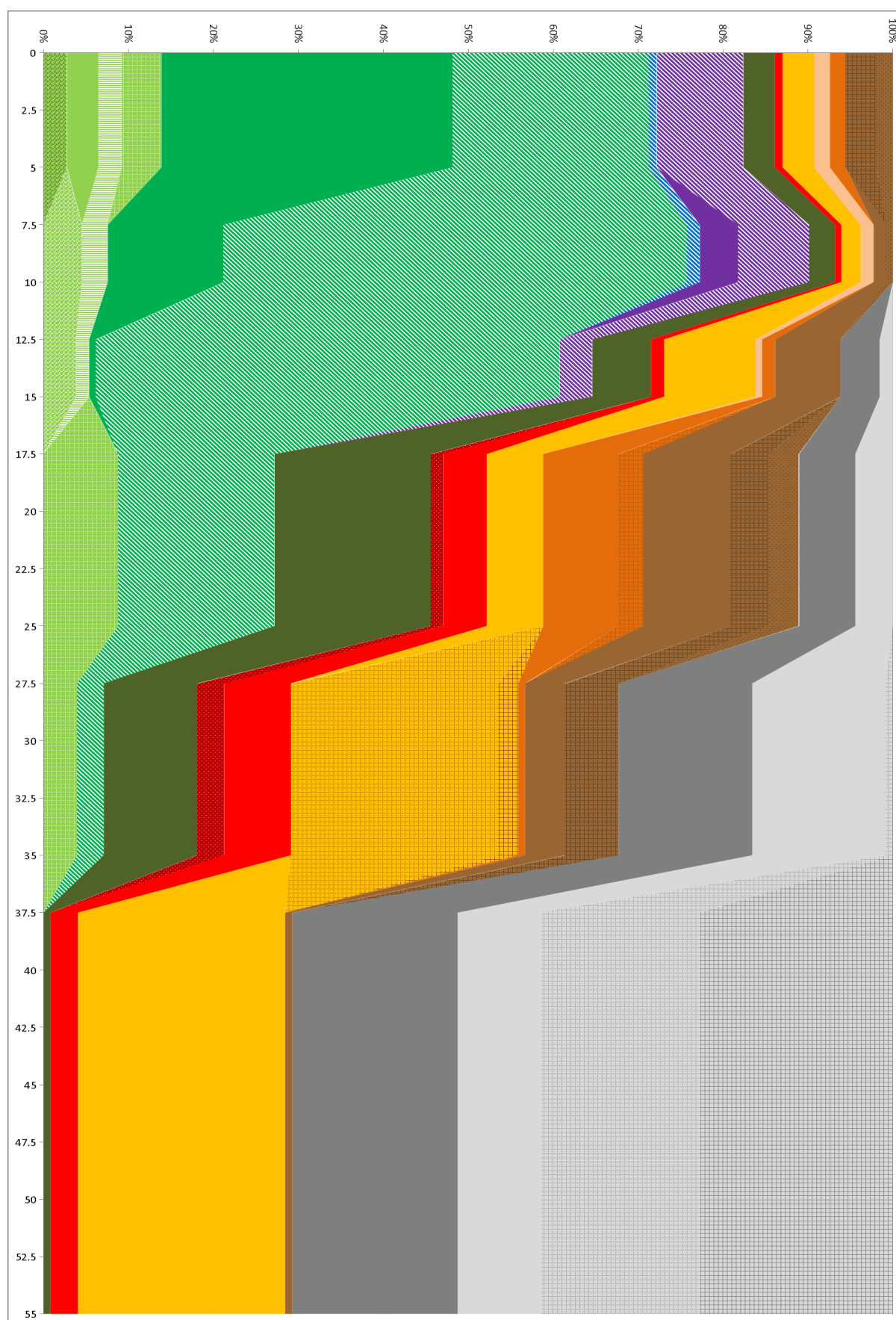
N01F2

0-5 : OL

5-25 : OF

25-35 : A

35-55 : USH

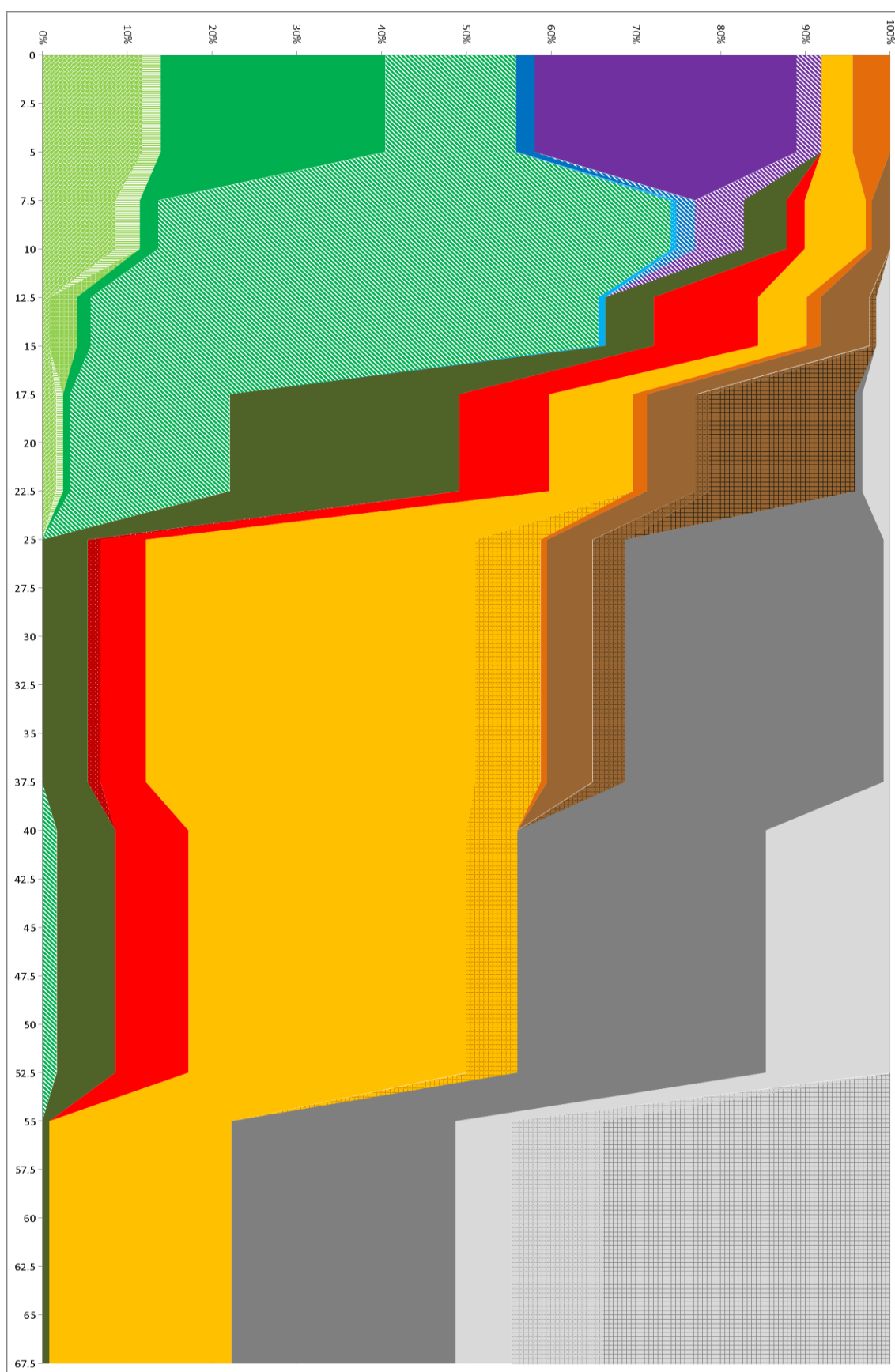


N01F3

0-5 : OL

5-23 : OF

23-67.5 : A



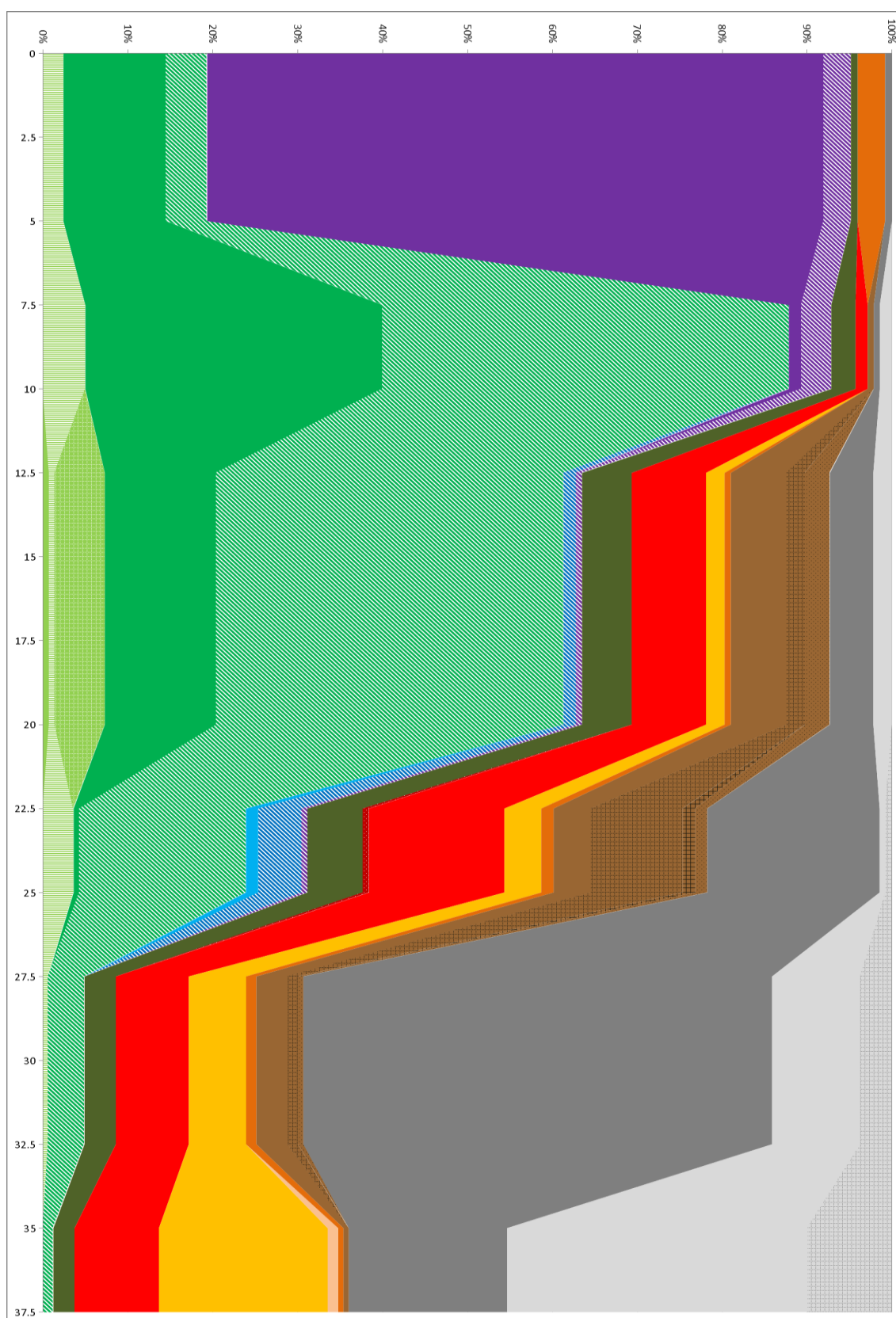
N01M1

0-5 : OL

5-20 : OF

20-25 : OF-A

25-37.5 : A



N01M2

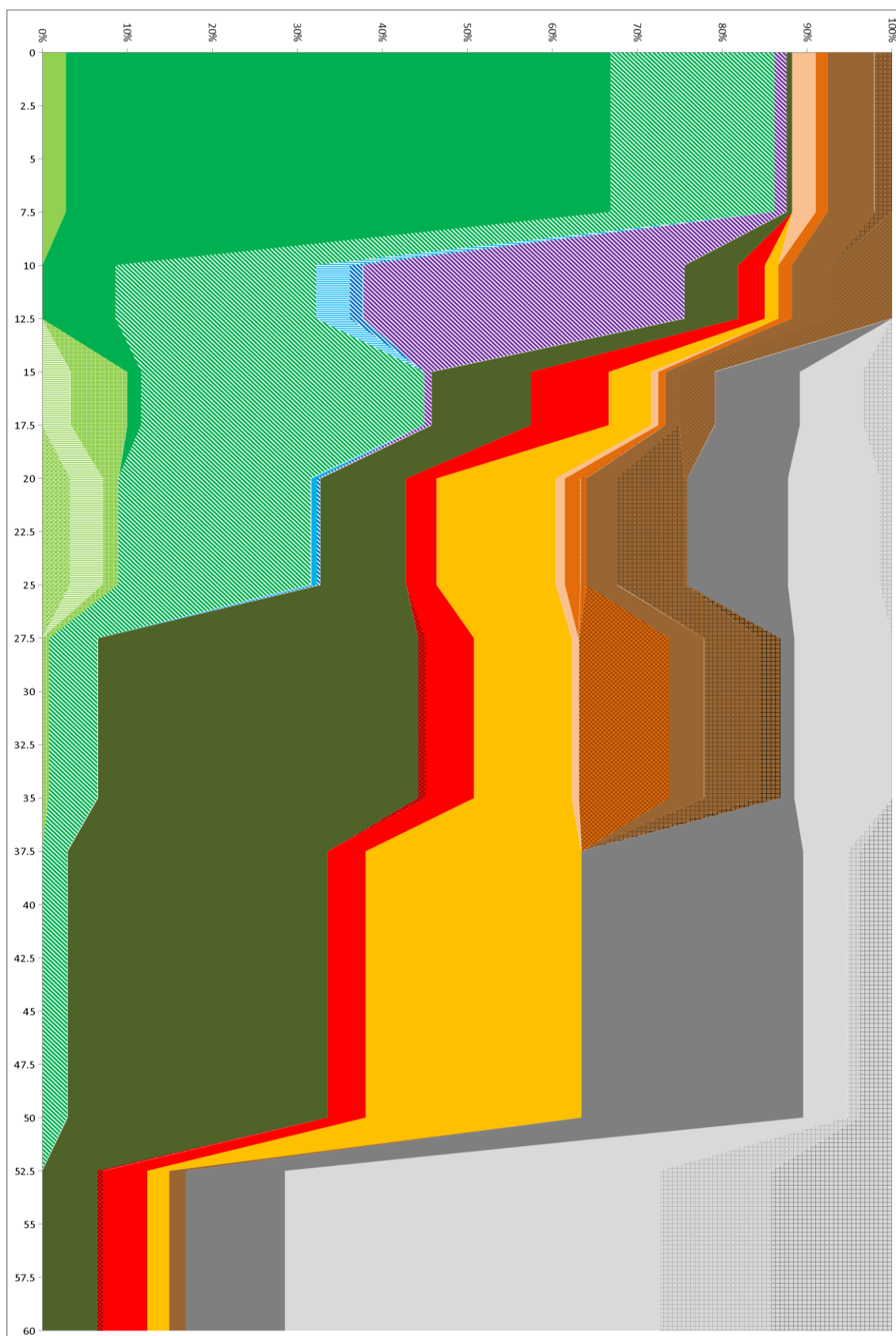
0-7 : OL

7-24 : OF

24-34 : OH

34-49 : A

49-60 : USH



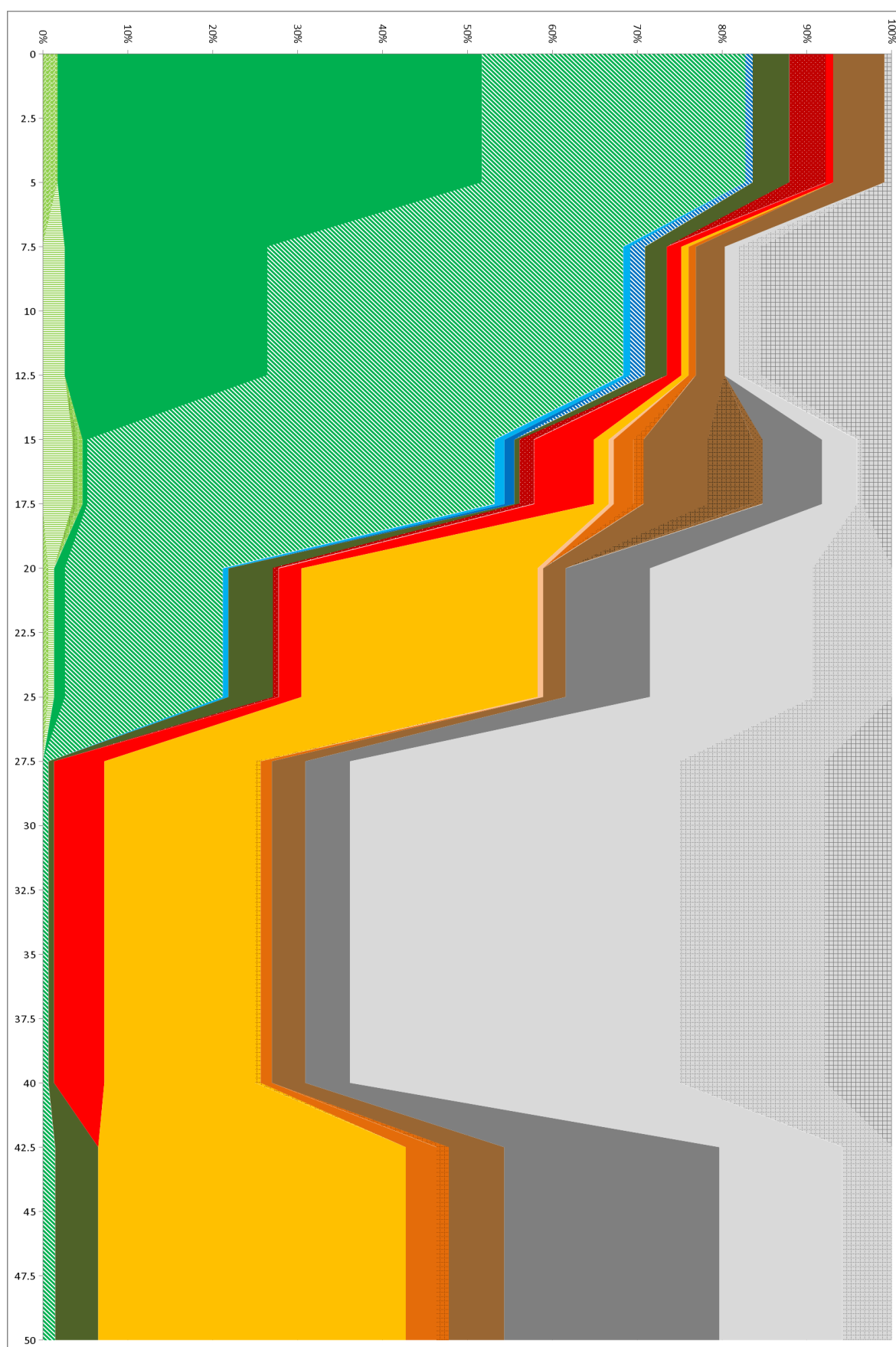
N01M3

0-5 : OL

5-17 : OF

17-24 : OF-A

24-50 : A



N03G1

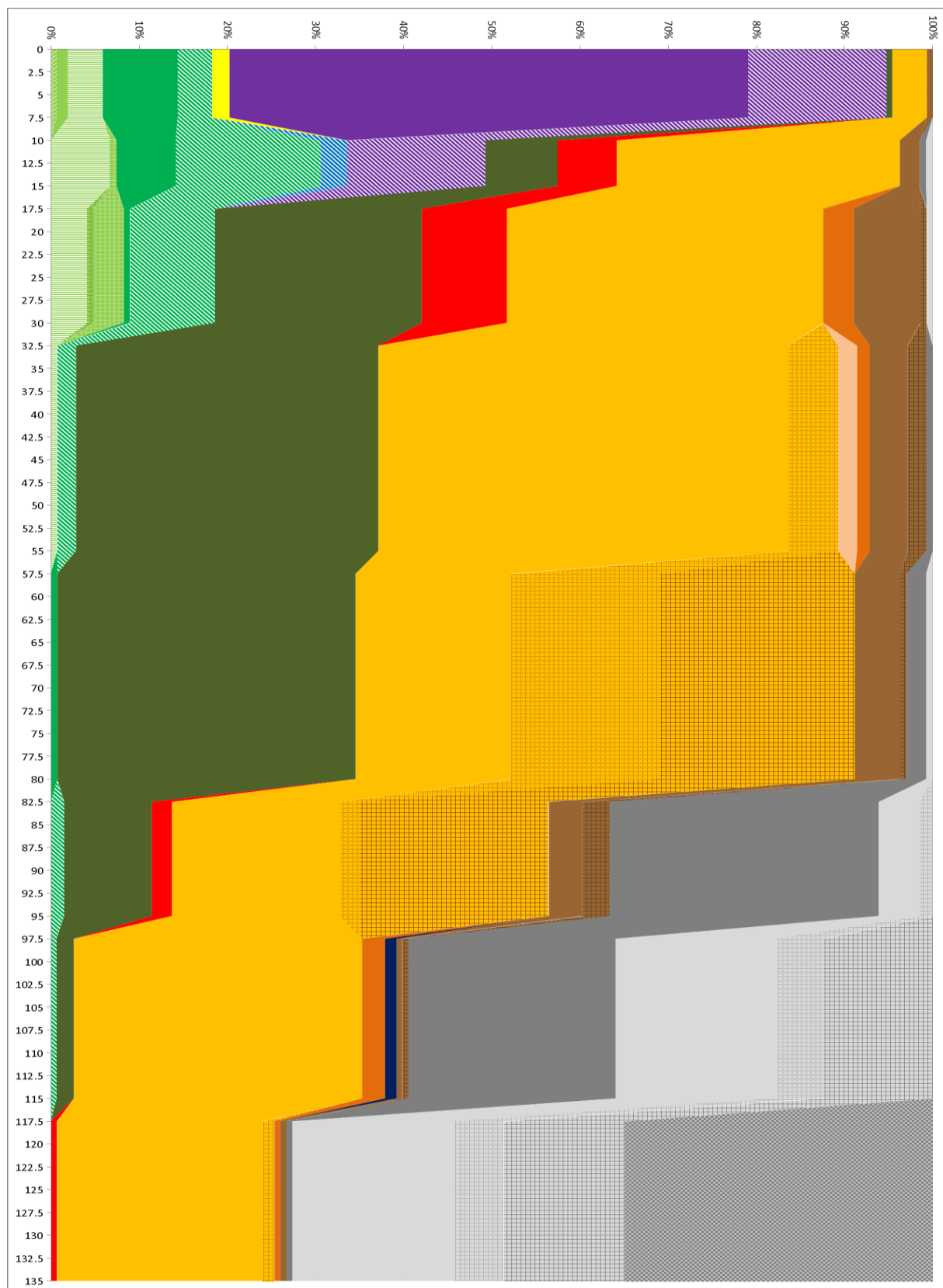
0-8 : OL

8-31 : OF

31-81 : OH

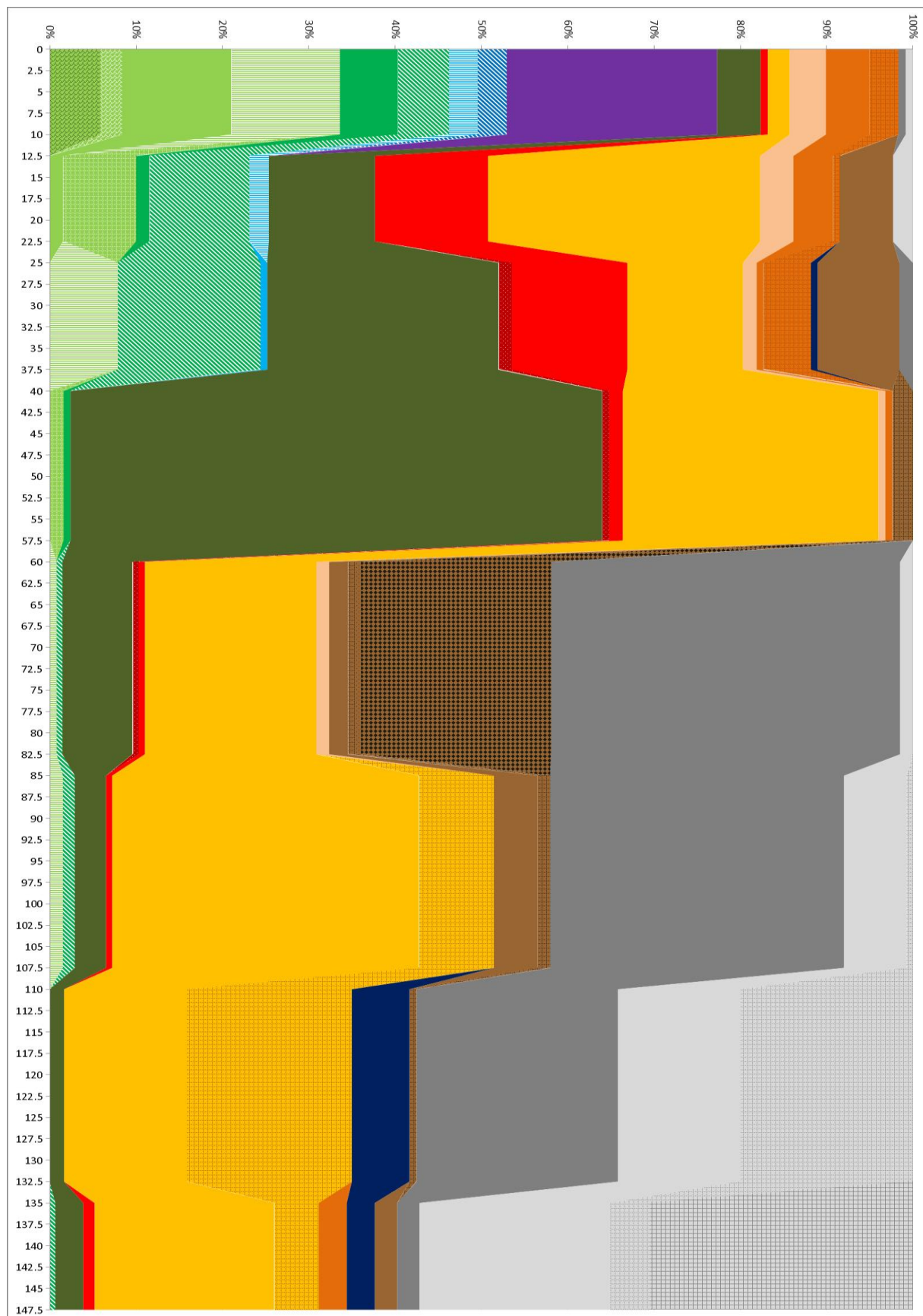
81-116 : AE

116-135 : USH



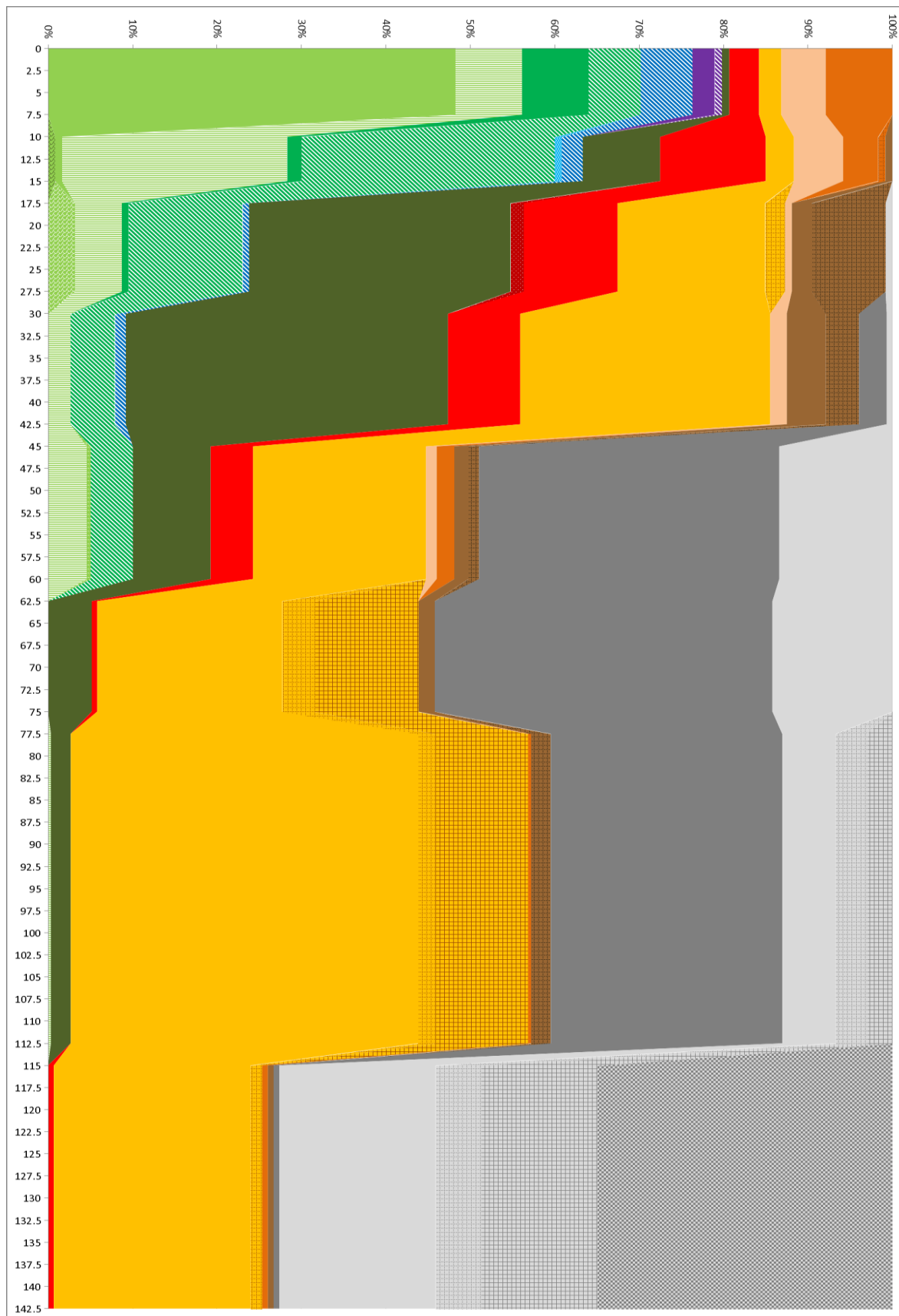
N03G2

0-10 : OL 10-22 : OF 22-37 : OF-OH 37-57 : OH 57-107 : 4 107-147.5 : USH



N03G3

0-8 : OL 8-15 : OF 15-27 : OF-OH 27-42 : OH 42-113 : Ae 113-142.5 : USH



N03M1

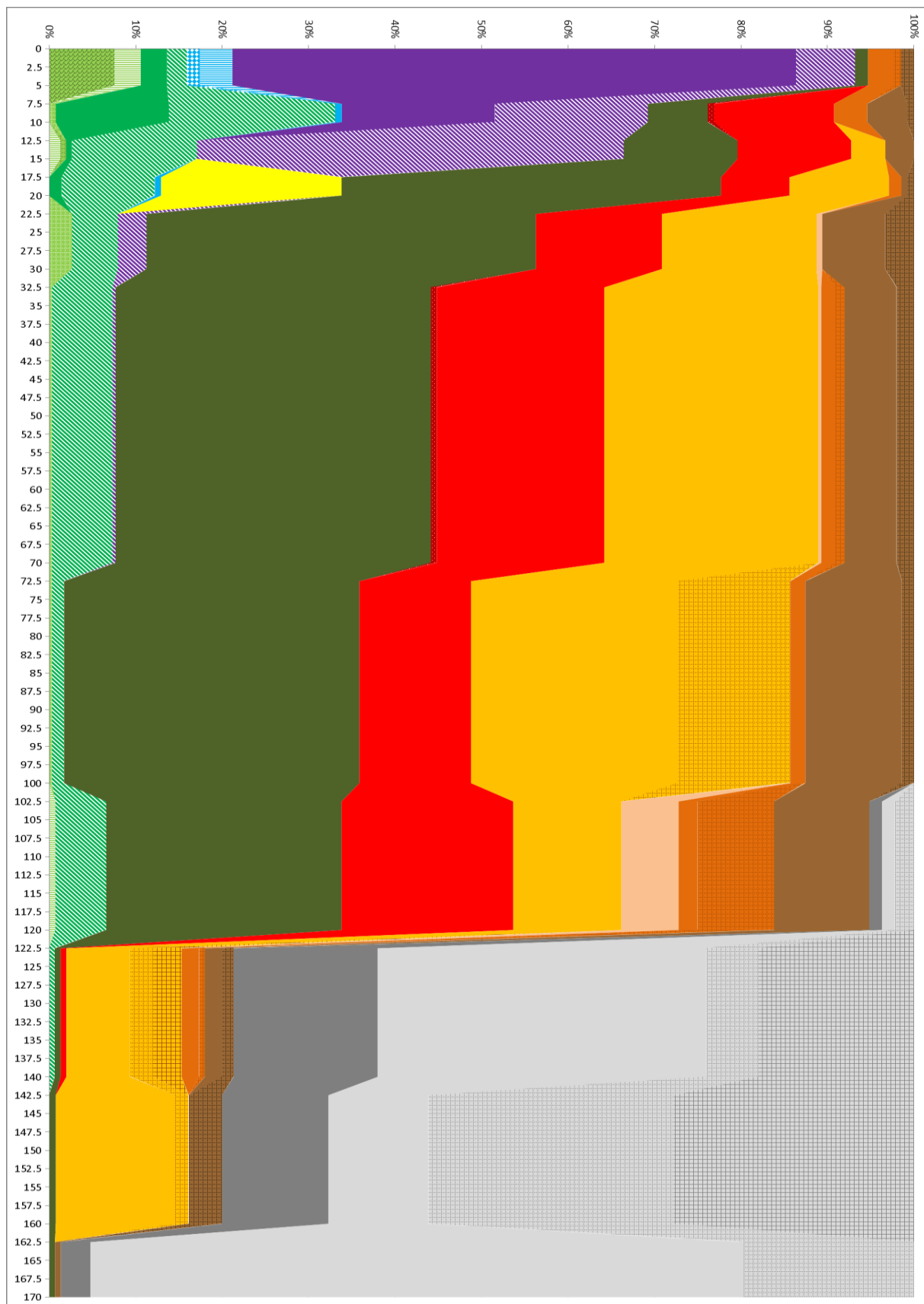
0-6 : OL

6-16 : OF

16-121 : OH

121-161 : Ae

161-170 : USH



N03M2

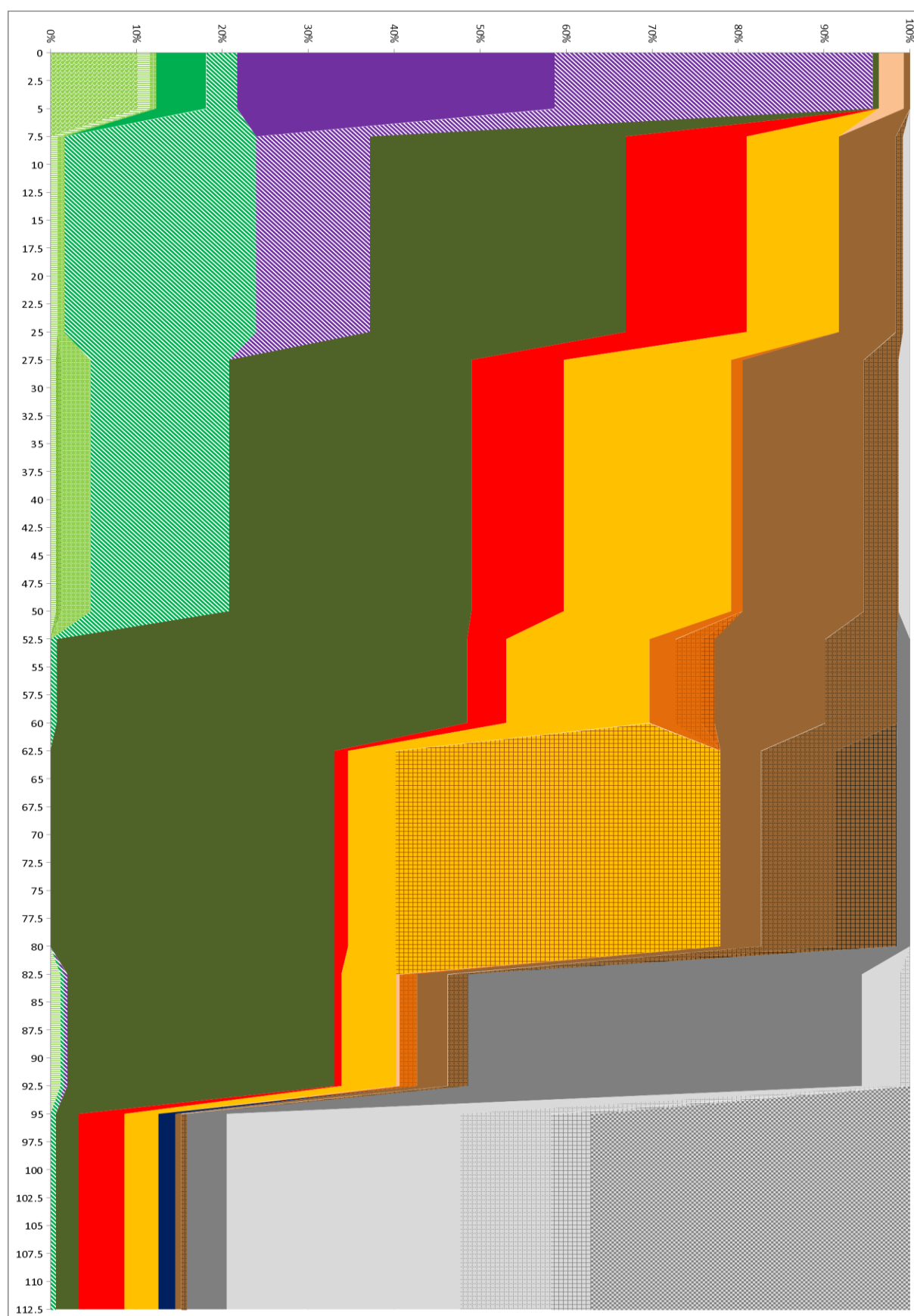
0-6 : OL

6-51 : OF

51-81 : OH

81-93 : OH-E

93-112.5 : USH



N03M3

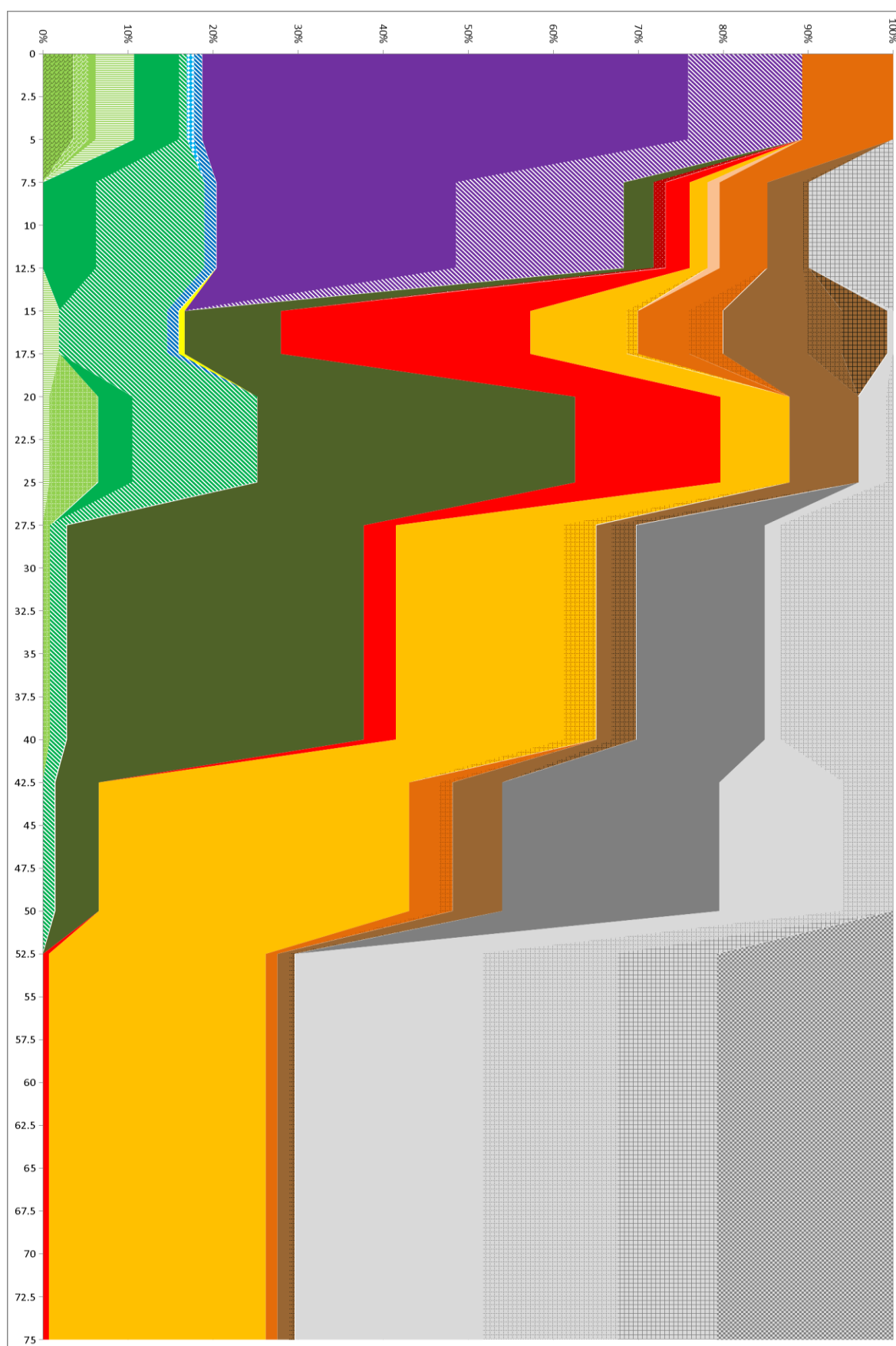
0-12 : OL

12-24 : OF

24-39 : OH

39-49 : A

49-75 : USH



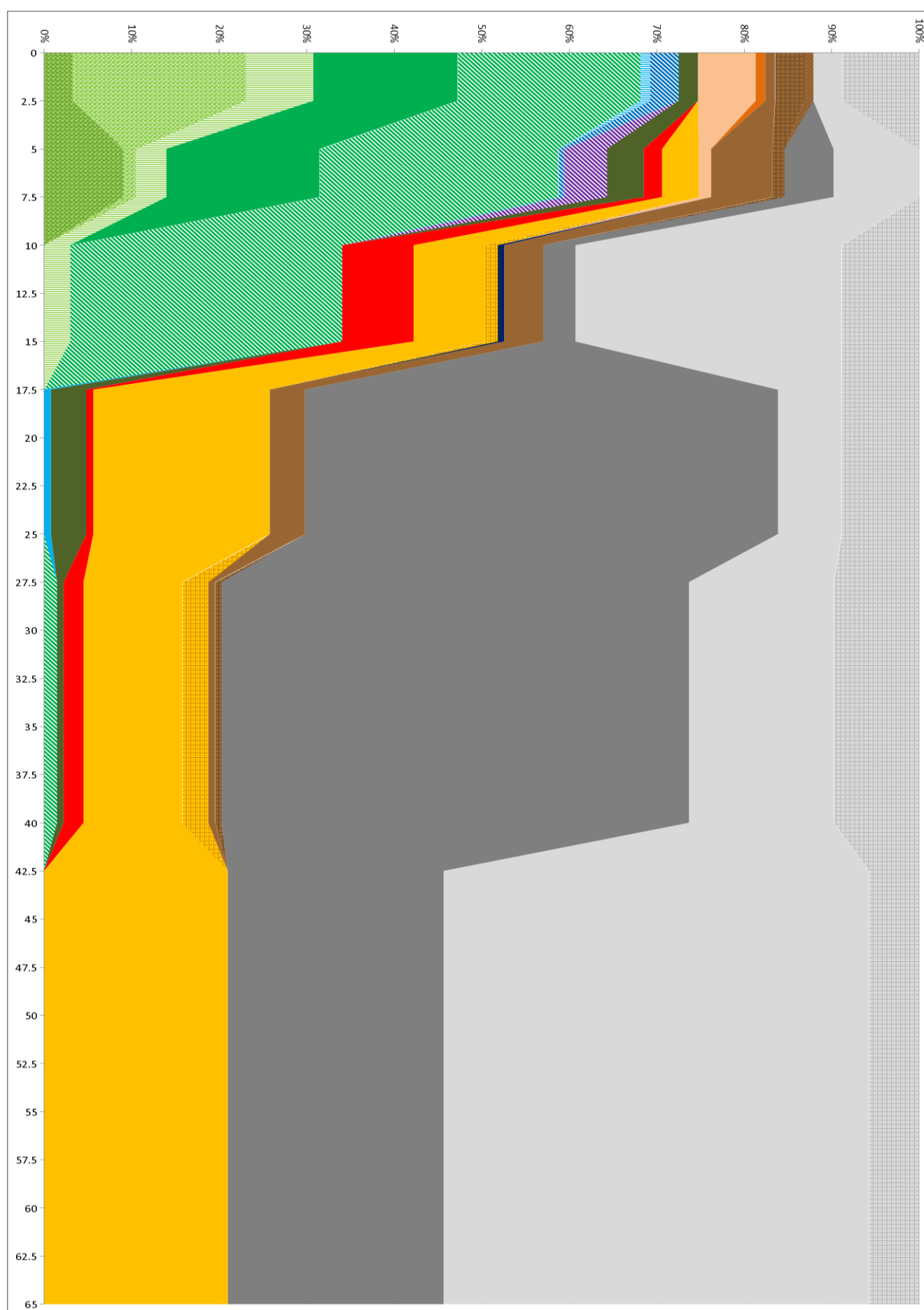
S06G1

0-3 : OL

3-14 : OF

14-39 : A

39-65 : A-USH



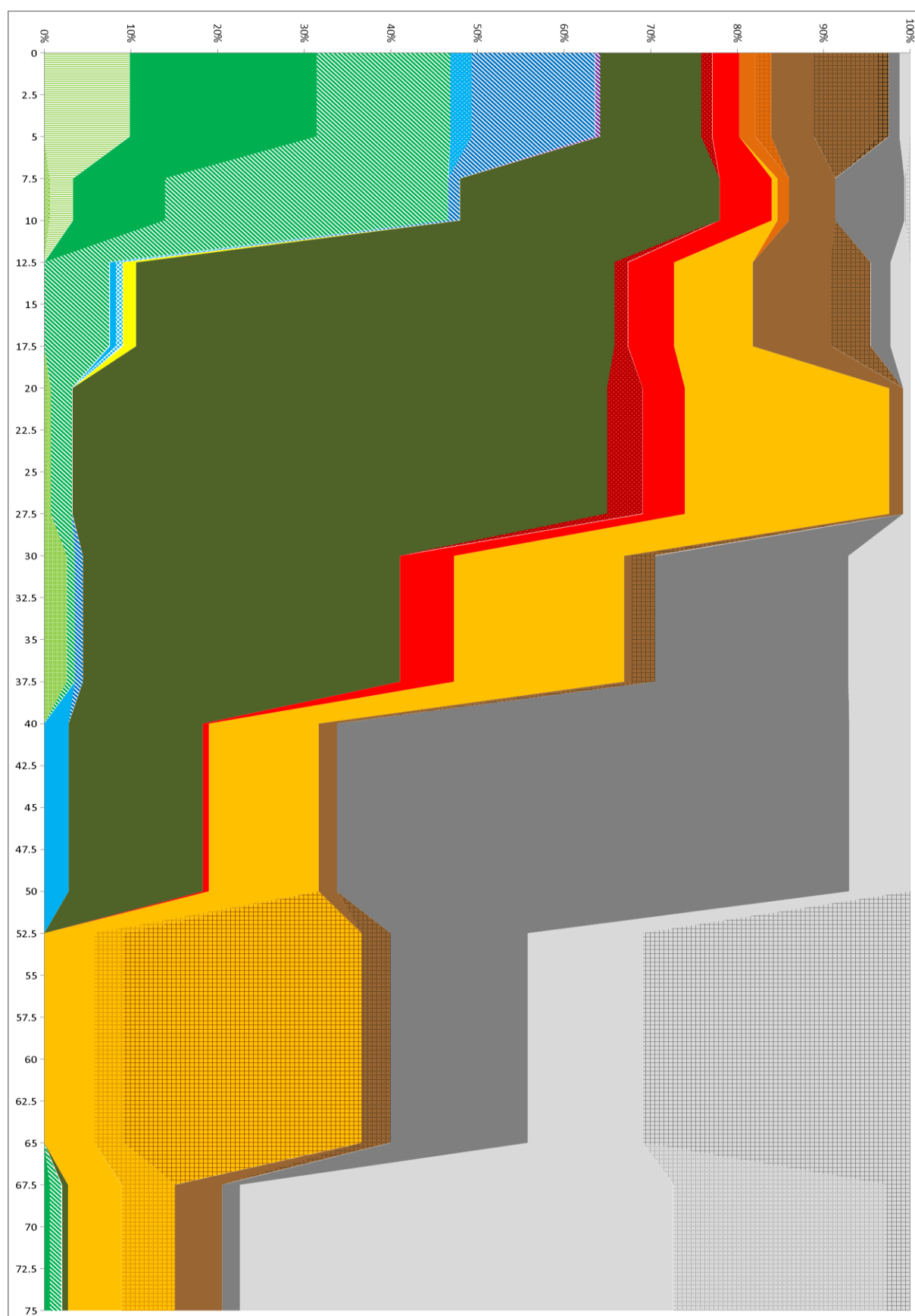
S06G2 0-5 : OL

5-10 : OF

10-38 : OH

38-50 : AE

50-75 USH



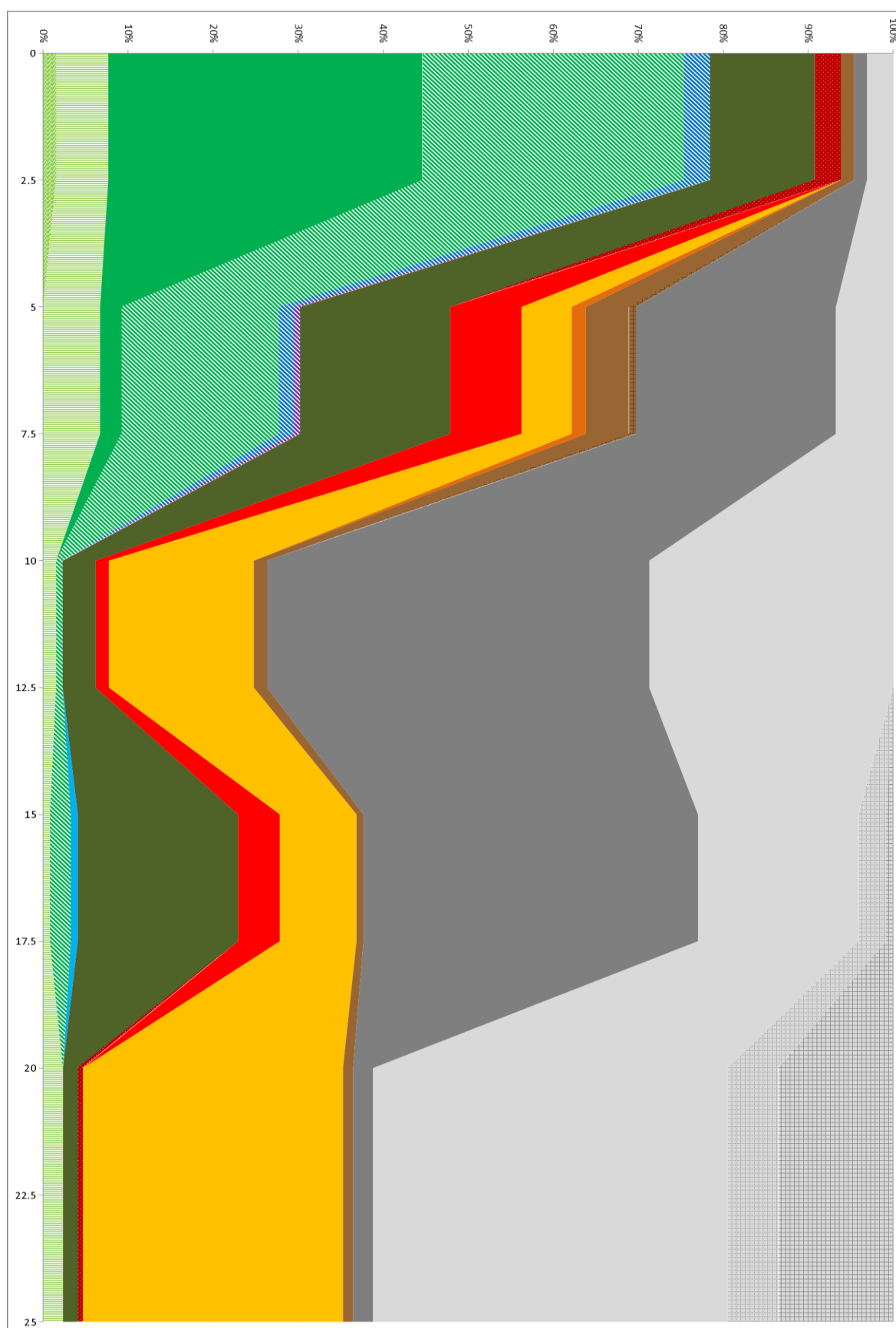
S06G3

0-3 : OF

3-8 : OH

8-18 : AE

18-25 : USH

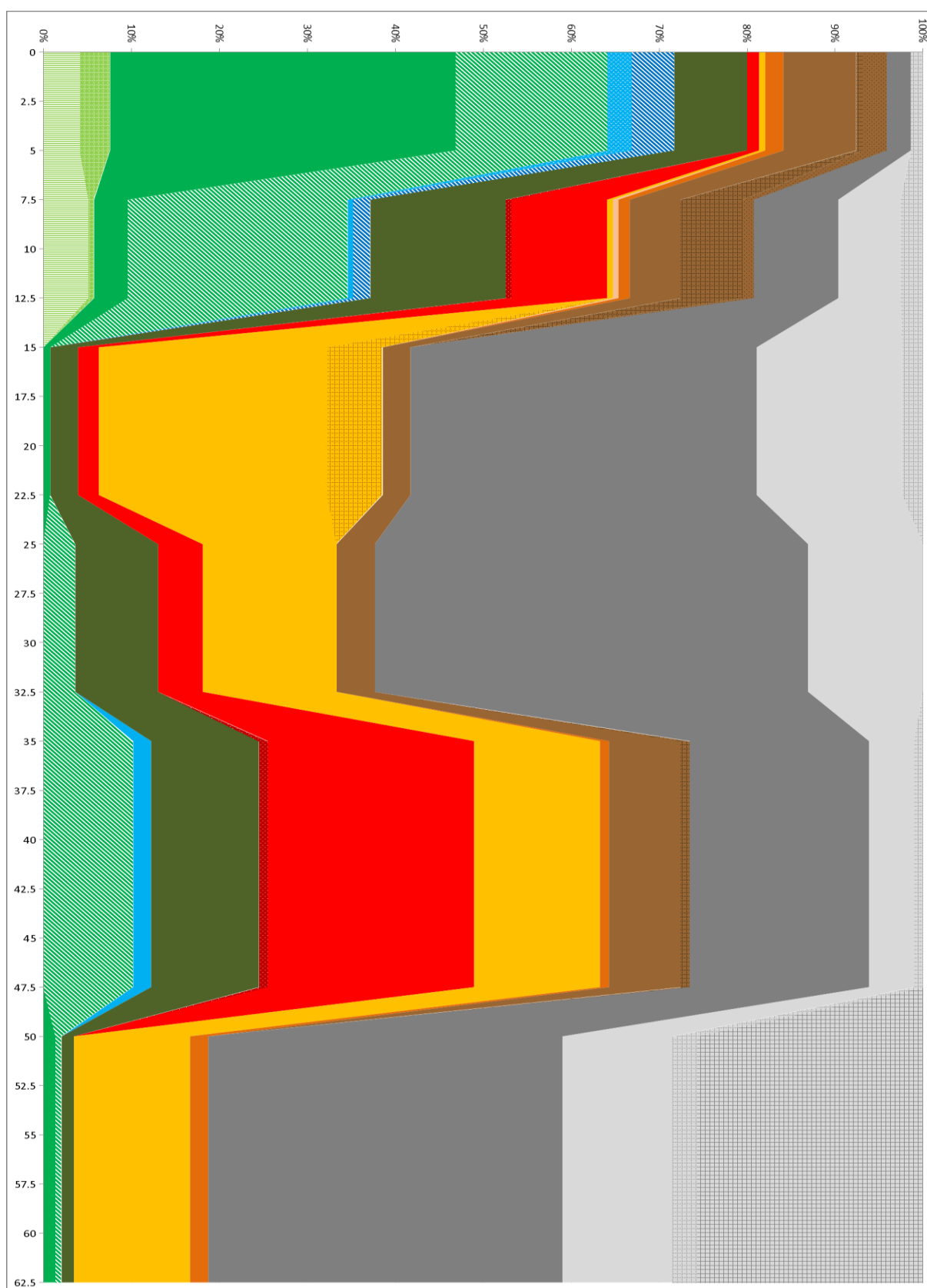


S06L1

0-6 : OL

6-12 : OF

12-62.5 : A



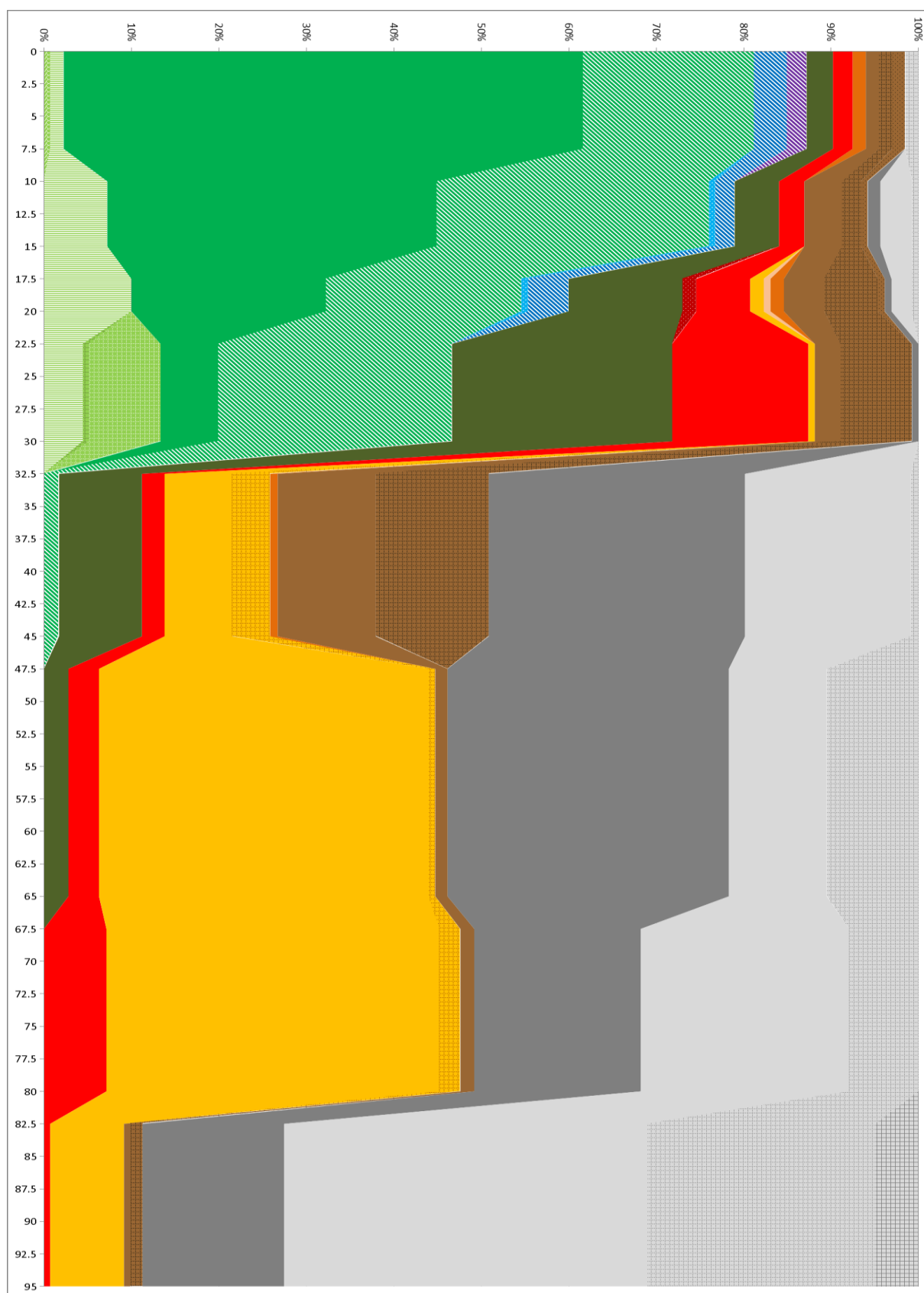
S06L2

0-8 : OL

8-30 : OF

30-80 : A

80-95 : USH



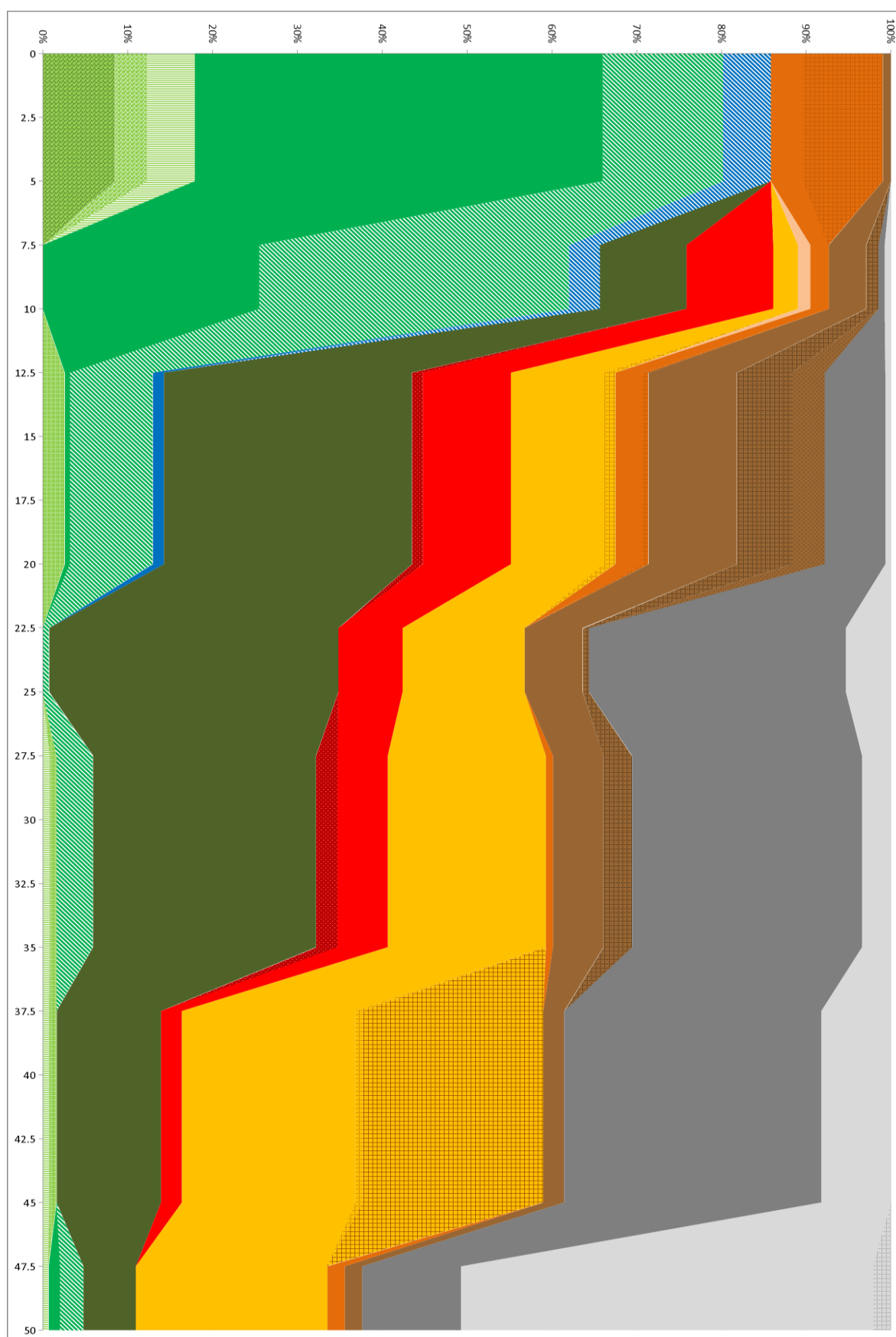
S06L3

0-5 : OL

5-19 : OF

19-45 : A

45-50 : USH



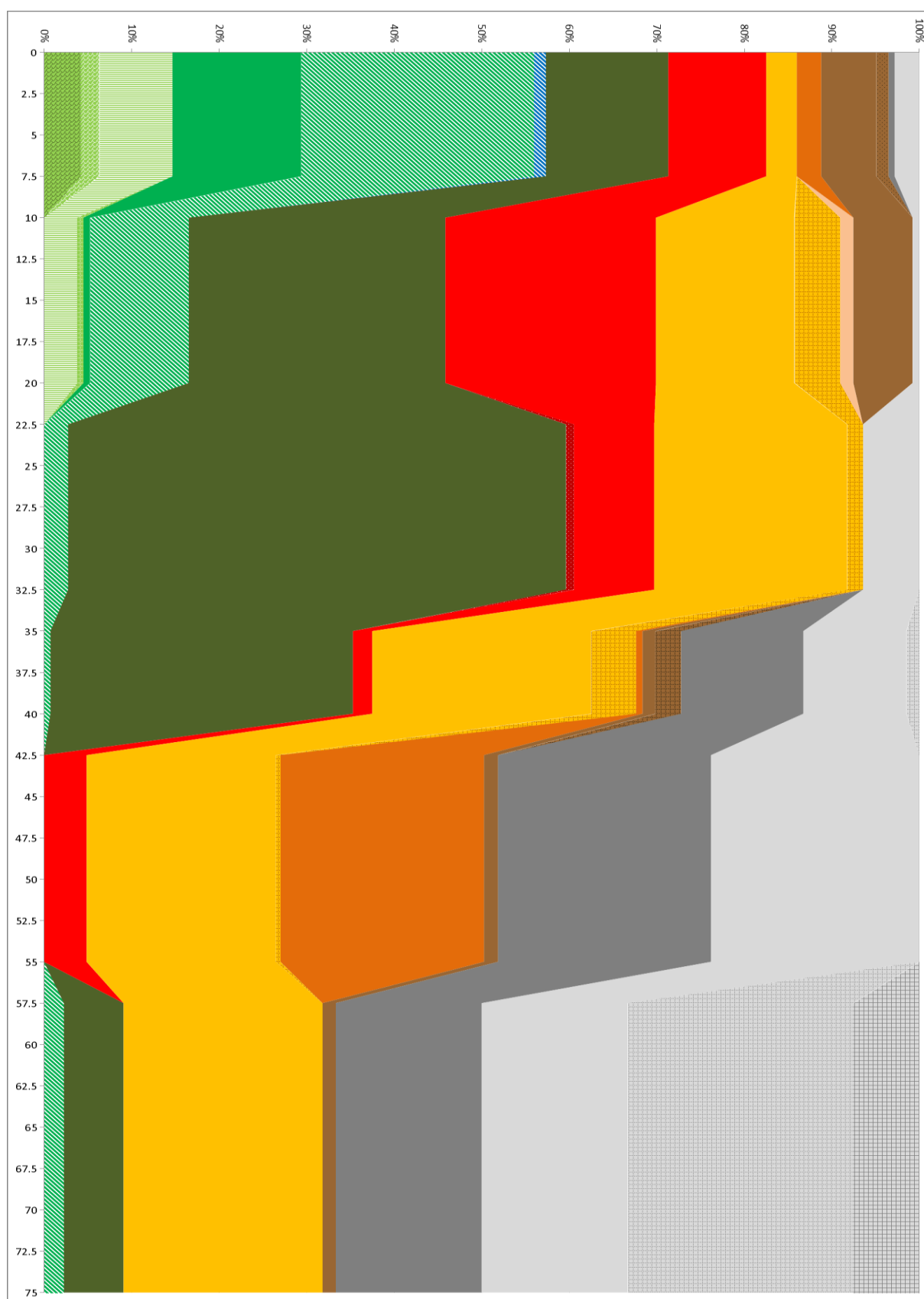
S08G1

0-8 : OL

8-20 : OF

20-40 : OH

40-75 A

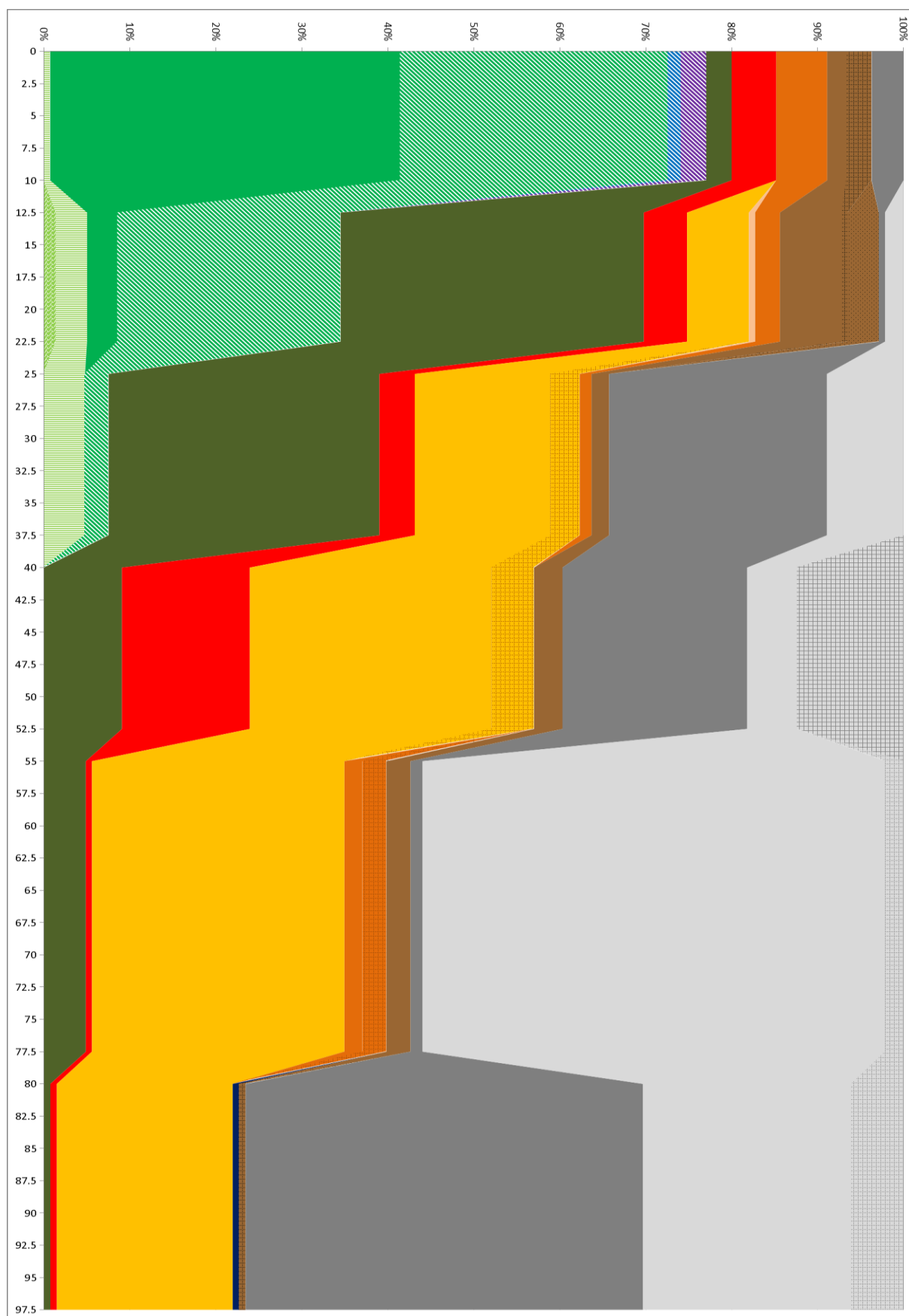


S08G2

0-10 : OL

10-22 : OF

22-97.5 : Ae



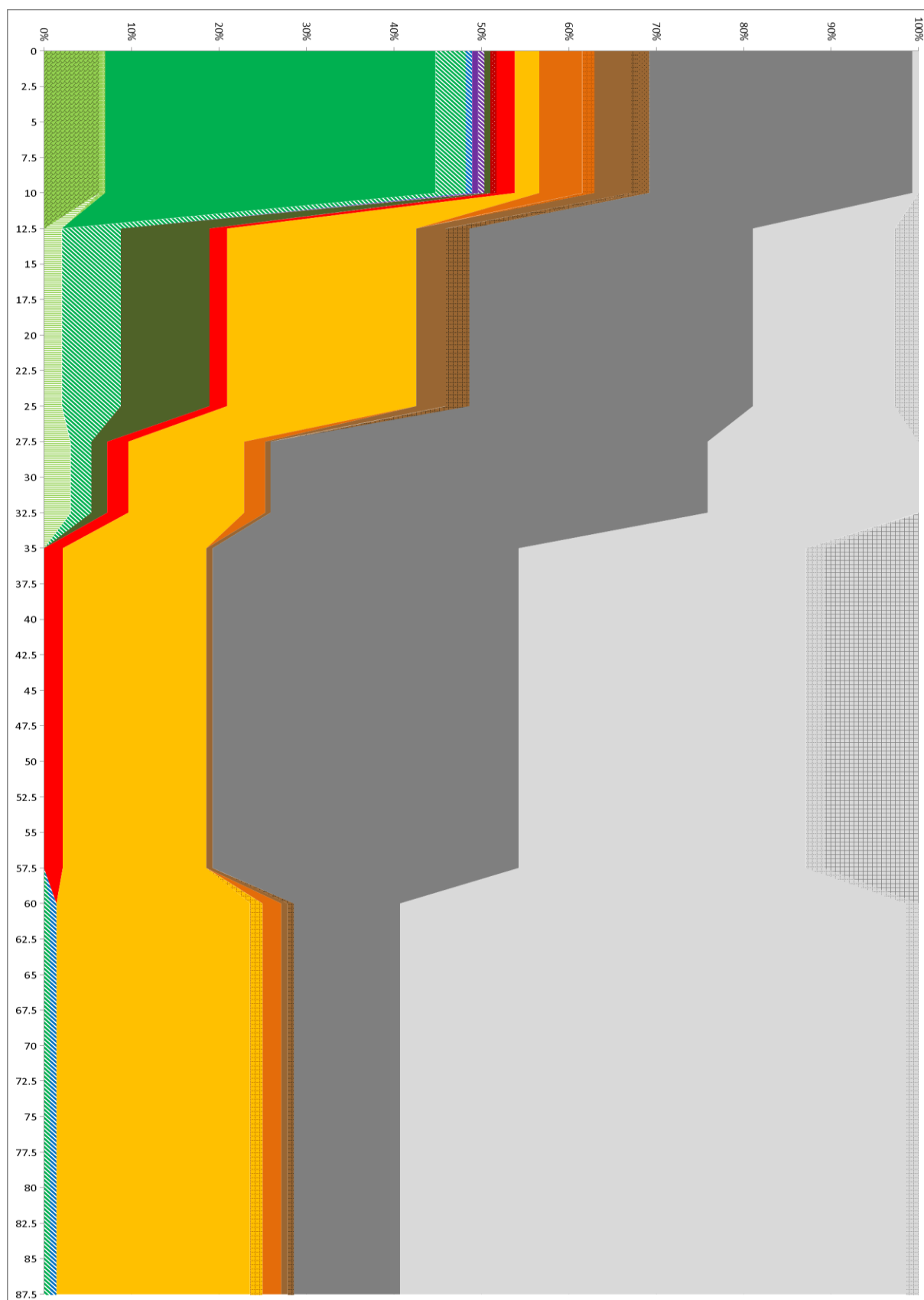
S08G3

0-10 : OL

10-25 : OF

25-58 : Ae

58-87.5 : USH



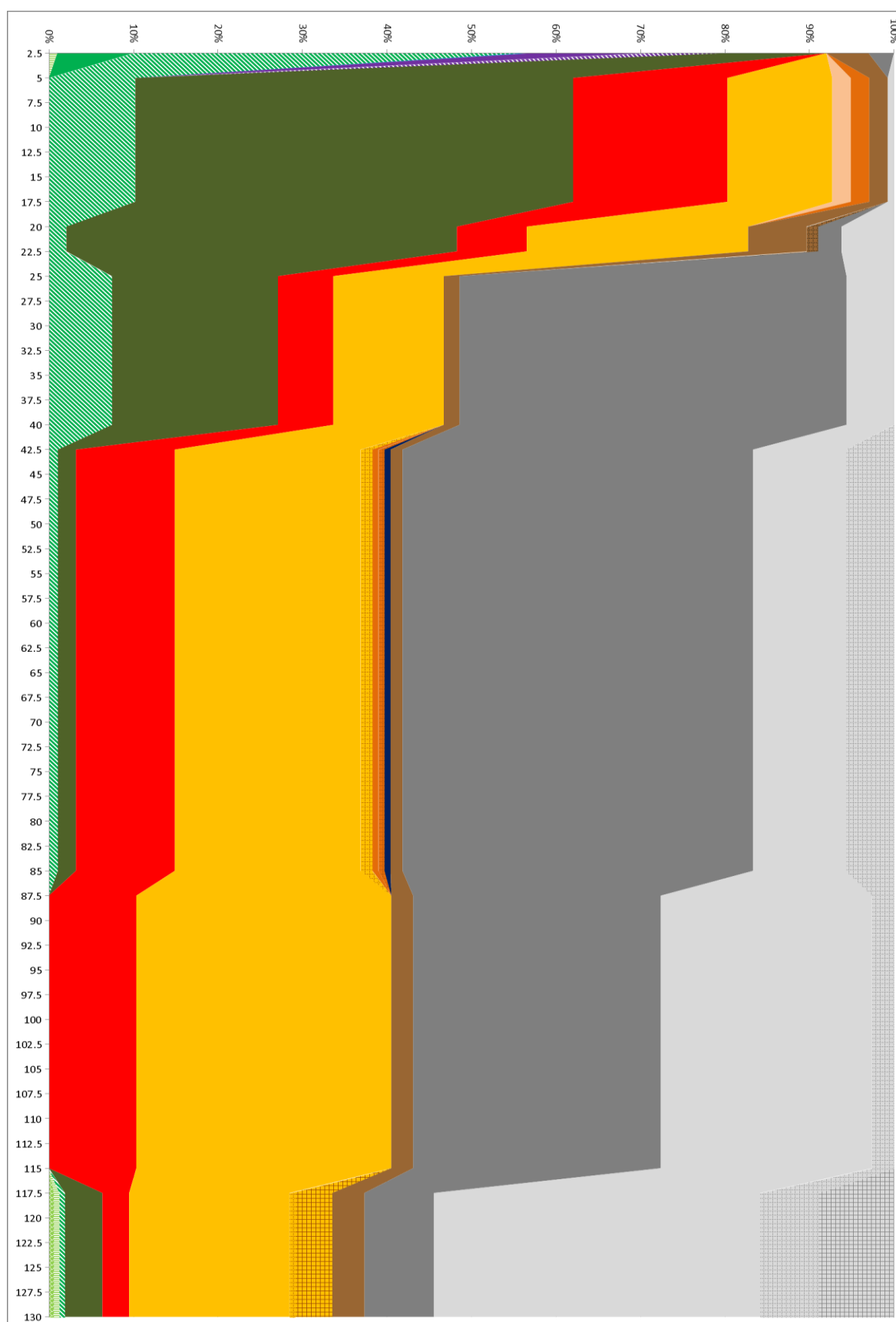
S08L1

0-2 : OF

2-23 : OH

23-40 : OH-Ae 40-115 : Ae

115-130 : USH



S08L2

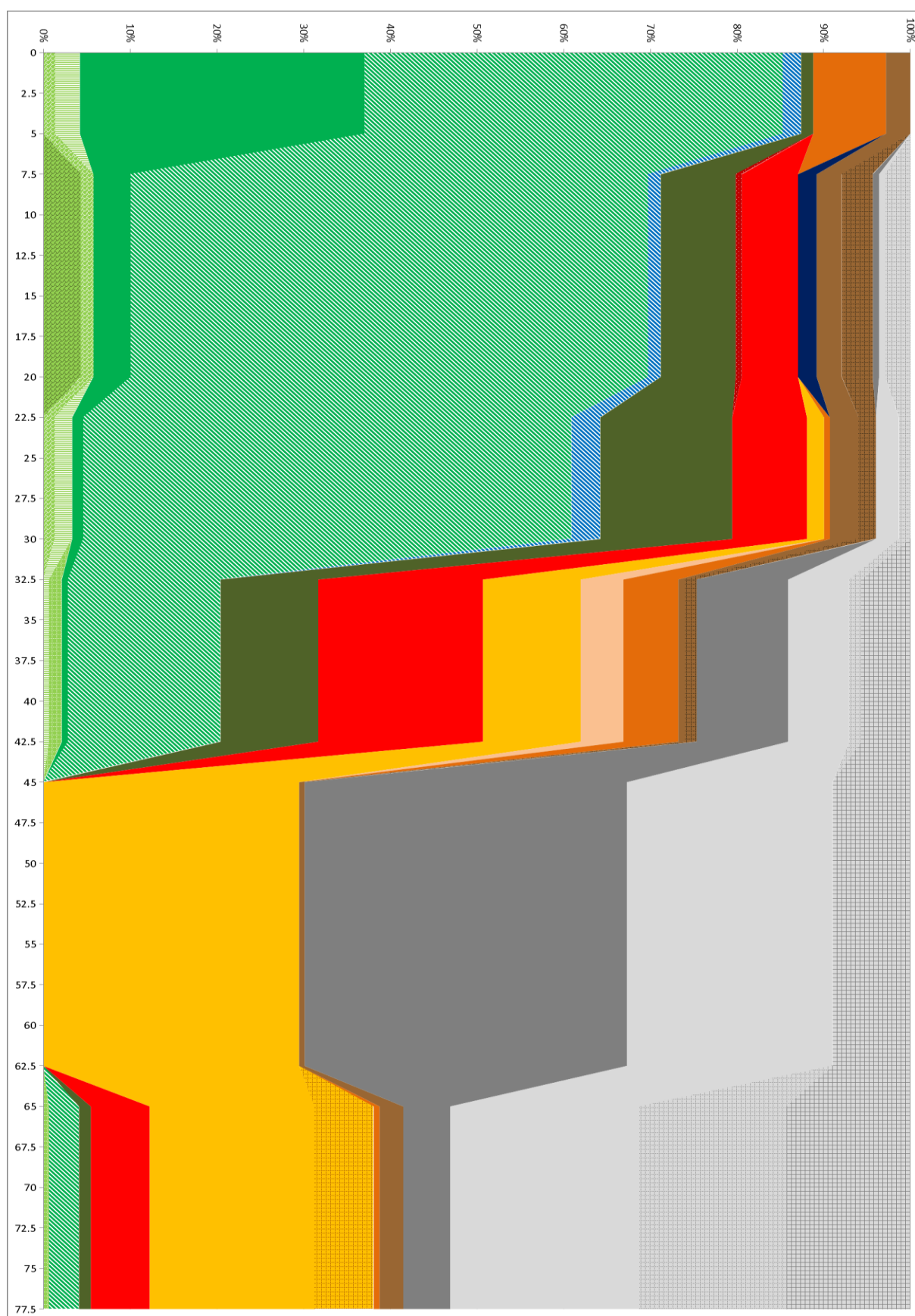
0-6 : OL

6-31 : OF

31-43 : OF-Ae

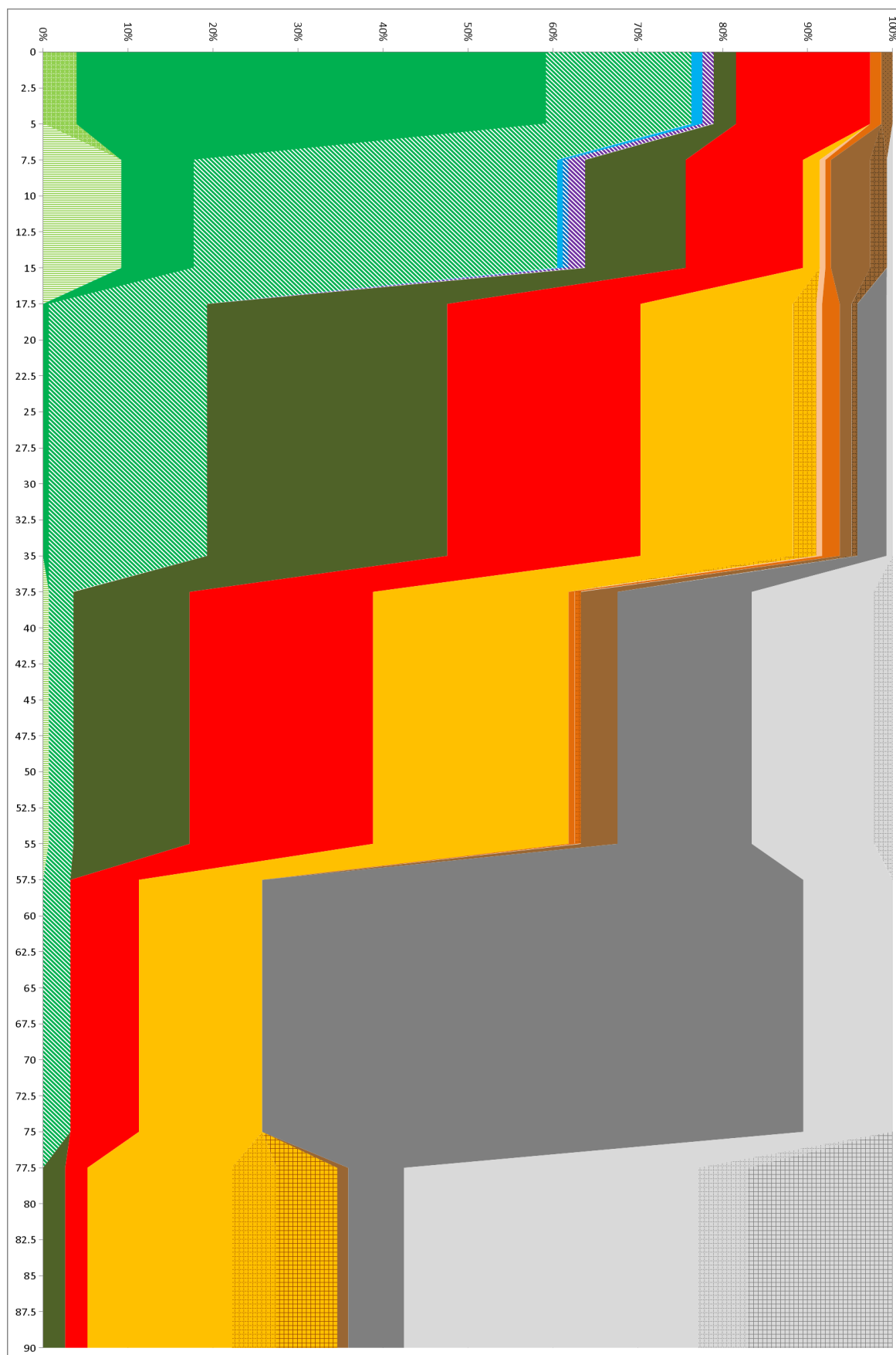
43-63 : Ae

63-78 : USH



S08L3

0-5 : OL 5-15 : OF 15-35 : OF-OH 35-55 : OH 55-75 : AE 75-90 : USH

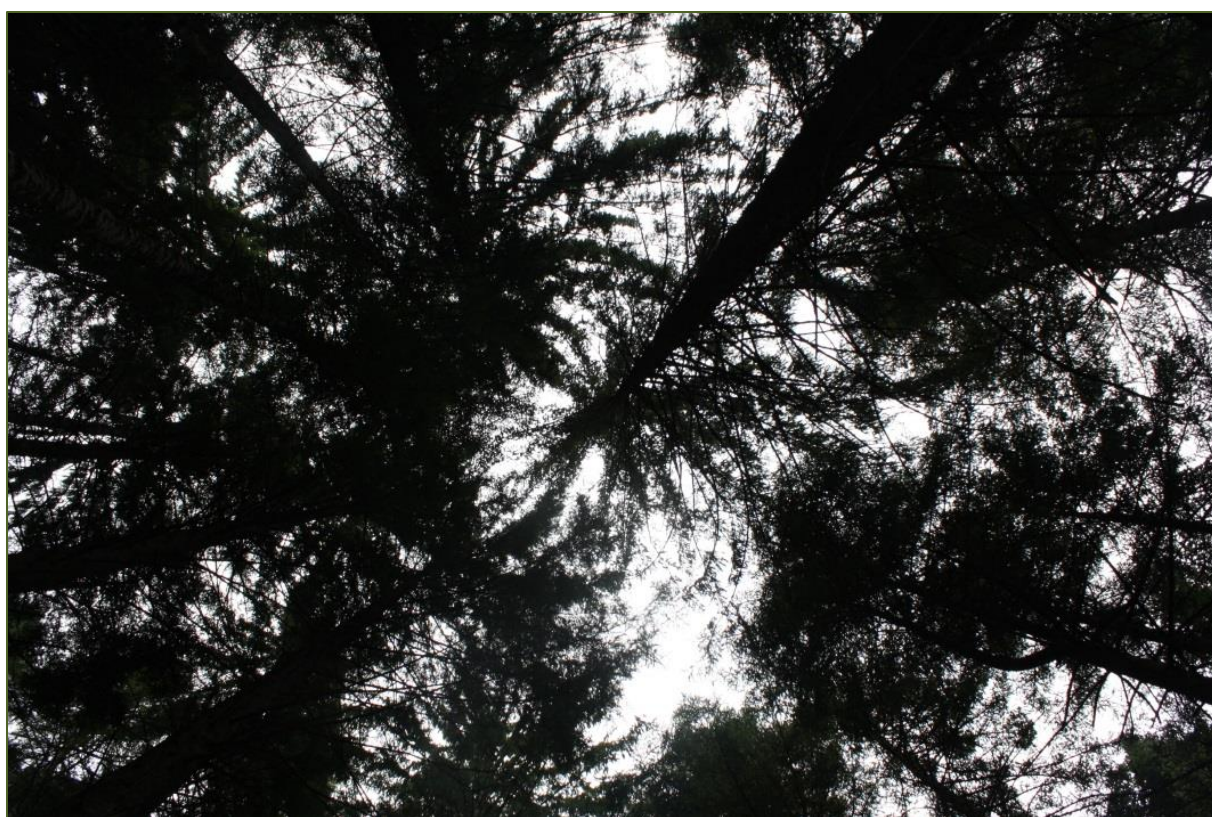


Lignoformes

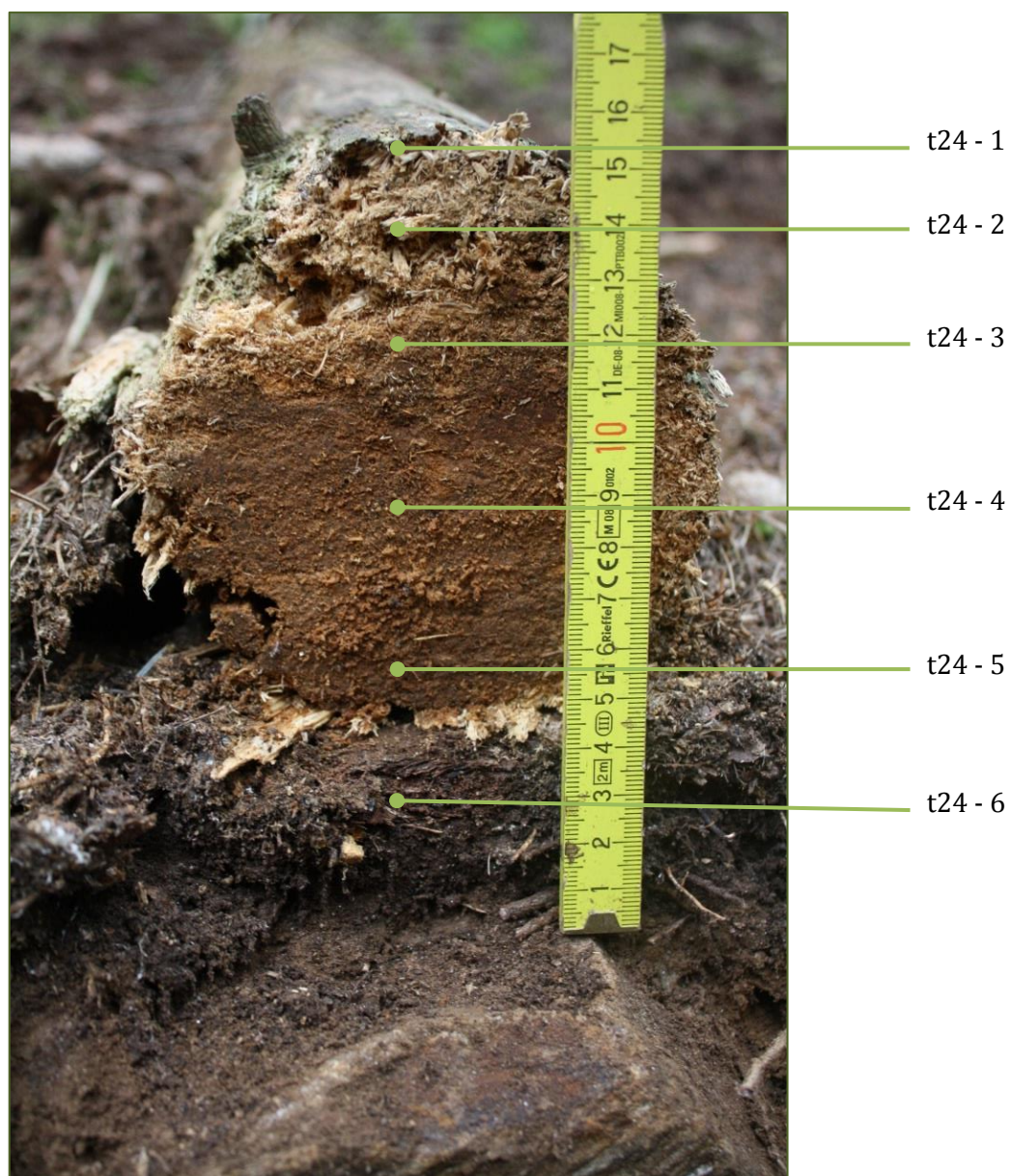
Tronc : t24

Coordonnées GPS	46°21.662' +/- 3 m 10°53.303'
Pente [°]	32
Exposition de la pente [°N]	347
Exposition du tronc [°N]	350
Espèce	<i>Picea abies</i>
Raison de la chute	naturelle
Longueur totale [cm]	670
Diamètre [cm]	10-20
Classe de décomposition générale	4
Végétation herbacée à proximité	<i>Abies alba</i> , <i>Oxalis acetosella</i>
Recouvrement arborescent (%)	80-90 % (65 % <i>Abies alba</i> , 35 % <i>Picea abies</i>)

Lignoformes



Lignoformes



Lignoformes

t24 - 1



t24 - 4



t24 - 2



t24 - 5



t24 - 3



t24 - 6



Lignoformes

couche	épaisseur [mm]	pH H ₂ O	CHN [%]			Indice pyrophosphate
t24 - 1	3	3.70	48.424	5.623	0.000	0.022
t24 - 2	15	3.67	50.543	5.518	0.000	0.046
t24 - 3	24	3.69	51.208	5.412	0.000	0.038
t24 - 4	72	3.62	45.867	5.193	0.629	0.092
t24 - 5	11	3.92	34.292	4.012	1.252	0.150
t24 - 6	21	4.08	15.708	2.350	0.558	0.078

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE*	ΔL*	Δa*	Δb*	réplicat
t24 - 1	49.36	8.46	24.81	11.62	-11.19	3.03	-0.69	I
t24 - 2	46.16	10.85	25.90	15.39	-14.39	5.42	0.40	
t24 - 3	47.05	10.83	24.58	14.57	-13.51	5.39	-0.92	
t24 - 4	41.78	7.37	20.26	19.59	-18.77	1.94	-5.24	
t24 - 5	33.38	5.66	13.00	29.92	-27.18	0.23	-12.50	
t24 - 6	36.37	6.03	13.41	27.05	-24.19	0.60	-12.09	
t24 - 1	49.16	8.43	24.30	11.84	-11.39	3.00	-1.20	II
t24 - 2	46.30	10.80	25.82	15.24	-14.25	5.37	0.32	
t24 - 3	46.93	10.86	24.81	14.69	-13.63	5.43	-0.69	
t24 - 4	46.93	10.86	24.81	14.69	-13.63	5.43	-0.69	
t24 - 5	41.76	7.35	20.31	19.59	-18.79	1.92	-5.19	
t24 - 6	33.60	5.64	12.88	29.76	-26.95	0.21	-12.62	
t24 - 1	49.26	8.38	24.02	11.77	-11.30	2.95	-1.47	III
t24 - 2	46.22	10.79	25.79	15.31	-14.34	5.36	0.29	
t24 - 3	47.23	10.77	24.42	14.40	-13.33	5.34	-1.08	
t24 - 4	42.14	7.32	19.99	19.32	-18.42	1.89	-5.51	
t24 - 5	33.41	5.68	13.20	29.80	-27.15	0.25	-12.30	
t24 - 6	36.22	6.04	13.40	27.18	-24.33	0.61	-12.10	

Lignoformes

Couche t24 - 6

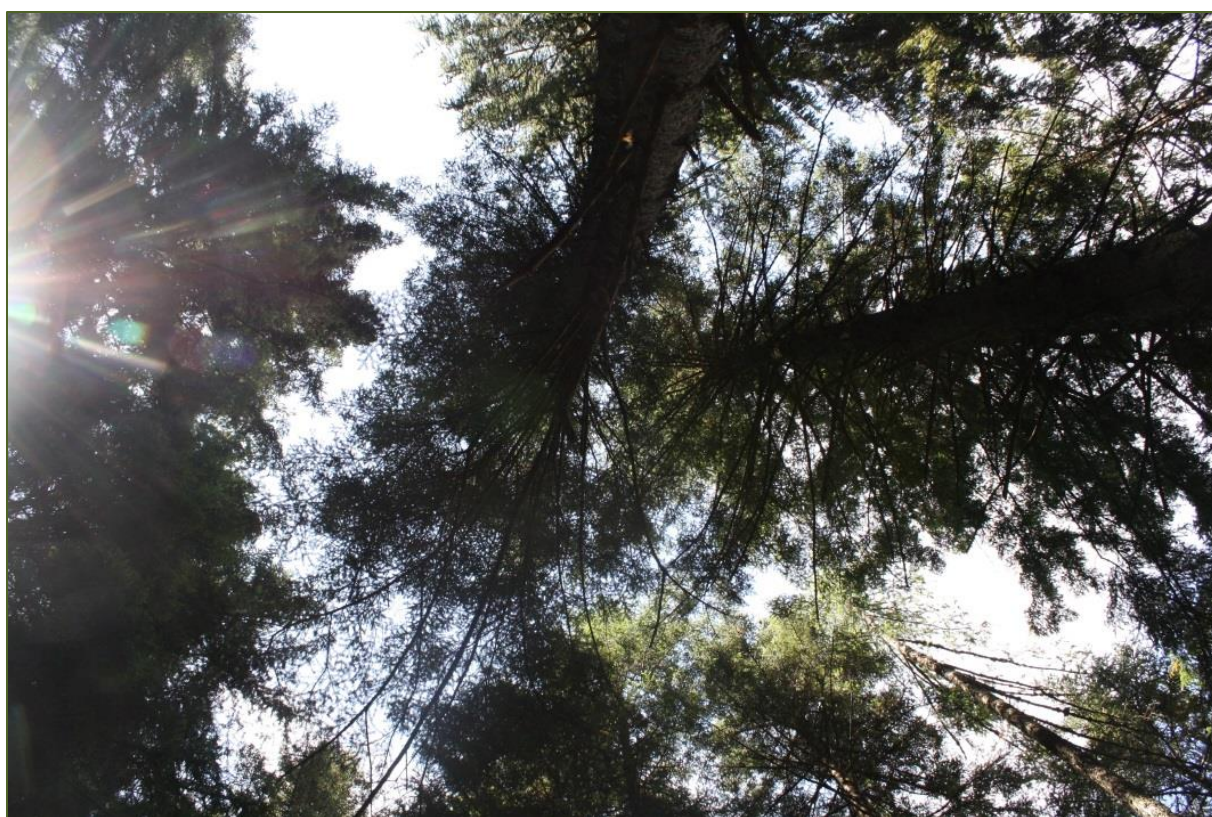
- Texture
 - Aspect : grumeleux-granuleux à subpolyédrique
 - Cohésion : 1/3
 - Macro : 10 %
 - Méso : 40 %
 - Micro : 50 %
- Structure
 - Limono-argileux
- HCl
 - 0/4
- Éléments grossiers
 - Total : 6 %
 - 2 – 20 mm : 75 %
 - 20 – 50 mm : 25 %
 - Dureté : 1/2
 - Sphéricité : 0/2
 - Angulosité : 2.5/3
- Racines
 - Abondance
 - 0 – 2 mm : 2/5
 - 2 – 5 mm : 3.5/5
 - > 5 mm : 2/5
 - Distribution
 - 0 – 2 mm : irrégulière
 - 2 – 5 mm : irrégulière
 - > 5 mm : irrégulière
 - Orientation
 - 0 – 2 mm : horizontale
 - 2 – 5 mm : horizontale
 - > 5 mm : horizontale
- Porosité
 - Abondance : 2/4
 - Orientation : horizontale à oblique
 - Diamètre médian : 1.5 mm
- Propriétés physiques
 - Adhésivité : 1/3
 - Compacité : 1/3
 - Plasticité : 1/3

Lignoformes

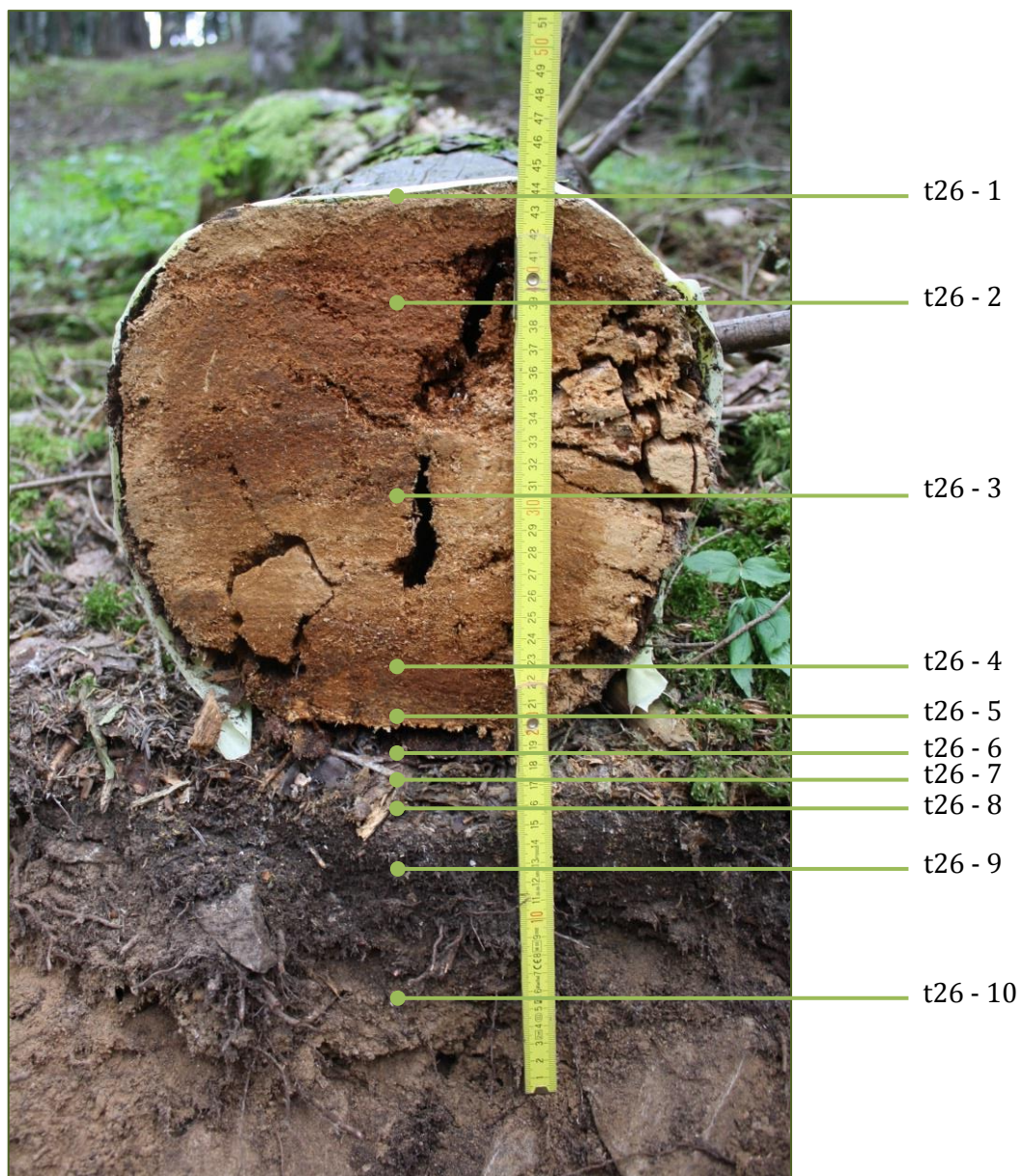
Tronc : t26

Coordonnées GPS	46°21.659' +/- 6 m 10°53.303'
Pente [°]	30
Exposition de la pente [°N]	320
Exposition du tronc [°N]	320
Espèce	<i>Picea abies</i>
Raison de la chute	coupe
Longueur totale [cm]	400
Diamètre [cm]	25-53
Classe de décomposition générale	3
Végétation herbacée à proximité	<i>Hieracium murorum</i> , <i>Luzula nivea</i> , <i>Oxalis acetosella</i> , <i>Carex</i> sp., <i>Festuca altissima</i> , <i>Veronica urticifolia</i>
Recouvrement arborescent (%)	80-90

Lignoformes



Lignoformes



Lignoformes

t26 - 1



t26 - 6



t26 - 4



t26 - 7



t26 - 3



t26 - 8



t26 - 4



t26 - 9



t26 - 5



t26 - 10



2

Lignoformes

couche	épaisseur [mm]	pH H ₂ O	C	H	N	Indice pyrophosphate
t26 - 1	10	3.54	49.066	5.872	0.000	0.044
t26 - 2	80	3.76	56.301	5.429	0.000	0.100
t26 - 3	106	3.43	57.937	5.724	0.000	0.115
t26 - 4	34	3.74	55.445	5.614	0.000	0.123
t26 - 5	11	4.08	48.386	5.975	0.302	0.033
t26 - 6	10	4.12	50.019	5.322	0.442	0.082
t26 - 7	21	4.42	46.229	5.406	1.283	0.083
t26 - 8	14	4.08	40.841	4.674	1.459	0.167
t26 - 9	73	3.94	33.386	3.158	1.367	0.188
t26 - 10	NA	4.24	3.917	0.969	0.168	0.033

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE*	ΔL*	Δa*	Δb*	réplicat
t26 - 1	51.74	7.88	22.34	9.68	-8.82	2.45	-3.16	I
t26 - 2	47.71	14.27	27.07	15.67	-12.84	8.84	1.57	
t26 - 3	53.94	13.52	30.11	11.42	-6.61	8.09	4.61	
t26 - 4	43.89	14.50	27.51	19.09	-16.67	9.07	2.01	
t26 - 5	55.35	8.51	24.61	6.12	-5.21	3.08	-0.89	
t26 - 6	36.41	8.79	20.09	24.97	-24.15	3.36	-5.41	
t26 - 7	33.24	6.45	14.90	29.32	-27.31	1.01	-10.60	
t26 - 8	29.31	5.12	13.02	33.65	-31.25	-0.31	-12.48	
t26 - 9	26.90	4.77	11.19	36.58	-33.66	-0.66	-14.31	
t26 - 10	50.36	7.42	19.56	11.96	-10.19	1.99	-5.94	
t26 - 1	51.50	7.92	22.42	9.89	-9.06	2.49	-3.08	II
t26 - 2	47.82	14.21	26.79	15.52	-12.74	8.78	1.29	
t26 - 3	53.90	13.53	30.17	11.48	-6.66	8.10	4.67	
t26 - 4	44.00	14.37	27.24	18.90	-16.56	8.94	1.74	
t26 - 5	55.45	8.43	24.62	5.99	-5.10	3.00	-0.88	
t26 - 6	36.56	8.67	19.75	24.89	-23.99	3.24	-5.75	
t26 - 7	33.05	6.49	15.07	29.44	-27.51	1.06	-10.43	
t26 - 8	29.25	5.14	13.06	33.69	-31.31	-0.29	-12.44	
t26 - 9	26.85	4.76	11.13	36.65	-33.71	-0.67	-14.37	
t26 - 10	50.60	7.39	19.69	11.69	-9.95	1.96	-5.81	
t26 - 1	51.48	7.95	22.67	9.84	-9.08	2.52	-2.83	III
t26 - 2	47.88	14.17	26.72	15.44	-12.67	8.74	1.22	
t26 - 3	53.86	13.51	30.16	11.48	-6.70	8.08	4.66	
t26 - 4	43.91	14.44	27.45	19.03	-16.65	9.01	1.95	
t26 - 5	55.29	8.48	24.71	6.13	-5.26	3.04	-0.79	
t26 - 6	36.59	8.71	19.71	24.87	-23.97	3.28	-5.79	
t26 - 7	33.20	6.48	14.97	29.33	-27.35	1.05	-10.53	
t26 - 8	29.42	5.06	12.90	33.59	-31.14	-0.37	-12.60	
t26 - 9	26.88	4.78	11.16	36.61	-33.67	-0.65	-14.34	
t26 - 10	50.73	7.35	19.61	11.62	-9.83	1.92	-5.89	

Lignoformes

Couche t26 - 6

- Texture
 - Aspect : grumeleux
 - Cohésion : 1/3
 - Macro : 10 %
 - Méso : 50 %
 - Micro : 40 %
- Structure
 - Limono-sableux
- Code Munsell (hue, value, chroma)
 - 7.5YR 2.5/2
- HCl
 - 0/4
- Éléments grossiers
 - Total : 5 %
 - 2 – 20 mm : 30 %
 - 20 – 50 mm : 40 %
 - 50 – 200 mm : 30 %
 - Dureté : 1/2
 - Sphéricité : 0/2
 - Angulosité : 2.5/3
- Racines
 - Abondance
 - 0 – 2 mm : 4/5
 - 2 – 5 mm : 2.5/5
 - > 5 mm : 2/5
 - Distribution
 - 0 – 2 mm : régulière
 - 2 – 5 mm : régulière
 - > 5 mm : irrégulière
 - Orientation
 - 0 – 2 mm : oblique à verticale
 - 2 – 5 mm : horizontale à oblique
 - > 5 mm : horizontale
- Porosité
 - Abondance : 2/4
 - Orientation : horizontale à oblique
 - Diamètre médian : 1.5 mm
- Propriétés physiques
 - Adhésivité : 0/3
 - Compacité : 1/3
 - Plasticité : 0.75/3

Lignoformes

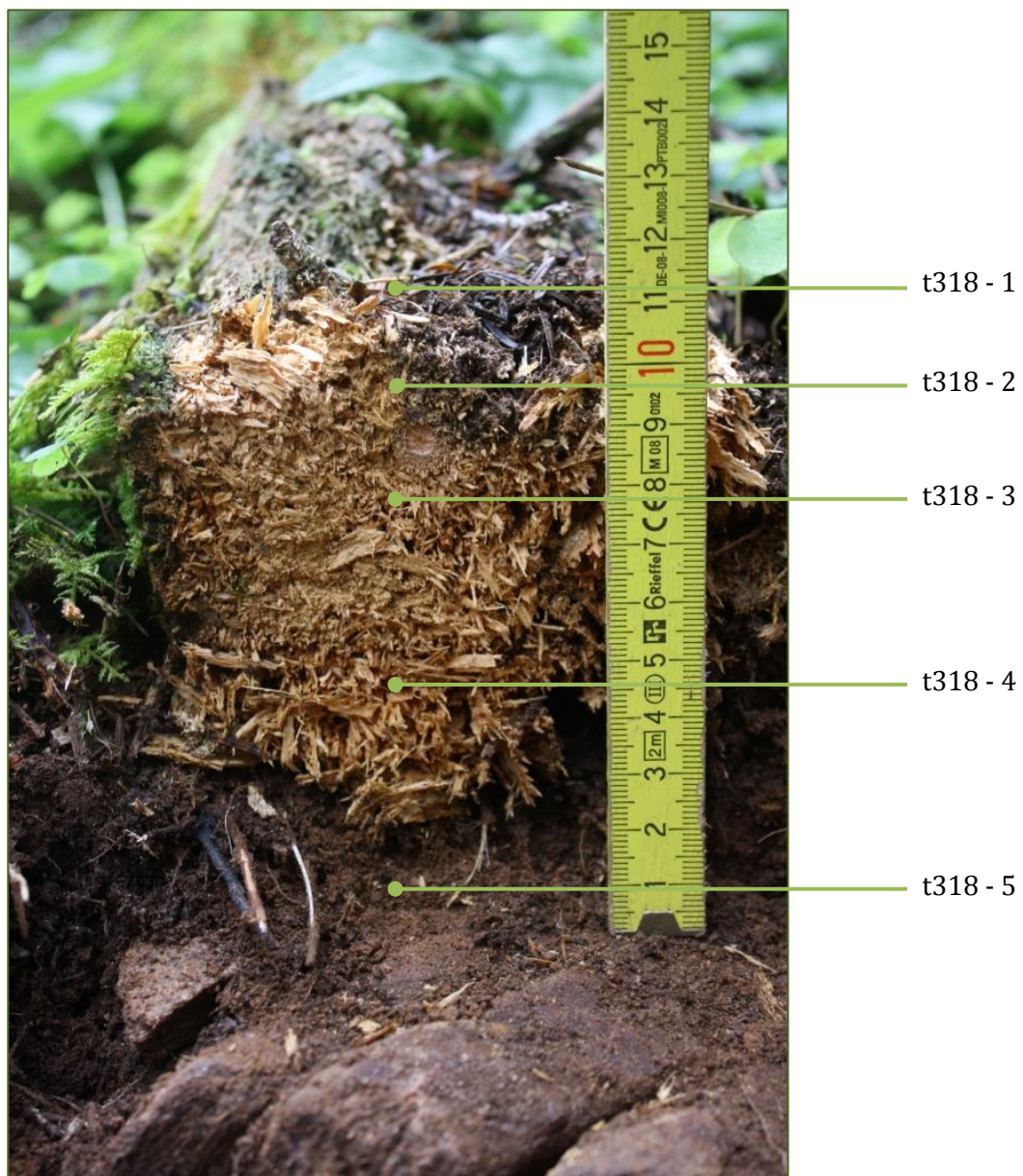
Tronc : t318

Coordonnées GPS	46°21.663' +/- 14 m 10°53.314'
Pente [°]	28
Exposition de la pente [°N]	326
Exposition du tronc [°N]	320
Espèce	<i>Picea abies</i>
Raison de la chute	indéterminée
Longueur totale [cm]	252
Diamètre [cm]	6-14
Classe de décomposition générale	5
Végétation herbacée à proximité	<i>Oxalis acetosella</i> , <i>Hieracium murorum</i> , <i>Veronica urticifolia</i> , <i>Luzula nivea</i> , <i>Solidago virgaurea</i> s.str.
Recouvrement arborescent (%)	70-80

Lignoformes



Lignoformes



Lignoformes

t318 - 1



t318 - 4



t318 - 2



t318 - 5



t318 - 3



Lignoformes

couche	épaisseur [mm]	pH H ₂ O	C	H	N	Indice pyrophosphate
t318 - 1	5	4.56	48.904	6.067	0.807	0.019
t318 - 2	10	4.66	46.728	5.583	0.995	0.011
t318 - 3	30	3.51	46.961	6.012	0.000	0.023
t318 - 4	40	3.60	46.211	5.793	0.132	0.027
t318 - 5	15	4.42	11.613	1.737	0.531	0.117

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE^*	ΔL^*	Δa^*	Δb^*	réplicat
t318 - 1	33.00	7.85	17.39	28.82	-27.55	2.41	-8.11	I
t318 - 2	30.11	6.42	14.52	32.38	-30.44	0.99	-10.98	
t318 - 3	57.48	10.40	28.23	6.45	-3.07	4.97	2.73	
t318 - 4	55.55	11.47	31.33	9.78	-5.00	6.04	5.83	
t318 - 5	32.46	5.73	13.38	30.60	-28.09	0.30	-12.12	
t318 - 1	33.10	7.87	17.36	28.74	-27.45	2.44	-8.14	II
t318 - 2	30.39	6.48	14.54	32.11	-30.17	1.05	-10.96	
t318 - 3	57.59	10.28	27.87	6.16	-2.97	4.85	2.37	
t318 - 4	55.65	11.42	31.07	9.54	-4.91	5.99	5.58	
t318 - 5	32.50	5.73	13.40	30.56	-28.06	0.30	-12.10	
t318 - 1	33.12	7.92	17.48	28.70	-27.44	2.49	-8.02	III
t318 - 2	29.45	6.76	15.66	32.65	-31.11	1.33	-9.84	
t318 - 3	57.73	10.25	27.99	6.11	-2.83	4.82	2.49	
t318 - 4	56.06	11.31	30.55	8.96	-4.49	5.88	5.06	
t318 - 5	33.11	5.60	12.89	30.20	-27.44	0.17	-12.61	

Lignoformes

Couche t318 - 5

- Texture
 - Aspect : micro-grumeleux
 - Cohésion : 0.5/3
 - Macro : 2.5 %
 - Méso : 47.5 %
 - Micro : 50 %
- Structure
 - Limono-sableux
- Code Munsell (hue, value, chroma)
 - 7.5YR 3/4
- HCl
 - 0/4
- Éléments grossiers
 - Total : 4 %
 - 2 – 20 mm : 62.5 %
 - 20 – 50 mm : 37.5 %
 - Dureté : 1/2
 - Sphéricité : 0/2
 - Angulosité : 2.5/3
- Porosité
 - Abondance : 1.5/4
 - Orientation : horizontale à oblique
 - Diamètre médian : 1.5 mm
- Propriétés physiques
 - Adhésivité : 0.5/3
 - Compacité : 1/3
 - Plasticité : 1/3

Lignoformes

Tronc : t319

Coordonnées GPS	46°21.651' +/- 5 m 10°53.365
Pente [°]	34
Exposition de la pente [°N]	10.5
Exposition du tronc [°N]	10.5
Espèce	<i>Picea abies</i>
Raison de la chute	coupe
Longueur totale [cm]	221
Diamètre [cm]	21
Classe de décomposition générale	4
Végétation herbacée à proximité	<i>Abies alba</i>
Recouvrement arborescent (%)	70-80 (75 % <i>Abies alba</i> , 25 % <i>Larix decidua</i>)

Lignoformes



Lignoformes



Lignoformes

t319 - 1



t319 - 4



t319 - 2



t319 - 5



t319 - 3



t319 - 6



Lignoformes

couche	épaisseur [mm]	pH H ₂ O	C	H	N	Indice pyrophosphate
t319 - 1	5	3.58	48.828	5.839	0.000	0.039
t319 - 2	41	3.97	53.153	5.691	0.000	0.064
t319 - 3	68	4.21	55.114	5.850	0.000	0.094
t319 - 4	73.5	4.13	51.747	5.628	0.000	0.082
t319 - 5	30	4.31	33.853	3.881	0.480	0.111
t319 - 6	53	4.86	11.709	1.829	0.430	0.074

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE*	ΔL*	Δa*	Δb*	réplicat
t319 - 1	51.15	9.60	25.67	10.29	-9.41	4.17	0.17	I
t319 - 2	47.71	13.90	28.89	15.75	-12.84	8.47	3.39	
t319 - 3	40.29	15.24	29.91	22.94	-20.26	9.81	4.41	
t319 - 4	45.28	12.72	26.84	16.98	-15.28	7.29	1.34	
t319 - 5	38.18	7.98	19.13	23.41	-22.38	2.55	-6.37	
t319 - 6	43.14	4.90	14.09	20.83	-17.42	-0.53	-11.41	
t319 - 1	51.70	9.44	25.22	9.73	-8.86	4.01	-0.28	II
t319 - 2	47.73	13.86	28.80	15.70	-12.83	8.43	3.30	
t319 - 3	40.59	15.16	29.59	22.58	-19.96	9.73	4.09	
t319 - 4	44.95	12.85	27.12	17.36	-15.61	7.42	1.62	
t319 - 5	38.02	8.00	19.23	23.53	-22.53	2.57	-6.27	
t319 - 6	42.79	4.97	14.54	20.88	-17.77	-0.46	-10.96	
t319 - 1	51.62	9.46	25.38	9.80	-8.93	4.03	-0.12	III
t319 - 2	47.40	13.95	29.10	16.08	-13.15	8.52	3.60	
t319 - 3	40.48	15.18	29.92	22.75	-20.07	9.75	4.42	
t319 - 4	44.85	12.91	27.46	17.51	-15.71	7.48	1.96	
t319 - 5	37.65	8.14	19.59	23.81	-22.90	2.71	-5.91	
t319 - 6	44.28	4.73	13.45	20.27	-16.28	-0.70	-12.05	

Lignoformes

Couche t319 - 6

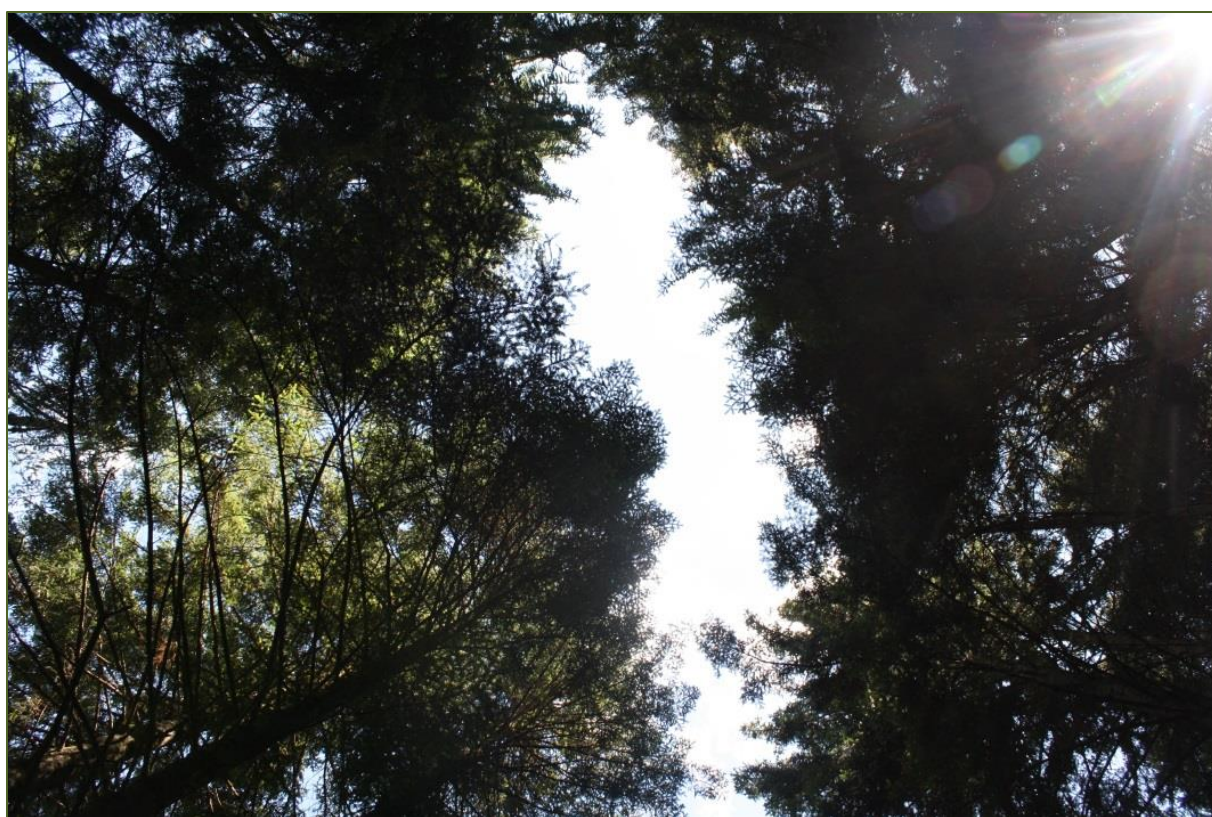
- Texture
 - Aspect : grumeleux à subpolyédrique
 - Cohésion : 1/3
 - Macro : 10 %
 - Méso : 40 %
 - Micro : 50 %
- Structure
 - Limono-sableux
- Code Munsell (hue, value, chroma)
 - 7.5YR 5.5/4
- HCl
 - 0/4
- Éléments grossiers
 - Total : 15.5 %
 - 2 – 20 mm : 55 %
 - 20 – 50 mm : 16 %
 - 50 – 200 mm : 29 %
 - Dureté : 1/2
 - Sphéricité : 0/2
 - Angulosité : 2.5/3
- Racines
 - Abondance
 - 0 – 2 mm : 2/5
 - 2 – 5 mm : 1/5
 - > 5 mm : 1/5
 - Distribution
 - 0 – 2 mm : régulière
 - 2 – 5 mm : régulière
 - > 5 mm : irrégulière
 - Orientation
 - 0 – 2 mm : oblique à verticale
 - 2 – 5 mm : horizontale à oblique
 - > 5 mm : horizontale
- Porosité
 - Abondance : 2/4
 - Orientation : horizontale à oblique
 - Diamètre médian : 1.5 mm
- Propriétés physiques
 - Adhésivité : 0/3
 - Compacité : 1/3
 - Plasticité : 0/3

Lignoformes

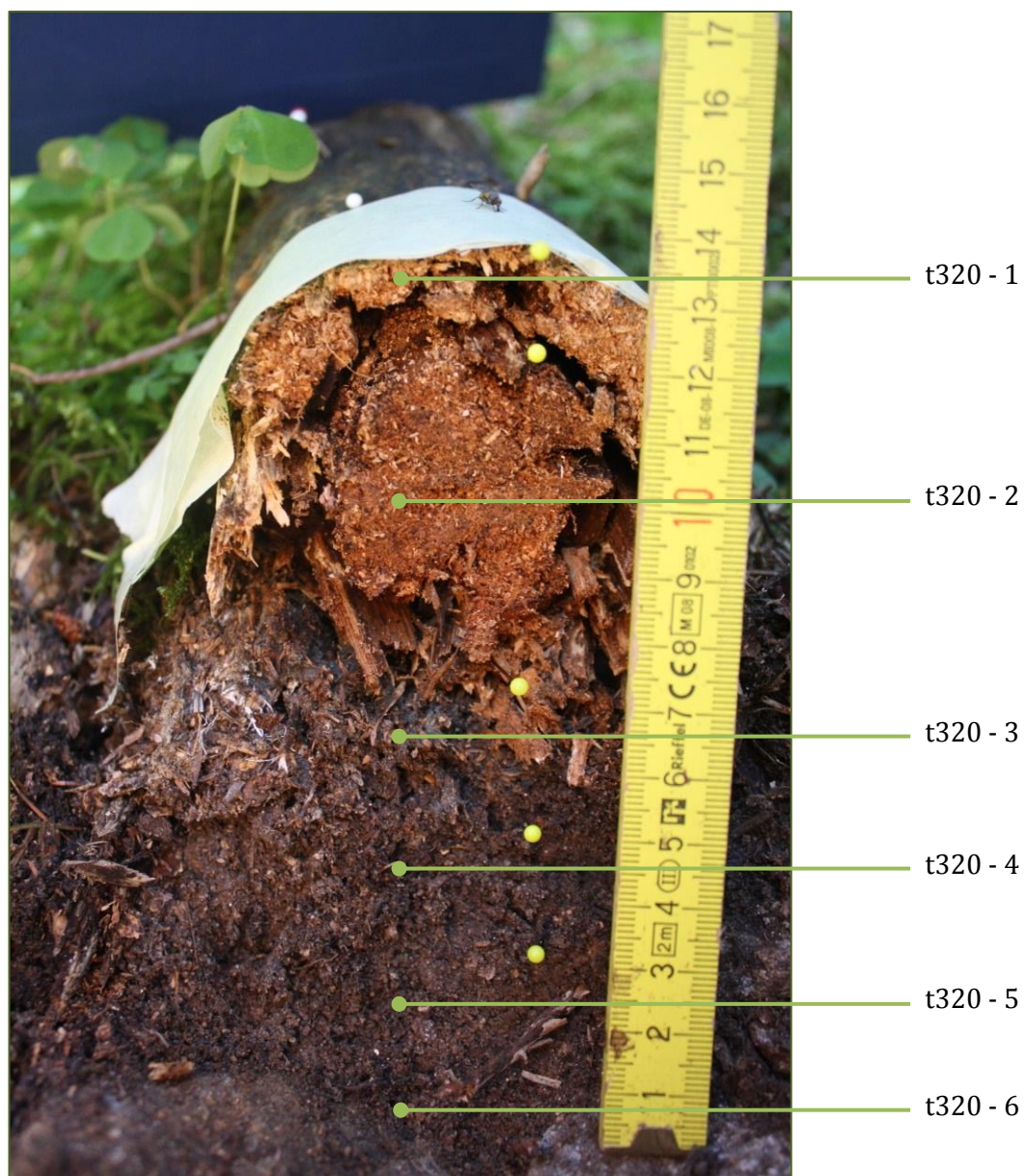
Tronc : t320

Coordonnées GPS	46°21.652 +/- 5 m 10°53.341
Pente [°]	29
Exposition de la pente [°N]	335
Exposition du tronc [°N]	335
Espèce	<i>Picea abies</i>
Raison de la chute	coupe
Longueur totale [cm]	68
Diamètre [cm]	10
Classe de décomposition générale	4
Végétation herbacée à proximité	<i>Oxalis acetosella</i> , <i>Hieracium murorum</i> , <i>Festuca altissima</i> , <i>Luzula nivea</i> , <i>Veronica urticifolia</i> , <i>Abies alba</i> , <i>Mycelis muralis</i>
Recouvrement arborescent (%)	80-90

Lignoformes



Lignoformes



Lignoformes

t320 - 1



t320 - 4



t320 - 2



t320 - 5



t320 - 3



t320 - 6



Lignoformes

couche	épaisseur [mm]	pH H ₂ O	C	H	N	Indice pyrophosphate
t320 - 1	15	3.81	47.980	6.098	0.266	0.028
t320 - 2	50	3.93	55.460	5.613	0.000	0.108
t320 - 3	23	4.39	43.776	4.978	0.968	0.085
t320 - 4	19	4.58	23.250	2.884	0.746	0.121
t320 - 5	7	4.88	16.707	2.286	0.616	0.094
t320 - 6	NA	4.89	10.967	1.731	0.516	0.100

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE*	ΔL*	Δa*	Δb*	réplicat
t320 - 1	50.55	9.29	25.77	10.73	-10.00	3.86	0.27	I
t320 - 2	43.77	13.70	27.09	18.78	-16.79	8.27	1.59	
t320 - 3	42.22	4.47	10.36	23.80	-18.34	-0.96	-15.14	
t320 - 4	30.26	4.99	12.06	33.14	-30.29	-0.44	-13.44	
t320 - 5	28.85	5.04	11.20	34.78	-31.70	-0.39	-14.29	
t320 - 6	35.15	5.31	12.99	28.32	-25.40	-0.12	-12.51	
t320 - 1	50.48	9.26	25.74	10.78	-10.08	3.83	0.24	II
t320 - 2	43.76	13.68	26.94	18.77	-16.80	8.25	1.44	
t320 - 3	42.35	4.45	10.22	23.79	-18.21	-0.98	-15.28	
t320 - 4	30.39	4.95	11.88	33.10	-30.17	-0.48	-13.62	
t320 - 5	28.94	4.99	11.01	34.78	-31.61	-0.44	-14.49	
t320 - 6	35.36	5.28	12.85	28.20	-25.20	-0.15	-12.65	
t320 - 1	50.59	9.24	25.69	10.67	-9.96	3.81	0.20	III
t320 - 2	43.93	13.58	26.80	18.56	-16.63	8.15	1.30	
t320 - 3	42.16	4.48	10.34	23.86	-18.40	-0.95	-15.16	
t320 - 4	30.11	5.03	12.20	33.23	-30.44	-0.40	-13.30	
t320 - 5	28.71	5.05	11.30	34.88	-31.85	-0.38	-14.20	
t320 - 6	35.58	5.25	12.82	28.01	-24.98	-0.18	-12.68	

Lignoformes

Couche t320 - 6

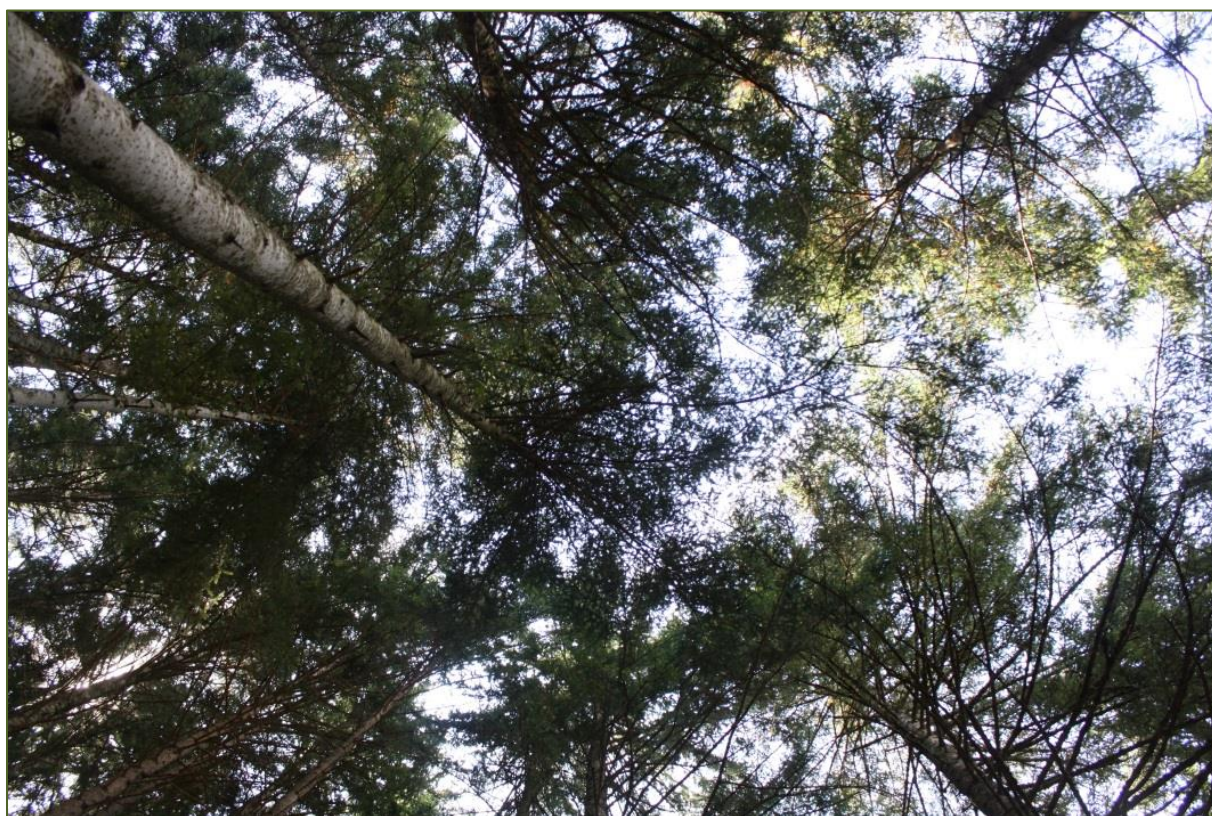
- Texture
 - Aspect : grumeleux fin
 - Cohésion : 1/3
 - Macro : 0 %
 - Méso : 50 %
 - Micro : 50 %
- Structure
 - Limono-sableux
- Code Munsell (hue, value, chroma)
 - 7.5YR 3/2
- HCl
 - 0/4
- Éléments grossiers
 - Total : 40.5 %
 - 2 – 20 mm : 18.5 %
 - 20 – 50 mm : 18.5 %
 - 50 – 200 mm : 63 %
 - Dureté : 1/2
 - Sphéricité : 0/2
 - Angulosité : 2.5/3
- Racines
 - Abondance
 - 0 – 2 mm : 2/5
 - 2 – 5 mm : 1/5
 - > 5 mm : 0/5
 - Distribution
 - 0 – 2 mm : régulière
 - 2 – 5 mm : irrégulière
 - Orientation
 - 0 – 2 mm : horizontal à oblique
 - 2 – 5 mm : horizontale à oblique
- Porosité
 - Abondance : 2/4
 - Orientation : horizontale à oblique
 - Diamètre médian : ≤ 1 mm
- Propriétés physiques
 - Adhésivité : 0/3
 - Compacité : 1/3
 - Plasticité : 0/3

Lignoformes

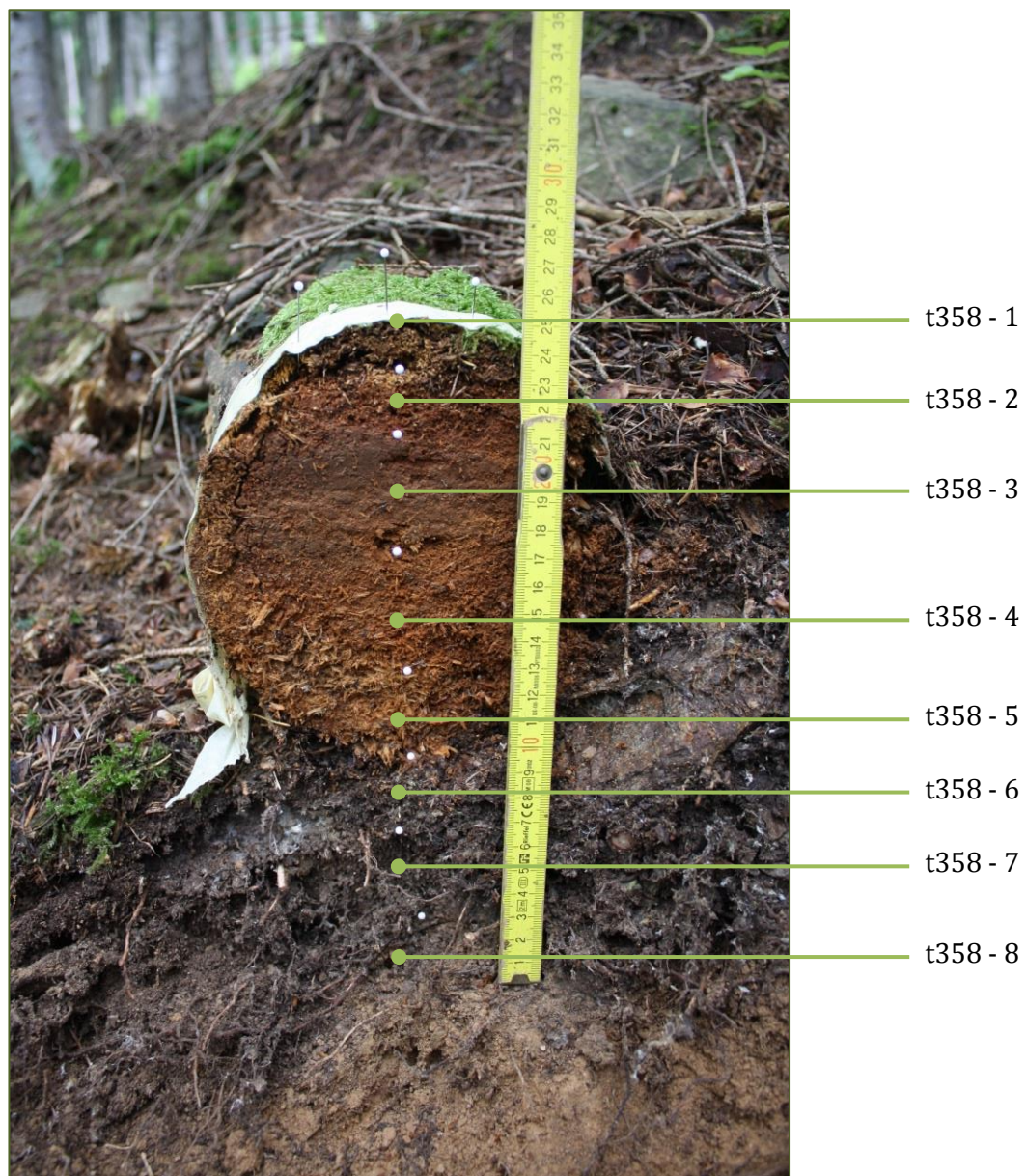
Tronc : t358

Espèce	<i>Picea abies</i>
Raison de la chute	naturelle
Longueur totale [cm]	535 cm
Diamètre [cm]	14-17
Classe de décomposition générale	4
Végétation herbacée à proximité	<i>Picea abies</i> , <i>Abies alba</i>
Recouvrement arborescent (%)	62.5 (90 % <i>Abies alba</i> , 10 % <i>Picea abies</i>)

Lignoformes



Lignoformes



Lignoformes

t358 - 1



t358 - 5



t358 - 2



t358 - 6



t358 - 3



t358 - 7



t358 - 4



t358 - 8



Lignoformes

couche	épaisseur [mm]	pH H ₂ O	C	H	N	Indice pyrophosphate
t358 - 1	20	4.06	NA	NA	NA	0.051
t358 - 2	25	4.05	NA	NA	NA	0.076
t358 - 3	45	3.97	NA	NA	NA	0.044
t358 - 4	45	3.65	NA	NA	NA	0.045
t358 - 5	40	3.83	NA	NA	NA	0.049
t358 - 6	30	4.96	NA	NA	NA	0.076
t358 - 7	40	5.22	NA	NA	NA	0.080
t358 - 8	NA	4.75	NA	NA	NA	0.081

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE*	ΔL*	Δa*	Δb*	réplicat
t358 - 1	42.24	7.71	20.71	19.06	-18.31	2.28	-4.78	I
t358 - 2	41.72	11.86	25.25	-19.90	-18.84	6.43	-0.25	
t358 - 3	47.61	12.52	27.14	14.85	-12.95	7.09	1.64	
t358 - 4	48.84	12.54	28.81	14.11	-11.73	7.11	3.31	
t358 - 5	48.93	12.23	28.38	13.77	-11.63	6.80	2.88	
t358 - 6	37.14	6.41	15.57	25.46	-23.42	0.98	-9.93	
t358 - 7	36.95	5.08	13.03	26.70	-23.61	-0.36	-12.47	
t358 - 8	55.21	8.01	22.74	6.55	-5.35	2.58	-2.76	
t358 - 1	42.34	7.64	20.52	19.02	-18.22	2.21	-4.97	II
t358 - 2	41.64	11.91	25.39	19.99	-18.91	6.48	-0.11	
t358 - 3	47.65	12.35	26.65	14.69	-12.90	6.92	1.15	
t358 - 4	48.90	12.49	28.70	14.00	-11.66	7.06	3.20	
t358 - 5	48.86	12.25	28.37	13.84	-11.70	6.82	2.87	
t358 - 6	37.11	6.38	15.52	25.50	-23.45	0.95	-9.98	
t358 - 7	36.81	5.10	13.11	26.78	-23.74	-0.33	-12.39	
t358 - 8	55.35	8.01	22.80	6.40	-5.21	2.58	-2.70	
t358 - 1	42.39	7.64	20.46	18.98	-18.17	2.21	-5.04	III
t358 - 2	41.69	11.87	25.38	19.93	-18.86	6.44	-0.12	
t358 - 3	47.41	12.40	26.95	14.94	-13.14	6.97	1.45	
t358 - 4	48.77	12.46	28.68	14.09	-11.79	7.02	3.18	
t358 - 5	48.80	12.24	28.45	13.90	-11.76	6.81	2.95	
t358 - 6	37.39	6.28	15.26	25.35	-23.17	0.85	-10.24	
t358 - 7	36.83	5.07	13.11	26.77	-23.77	-0.36	-12.39	
t358 - 8	55.36	8.00	22.79	6.39	-5.19	2.56	-2.71	

Lignoformes

Couche t358- 7

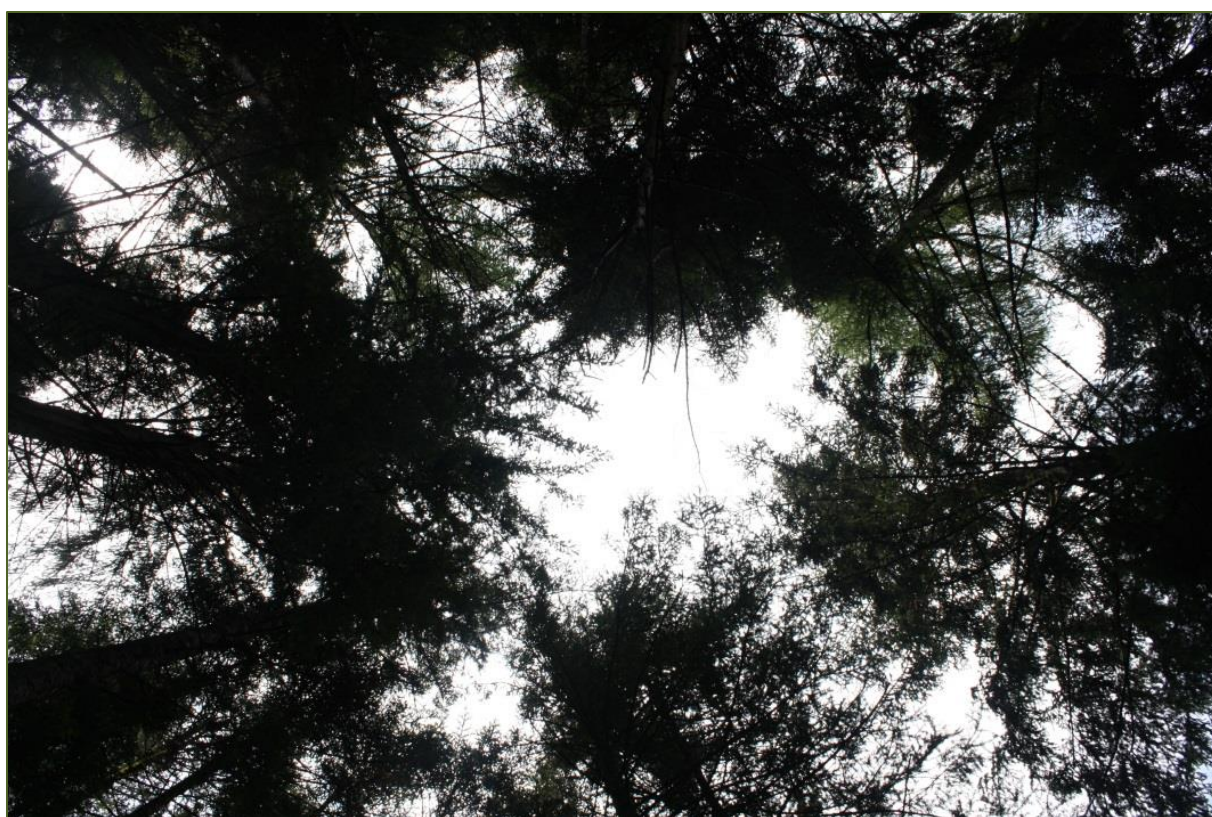
- Texture
 - Aspect : grumeleux à subpolyédrique
 - Cohésion : 1/3
 - Macro : 10 %
 - Méso : 70 %
 - Micro : 20 %
- Structure
 - Limoneux avec sables
- HCl
 - 0/4
- Éléments grossiers
 - Total : 10 %
 - 2 – 20 mm : 20 %
 - 20 – 50 mm : 10 %
 - 50 – 200 mm : 30 %
 - > 200 mm : 40 %
 - Dureté : 0.5/2
 - Sphéricité : 0.5/2
 - Angulosité : 0.5/3
- Racines
 - Abondance
 - 0 – 2 mm : 4/5
 - 2 – 5 mm : 2/5
 - > 5 mm : 1/5
 - Distribution
 - 0 – 2 mm : régulière
 - 2 – 5 mm : irrégulière
 - > 5 mm : irrégulière
 - Orientation
 - 0 – 2 mm : horizontale à oblique
 - 2 – 5 mm : horizontale à oblique
 - > 5 mm : horizontale
- Porosité
 - Abondance : 3/4
 - Orientation : horizontale à oblique
 - Diamètre médian : 1.5 mm
- Propriétés physiques
 - Adhésivité : 0/3
 - Compacité : 1/3
 - Plasticité : 0/3

Lignoformes

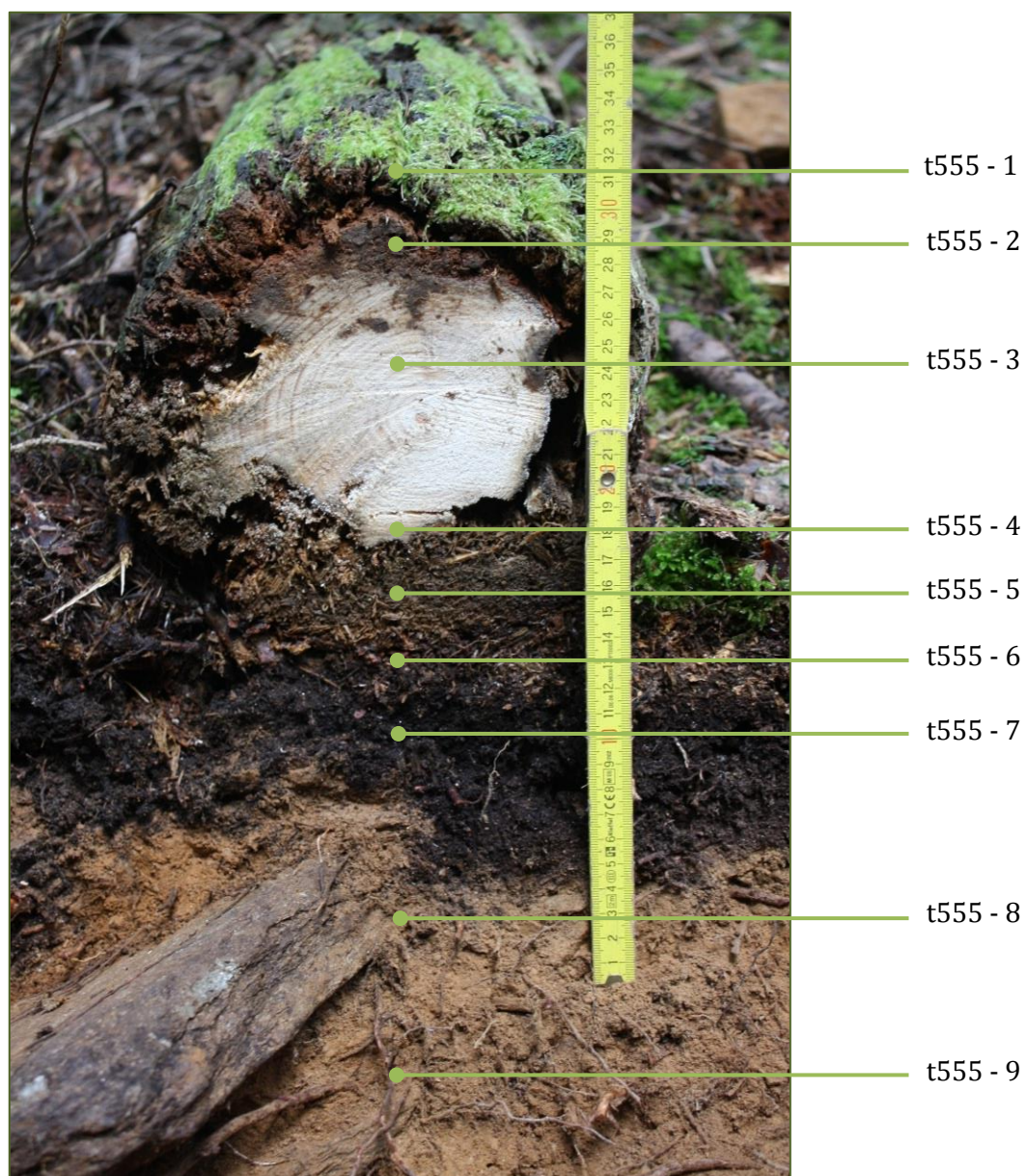
Tronc : t555

Coordonnées GPS	46°21.645' +/- 7 m 10°53.344'
Pente [°]	37.5
Exposition de la pente [°N]	358
Exposition du tronc [°N]	20
Espèce	<i>Picea abies</i>
Raison de la chute	coupe
Longueur totale [cm]	380
Diamètre [cm]	18-23
Classe de décomposition générale	4
Végétation herbacée à proximité	<i>Abies albs</i> , <i>Larix decidua</i>
Recouvrement arborescent (%)	47.5 (47.5 % <i>Picea abies</i> , 47.5 % <i>Abies alba</i> , 5 % <i>Larix decidua</i>)

Lignoformes



Lignoformes



Lignoformes

t555 - 1



t555 - 4



t555 - 2



t555 - 5



t555 - 3



t555 - 6



t555 - 7



t555 - 8



t555 - 9



Lignoformes

couche	épaisseur [mm]	pH H ₂ O	C	H	N	Indice pyrophosphate
t555 - 1	20	4.15	50.38	NA	0.50	0.047
t555 - 2	20	4.04	53.19	NA	0.25	0.054
t555 - 3	105	4.25	49.14	NA	0.07	0.012
t555 - 4	45	4.04	50.74	NA	0.40	0.046
t555 - 5	40	4.32	47.62	NA	0.74	0.101
t555 - 6	20	5.02	44.71	NA	1.46	0.122
t555 - 7	75	4.93	33.96	NA	1.45	0.175
t555 - 8	75	4.50	5.37	NA	0.24	0.153
t555 - 9	NA	4.72	1.90	NA	0.10	0.024

Colorimétrie CIELab								
couche	L*	a*	b*	ΔE*	ΔL*	Δa*	Δb*	réplicat
t555 - 1	46.29	7.78	21.92	14.90	-14.27	2.35	-3.38	I
t555 - 2	43.97	10.96	25.20	17.48	-16.59	5.53	-0.30	
t555 - 3	69.83	3.61	19.90	10.98	9.27	-1.82	-5.60	
t555 - 4	45.52	7.66	22.23	15.54	-15.03	2.22	-3.27	
t555 - 5	33.57	8.87	17.89	28.25	-26.99	3.44	-7.61	
t555 - 6	31.26	6.54	15.74	30.90	-29.30	1.11	-9.76	
t555 - 7	30.21	5.46	13.10	32.78	-30.35	0.03	-12.40	
t555 - 8	50.63	7.98	21.92	10.86	-9.93	2.55	-3.58	
t555 - 9	55.50	9.38	27.05	6.60	-5.05	3.95	-1.55	
t555 - 1	46.24	7.78	21.93	14.94	-14.32	2.35	-3.57	II
t555 - 2	44.24	10.89	24.92	17.22	-16.32	5.46	-0.58	
t555 - 3	69.88	3.59	19.86	11.05	9.32	-1.84	-5.64	
t555 - 4	45.56	7.66	22.22	15.51	-14.99	2.23	-3.28	
t555 - 5	33.53	8.86	17.87	28.29	-27.03	3.43	-7.63	
t555 - 6	31.35	6.50	15.69	30.83	-29.21	1.07	-9.81	
t555 - 7	30.11	5.50	13.21	32.83	-30.45	0.07	-12.29	
t555 - 8	50.72	7.95	21.83	10.80	-9.83	2.52	-3.67	
t555 - 9	55.63	9.36	27.00	6.48	-4.93	3.93	1.50	
t555 - 1	46.20	7.77	21.98	14.96	-14.35	2.33	-3.52	III
t555 - 2	43.87	10.93	25.10	17.57	-16.68	5.50	-0.40	
t555 - 3	69.95	3.55	19.70	11.20	9.40	-1.88	-5.80	
t555 - 4	45.53	7.65	22.17	15.55	-15.02	2.22	-3.33	
t555 - 5	33.64	8.84	17.77	28.21	-26.92	3.41	-7.73	
t555 - 6	31.32	6.51	15.71	30.85	-29.23	1.07	-9.79	
t555 - 7	30.01	5.53	13.38	32.86	-30.55	0.10	-12.12	
t555 - 8	50.67	7.95	21.84	10.83	-9.88	2.52	-3.66	
t555 - 9	55.69	9.34	26.97	6.41	-4.87	3.91	1.47	

Lignoformes

Couche t555-8

- Texture
 - Aspect : micro-grumeleux à subpolyédrique
 - Cohésion : 0/3
 - Macro : 20 %
 - Méso : 50 %
 - Micro : 30 %
- Structure
 - Limoneux avec des sables
- HCl
 - 0/4
- Éléments grossiers
 - Total : 7.5 %
 - 2 – 20 mm : 80 %
 - 20 – 50 mm : 15 %
 - 50 – 200 mm : 5 %
 - > 200 mm : quelques-uns présents
 - Dureté : 0.5/2
 - Sphéricité : 0/2
 - Angulosité : 0.5/3
 - Altération : 1/3
- Racines
 - Abondance
 - 0 – 2 mm : 3/5
 - 2 – 5 mm : 2/5
 - > 5 mm : 2/5
 - Distribution
 - 0 – 2 mm : régulière
 - 2 – 5 mm : régulière
 - > 5 mm : régulière
 - Orientation
 - 0 – 2 mm : horizontale à oblique
 - 2 – 5 mm : horizontale à oblique
 - > 5 mm : horizontale à oblique
- Porosité
 - Abondance : 2/4
 - Orientation : horizontale à oblique
- Propriétés physiques
 - Adhésivité : 0/3
 - Compacité : 0/3
 - Plasticité : 0/3

B. PUBLICATIONS ANNEXES

Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil

DICHOTOMOUS FIELD KEYS FOR HUMUS FORMS IDENTIFICATION

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SUMMARY

This chapter aims at providing useful tools for humus forms identification at the field scale. Practical aspects are addressed from toolkits to field sheets and dichotomous keys. Impediments at the field scale are highlighted considering among others the heterogeneity of the study plot, seasonality as well as the pH threshold. Moreover, a section is dedicated to the differentiation between PARAHUMUS and TERROFORMS; several ecosystems are taken as examples such as floodplains, alpine grasslands and peatlands. The case of ecotones is also discussed by the way of research gradients taking into account slope, exposure and hydromorphy. In order to improve the current keys, proposals are made regarding new prefixes for PARAFORMS, ANTHROPOFORMS, HYDROFORMS and HISTOFORMS.

RÉSUMÉ

Ce chapitre a pour objectif de fournir des outils utiles à l'identification des formes d'humus sur le terrain. Les aspects pratiques sont abordés depuis des boîtes à outils jusqu'à des fiches de descriptions et des clés de détermination. Les problèmes rencontrés sur le terrain sont également évoqués tels que l'hétérogénéité spatiale, la saisonnalité ou encore le pH. De plus, une section est dédiée à la différenciation entre les PARAHUMUS et les TERROFORMES ; plusieurs écosystèmes sont pris en exemple tels que les zones alluviales, les pelouses alpines ou encore les tourbières. Le cas des écotones est aussi discuté par le biais de gradients prenant en compte la pente, l'exposition et l'hydromorphy. Afin d'améliorer les clés d'identification actuelles, des propositions sont faites notamment sur de nouveaux préfixes pour les PARAFORMES, ANTHROPOFORMES, HYROFORMES et HISTOFORMES.

PART SEVEN: SPECIAL REPORTS - IN-DEPTH SPECIFIC STUDIES

Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil

1. A USEFUL TOOL AT THE FIELD SCALE

Humus forms are indicators of ecosystem functioning. Therefore, a fundamental first approach when aiming at describing humus forms is to take into account the ecosystem context and the ecological conditions of the sampling stations. The humus forms are at the core of the energy flows and the nutrient storage and fluxes, especially regarding C and N due to organic matter recycling. Being at the close interface between vegetation and mineral soil layers, the humipedon then offers its own spatio-temporal scale functions. As a consequence, a morpho-functional classification of humus forms implies being able to understand not only how litterfall decomposes, how bedrock alters and how pedogenesis processes occur, but to integrate both the humipedon and the overall ecosystem functioning at a small and wide spatio-temporal scales, respectively.

In concrete terms in the field, the choice of study plots and the level of precision largely both depend on the research question that has been raised (see practical aspects below). Moreover, identifying humipedon boundaries for an inexperienced person may be a challenge, humus forms being at the close interface of soil and vegetation. A minimum is indeed required about the knowledge of basics in pedology and the recognition of soil horizons, most of them having the same names in both classifications. Then, the nature and successive hierarchical position of soil layers in the humipedon allow giving a name at the humus form as for soils by the way of an identification key (see Part Two of the present book). Using dichotomous keys of humus forms is hence essential to have a quick and efficient overview of the humus forms observed at the field scale. Easy to use, the sequence and structure of identification steps help to identify humus forms using several basic criteria that are i) usable directly in the field and ii) accessible to a broad audience.

2. PRACTICAL ASPECTS

Depending on the goal of the research and the main question raised, several approaches may be conducted to study humus forms: preferential or stratified sampling (random or systematic using transects) are the most common. Whatever the sampling method chosen, the general procedure is quite the same at the humipedon level. Statistical analyses will also depend on what you aim to compare for instance in terms of humus forms groups (cladistic analyses), or relationships with environmental variables (multivariate analyses).

2.1 MATERIAL SET

- A shovel allows digging a cubic pit in the soil of at least 30 cm width x 30 cm length x variable depth, depending on the context. A bread knife is particularly relevant for HISTOFORMS AND PARAFORMS, especially RHIZOFORMS, while a saw is essential for LIGNOFORMS (see Part Four of the present book).
- A linear meter to measure the thickness of soil horizons and to put the humipedon to scale when taking a photo.
- Two sieves of 4 mm and 1 mm mesh respectively help to focus thoroughly on soil aggregates in the organo-mineral layer(s), and thus to discriminate maA (> 4 mm), meA (< 4 mm and > 1 mm) and miA (< 1 mm).
- A Munsell soil color chart to evaluate and classify the color of soil samples

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil

- A dropper containing HCl 6N allows detecting the presence of carbonates.
- Portable pH-meter probe, or at least pH-meter Hellige, may be useful to measure water pH.
- The von Post scale of humification is required to distinguish between HF, HM and HS layers.
- Sampling material (bags, tubes, alcohol...etc.), notebook, camera, GPS, etc., are useful.

2.2 PROCEDURE

- Site conditions are observed and written down as precisely as possible (date, elevation, weather, exposure, slope, GPS coordinates, small drawing of the situation, vegetation type, soil type, etc.).
- A hole is dug and, if possible, the humipedon sample is carefully extracted and deposited onto the soil surface (or on a canvas sheet, in plastic gutters or plates, etc.) nearby the hole. Caution must be taken not to stamp around the hole, especially above the side that will be studied, in order to preserve the soil layers entirely (thickness, composition, etc.).
- Before any manipulation, a photo is taken to scale with a tape measure. Then, each layer is rigorously identified and assigned to a diagnostic horizon using the appropriate tools and the most relevant dichotomous key (PARAHUMUS; TERROFORMS, HYDROFORMS; EPIHISTOFORMS, HISTOFORMS).
- A field descriptive form is commonly used to have a clear and accurate tool for description in the field. This form summarizes the criteria in a very simple way and allows a quick overview of the different humus forms identified over field campaign. An example is provided in Figure 13 (Tatti, 2016, pers. com).
- If samples are collected for further soil analyses, one should take them from the bottom to the top of the humipedon sample to prevent any contamination in-between layers. For the small volume method (Ponge, 1984), a special procedure is recommended.
- The hole should then be re-filled in order to avoid any injured person and/or animal as well as to preserve nature. As possible, the original soil layers organization should be respected.

3. IMPEDIMENTS AT THE FIELD SCALE

If the previous procedure seems to be more or less easy to understand and use, several problems may occur in the field. Focusing on specific cases encountered in the field, several highlights may be also pointed out as problematic situations. The list below, although not exhaustive, summarizes several years of research and teaching activities performed by a team of students and teachers.

3.1 HETEROGENEITY VERSUS HOMOGENEITY OF THE STATION

Studying humus forms requires tackling the problem of spatial scales. At the ecosystem level (i.e. forests, grasslands, floodplains, etc.), the question may be to identify where the study will take place, which areas will be selected (Figures 1 and 2). Of course, this choice will strongly be related to the questions and hypotheses raised, however plant communities, soil types and even transitional areas such as ecotones and biological corridors may be relevant aspects to consider. Moreover, when the sampling area is finally selected, the small-scale heterogeneity may also lead to new questions. In this case, local micro-

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil topography influences floristic variations and ecological succession, as well as soil characteristics and pedogenetic processes directly linked to ecosystem engineers (earthworms, ants, termites, etc.) bioturbation activities. As a consequence, regarding the heterogeneity encountered at the field scale, all is usually done to avoid any special case. This is true in all ecological studies but very especially for humus forms and most of the time, wood trunks, cavities or humps, thick layers of mosses, etc. are left out.



Figure 1. Variation of the microtopography highlighting the difficulty to select the sampling area for humus forms (Anniviers, VS; CH). © Magali Matteodo.

PART SEVEN: SPECIAL REPORTS - IN-DEPTH SPECIFIC STUDIES

Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil



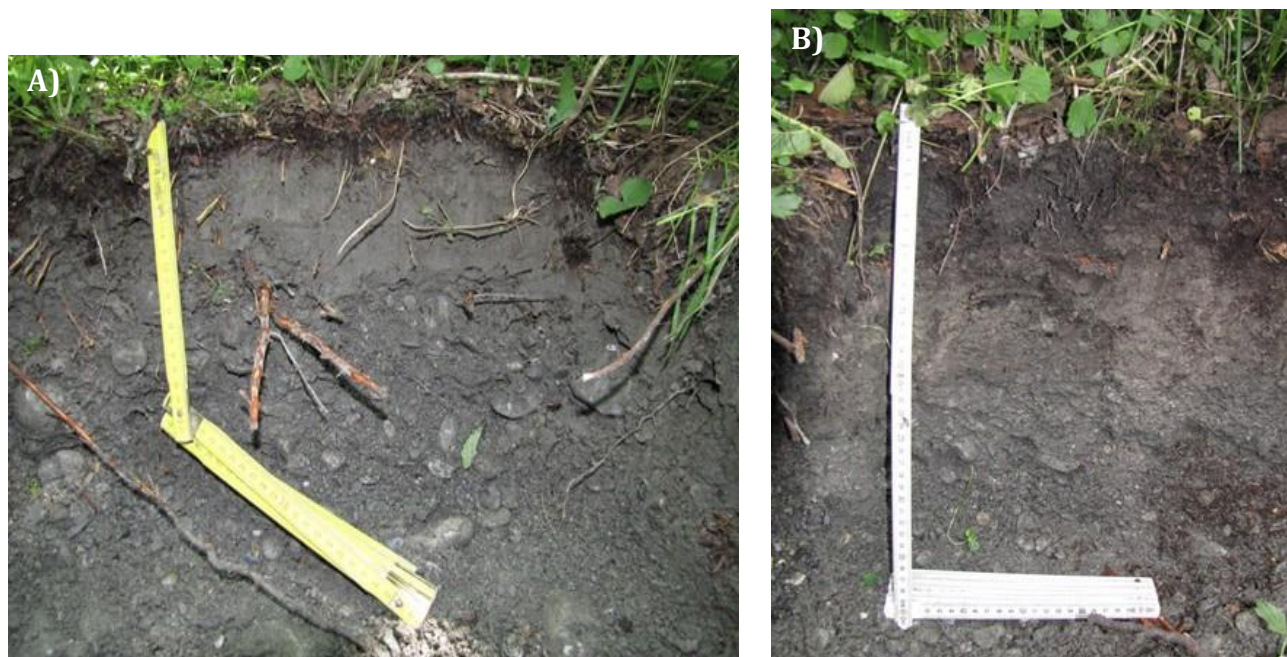
Figures 2A, B, C and D: local micro-topography variations in floodplains and consequences on humus forms (Gasterntal, BE; CH). A) Sand deposits (20 to 30 cm) after a flood event. B) Local deposits of gravels, sand, silt and organic matter. C) and D) soil profiles strongly linked to sediment accretion and organic matter supply. © Alessandro Staehli, Claire Le Bayon.

3.2 SEASONALITY

Temporal variations over the year play also a crucial part in taxonomic classification of humus forms. Topsoil organic layers are made of remnants of plants and decomposing litter (leaves, roots, branches, etc.) that strongly depend on seasonality. In forests, the temporal dynamics of litter inputs play an important role in humipedon functioning because they determine the temporal variation in the supply of organic matter to the system. Litterfall quantity, degradation stage and timing are thus essential in the humus forms identification and classification. Indeed, in a willow forest with high leaf palatability and strong biological activities, organic matter is rapidly decomposed and mixed with soil mineral matrix leading to the disappearance of surface litter in some weeks. As a consequence, a humus form in such context may be named MESOMULL just after a litterfall event but EUMULL several weeks later following bioturbation activities. Moreover, microbiological and faunal activities are also season-dependant mainly due to climate conditions, altitude, and biological clock of soil organisms as inactive periods or dormancy

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil needs, etc. Their impact on organic matter decomposition and integration into the soil matrix strongly depends on pedoclimatic conditions (Figure 4).



Figures 4A and B. Humus forms variations in an alder alluvial forest (Gasterntal, BE; CH). A) MESOMULL with a meA layer, B) MESOMULL with a maA layer. © Claire Le Bayon.

3.3 THE pH THRESHOLD

Regarding the taxonomic keys for TERROFORMS and HYDROFORMS, the water pH value is one of the most important criteria to progress over the identification steps. Field experience, especially studying alkaline soils containing high amounts of carbonates, reveals that pH measured directly in the field may sometimes not be a relevant parameter. In such context, water pH values are indeed often close to 5, freezing therefore the observer to go far deeper into the keys. In any case, a usual recommendation is to try the two ways offered by the key ($\text{pH} \geq 5$ or $\text{pH} < 5$ in most cases) and to choose the most appropriate one in the current ecosystem context. Further investigations at the laboratory, using suitable and accurate probes, may be useful to measure more precisely the pH value.

3.4. PARAHUMUS VERSUS TERROFORMS

In some cases, the distinction between PARAHUMUS and TERROFORMS is not so easy to the naked eye. Identifying the presence of an A functional layer is sometimes not so obvious and ambiguous situations are often encountered.

3.4.1 THE CASE OF ALLUVIAL ECOSYSTEMS

In floodplains, the predominance of sediment deposits varying from coarse sands to fine silts widely influence soil pedogenesis and particularly organic matter incorporation. Young and slightly evolved soils are commonly observed in alluvial context due to river dynamics and especially to flood events when sediment deposition and/or erosion occur. Most Fluvisols in the direct vicinity of the river show PARAHUMUS in the epipedon. However, moving away from the river bed, at the very beginning of organic

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil matter incorporation to mineral matrix, mainly due to ecosystem engineering, a “young” organo-mineral soil layer may appear: the Js layer, with few amounts of organic matter but still organo-mineral aggregates created by plants roots and earthworms (mainly pioneer species such as *Lumbricus rubellus*). Despite the fact that this topsoil layer is faintly developed and evolved, organic-mineral aggregates reflect bioturbation activities by earthworms and enmeshing through plant roots and fungal hyphae action (Figure 3). In this case, micro-, meso- and even macroaggregates are described and Js layer is then considered as a functional organo-mineral layer. As a consequence, the horizons sequence observed in the field leads to a humus form belonging to the TERROFORMS: [nOL]/Js or nOL/Js or in some cases nOL/[vOL]/Js. Thus, at the humus form scale, the functional horizon is the Js layer which contains less stable aggregates than an A, but functions as a “young” A layer. The possible substitution of A layers by Js layers in alluvial ecosystems highlights the necessity to enlarge the current taxonomic keys of humus forms, in order to take care of special cases working as intermediate stages between PARAHUMUS and TERROFORMS.



Figures 3A1, A2 and B. Soil biota activities are very strong in alluvial soils (Gasterntal and Sensee rivers, BE; CH). A1) and A2) at the beginning of soil aggregates formation, B) an earthworm burrow with linings covered by organic matter. © Claire Le Bayon.

Moreover, floodplain soils are usually characterized by stratification due to flood events and it is common to observe along the soil profile the presence of deep A layers. These buried A soil layers reflect previous stages of the Fluvisols with pedogenetic processes that may have been stopped by a flood event, i.e. the

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil deposition of new sediments. The question of the involvement and participation of these old-buried A to the global functioning of the soil may be raised: how these buried A layers, deep down (several ten cm or so) in the soil may be used as refuge for plant roots or endogeic earthworm when coarse sands deposits occur onto the soil surface? May they interfere with the current pedogenesis, serving as stimuli that enhance biological processes, especially as cores for soil macroaggregates formation? How taking into account these A layers in the humipedon identification? May paleo-humus forms exist as observed for paleosols? These questions are still unresolved and may improve the humus forms approach in alluvial ecosystems.

3.4.2 THE CASE OF ALPINE ECOSYSTEMS

Understanding humipedon functioning in alpine ecosystem is relatively new. Recent research projects try to focus on this tricky subject (Matteodo M., Tatti D., pers. com.). In alpine environment, litter deposits and OF layers are often discontinuous and limited to tussocks. This is particularly true regarding species from genera *Carex* (i.e. *C. sempervirens*) and *Festuca* (i.e. *F. ovina* aggr. and *F. rubra* aggr.) whose litter usually remains attached to the stem basis during many years and thus may form a very thick layer (Figure 5). Old leaves have to be considered as vOL even if they are not independent from the original plant. At the basis of the tuft, leaves are separated from the stem and start to be fragmented by soil macro- and micro- fauna thus progressively being incorporated to fine soil material (< 2 mm): this layer is then called OF. A part from the tussock, or between two tussocks, litter can be very sparse or even absent, highlighting the wide heterogeneity of organic matter supply at a small scale.

Moreover, the spatial distribution of tussocks does not only influence the presence and thickness of vOL and OF horizons, but also the whole humus form system. As regularly observed at the field scale, a kind of "rhizo" system occurs below the tussock, while a "terro" system exists otherwise. Root density is indeed usually very high in alpine environment and especially in the direct vicinity of grasses and sedges (Figure 6). In alpine grasslands, it's therefore probable to find rhizo-systems and terro-systems side by side forming a mosaic of humus forms or, at least, a rhizic layer nested in a terro-system when the volume of roots does not exceed 50% in the whole humipedon. In this context, plant roots are commonly considered as ecosystem engineers as they influence the soil structure and aggregates formation and stability. Nevertheless, different soil structures are associated with rhizic horizons in subalpine and alpine soils. Both micro- and meso-aggregates are often observed usually being texture-related. As a consequence, sandy layers in acidic soils are mainly composed of soil micro-aggregates while silty and loamy layers include most of the time meso-aggregates. Macro-aggregates are very rare at these elevations, but sometimes sub-polyedric aggregates are found around roots, especially in the presence of alternating periods of freeze-thaw and dry-wet conditions.

The size of soil aggregates in alpine soils is therefore highly variable and, contrary to expectations, meso-aggregates are found at both subalpine and alpine levels (between 1800 and 2500 m in the Alps; Matteodo M., unpublished data). Moreover, as directly observed in the field, A layers with micro-aggregates are often associated with very thin or discontinuous OF layers, but without any OH layer (Matteodo M., unpublished data). Consequently, identification of such humus forms appears very tricky using current taxonomic keys because this new result completely disagrees with the general view of alpine soils being mostly characterized by litter accumulation and humification processes resulting in MODER and MOR

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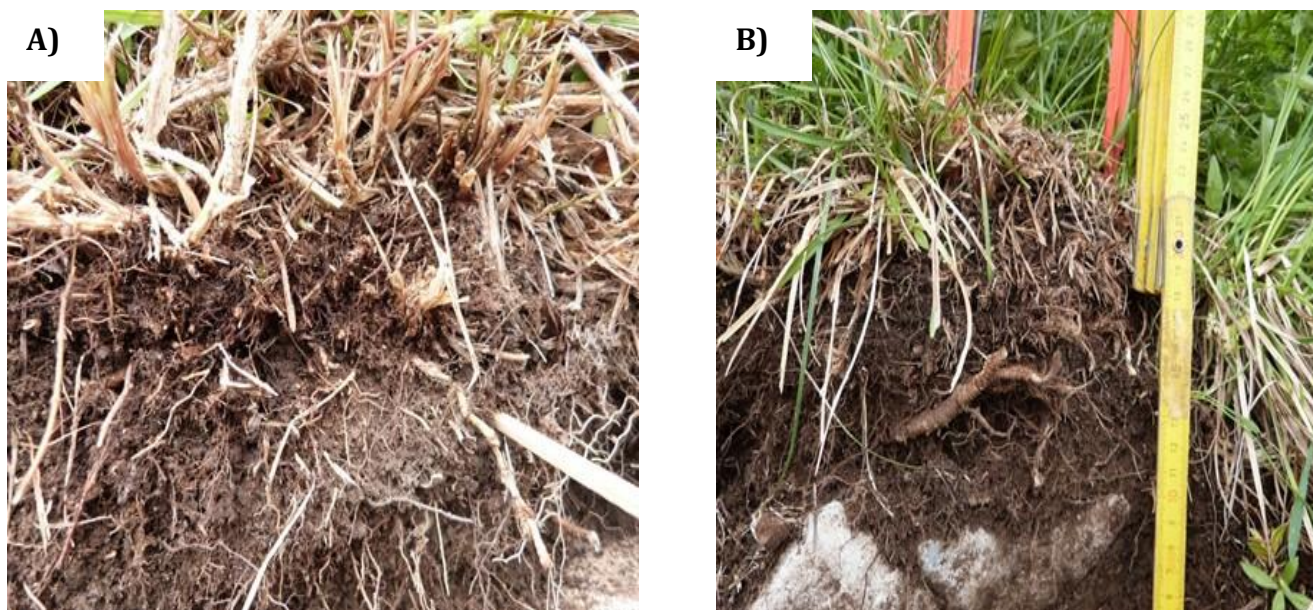
Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil humus forms. In such context, further researches are needed in order to determine if the layers sequence vOL/OF/miA indicates a MULL form (because of no OH layer) or a MODER form (because of the A layer structure). Focusing on organo-mineral layers, where cold and wet climate conditions occur at high altitude, organic matter tends to accumulate leading to the formation of humiferous A (Ah, Aho according to Baize & Girard, 2009). One of the most problems encountered is then to discriminate OH from A layers directly in the field; further soil analyses are then usually required regarding total organic carbon.



Figure 5. Turf of *Carex sempervirens* in a subalpine calcareous grassland. (Vallon des Morteys, FR ; CH). , 1710 m a.s.l. © Magali Matteodo.

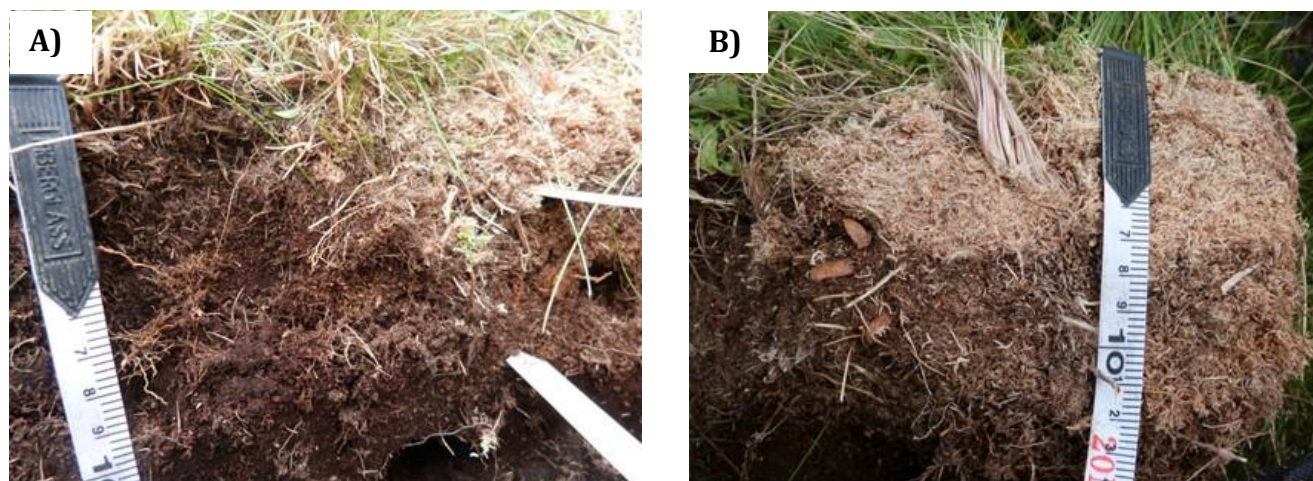
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Figures 6A and B. Rhizo-system in two subalpine calcareous grasslands (Vallon des Morteys, FR; CH). © Magali Matteodo.

Another distinctive feature of alpine humus forms is the presence of bryoic horizons (OM) that lie on A layers. Bryoic-systems are often juxtaposed to rhizo-systems (Figure 7) and the whole offers a mosaic relative to microtopography and tussocks distribution (see above). While mosses are known to be involved in temperature and humidity regulation, their functional role as ecosystem engineers in the humipedon genesis is still poorly understood in alpine ecosystems. So, further investigations are essential to better document their implication in humus forms ecology and functioning.



Figures 7A and B. Rhizo-system (A) and bryoic-system (B), few centimeters apart between many small alpine streams. (Anniviers, VS ; CH). © Magali Matteodo.

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3.4.3 THE CASE OF LAKE MARGINS, WETLANDS AND MARSHES

In ecosystems influenced by hydrology, water saturation is the key factor influencing soil redox potential, biota activities as well as organic matter mineralization and/or humification. As a consequence, the presence of a groundwater table or intensive rainfall events drastically govern water level in soils, leading thus to wide influences on humus forms functioning.

Relative to the increase on water amount in soil and its residence time, a gradient of humus forms may be highlighted (see Figure 1.9, Chapter 1):

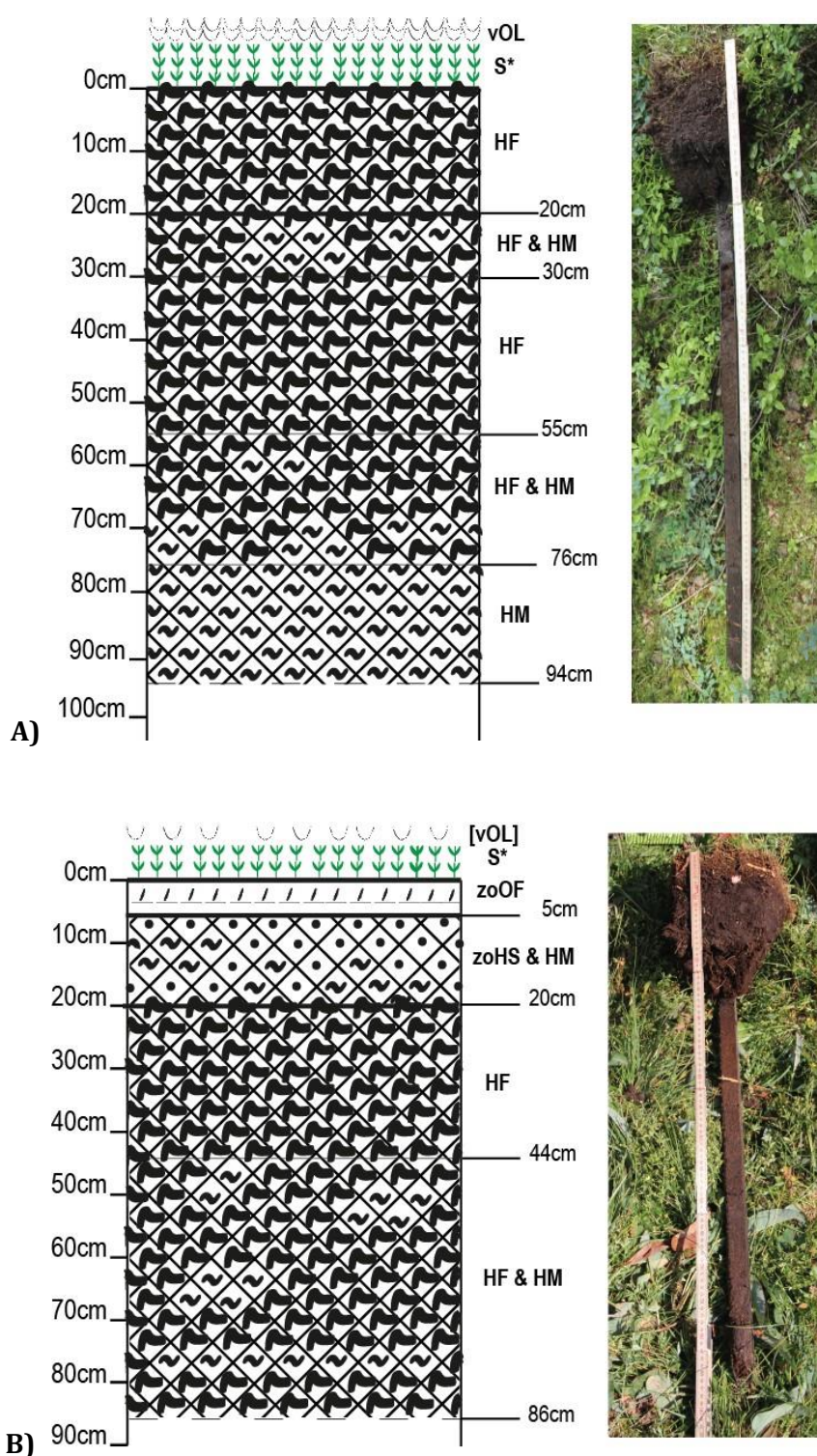
- TERROFORMS: no water saturation, however enough humidity allowing soil biological activities.
- HYDROFORMS: usually characterized by Ag horizons typical of water saturation occurring less than 6 months per year. In these cases, the water table fluctuates during the whole year often reaching the soil surface especially after rainfall events or snow-melting. Biological activities are then improved when water level decreased and macroorganisms as earthworms create biogenic structures as macroaggregates leading thus to the formation of meA or maA soil layers.
- EPIHISTOFORMS: water table fluctuates less compared to HYDROFORMS and water saturation occurs over at least 6 months. Biological activities are reduced in waterlogged conditions however enhanced over low water level periods enhancing the formation of an anmoor diagnostic anA horizon which is usually observed in such environments. Histic horizons may also occur.
- HISTOFORMS: always composed of histic horizons (See chapter XXX for more details). The almost constant presence of water prevents from any soil faunal activity and favours microbial activities in anaerobic conditions. Deep but also perched water tables may exist in these ecosystems, especially when fibric and mesic organic material act as small sponges.

Focusing on organic matter decomposition processes, bacteria represent the main actors using specific soil enzymes (mainly peroxidases) especially in peat bogs in acidic environment maintained by *Sphagnum* sp. When local soil conditions become more alkaline and/or aerobic, peat mineralization leads to the formation of sapric material and even sometimes lumpy aggregates in dry conditions relative to ecosystem engineers such as plants roots and/or epigeic earthworms.

Variations of organic matter state at the field scale thus humus forms may be helpful to redraw the history of the study plot. Regarding HISTOFORMS, histic layers succession usually follows the classical hierarchy relative to organic matter decomposition: HF/HM/HS (Figure 8A). However, this succession may be reversed with humified material at the soil surface (HS&HM/HF; Figure 8B; Rion, 2015) notifying a change in organic matter evolution. Such short-circuit of the system may be explained by hydrological pathways derivation mostly due to human activities (river embankments, artificial decrease of the groundwater level, irrigation, drainage, etc.). Consequences may be modifications of the vegetation succession, and probably further pedogenesis alterations, with biota and trophic networks impacts and, as whole, drastic changes of ecosystem functioning on a holistic point of view.

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Figures 8A and B. Examples of histic layers succession in wetlands (La Vallée de Joux, VD; CH). (A) Classical succession and (B) reverse one. © Vanessa Rion.

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3.4.4 GRADIENT STUDIES: THE IMPORTANCE OF ECOTONES

Being at the interface of vegetation and soils, humus forms integrate functional properties belonging to both vegetation community and soil scales. They are at the core of nutrient and energy cycles that govern the whole ecosystem while having their own spatio-temporal scale of functioning. This specificity may allow humus forms to be good indicators of transition areas (ecotones) between ecosystems. In this context, we conducted studies on vegetation transects in order to underline how humus forms may highlight some variations at a fine scale. We thus compared two situations: i) one in a lobed-leaved trees forest varying variables as the exposition and the slope, and ii) the other following a gradient of decreasing hydromorphy from a lake to an alluvial forest.

The first transect (Figure 9) was set up in a mixed forest mainly composed of beech (*Fagus sylvatica*), but also oak (*Quercus sp.*), spruce (*Picea abies*), fir (*Abies alba*) and some lime trees (*Tilia sp.*). The geology is the same everywhere (calcareous rock with moraine material in places). The visual preferential choice was the most appropriate field method in such situation to select the plots because the microtopography varies according to the presence of lapiaz and/or cuvettes. As showed by the Figure 9, all humus forms were classified as TERROFORMS, mainly OLIGOMULLs and DYSMULLs reflecting high activities from soil biota thus a rapid turnover and recycling of organic matter (Jabiol et al., 2013). This is not surprising regarding the initial quality of organic matter (easy-digest litter) as well as the diversity and abundance of soil meso- and macrofauna (field observations). Focusing on the two OLIGOMULLs, they are both of them south-exposed and located on berms thus facilitating decomposition processes of organic matter by arthropods (A1) and/or its incorporation by soil-dwelling earthworms in deeper soils (A3; many surface- casts were noticed).

Concerning DYSMULLs, two variables help explaining their presence at a local scale. First, the amount of skeleton (A2, A5) and the presence of calcareous slab at several centimeters depth (A1) may reduce the activity of anecic earthworms. Second the exposure, the north side probably maintains humidity over longer periods than on the south side. As a consequence of these two parameters, organic matter incorporation may be reduced on the north versant, probably reinforced by a fine calcite layer all around organic particles, thus decreasing enzymes efficiency (A4 and A5, presence of Ah layer).

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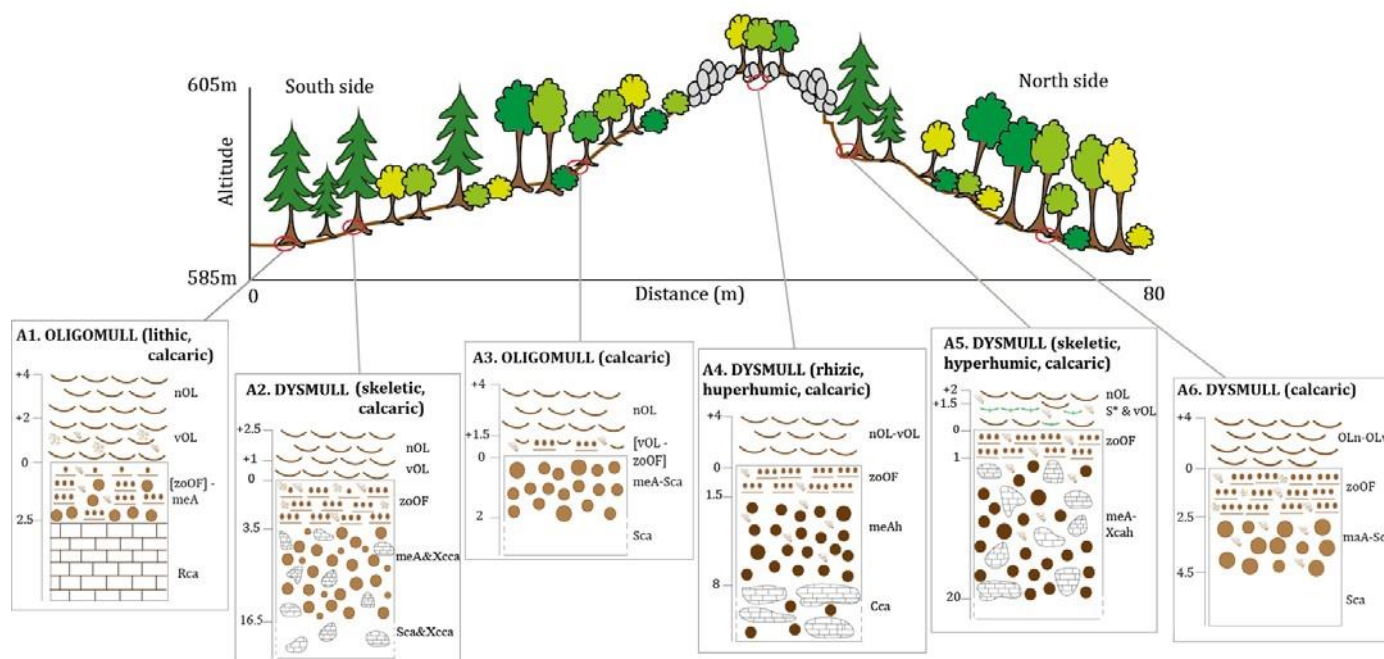


Figure 9. Transect of humus forms in a forest composed of mixed lobed-leaved trees (Le Bois de l'Hôpital, NE; CH). Humus forms names were attributed using Jabiol et al., 2013. © Claire Le Bayon, adapted from Grandgirard et al., 2015.

The second transect (Figure 10) followed a gradient of hydromorphy, from a lake edge to an alluvial forest. What is really interesting is the variation of humus forms over a very short distance (150m) which is mainly driven by the hydromorphic gradient that governs the vegetation composition. Faunal activities and organic matter decay of the first three humus forms (B1, B2 and B3) are strongly limited by anaerobic conditions. Near the lake, mosses, reeds and the *Carex sp.* supply recalcitrant organic matter and maintain humidity. As a consequence, histic and gleyic soil layers are then observed and hydromorphic features are encountered until at least 50 cm depth (using a gutter auger). Humus form B4 (EUANMOOR) could be seen as a transition from the semi-terrestrial to the terrestrial humus forms. Then, farthest we are from the lake, better is the humus form functioning, with respectively a DYSMULL (B5), an OLIGOMULL (B6) and a MESOMULL (B7).

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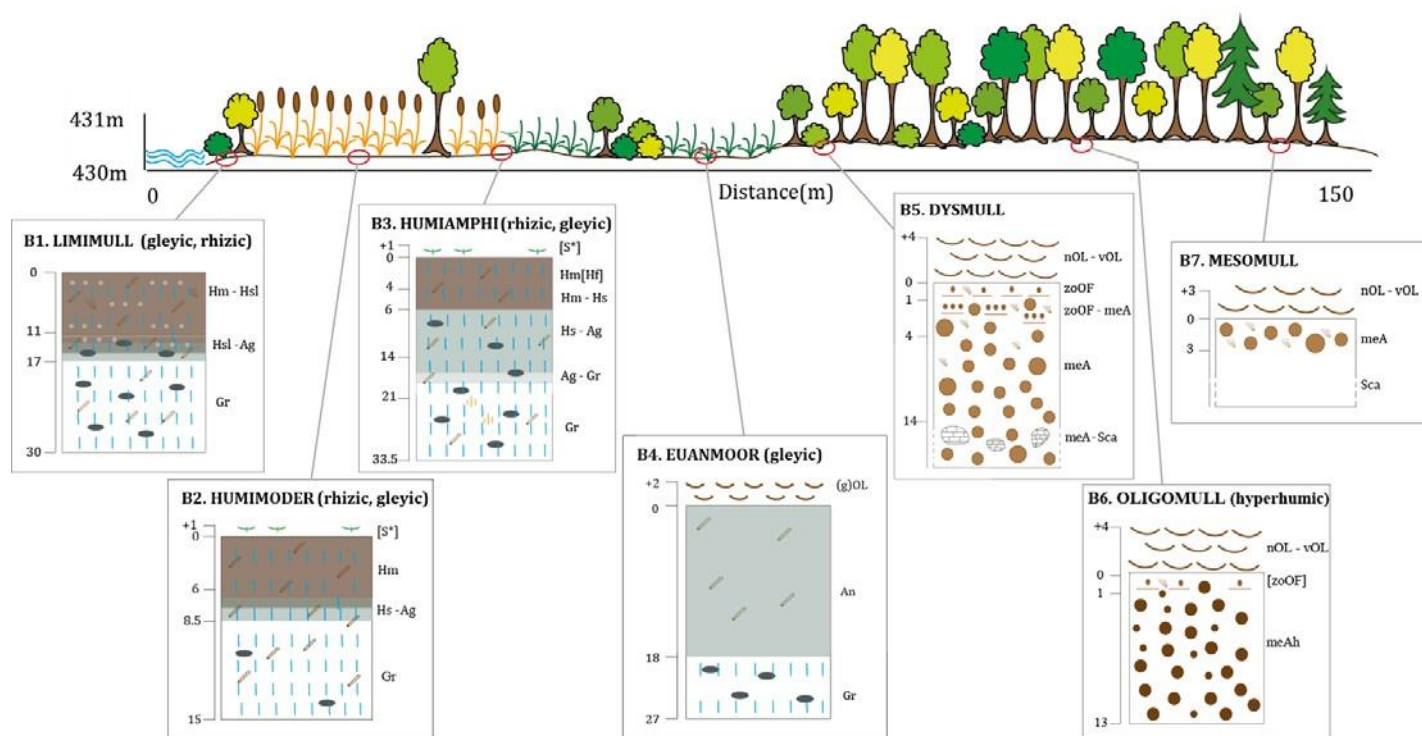


Figure 10. Transect of humus forms From a lake edge to an alluvial forest (La Ramée, NE; CH). Humus forms names were attributed using Jabiol et al., 2013. © Claire Le Bayon, adapted from Grandgirard et al., 2015.

4. EVOLUTION AND IMPROVEMENTS OF THE CURRENT KEYS

4.1 PARAFORMS

In the present book, several chapters are dedicated to PARAHUMUS highlighting the diversity of such humus forms and their occurrence in several ecosystems. High amounts of inorganic material (rock, pebbles, sand, etc.) or organic material (roots, wood, mosses, lichens, etc.) in the humipedon led Jabiol et al. (2013) to classify such humus forms as PARAHUMUS to which several qualifiers may be added. This definition originated from the merging of previous ENTIFORMS and PARAFORMS (Zanella et al., 2011) and aimed at simplifying the system at the WRB level for soils, however it caused the loss of precision on the context and the processes within the humipedon occurs, i.e. the humipedogenesis.

In this way, prefixes may be a very useful tool to clarify and highlight the ecological conditions of the studied plot directly in the humus forms' name. Some of them proposed by Jabiol et al. (2007) and Zanella et al. (2011) are relevant to describe humus forms characteristics and new ones are proposed in this book. A classification is proposed below to organize these prefixes; this list is of course not exhaustive and further suggestions based on field experience are greatly encouraged. Moreover, future research and reflection should be conducted in order to adapt these prefixes to the different types of humus forms

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil (MULL, MODER, MOR, TANGEL, AMPHI) depending to the humipedon layers observed in the field and their global functioning.

4.1.1 PREFIXES RELATED TO THE PARENT MATERIAL

Depending on the relative importance and the nature of parent material, three prefixes were previously proposed and may be re-updated in the current humus forms classification:

- Litho: humipedon lying on large slabs composed of hard rock (unbreakable with tools).
- Peyro: humipedon lying on fragmented rocks mainly ≥ 2 cm (pebbles, stones, gravel); see Figure 11.
- Psammo: humipedon lying on fine mineral particles mainly ≤ 2 cm (sand and silt).

Another one should be added:

- Fendo: in rock cracks such as karren on granite, or lapiaz on calcareous substrate or gypsies (karstic forms) where organic matter accumulates.

Specific diagnostic horizons may be also proposed such as: LitOL, PeyOL, PsamOL, FenOL, etc. in order to identify and highlight the particularity of these humipedon layers.



Figure 11. PEYROSOL (Hyperskeletic Leptosol) with a large amount of stones (Soubey, JU; CH). The humus form is here classified as a PARAHUMUS; more specifically as a PEYROFORM. © Claire Le Bayon.

4.1.2 PREFIXES RELATED TO ORGANIC MATERIAL

Two prefixes are commonly used since 2011 (Zanella et al.):

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- Ligno: humipedon composed of decaying wood; a special chapter is dedicated to this topic (Tatti et al., XXX).
- Rhizo: humipedon with a horizon containing roots and/or rhizomes that represent more than 50% of the total volume.

Two new ones are proposed in the present book (Chapters XXX):

- Bryo: humipedon with mosses that represent between 30% and 90 % of the total volume.
- Crusto: relative to a crust formed at the humipedon surface and composed of a biological complex of cyanobacteria, green algae, lichens, mosses, microfungi, etc.

Other prefixes should be added:

- Faeco: under animal faeces (cowpats, droppings, dung).
- Compo: under a pile of organic matter such a compost heap.

As above, diagnostic horizons may be proposed: LigOL, RhiOF, BryOL, CruOL, FaeOL, CompOL, etc. to focus on respective special features.

4.1.3 PREFIXES RELATED TO ENVIRONMENTAL CONDITIONS

Taking into account environmental and local conditions is new and an innovative concept in humus forms classification. In this book (Chapter XXX), two new prefixes are proposed:

- Anaero: humipedon influenced by anaerobic conditions (redox potential).
- Archeo: humipedon influenced by extreme conditions (saline, acidic, alkaline,

etc.). Other prefixes should be added:

- Cryo: relative to humipedons subject to temperatures below zero Celsius degrees over at least 6 months.
- Thermo: relative to humipedons subject to daily temperatures higher than 40 Celsius degrees over at least 6 months.

Diagnostic horizons may be proposed: AnOL, ArcOL, CryOL, TheOL, etc.

4.2 ANTHROPOFORMS (AGRICULTURAL SOILS, URBAN SOILS, Z AND L LAYERS...)

The influence of human activities is also of great importance on humus forms. Most of the time, humus forms are neglected in anthropogenic contexts because of the soil engineering reshuffle due for instance to ploughing activities, addition of building material, soils artificial set up after tunnel or road constructions, etc. So, the classical hierarchical of soil horizons relative to pedogenesis is largely disturbed with all these human bioturbations whatever a shovel or a mechanical digger is used. In such conditions, finding a succession of soil layers as clearly explainable as in natural environments is unreal.

In this book (Chapter XXX), two new prefixes are proposed:

- Agro: when the “characters” of the original humus forms horizons are still recognizable even if strongly modified by man with the purposes of food production or soil management.

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- Techno: when at least 10% of the combined volume of the humus horizon is occupied by artificial (manmade) substrates. A key is also necessary here to identify the artefacts (bricks, bones, scrap iron, chard of glass...etc.).

Precisions of each of these two prefixes may also be added in the text when describing in details the humipedon. For instance, in the AGROFORMS, the type of farming, the nature of the crop, the frequency of ploughing activities over the year, if the system is conventional or organic, etc. Regarding the TECHNOFORMS, specifications must be made about the construction site, if compost was added to rebuild artificial soils, if the plot is a private garden or an allotment, the urban context (individual houses or block of flats, village, megalopolis, etc.).

Diagnostic horizons may also be proposed: AgrOL, TecOL, etc.



Figure 12. ANTHROPOSOL (Anthrosol) with large amount of human artefacts in the whole soil profile (Hauterive, NE; CH). The humus form is here classified as an ANTHROPOFORM, more specifically a TECHNOFORM. © Claire Le Bayon.

4.3 HISTOFORMS AND HYDROFORMS

Hydrological modifications caused by human activities could have strong impacts on humus forms functioning in wet ecosystems (see section 3.4.3). As observed by V. Rion (2015), the presence of more humified and drier horizons at the soil surface should be thus taken into account in humus forms keys while it reflects intermediate situations (intergrades like AMPHIFORMS) as well as humus forms' evolution.

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Another point concern intergrades between HYDROFORMS and TERROFORMS. Terrestrial holorganic (OL, OF, OH) and/or organo-mineral (A) horizons could also be observed directly above typical mineral horizons characteristic of temporary or permanent water table, as reductic (G) or redoxic (g) layers (Rion, 2015). So, not only HYDROFORMS but also TERROFORMS may exist above REDUCTISOLS or REDOXISOLS (Gleysols).

Thus, a decreasing gradient in water saturation may lead to the conversion of HISTOFORMS into HYDROFORMS these latter evolving in the extreme cases to TERROFORMS. Therefore, a prefix such as *Transi* may be used as a prefix to highlight these changes.

5. PRACTICAL TOOLS AT THE FIELD SCALE

5.1 FIELD SHEET FOR HUMUS FORMS DESCRIPTION

In addition to material and procedure (see section 2.), a field sheet is proposed in order to help the observer to describe humus forms at the field scale (Figure 13). This sheet is also useful to avoid mistakes as much as possible and to provide a kind of homogeneous framework for everybody.

5.2 DICHOTOMOUS FIELD KEYS FOR HUMUS FORMS IDENTIFICATION

Three dichotomous keys are also proposed (Figures 14, 15 and 16) in order to provide a quick and easy field tool system. These keys are upgradeable using the future research in this domain.

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Station (from I to XII)		Holorganic horizons (numbers from 1 to 20)																			
I) station	II) date / hour	1) thickness		2) limit shape		3) transition		4) nature(s)													
III) ID	IV) by	minimum		linear		3-5															
V) exposition	VI) slope	median		wavy		5 > x ≤ 10															
VII) GPS		maximum		irregular		10 > x ≤ 20															
VIII) μ-topo		n°		broken		> 20															
IX) meteo				undert.		undert.															
X) notes																					
		5) OL age		6) transfo.		7) fragm.		8) cohesion		9) OM type		10) rec. remains vol. [%]		11) hum. comp. vol. [%]		12) type		13) structure		14) humidity	
XI) photo(s) station		n°		< 1 year		bleached		absence		100		[100] - [100]		[100] - [100]		OL		SP 0-2		< rec. rem.	
				> 1 year		skeletonised		absence		[100] - [100]		[100] - [100]		[100] - [100]		CF 20		SP 2-20		MCO	
				absence		fragmented		absence		[100] - [100]		[100] - [100]		[100] - [100]		OH		SP 20+		MCO	
				absence		adomised		absence		[100] - [100]		[100] - [100]		[100] - [100]				SG 0-2		MCO	
				absence		coherent		absence		[100] - [100]		[100] - [100]		[100] - [100]				SG 2-20		MCO	
				absence		glued		absence		[100] - [100]		[100] - [100]		[100] - [100]				SG 20+		MCO	
				absence		veg. remains		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		feces		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
				absence		undert.		absence		[100] - [100]		[100] - [100]		[100] - [100]				undert.		MCO	
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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil

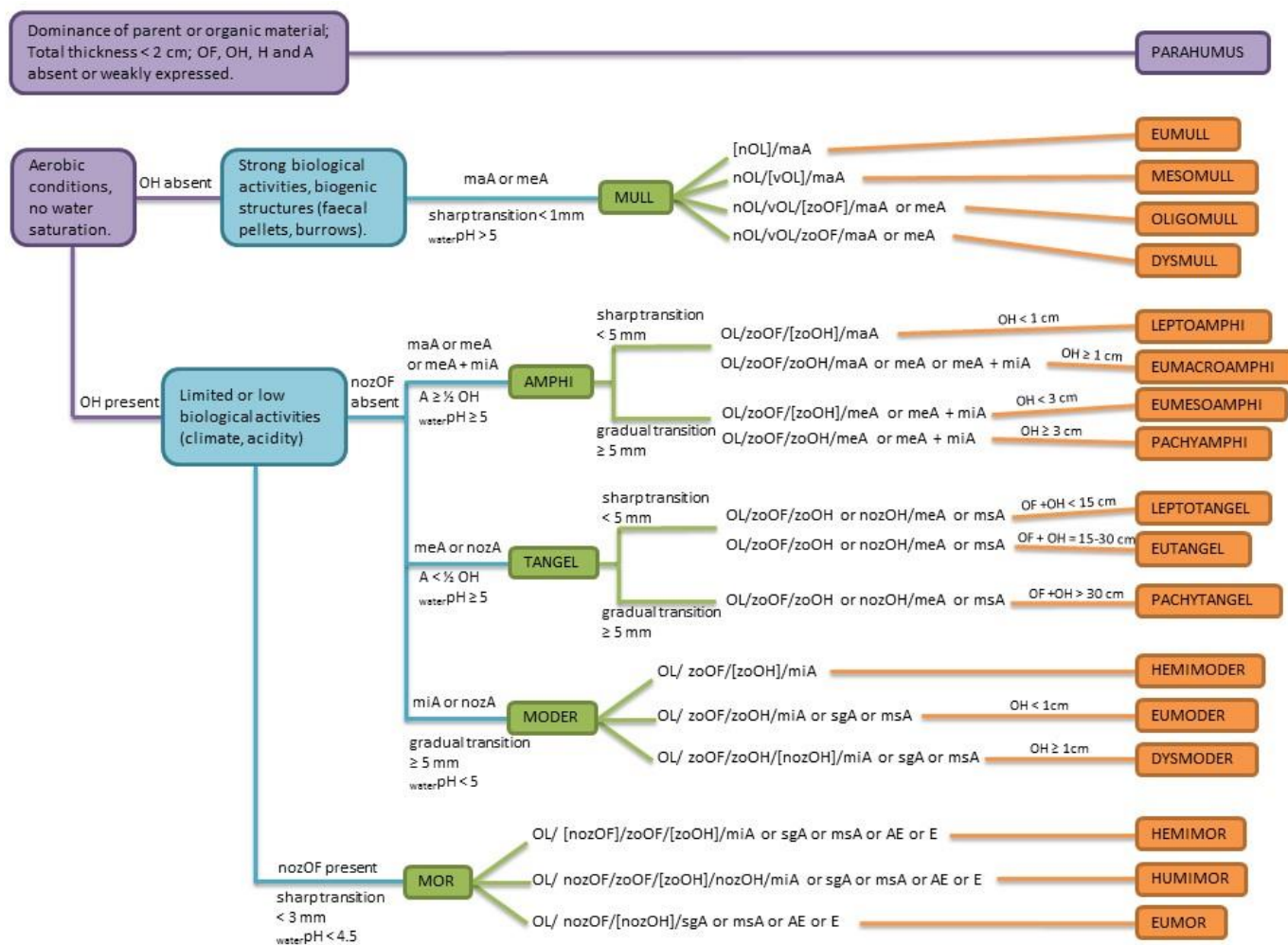


Figure 14. Dichotomous key for the identification of terrestrial humus forms. © Claire Le Bayon.

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Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil

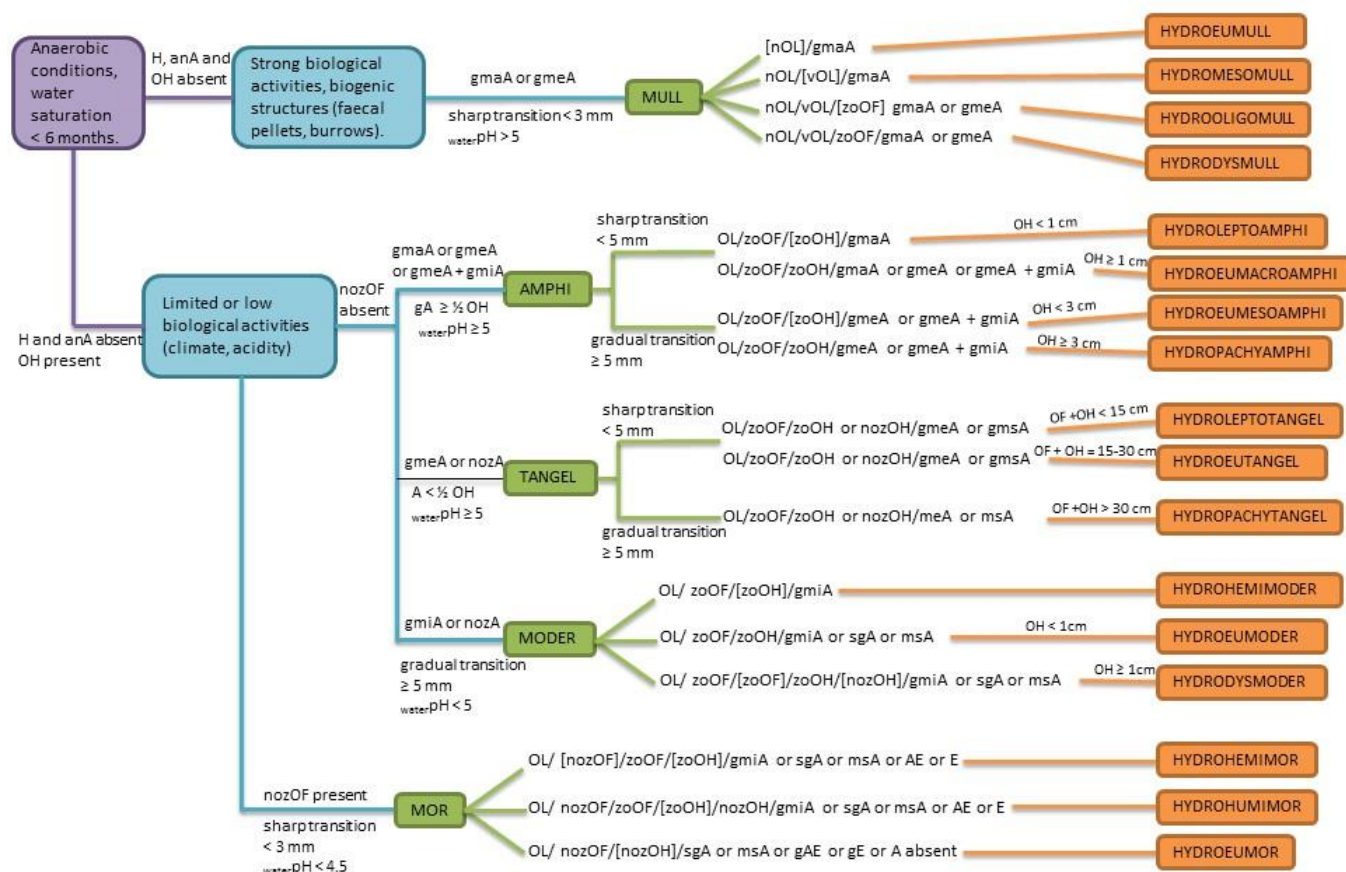


Figure 15. Dichotomous key for the identification of semi-terrestrial humus forms; the case of HYDROFORMS. © Claire Le Bayon.

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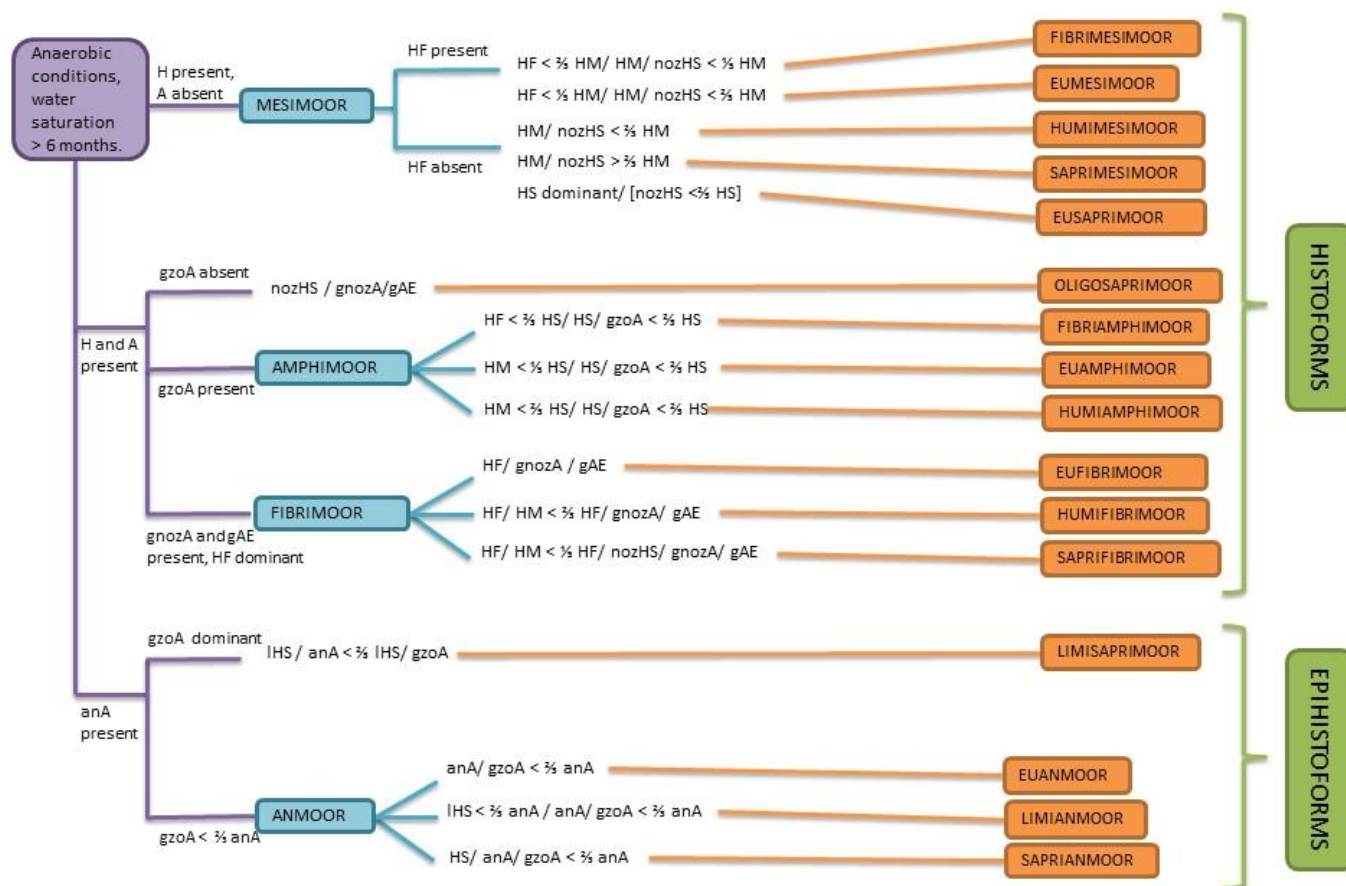


Figure 16. Dichotomous key for the identification of semi-terrestrial humus forms; the case of EPIHISTO- and HISTOFORMS. © Claire Le Bayon.

6. CONCLUSION

The main aim of this chapter is to provide new and practical tools for humus forms identification at the field scale using the current knowledge in this research field. Despite a lot of improvements in this domain, some unresolved gaps remain more specifically in less studied ecosystems as highlighted above: alpine ecosystems, lake margins and peatlands, floodplains, but also proglacial lakes, urban ecosystems, etc. Ecotones may also be essential transitions to take into account where humus forms may play a crucial role in identifying slight modifications of vegetation succession and/or pedogenesis processes. Further research is so needed to better understand humus forms functioning integrating several scales of time and space.

PART SEVEN: SPECIAL REPORTS - IN-DEPTH SPECIFIC STUDIES

Scientific advances about humus and soil practical procedures for a sustainable exploitation of the soil

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1 **Upscaling the spatial distribution of enchytraeids and humus**
 2 **forms in a high mountain environment on the basis of GIS**
 3 **and fuzzy logic**

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15 **Running Title:** Spatial modeling of enchytraeids and humus forms

16 Summary

- 17 • We analyze the variety of humus forms and enchytraeid species in
- 18 mountain forests.
- 19 • We apply a knowledge-based modeling approach to map mull and moder
- 20 conditions.
- 21 • Forest humus forms and enchytraeid species differ depending on slope
- 22 exposure.
- 23 • Spatial modeling of humus forms and enchytraeids predicts decomposition
- 24 patterns.

25 The aim of this study was to map the spatial distribution of enchytraeids and humus
 26 forms in a study area in the Italian Alps by means of a knowledge-based modeling
 27 approach. The modeled area is located around Val di Sole and Val di Rabbi (Trentino,
 28 Italy) and includes the forested parts in the range between 1100 m and 1800 m a.s.l.
 29 Elevation and slope exposure are considered as environmental covariates. Models were
 30 implemented regarding the spatial distribution of three variables at the landscape scale:
 31 1) enchytraeids indicating mull humus forms, 2) enchytraeids indicating moder/moder
 32 humus forms, 3) humus forms showing an OH horizon. All three models reveal a
 33 consistent trend of an increasing accumulation of plant residues and humus in organic
 34 layers from low to high elevations and from south-facing to north-facing slopes.
 35 Validation and sensitivity analyses confirm these trends, although some deviations are
 36 to be expected (RMSE values from validation sites range from 26.3 to 36.2 percentage
 37 points). Effects of additional potentially influencing variables may lead to uncertainties
 38 of the model predictions especially at positions with particular landforms (e.g. gullies
 39 and ridges). In the high mountains environmental conditions are often quite
 40 heterogeneous due to a highly variable topography, which also affects the species

41 composition of the decomposer community and the occurrence of different humus
42 forms.

43

44 **Keywords:** Decomposition, Soil mesofauna, Decomposer community, Knowledge-
45 based modeling, Forest ecosystem, Italian Alps

46 1. Introduction

47 Soil organisms are of high relevance for the function of terrestrial ecosystems, driven by
48 their response to environmental conditions and by a variety of interactions among
49 themselves and with aboveground organisms [1,2]. With reference to decomposition,
50 soil organisms are classified into decomposer community types, i.e. typical,
51 environmentally controlled species assemblages of decomposer organisms [3,4].

52 Enchytraeids are usually colorless worms belonging to the soil mesofauna (length
53 ca. 2-40 mm) and inhabiting the topsoil [5]. As key members of the decomposer
54 community enchytraeids strongly interact with other species within the soil food web.
55 Thus an externally induced shift in the decomposer community (e.g. land-use change,
56 soil acidification, invasion of earthworms) also alters the composition of the enchytraeid
57 assemblage [6,7]. Hence, the species composition of the enchytraeid assemblage serves
58 as indicator for the state of the entire decomposition system in the topsoil. For
59 characterizing the decomposer community of a particular site, one can infer from
60 analyzing the annelid coenosis [8].

61 Variations in the activity of decomposing soil organisms also reflect differences in
62 the kind of dead organic matter accumulated in the topsoil. In forest ecosystems, humus
63 forms are distinguished by the presence of different organic layers (OL = litter, OF =
64 fragmented residues, OH = humified residues) and by the characteristics of the
65 uppermost horizon of the mineral soil [9]. As the relationship between decay processes
66 and main features of the organic layers is obvious, humus forms are considered as
67 indicators for soil ecological activity linked with decomposition [10]. Owing to this
68 indicator function, humus forms serve as a valuable site-specific feature for the
69 investigation of environmental changes in ecosystems.

70 As to the annelid coenosis, it has been shown that the occurrence of enchytraeid
71 species varies according to the humus form, with a threshold between mull and
72 moder/mor humus forms [8]. Mull humus forms are characterized by a high activity of
73 soil organisms incorporating dead organic matter into the mineral soil, whereas
74 moder/mor humus forms are characterized by the accumulation of highly decomposed
75 dead organic matter above the mineral soil in the form of an OH horizon.

76 With this study, we aim at examining the spatial distribution of enchytraeids and
77 forest humus forms depending on the elevation and slope exposure in a study area
78 located in the Italian Alps. Correlations between the occurrence of humus forms and the
79 associated enchytraeid species are supposed to be revealed by means of a GIS-based
80 modeling approach. In order to assess the current state of an ecosystem, it is often
81 necessary to analyze patterns of decomposition processes at a scale higher than the local
82 plot level. The focus of this study is on a mountainous, thus topographically highly
83 heterogeneous and for the most part hardly accessible area. In this situation, upscaling
84 of local information to the landscape scale faces challenges due to a relatively low
85 number of sampling points and a high local variability of environmental parameters.
86 Therefore, a spatial modeling technique specially designed to consider these issues is
87 needed. We utilize a knowledge-based approach applying decision trees and fuzzy
88 logic.

89 2. Material and Methods

90 2.1. Study area

91 The study area is located in the northern Italian Alps in the north-western part of the
 92 Autonomous Province of Trento. It covers about 500 km² and includes most parts of the
 93 catchment area of Val di Sole (Figure 1). The climatic conditions in the study area are
 94 temperate continental to subcontinental [11]. Local climatic conditions vary mainly
 95 according to the topography. Different slope angles and exposures cause high variations
 96 of solar radiation [12]. The entire study area embraces a siliceous parent material,
 97 dominated by paragneiss, mica schists, phyllites and orthogneiss [13]. Soil classes differ
 98 primarily with the elevation: below ca. 1900 m a.s.l. Haplic Cambisols (Dystric) and
 99 Umbric Podzols prevail, above ca. 1900 m a.s.l. the predominating classes are Entic
 100 Podzols, Albic Podzols and Umbric Podzols [14].

101 The focus of this study is on the forested mid-elevation areas (between 1100 and
 102 1800 m a.s.l.), which cover the slopes on both sides of the valleys. Norway spruce
 103 (*Picea abies*) and European larch (*Larix decidua*) are the prevailing tree species
 104 constituting these forests.

105

106 **Figure 1** Location of the study area in the Autonomous Province of Trento (Italy)

107 (modified from Egli et al. [15]).

108

109 2.2. Experimental design

110 On the basis of previous research [15] and with the help of experts with local
 111 knowledge, six study sites (N1, N2, N3, S6, S7 and S8, ca. 25 m² each) have been
 112 selected. They are located at three different elevations (on north and south exposed

113 slopes respectively) and represent typical site conditions within the investigated slope
 114 areas. The main characteristics of these study sites are summarized in Table 1. Although
 115 the dominating humus forms differ between the sites, we often find a mosaic-like
 116 pattern of humus forms. This is manifested by the occurrence of humus forms with an
 117 OH horizon and a weak structure of the mineral soil (without biogenic features) right
 118 beside humus forms without OH horizon but with a well-structured A horizon inhabited
 119 by endogeic earthworms. The study sites are all located inside the coniferous forest.
 120 Norway spruce (*Picea abies*) prevails at the north-exposed sites, whereas European
 121 larch (*Larix decidua*) is dominant at the south-exposed sites. In order to solidly detect
 122 the effects of elevation, we performed an intensive sampling at the lowest and highest
 123 study sites including six plots each (N1, N3, S6, S8). At the mid-elevation sites N2 and
 124 S7 three plots were sampled, respectively. Samples for this study were taken between
 125 June and August 2013.

126
 127 **Table 1** Dominating humus forms and profiles at the investigation sites (N1-N3:
 128 northern slope exposure, S6-S8: southern slope exposure) (elevations according to Egli
 129 et al. [15])

130
 131 At each plot ($n = 30$ in total) humus forms were described in the field at topsoil profiles
 132 with a width of 50-100 cm using classifications and determination keys from Germany
 133 [16] and Switzerland [17]. Soil samples for the extraction of enchytraeids were acquired
 134 in the immediate vicinity of the profiles using a soil corer of 5 cm in diameter. Samples
 135 were divided into subsamples of 2.5 cm depth intervals up to 15 cm depth starting at the
 136 top of the organic layer. As one of the samples at study site S6 could not be analyzed, a
 137 total of 29 plots remained.

138 Six additional validation sites V1-V6 were sampled with a reduced number of plots
 139 (three validation sites at different elevations on a north- and south-exposed slope,
 140 respectively). Samples for validation were taken in September 2015.

141 All samples for the investigation of enchytraeids were transported to the IFAB
 142 laboratory, where enchytraeids were extracted. The enchytraeid species were identified
 143 according to Schmelz and Collado [18]. Annelids from other families than
 144 Enchytraeidae but belonging to the same size class were recovered with the extraction
 145 as well. Thus we use the term ‘microannelids’ when we refer to all species determined.
 146 Species counting and determination were conducted at IFAB laboratory using dissecting
 147 and light microscopes. Additional laboratory analyzes for the final determination of
 148 humus forms have been conducted at Functional ecology laboratory (University of
 149 Neuchâtel).

150

151 2.3. Data analysis

152 To evaluate the co-occurrence of enchytraeid species with different humus forms, the
 153 life form (H-type) of enchytraeids and other microannelids is applied. The concept of
 154 life form types indicates the typical habitat of species in the sequence of humus forms
 155 (represented by the four classes Mull, Mullmoder, Moder and Mor) together with their
 156 vertical distribution in the humus horizons [19]. The life forms of three species are
 157 presented as examples in Figure 2. For modeling enchytraeid species are categorized as
 158 mull indicators and moder indicators: Species with a life form including the letter a are
 159 assigned to the mull indicators (e.g. *Fridericia bulboides*), species with a life form
 160 including the letters c or d belong to the moder indicators (e.g. *Cognettia*
 161 *sphagnetorum*). Both species with a life form limited to the class Mullmoder (letter b)
 162 and species inhabiting both mull and moder humus forms (life form includes letter a and

letter c, e.g. *Enchytronia parva*) are disregarded, since they neither indicate explicitly mull nor moder/moder conditions. Table 2 specifies the enchytraeid species considered for modeling together with their mull and moder affinities.

Figure 2 Life forms (H-type) of three selected enchytraeid species (modified from Graefe and Schmelz [19]). Humus horizons are indicated by the numbers 1 to 4, humus forms are indicated by the letters a to d as follows: MU = Mull, MOM = Mullmoder, MO = Moder, RO = Mor (“Rohhumus”). The cells representing the typical habitat of the species are colored in grey.

Table 2 Microannelid species found in the samples and their classification as indicators of mull or moder humus forms in the model

As one of the determining factors for humus forms and main criterion for the discrimination of mull-like and moder/moder-like humus forms, the occurrence of an OH horizon is used for modeling. Percentage values of humus forms showing an OH horizon are attributed to every plot. We apply a percentage of 100 % to plots with a continuous OH horizon, a percentage of 50 % to plots with a discontinuous OH horizon and a percentage of 0 % to plots without OH horizon.

For modeling sample data on enchytraeids and humus forms are aggregated from all sampling plots per investigation site. This aggregation is accomplished by weighting the plot data according to the prevalence of the respective soil cover types at the investigation site (Table S1).

As variables influencing humus forms the topographical parameters elevation and slope exposure are examined. Elevation values are transferred from a digital elevation model with a grid width of 10 m [13] (provided by Museo Tridentino di Scienze

189 Naturali). Data on slope exposure are derived from the digital elevation model with the
190 help of the aspect tool in ArcGIS [20].
191

192 *2.4. Modeling*

193 A methodological framework specifically designed to spatially predict indicators for
194 decomposition processes is applied (Hellwig et al., unpublished). Modeling is based on
195 binary decision trees built with the CART algorithm [21] using the statistical software R
196 [22] and the R package rpart [23]. From these trees, bell-shaped or S-/Z-shaped fuzzy
197 membership functions are derived referring to the concept of fuzzy logic [24-26]. Fuzzy
198 logic is used because it enables the complex relationship between the landscape and soil
199 to be modeled in a continuous way. In this manner an allocation of sharp boundaries
200 between different soil properties, whose spatial position is quite uncertain, is not
201 required [27]. The fuzzy membership functions describe the distribution of enchytraeid
202 indicator classes and the occurrence of humus forms showing an OH horizon in
203 dependence on the elevation and the slope exposure, respectively. For this, values of
204 elevation and slope exposure have been aggregated from all sampling plots per
205 investigation site. The exposure value 0° N is assigned to the sites at north-exposed
206 slopes, the value 180° N is assigned to the sites at south-exposed slopes. For the three
207 different elevation ranges the values 1200 m, 1400 m and 1630 m a.s.l. are used. These
208 aggregations are necessary for avoiding unrealistic tree splits when the combined effects
209 of elevation and slope exposure are analyzed. Prediction maps are compiled with the
210 ArcGIS extension tool ArcSIE [28].

211 The areas for modeling include all coniferous forests inside the study area, which
 212 are located between 1100 m and 1800 m a.s.l. (corresponding to the valley sides of Val
 213 di Sole, Val di Rabbi and adjacent valleys) and on siliceous bedrock.

214

215 *2.5. Model assessment*

216 The assessment of the model is accomplished in terms of different subjects: 1) the
 217 validity of the model structure (using a resampling approach) and of the prediction
 218 results (analyzing independent validation sites); 2) the uncertainty of the input data from
 219 the study sites (using a sensitivity analysis); 3) the uncertainty of the model predictions
 220 regarding the applicability of the model for varying landform types.

221 Resampling is used to test the validity of the internal model structure. For each modeled
 222 variable (OH horizon, Mull indicators, Moder indicators) 27 models are built on the
 223 basis of a reduced number of sample plots per study site (2/3 of the original samples at
 224 every site) (Table S2).

225 For the assessment of the prediction results at the validation sites, the mean error (ME)
 226 (1) and the root mean squared error (RMSE) (2) are calculated where n is the number of
 227 samples, y_i are the observed values and $\hat{y}_i$ are the related values predicted by the model:

$$228 \quad ME = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (1)$$

$$229 \quad RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (2)$$

230 Input data from the study sites are subject to uncertainties, as the ecology of the humus
 231 layers generally shows a high small-scale variability. Therefore, the effects of potential
 232 deviations of the input site data on the model structure and results are studied by means
 233 of a sensitivity analysis. For all of the modeled variables (OH horizon, Mull indicators,

234 Moder indicators) the observed percentage values are both diminished (simulating an
235 overestimation in the model) and increased (simulating an underestimation in the
236 model) by 20 percentage points at each plot (as far as possible, up to 0 % or 100 %).

237 With reference to the predicted values, uncertainties are also caused as landform
238 types different from those at the study sites might show deviations of soil ecological
239 parameters from the modeled trends along gradients of elevation and slope exposure. In
240 order to identify the relevant areas, two prominent topographic factors are examined:
241 the LS factor (describing conditions for erosion by means of the slope length and
242 steepness) and the Topographic Wetness Index (TWI) [29-30]. At the study sites both
243 parameters attain intermediate values (the LS factor ranges between 9 and 13, the TWI
244 ranges between 4 and 6.5). A measure of uncertainty is calculated by comparing the LS
245 and TWI values of each position in the study area to those at the study sites: if both
246 parameter values are within the reference ranges stemming from the study sites, a low
247 uncertainty is attributed to the predictions (in this situation an uncertainty value of 0
248 applies); if a parameter value is outside of the particular reference range, the uncertainty
249 increases. In this situation, we index the uncertainty in proportion to the deviation from
250 the reference range, up to a maximum uncertainty of 1 whenever the deviation amounts
251 to 5 or more (i.e. $LS \leq 4$ or $LS \geq 18$, $TWI \geq 11.5$). The combined uncertainty value
252 assigned to every location is calculated by applying the maximum of the single
253 uncertainty values from the LS factor and the TWI.

254 **3. Results**

255 *3.1. Data analysis*

256 At the south-exposed study sites we found high percentages of mull-indicating
 257 enchytraeids, whereas percentages of both moder-indicating enchytraeids and of forest
 258 humus forms showing an OH horizon are low (Table 3, Table S1). The highest
 259 percentage of mull indicators (ca. 95.1 %) was found at the study site S6, located at low
 260 elevation. This coincides with the absence of moder indicators and with the low
 261 occurrence of humus forms with OH horizon (ca. 6.7 %). Comparing the study sites S7
 262 and S8 (at middle and high elevations) with study site S6 (at low elevation), we found a
 263 lower percentage of mull indicators (ca. 62.1 % and 63.4 %) along with higher
 264 percentages of moder indicators (ca. 5.3 % and 8.1 %) and humus forms showing an OH
 265 horizon (ca. 50.0 % and 46.7 %).

266 The north-exposed study sites show generally lower percentages of mull indicators
 267 and higher percentages of moder indicators and also of forest humus forms with OH
 268 horizon than the south-exposed sites (Table 3, Table S1). The highest percentage of
 269 moder indicators was found at the study site N2 (ca. 90.7 %), whereas the highest
 270 percentage of humus forms with OH horizon occurs at site N3 (ca. 90.0 %). The results
 271 at station N1 appear ambiguous: a relatively high percentage of moder indicators (ca.
 272 44.9 %) coincides with a relatively low percentage of humus forms with OH horizon
 273 (ca. 18.3 %).

274

275 **Table 3** Data basis for modeling. Percentages of enchytraeid indicator classes and
 276 humus forms with an OH horizon have been aggregated from all sampling plots per
 277 investigation site. See Table S1 for data of sampling plots

278

279 3.2. *Spatial modeling of enchytraeids*

280 Decision trees revealing variations in the distribution of mull- and moder-indicating
 281 enchytraeids related to elevation and slope exposure have been accomplished by
 282 recursive partitioning of the sample set. They reflect the observations at the study sites
 283 as described above with the slope exposure being the more decisive factor for the spatial
 284 distribution of enchytraeids (first-level split in decision trees) in comparison with the
 285 elevation (second-level split in decision trees) (Figure 3, Figure 4).

286

287 **Figure 3** Decision tree for the distribution model of enchytraeids indicating mull humus
 288 forms. The upper value inside the tree nodes represents the projected percentage of mull
 289 indicators in relation to all enchytraeids at this elevation and slope exposure, the lower
 290 value n indicates the number of related samples.

291

292 **Figure 4** Decision tree for the distribution model of enchytraeids indicating moder
 293 humus forms. The upper value inside the tree nodes represents the projected percentage
 294 of moder indicators in relation to all enchytraeids at this elevation and slope exposure,
 295 the lower value n indicates the number of related samples.

296

297 Fuzzy membership functions are derived by deploying the results from these trees and
 298 fuzzifying them along the elevation gradient to two submodels for contrasting slope
 299 exposures (corresponding to the left and right subtrees in Figure 3 and Figure 4). The
 300 occurrence of mull indicators on south-exposed slopes is modeled with a Z-shape
 301 function, as it decreases with increasing elevation. The parametrization is realized by
 302 fitting the general function rule based on the decision tree using the values 0.9506 at
 303 1200 m (occurrence at site S6), 0.7352 at 1300 m (overall occurrence taken as
 304 approximation at the split value) and 0.6276 at 1515 m (mean occurrence at sites S7 and

305 S8). Below 1200 m the function is fixed at the value 0.9506 because this was the
 306 maximum percentage of mull indicators found at south-exposed slopes and there were
 307 no investigation sites located further downhill. This leads to function (3) for south-
 308 exposed slopes. For north-exposed slopes an S-shape function is derived from the
 309 decision tree analogously, resulting in function (4). The fuzzy membership $s_{ij,k,a}$ of a
 310 modeled variable k depends on the value $z_{ij,a}$ of a single environmental variable a at
 311 location (i,j) .

$$312 \quad \begin{cases} s_{ij,k,a} = 0.9506 & \text{if } z_{ij,a} \leq 1200, \\ s_{ij,k,a} = 0.9506 * \exp\left(\left[(z_{ij,a}-1200) / 1072.83\right]^{0.418208} \ln(0.5)\right) & \text{if } z_{ij,a} > 1200 \end{cases} \quad (3)$$

$$313 \quad \begin{cases} s_{ij,k,a} = 0.2053 * \exp\left(\left[(z_{ij,a}-1630) / 317.15\right]^{0.511492} \ln(0.5)\right) & \text{if } z_{ij,a} \leq 1630, \\ s_{ij,k,a} = 0.2053 & \text{if } z_{ij,a} > 1630 \end{cases} \quad (4)$$

314 The occurrence of moder indicators is modeled with the function (5) for north-exposed
 315 slopes (derived in the same way as functions (3) and (4)). As in the decision tree there is
 316 no further split for south-exposed slopes (Fig. 4), a constant function is applied for these
 317 slopes ($s_{ij,k,a} = 0.04457$).

$$318 \quad \begin{cases} s_{ij,k,a} = 0.4493 & \text{if } z_{ij,a} \leq 1200, \\ s_{ij,k,a} = 1 - 0.5507 * \exp\left(\left[(z_{ij,a} - 1200) / 130.458\right]^{0.550436} \ln(0.5)\right) & \text{if } z_{ij,a} > 1200 \end{cases} \quad (5)$$

319 Integrating the models for south- and north-exposed sites is realized both for mull and
 320 moder indicators utilizing weighting functions depending on the local slope exposure x .

321 The model for northern slope exposures is weighted with $0.5 * \cos\left(x * \frac{\pi}{180}\right) + 0.5$, the
 322 model for southern slope exposures with $-0.5 * \cos\left(x * \frac{\pi}{180}\right) + 0.5$. Cosine functions are

utilized in order to reflect the similarity of the slope exposure at site x in comparison with south and north exposure with regard to sunlight.

The model results deliver predictions of the spatial distributions of mull and moder indicators in the study area. An evaluation of the predicted percentage values as emergent areas of dominance of mull- and moder-indicating enchytraeids exhibits again a major relationship to the slope exposure and a minor relationship to the elevation, which is more pronounced at southern exposures (Figure 5).

Figure 5 Prediction of the areas of dominance of mull- and moder-indicating enchytraeids.

3.3. Spatial modeling of humus forms

Decision tree analysis and an ensuing fuzzification procedure examining the dependence of the distribution of forest humus forms showing an OH horizon on the factors elevation and slope exposure have been carried out similarly to those for enchytraeids. Unlike in the model of enchytraeids, elevation rather than slope exposure appears as the superior factor accounting for changes in the presence of an OH horizon (first-level split in the related decision tree) (Figure 6).

Figure 6 Decision tree for the distribution of forest humus forms showing an OH horizon. The upper value inside the tree nodes represents the projected percentage of humus forms with OH horizon in relation to all humus forms at this elevation and slope exposure, the lower value n indicates the number of related samples.

The transformation to fuzzy membership functions (fuzzification along the slope exposure from 0° to 360° with reference to north exposure) yields the constant function $s_{ij,k,a} = 0.125$ for elevations below 1300 m a.s.l. and the bell-shape-function (6) for elevations above 1300 m a.s.l.

$$s_{ij,k,a} = 1 - 0.5166 * \exp \left(\left[\frac{(z_{ij,a} - 180)}{161} \right]^2 \ln(0.5) \right) \quad (6)$$

For assembly of the submodels for these two elevation ranges, they are weighted considering the margins of uncertainty (due to a lack of data at elevations between 1200 m and 1400 m a.s.l.) as represented in Figure 7.

355

Figure 7 Weights applied for the fuzzification of the elevation. Dashed line: weighting of the model below 1300 m a.s.l.; solid line: weighting of the model from 1300 m a.s.l. upwards.

359

A prediction map that depicts the spatial distribution of forest humus forms showing an OH horizon is obtained from the total model (Figure 8). Corresponding with the domain of the fuzzy membership functions, the predicted percentage values range between 12.5 % and 90.0 %. The lowest values are to be found at low elevations. At high elevations (above 1300 m a.s.l.) the percentages of forest humus forms with OH horizon depend on the slope exposure: intermediate percentages around 50 % are predicted at slopes with southern exposures, high percentages up to 90 % arise at slopes with northern exposures.

368

Figure 8 Prediction of the spatial distribution of forest humus forms showing an OH horizon.

370

371

372 *3.4. Model assessment*

373 Validation of the model structure shows a generally consistent model behavior when
 374 using different resampled data sets. This is reflected by a relatively low variability of
 375 the model results. Resampling shows RMSE values up to 11.34 percentage points for
 376 mull-indicating enchytraeids. The highest variability occurs at high elevation and south-
 377 exposed slopes (Figure S1). For moder-indicating enchytraeids the maximum RMSE
 378 value is 16.46 percentage points, which is found at low elevation on north-exposed
 379 slopes (Figure S2). The resampled model results for humus forms with an OH horizon
 380 show RMSE values up to 19.39 percentage points. They are highest at high elevation on
 381 south-exposed slopes and at mid-elevation on north-exposed slopes (Figure S3).

382 The assessment of the model results generally shows deviations of the predicted values
 383 from the observed values at the validation sites in the range of 5 to 25 percentage points
 384 (Table 4). We found high deviations especially in the model addressing the distribution
 385 of humus forms with an OH horizon (up to 49.3 percentage points at site V5) but also in
 386 the models of enchytraeids (especially at site V1: 80.3 percentage points for mull
 387 indicators and 61.1 percentage points for moder indicators). Because of the highest
 388 deviation at site V1 and the relatively high deviation at site V5 the RMSE is highest in
 389 the model of mull indicators (36.2 percentage points). In the model of moder indicators
 390 the RMSE equals 30.1 percentage points, whereas in the model of humus forms with an
 391 OH horizon it amounts to 26.3 percentage points.

392

393 **Table 4** Validation sites: topographic position and percentage values (observed and
 394 predicted) of modeled parameters

395

396 The results from sensitivity analysis reveal a consistency regarding the structures of the
 397 decision trees for the majority of modifications of the data (Table 5). However, in some
 398 cases the structure of a tree changes, i.e. node splits are added, eliminated or modified
 399 (new splitting criteria). The absolute mean deviations in the predicted values range
 400 between 0.20 and 10.38 percentage points, the absolute maximum deviation amounts to
 401 29.99 percentage points (when increasing the percentage of humus forms with an OH
 402 horizon by 20 percentage points at station S8).

403

404 **Table 5** Results of sensitivity analysis. Values represent the deviations of the predicted
 405 values in percentage points as compared to the unmodified models. Underlined values
 406 indicate an alteration in the structure of the underlying decision tree (Figure 3, Figure 4,
 407 Figure 6)

408

409 The uncertainties of the model predictions at landform types different from those at the
 410 study sites are derived from the values of the LS factor and the TWI. As the study sites,
 411 providing the data basis for modeling, are located on quite smooth slopes, the highest
 412 uncertainties appear at positions in gullies or on ridges. These topographical structures
 413 are clearly recognizable in the map illustrating the uncertainties of the model results
 414 (Figure 9).

415

416 **Figure 9** Uncertainties of the predictions related to LS factor and TWI.

417 **4. Discussion**

418 *4.1. Spatial distribution of enchytraeids and humus forms*

419 The occurrence of enchytraeids depends on factors such as soil pH, land use, soil
420 moisture, soil texture and soil organic matter content [19, 31-33]. The connections
421 between decomposer organisms like enchytraeids and humus forms are well known,
422 also from investigations at the landscape scale [34,35]. The results of our study reveal a
423 strong relationship between the occurrence of particular enchytraeid species and the
424 spatial distribution of forest humus forms also under climatic conditions of the Alps.
425 This relationship is obvious in all parts of the modeled areas except for north-facing
426 slopes at low elevation (Figure 5 and Figure 8). From our field experience this might be
427 due to a small-scale spatial mosaic pattern of varying conditions in the topsoil.

428 It has been previously shown that elevation and slope exposure have a major
429 influence on the spatial distribution of forest humus forms and enchytraeids in the high
430 mountains [36,37]. Our results confirm these findings and are in line with former
431 investigations of humus forms and soil organic matter in the study area [13,38,39]. The
432 spatial model we presented emphasizes the spatial patterns by yielding predictions for
433 the entire slope areas of the study area. The application of fuzzy logic facilitates the
434 representation of local spatial variability, as the percentage values reflect predicted
435 mean values at an area of 10x10 m².

436 In general, predicted percentages of moder/mor-indicating enchytraeids and related
437 forest humus forms with an OH horizon increase from low to high elevations and from
438 southern to northern exposures. At sites with high elevation and on north-exposed
439 slopes, low temperatures apparently hamper the activity of those decomposers
440 intermixing the topsoil and incorporating plant residues and humic substances into the
441 mineral soil [40].

442

443 *4.2. Model limitations*

444 Humus forms were distinguished regarding the presence of an OH horizon, in
445 consistence with the discrimination of enchytraeid species indicating mull and
446 moder/mor. Although common humus form classifications provide a variety of subtypes
447 [16,17,41], in this study we desisted from a further distinction. Those simplified
448 representations of humus forms and of the composition of the enchytraeid community
449 were necessary due to the relatively low number of study sites. These simplifications do
450 not allow the distinction of subtypes of humus forms or life forms of enchytraeids
451 indicating different intermediate stages between the two classes mull and moder/mor,
452 but enable the modeling of different degrees of similarity to both of these classes.

453 The validity of the model predictions is generally limited to areas between 1100 m
454 and 1800 m a.s.l. that are located inside the coniferous forest. As for the results of the
455 validation (from resampling and validation sites), they are ambiguous. The resampling
456 procedure reveals low variation in the model results, thus the structure of the models is
457 rather consistent. The analysis of the validation sites shows relatively high RMSE
458 values, whereas the deviations of the observed values from the modeled values are
459 relatively small (mostly up to ca. 25 percentage points). The highest deviations are
460 found at the sites V1 and V5. At site V1 this might originate from a small-scale mosaic
461 of varying topsoil conditions. At site V5 the development of mull conditions might be
462 promoted in comparison with S7 by gaps in the tree canopy, which potentially allows
463 for a better thermal absorption of the topsoil.

464 The sensitivity analyses show that effects of data modifications are attenuated in the
465 model predictions, as there are only a few cases where the structure of the decision tree
466 is moderately changed. This implies that the predictions do not deviate tremendously

467 from model results presented in our study even when assuming that the observations at
468 the study sites do not reflect the exact percentage values of humus forms with an OH
469 horizon and enchytraeid indicator classes. In general, these analyses confirm the
470 predicted trends related to elevation and slope exposure.

471 The analysis of uncertainties referring to the landform type accounts for possible
472 additional topographical influences on decomposition processes induced by erosion and
473 accumulation (LS factor) or the distribution of water within the soil (TWI). In order to
474 enhance the model a larger data basis is necessary, integrating sample sites with
475 concave and convex landforms as well as more detailed data on the litter composition
476 (e.g. a data layer differentiating various forest units).

477 Future research should also address the effects of the model scale on the results.
478 The investigations of this study refer to superordinate patterns of decomposition
479 processes at the landscape scale, including the slopes of several Alpine valleys.
480 However, decomposition processes show a considerable small-scale variability [42].
481 Thus we encourage investigations also at the slope scale, which should consider
482 subordinate influencing variables (e.g. forest units, areas of erosion or accumulation),
483 and at the local scale (e.g. 100 m²), where the micro-topography and local differences in
484 the ground vegetation should be regarded.

485 **5. Conclusion**

486 The spatial distributions of enchytraeids and forest humus forms in a study area in the
487 Italian Alps have been analyzed by means of a knowledge-based modeling approach,
488 accommodating a relatively small amount of data samples and a high spatial
489 heterogeneity of environmental variables. The predictions obtained from these models
490 distinctly show the effects of slope exposure on different conditions for decomposition,
491 which are characterized by the occurrence of different decomposer communities and
492 forest humus forms. The highest percentages of forest humus forms with OH horizon
493 occur at the uppermost north-exposed places inside the modeled area (up to 1800 m
494 a.s.l.), where also a high dominance of moder-indicating enchytraeids over mull-
495 indicating enchytraeids occurs. Those areas dominated by mull indicators are located at
496 the lowest south-exposed sites of the modeled area (down to 1100 m a.s.l.). The models
497 emphasize the coincidence of OH horizons with the related species of enchytraeids.
498 This implies a high potential not only of humus forms and enchytraeids to be used for
499 the prediction of decomposition patterns, but also of humus forms to serve as indicator
500 of the enchytraeid assemblage, at least in our study area.

501 Although the model considers the relatively small amount of sample data and the
502 small-scale variability of environmental conditions in the study area, the predictions are
503 subject to uncertainties, which in some places can be high. However, the model allows
504 the prediction of the overall trends in the distribution of forest humus forms and
505 enchytraeids because the selected study sites seem to be representative. In most cases
506 these trends were stable when modifying sample data in the context of a sensitivity
507 analysis. Uncertainties are usually to be expected in places where other environmental
508 factors than elevation and slope exposure influence decomposition processes greatly
509 (e.g. at landforms such as gullies and ridges).

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629 TABLES

630 **Table 1** Dominating humus forms and profiles at the investigation sites (N1-N3:
 631 northern slope exposure, S6-S8: southern slope exposure) (elevations according to Egli
 632 et al. [15])

Site	Elevation (m a.s.l.)	Dominating humus form according to German classification [16]	Dominating humus form according to determination key from Switzerland [17]	Typical humus profile
N1	1180	Mullartiger Moder	Hémimoder/ Eumoder/ Dysmoder/ Dysmull	OL-OF-(OH-)AE
N2	1390	Typischer Moder	Dysmoder	OL-OF-OH-AE
N3	1620	Typischer Moder	Dysmoder	OL-OF-OH-E
S6	1185	Mullartiger Moder	Eumésomphi / Dysmull	OL-OF-(OH-)A
S7	1400	Mullartiger Moder	Hémimoder	OL-OF-(OH-)AE
S8	1660	Mullartiger Moder/ Typischer Moder	Hémimoder	OL-OF-(OH-)AE

633

634 **Table 2** Microannelid species found in the samples and their classification as indicators
 635 of mull or moder humus forms in the model

Species	Indicator class
Enchytraeidae	
<i>Achaeta danica</i> Nielsen & Christensen, 1959	Moder
<i>Achaeta</i> sp. (dzwi)	Mull
<i>Bryodrilus ehlersi</i> Ude, 1892	Moder
<i>Buchholzia appendiculata</i> (Buchholz, 1862)	Mull
<i>Buchholzia simplex</i> Nielsen & Christensen, 1963	Mull
<i>Cognettia sphagnetorum</i> (Vejdovský, 1878)	Moder
<i>Enchytraeus buchholzi</i> Vejdovský, 1879	Mull
<i>Enchytraeus norvegicus</i> Abrahamsen, 1969	-
<i>Enchytronia christenseni</i> Dózsa-Farkas, 1970	Mull
<i>Enchytronia parva</i> Nielsen & Christensen, 1959	-
<i>Enchytronia</i> sp. (holo)	Mull
<i>Euenchytraeus bisetosus</i> Bretscher, 1906	Moder
<i>Fridericia auritoides</i> Schmelz, 2003	Mull
<i>Fridericia benti</i> Schmelz, 2002	Mull
<i>Fridericia bisetosa</i> (Levinsen, 1884)	Mull
<i>Fridericia bulboides</i> Nielsen & Christensen, 1959	Mull
<i>Fridericia christeri</i> Rota & Healy, 1999	Mull
<i>Fridericia connata</i> Bretscher, 1902	Mull
<i>Fridericia miraflores</i> Sesma & Dózsa-Farkas, 1993	Mull
<i>Fridericia paroniana</i> Issel, 1904	Mull
<i>Fridericia ratzeli</i> (Eisen, 1872)	Mull
<i>Fridericia stephensoni</i> Moszyński, 1933	Mull
<i>Fridericia waldenstroemi</i> Rota & Healy, 1999	Mull
<i>Fridericia</i> sp. juv.	Mull
<i>Hemifridericia parva</i> Nielsen & Christensen, 1959	Mull
<i>Henlea nasuta</i> (Eisen, 1878)	Mull
<i>Henlea perpusilla</i> Friend, 1911	Mull
<i>Marionina clavata</i> Nielsen & Christensen, 1961	Moder
<i>Mesenchytraeus glandulosus</i> (Levinsen, 1884)	-
<i>Mesenchytraeus pelicensis</i> Issel, 1905	Moder
Polychaeta	
<i>Hrabeiella periglandulata</i> Pizl & Chalupský, 1984	-

636

637 **Table 3** Data basis for modeling. Percentages of enchytraeid indicator classes and
 638 humus forms with an OH horizon have been aggregated from all sampling plots per
 639 investigation site. See Table S1 for data of sampling plots

Site	Number of sampling plots	Percentage of mull indicators to all microannelid individuals (%)	Percentage of moder indicators to all microannelid individuals (%)	Percentage of humus forms showing an OH horizon (%)
N1	6	15.07	44.93	18.33
N2	3	5.17	90.73	66.67
N3	6	20.53	73.55	90.00
S6	6 ^a	95.06	0.00	6.67
S7	3	62.12	5.31	50.00
S8	6	63.39	8.06	46.67

640 ^a At study site S6, the investigation of the enchytraeid indicator classes comprised only five samples

Table 4 Validation sites: topographic position and percentage values (observed and predicted) of modeled parameters

Site	Elevation (m a.s.l.)	Slope exposure	Observed value (%)	Predicted value (%)	Deviation (percentage points)
<i>OH horizon</i> (ME = 22.1 percentage points, RMSE = 26.3 percentage points)					
V1	1270	north	50.0	31.5	18.5
V2	1480	north	50.0	73.6	- 23.6
V3	1650	north	50.0	74.5	- 24.4
V4	1240	south	0.0	14.9	- 14.9
V5	1420	south	0.0	49.3	- 49.3
V6	1730	south	50.0	48.3	1.7
<i>Mull indicators</i> (ME = 26.1 percentage points, RMSE = 36.2 percentage points)					
V1	1270	north	90.2	9.9	80.3
V2	1480	north	0.0	14.5	- 14.5
V3	1650	north	0.0	21.4	- 21.4
V4	1240	south	88.3	76.2	12.1
V5	1420	south	87.5	63.6	23.9
V6	1730	south	60.9	56.6	4.3
<i>Moder indicators</i> (ME = 23.4 percentage points, RMSE = 30.1 percentage points)					
V1	1270	north	6.3	67.4	- 61.1
V2	1480	north	93.1	78.1	15.0
V3	1650	north	99.0	84.1	14.9
V4	1240	south	0.0	7.2	- 7.2
V5	1420	south	0.0	8.5	- 8.5
V6	1730	south	38.0	4.5	33.5

Table 5 Results of sensitivity analysis. Values represent the deviations of the predicted values in percentage points as compared to the unmodified models. Underlined values indicate an alteration in the structure of the underlying decision tree (Figure 3, Figure 4, Figure 6)

	Modified site					
	N1	N2	N3	S6	S7	S8
<i>OH horizon</i>						
Increase by 20 percentage points						
Mean	1.59	4.23	1.96	1.59	5.26	<u>10.38</u>
SD	3.33	3.75	1.80	3.33	3.57	<u>12.48</u>
Maximum	10.00	10.11	5.03	10.00	10.00	<u>29.99</u>
Minimum	0.00	0.00	0.00	0.00	0.00	<u>-19.92</u>
Decrease by 20 percentage points						
Mean	-1.46	<u>1.98</u>	-3.32	-0.53	-5.13	-5.13
SD	3.05	<u>11.56</u>	3.26	1.11	3.58	3.58
Maximum	0.00	<u>20.00</u>	0.00	0.00	0.00	0.00
Minimum	-9.17	<u>-29.92</u>	-9.91	-3.34	-10.01	-10.01
<i>Mull indicators</i>						
Increase by 20 percentage points						
Mean	<u>-0.20</u>	<u>2.27</u>	4.46	0.24	<u>5.33</u>	<u>4.29</u>
SD	<u>6.23</u>	<u>3.16</u>	6.00	1.07	<u>6.83</u>	<u>4.72</u>
Maximum	<u>26.73</u>	<u>11.92</u>	20.00	4.94	<u>18.47</u>	<u>12.13</u>
Minimum	<u>-11.96</u>	<u>-0.27</u>	-2.24	-1.05	<u>-6.94</u>	<u>-6.94</u>
Decrease by 20 percentage points						
Mean	-1.65	-0.58	<u>-5.00</u>	-0.94	-4.98	-4.98
SD	2.30	0.79	<u>5.89</u>	4.35	3.81	3.81
Maximum	0.40	0.03	<u>6.73</u>	4.52	0.01	0.01
Minimum	-7.59	-2.82	<u>-19.36</u>	-20.00	-11.90	-11.90
<i>Moder indicators</i>						
Increase by 20 percentage points						
Mean	0.87	1.77	3.70	<u>1.93</u>	<u>5.99</u>	<u>5.87</u>
SD	3.61	1.60	3.35	<u>3.10</u>	<u>5.22</u>	<u>8.01</u>
Maximum	20.00	4.69	10.00	<u>15.54</u>	<u>16.35</u>	<u>23.60</u>
Minimum	-3.06	-0.28	-1.04	<u>-0.24</u>	<u>-4.46</u>	<u>-3.68</u>
Decrease by 20 percentage points						
Mean	-0.98	-3.98	-3.98	- ^a	-0.97	-1.48
SD	3.57	3.58	3.58	- ^a	0.63	0.96
Maximum	2.17	0.15	0.15	- ^a	0.00	0.00
Minimum	-20.01	-10.90	-10.90	- ^a	-1.77	-2.69

^a No moder indicators were found at study site S6

649 **FIGURE CAPTIONS**

650 **Figure 1** Location of the study area in the Autonomous Province of Trento (Italy)

651 (modified from Egli et al. [15]).

652 **Figure 2** Life forms (H-type) of three selected enchytraeid species (modified from

653 Graefe and Schmelz [19]). Humus horizons are indicated by the numbers 1 to 4, humus

654 forms are indicated by the letters a to d as follows: MU = Mull, MOM = Mullmoder,

655 MO = Moder, RO = Mor (“Rohhumus”). The cells representing the typical habitat of

656 the species are colored in grey.

657 **Figure 3** Decision tree for the distribution model of enchytraeids indicating mull humus

658 forms. The upper value inside the tree nodes represents the projected percentage of mull

659 indicators in relation to all enchytraeids at this elevation and slope exposure, the lower

660 value n indicates the number of related samples.

661 **Figure 4** Decision tree for the distribution model of enchytraeids indicating moder

662 humus forms. The upper value inside the tree nodes represents the projected percentage

663 of moder indicators in relation to all enchytraeids at this elevation and slope exposure,

664 the lower value n indicates the number of related samples.

665 **Figure 5** Prediction of the areas of dominance of mull- and moder-indicating

666 enchytraeids.

667 **Figure 6** Decision tree for the distribution of forest humus forms showing an OH

668 horizon. The upper value inside the tree nodes represents the projected percentage of

669 humus forms with OH horizon in relation to all humus forms at this elevation and slope

670 exposure, the lower value n indicates the number of related samples.

671 **Figure 7** Weights applied for the fuzzification of the elevation. Dashed line: weighting
672 of the model below 1300 m a.s.l.; solid line: weighting of the model from 1300 m a.s.l.
673 upwards.

674 **Figure 8** Prediction of the spatial distribution of forest humus forms showing an OH
675 horizon.

676 **Figure 9** Uncertainties of the predictions related to LS factor and TWI.

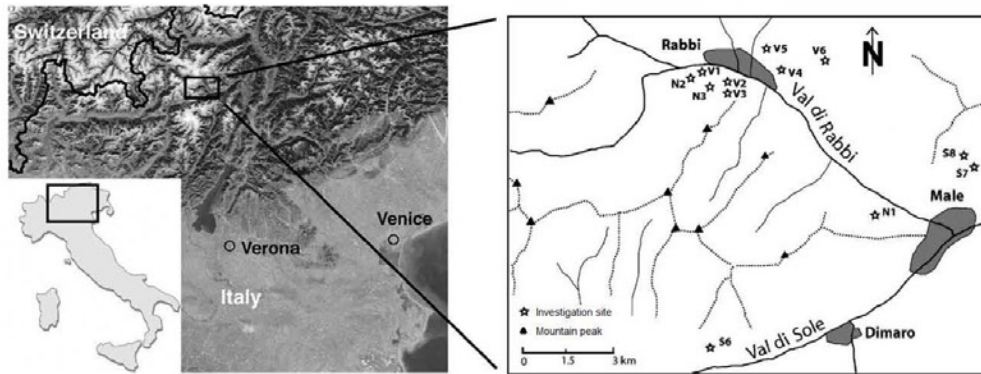


Figure 1 Location of the study area in the Autonomous Province of Trento (Italy) (modified from Egli et al. [15]).

	MU	MOM	MO	RO
OL	1a	1b	1c	1d
OF	2a	2b	2c	2d
OH			3c	3d
Ah	4a	4b	4c	4d

a) *Cognettia sphagnetorum*

	MU	MOM	MO	RO
OL	1a	1b	1c	1d
OF	2a	2b	2c	2d
OH			3c	3d
Ah	4a	4b	4c	4d

b) *Fridericia bulboides*

	MU	MOM	MO	RO
OL	1a	1b	1c	1d
OF	2a	2b	2c	2d
OH			3c	3d
Ah	4a	4b	4c	4d

c) *Enchytronia parva*

Figure 2 Life forms (H-type) of three selected enchytraeid species (modified from Graefe and Schmelz [19]). Humus horizons are indicated by the numbers 1 to 4, humus forms are indicated by the letters a to d as follows: MU = Mull, MOM = Mullmoder, MO = Moder, RO = Mor ("Rohhumus"). The cells representing the typical habitat of the species are coloured in grey.

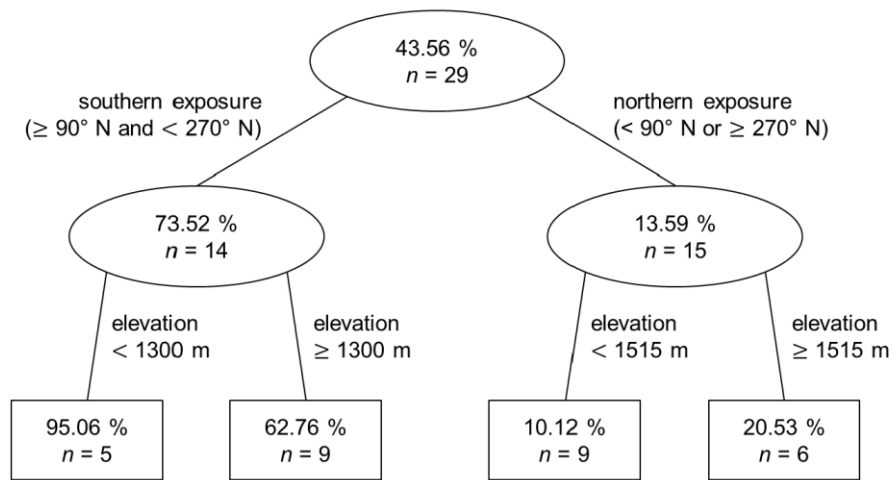


Figure 3 Decision tree for the distribution model of enchytraeids indicating mull humus forms. The upper value inside the tree nodes represents the projected percentage of mull indicators in relation to all enchytraeids at this elevation and slope exposure, the lower value n indicates the number of related samples.

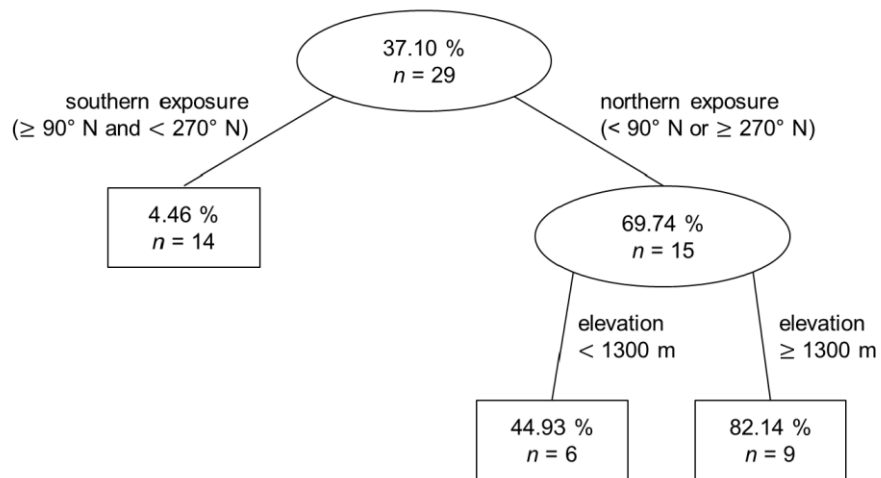


Figure 4 Decision tree for the distribution model of enchytraeids indicating moder humus forms. The upper value inside the tree nodes represents the projected percentage of moder indicators in relation to all enchytraeids at this elevation and slope exposure, the lower value n indicates the number of related samples.

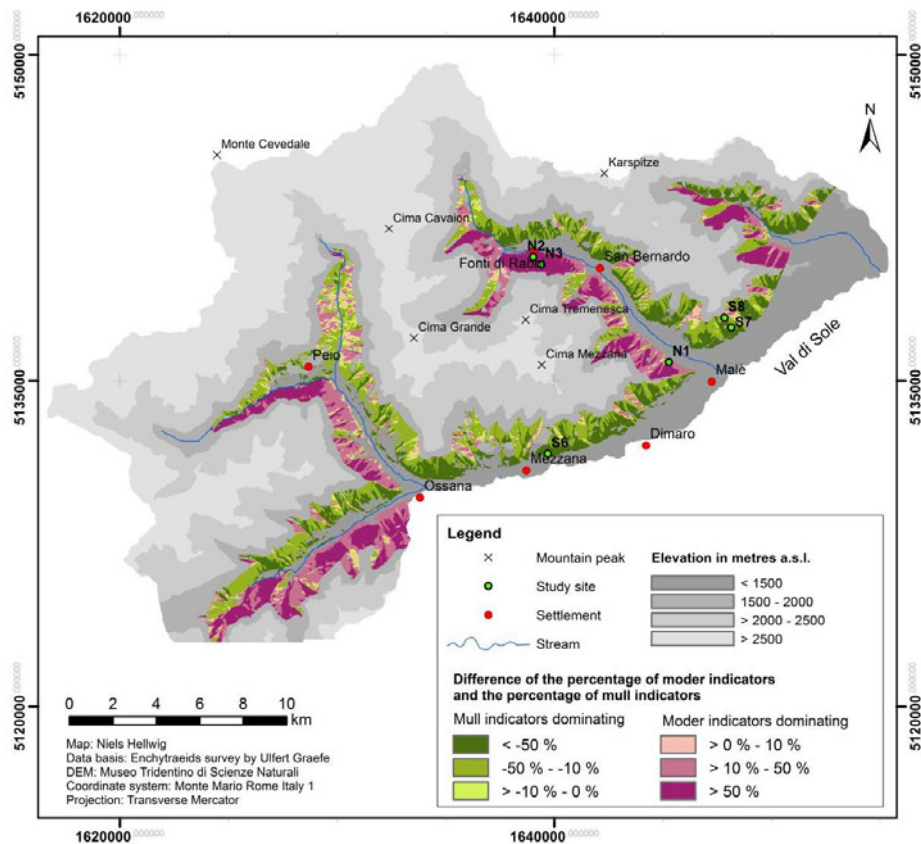


Figure 5 Prediction of the areas of dominance of mull- and moder-indicating enchytraeids.

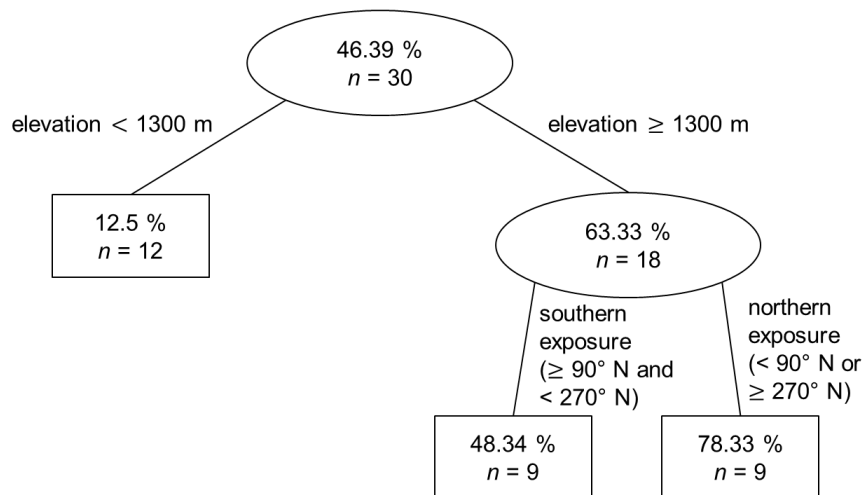


Figure 6 Decision tree for the distribution of forest humus forms showing an OH horizon. The upper value inside the tree nodes represents the projected percentage of humus forms with OH horizon in relation to all humus forms at this elevation and slope exposure, the lower value n indicates the number of related samples.

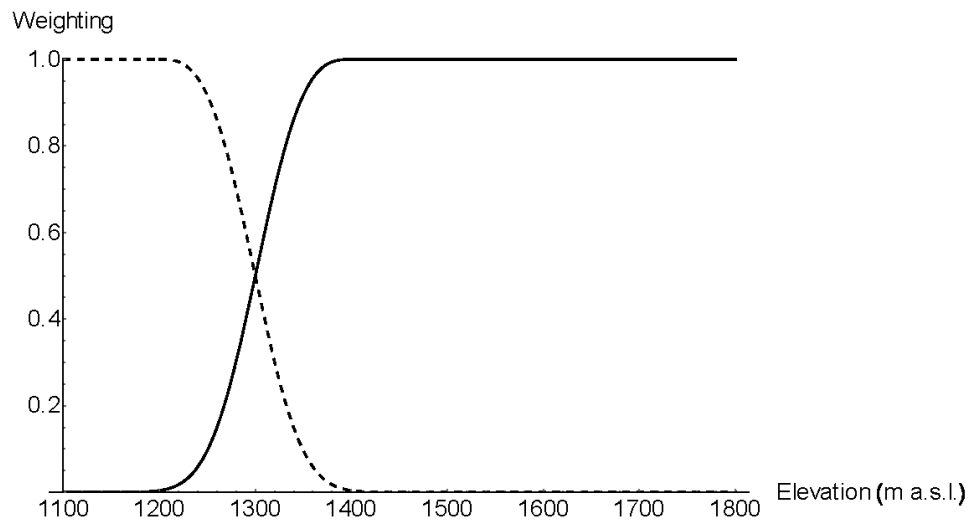


Figure 7 Weights applied for the fuzzification of the elevation. Dashed line: weighting of the model below 1300 m a.s.l.; solid line: weighting of the model from 1300 m a.s.l. upwards.

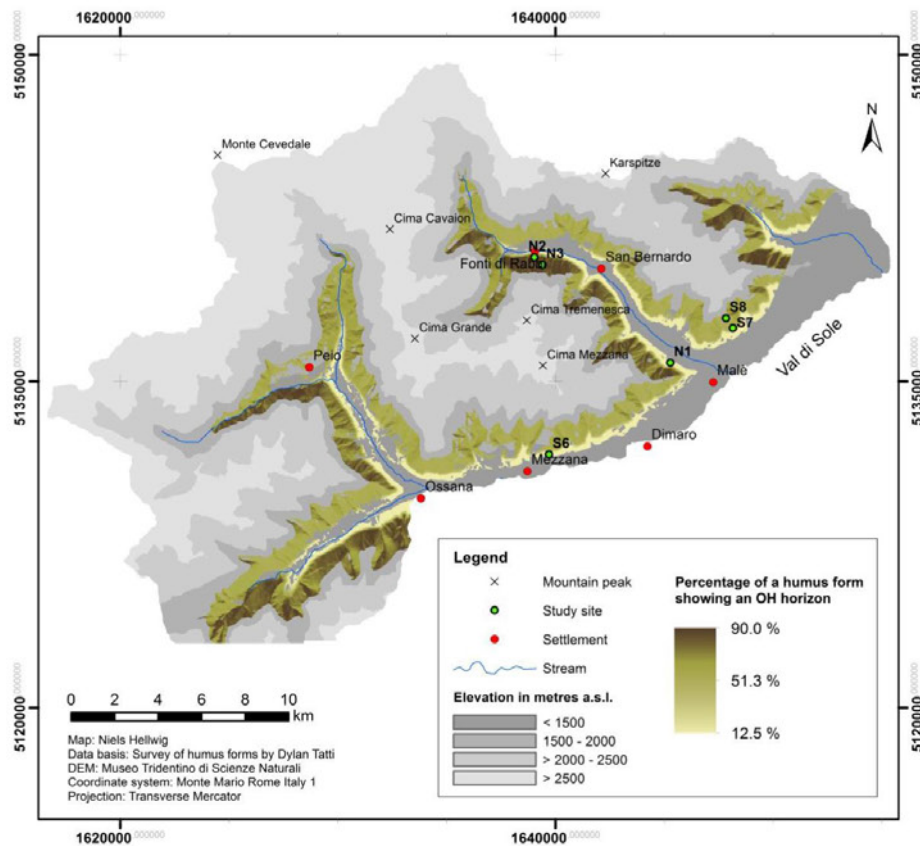


Figure 8 Prediction of the spatial distribution of forest humus forms showing an OH horizon.

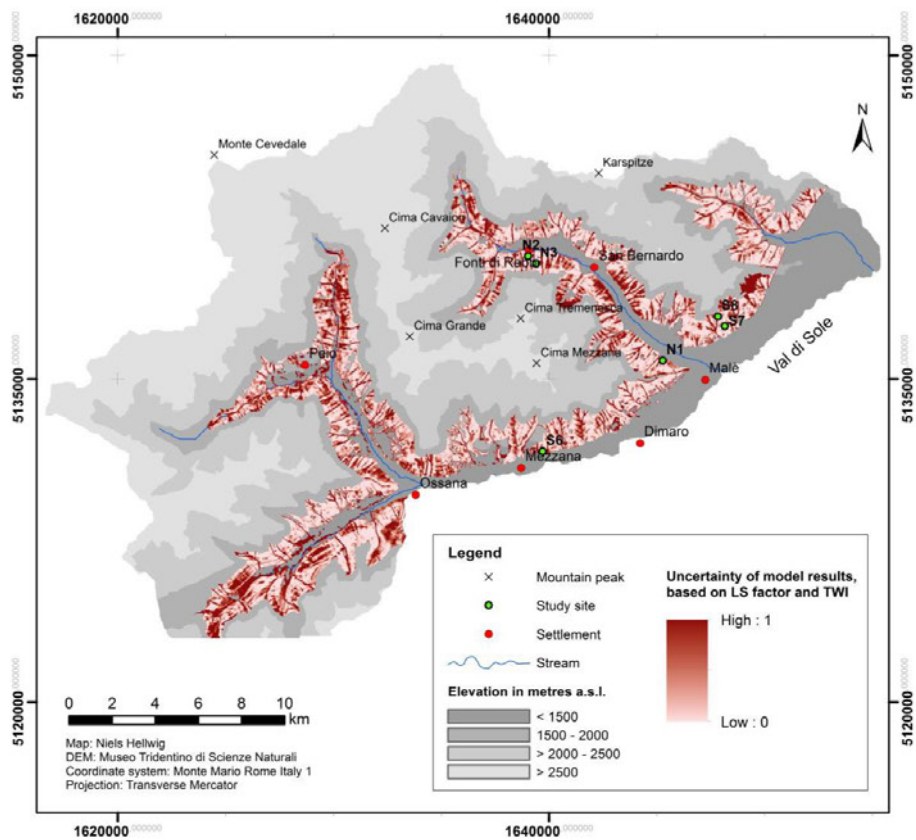


Figure 9 Uncertainties of the predictions related to LS factor and TWI.

Upscaling the spatial distribution of enchytraeids and humus forms in a high mountain environment on the basis of GIS and fuzzy logic

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Supplementary Material

Table S1 Sample data from the investigation sites N1-N3 (northern slope exposure) and S6-S8 (southern slope exposure)

Site	Soil cover types (weighting for aggregation)	Sample	Mull-indicating enchytraeids (%)	Moder-indicating enchytraeids (%)	Humus forms showing an OH horizon (%)
N1	moss (90 %)	M1	31.91	36.17	0.00
		M2	0.00	90.80	50.00
		M3	5.26	8.77	0.00
	fern (10 %)	F1	76.92	19.23	100.00
		F2	2.86	77.14	0.00
		F3	37.80	29.92	0.00
N2	moss (100 %)	M1	0.00	98.63	100.00
		M2	15.52	81.03	100.00
		M3	0.00	92.54	0.00
N3	grass (80 %)	G1	11.36	81.82	100.00
		G2	21.19	68.64	100.00
		G3	44.44	55.56	100.00
	moss (20 %)	M1	0.00	100.00	100.00
		M2	0.00	82.00	50.00
		M3	0.00	97.14	0.00
S6	litter (90 %)	L1	91.07	0.00	0.00
		L2	100.00	0.00	0.00
		L3	100.00	0.00	0.00
	grass (10 %)	G1	59.09	0.00	0.00
		G2	95.74	0.00	100.00
		G3	-	-	100.00
S7	grass (100 %)	G1	63.41	2.44	50.00
		G2	29.49	11.54	50.00
		G3	93.46	1.96	50.00
S8	litter (80 %)	L1	10.34	17.24	100.00
		L2	90.00	5.00	0.00
		L3	96.77	0.00	50.00
	grass (20 %)	G1	83.33	0.00	100.00
		G2	21.05	15.79	0.00
		G3	58.06	16.13	0.00

Table S2 Data basis for resampling

Model no.	Samples left out in resampled data set					
	N1	N2	N3	S6	S7	S8
1	M1, F1	M1	G1, M1	L1, G1	G1	L1, G1
2	M1, F1	M1	G2, M2	L1, G1	G1	L2, G2
3	M1, F1	M1	G3, M3	L1, G1	G1	L3, G3
4	M1, F1	M2	G1, M1	L1, G1	G2	L1, G1
5	M1, F1	M2	G2, M2	L1, G1	G2	L2, G2
6	M1, F1	M2	G3, M3	L1, G1	G2	L3, G3
7	M1, F1	M3	G1, M1	L1, G1	G3	L1, G1
8	M1, F1	M3	G2, M2	L1, G1	G3	L2, G2
9	M1, F1	M3	G3, M3	L1, G1	G3	L3, G3
10	M2, F2	M1	G1, M1	L2, G2	G1	L1, G1
11	M2, F2	M1	G2, M2	L2, G2	G1	L2, G2
12	M2, F2	M1	G3, M3	L2, G2	G1	L3, G3
13	M2, F2	M2	G1, M1	L2, G2	G2	L1, G1
14	M2, F2	M2	G2, M2	L2, G2	G2	L2, G2
15	M2, F2	M2	G3, M3	L2, G2	G2	L3, G3
16	M2, F2	M3	G1, M1	L2, G2	G3	L1, G1
17	M2, F2	M3	G2, M2	L2, G2	G3	L2, G2
18	M2, F2	M3	G3, M3	L2, G2	G3	L3, G3
19	M3, F3	M1	G1, M1	L3, G3	G1	L1, G1
20	M3, F3	M1	G2, M2	L3, G3	G1	L2, G2
21	M3, F3	M1	G3, M3	L3, G3	G1	L3, G3
22	M3, F3	M2	G1, M1	L3, G3	G2	L1, G1
23	M3, F3	M2	G2, M2	L3, G3	G2	L2, G2
24	M3, F3	M2	G3, M3	L3, G3	G2	L3, G3
25	M3, F3	M3	G1, M1	L3, G3	G3	L1, G1
26	M3, F3	M3	G2, M2	L3, G3	G3	L2, G2
27	M3, F3	M3	G3, M3	L3, G3	G3	L3, G3

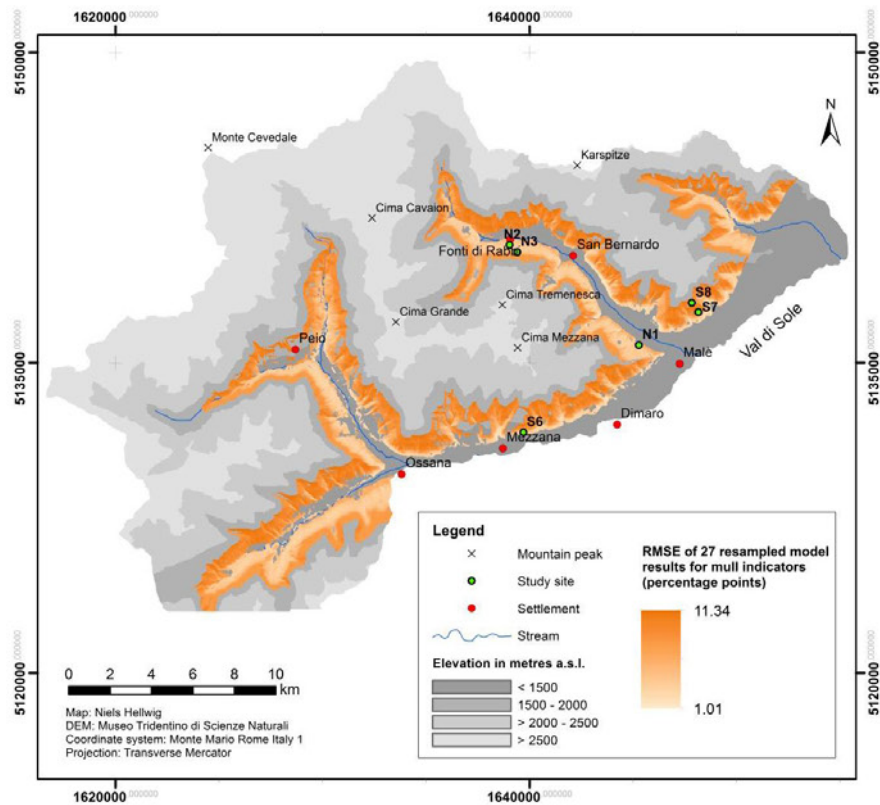


Figure S1 Spatial distribution of RMSE values of 27 resampled model results for mull-indicating enchytraeids.

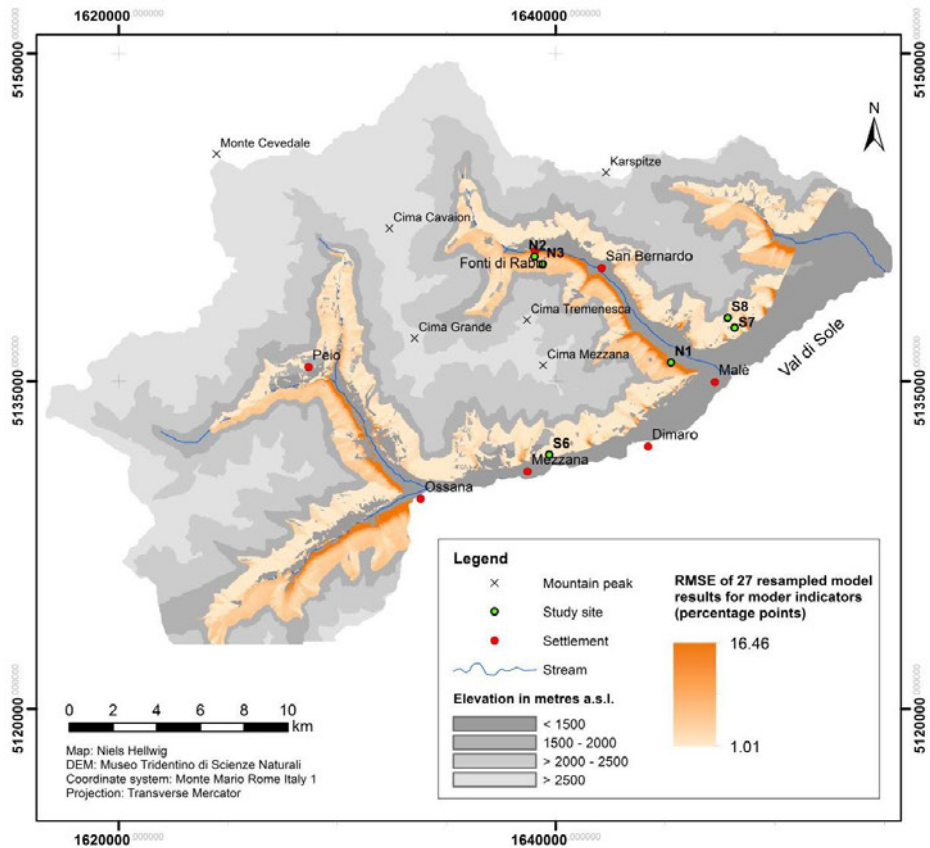


Figure S2 Spatial distribution of RMSE values of 27 resampled model results for moder-indicating enchytraeids.

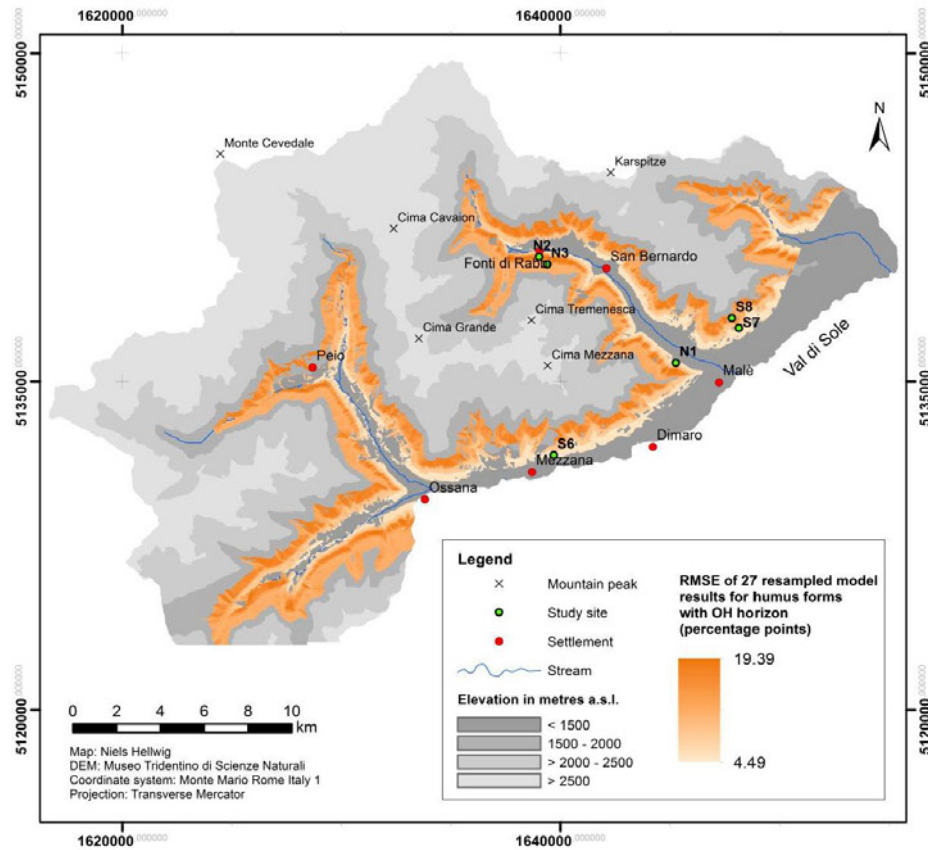


Figure S3 Spatial distribution of RMSE values of 27 resampled model results for forest humus forms showing an OH horizon.

C. POSTERS



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Context

Dead wood plays an **important role** in the majority of **terrestrial ecosystems** (C storage, highspot of biodiversity, slopes stabilisation...). Although essential part of the **forest carbon cycle**, processes concerning the **integration of dead wood into the soils** are **still largely unstudied**.

Summary

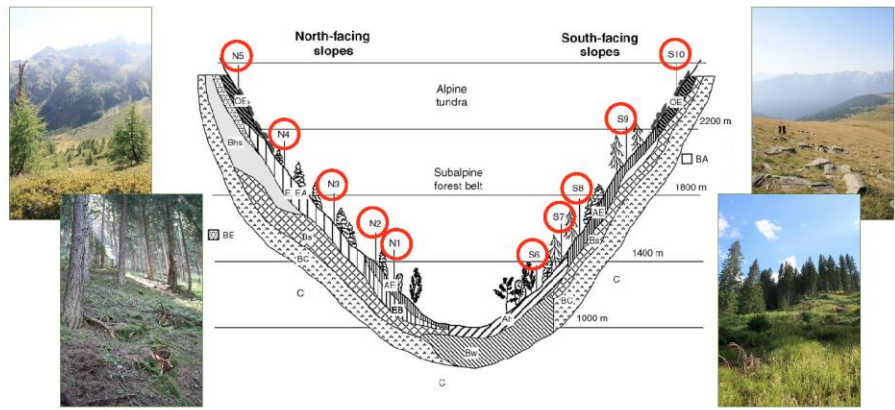
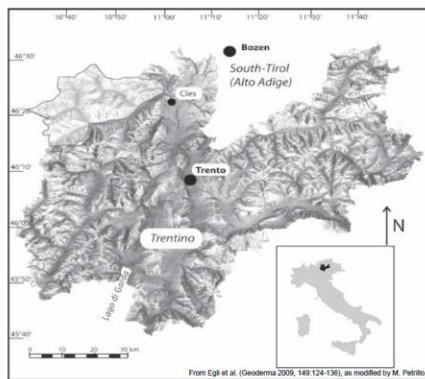
This project focuses on coarse woody debris (CWD) decomposition and integration into the soil via the first organic layers of the soil (called humus forms), under the action of living organisms and as a function of climate.

Research questions

are linked to the following topics:

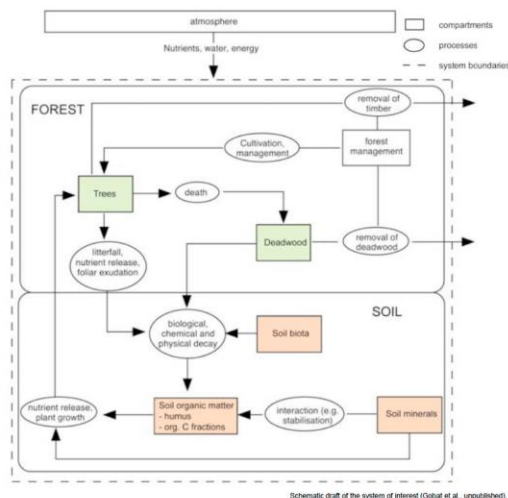
- Effect of climate on CWD decay above and especially in the soil of alpine sites?
- Time scales involved in CWD decay as a function of climate?
- Links between decay mechanisms and spatial distribution of humus forms?
- Can the humus forms serve as a proxy for the soil biota and for the spatial extrapolation?

Study sites



Modelisation

In order to better understand the different time- and spatial-scales involved and elaborate a decay model for coarse woody debris and its incorporation into the soil, research activities encompassed in this project can be grouped among distinct compartments.



Lignoforms

Research activities conducted in UNINE are mainly linked to the vegetation, soil fauna (earthworms) and humus forms, especially on the brand new topic of lignoforms (humus forms strongly linked to the decaying wood).



Räumliche Modellierung von Humusformen und Enchyträen in zwei italienischen Alpentälern auf der Basis von GIS und Fuzzy-Logik

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Fragestellung

Im D.A.C.H.-Projekt "Effect of climate on coarse woody debris decay dynamics and incorporation into the soils of forested Alpine areas" (DecAlp) werden bodenökologische Parameter untersucht, u. a. Humusformen und Enchyträengesellschaften. Ziel war die modellbasierte Erstellung von Prognosekarten für die Verbreitung von Oh-Horizonten und Enchyträen in der montanen Stufe. Die Enchyträen werden entsprechend ihres arttypischen Lebensraums als Moder- bzw. Mull-Indikatoren klassifiziert. Folgende Fragen sollen beantwortet werden:

- Wie wirken sich Höhe und Hangexposition auf die Ausbildung von Oh-Horizonten aus?
- In welchem Verhältnis kommen Enchyträenarten (Moder- und Mull-Indikatoren) in verschiedenen Höhen und Hangexpositionen vor?
- Stimmen die prognostizierten Gebiete mit einem hohen Anteil an Oh-Horizonten und einem hohen Vorkommen von Moder-Indikatoren überein?
- Wo sind die größten Unsicherheiten der Modellprognosen zu erwarten?

Schlussfolgerungen

- Die prognostizierten Anteile an Humusformen mit Oh-Horizont nehmen innerhalb des Waldes mit der Höhe zu (bis ca. 1900 m). Die höchsten Prognosewerte für Humusformen mit Oh-Horizont finden sich an nordexponierten Hängen.
- Das Vorkommen von Enchyträenarten zeigt einen Zusammenhang vor allem mit der Hangexposition. Moder-Indikatoren dominieren an nordexponierten Hängen, Mull-Indikatoren überwiegen bei Südexposition, vor allem in tieferen Lagen.
- Die Flächen der modellierten Verbreitung von Oh-Horizonten und den zugehörigen Enchyträenarten (Moder-Indikatoren) zeigen deutliche Übereinstimmungen.
- Die größten Unsicherheiten der Prognosen bestehen bei Geländeformen, die deutlich von denen der Untersuchungsstandorte abweichen.

Ergebnisse

Der prognostizierte Anteil an Humusformen mit Oh-Horizont liegt bei einer Höhe bis ca. 1200 m bei etwa 11 %, an Standorten ab ca. 1400 m bei etwa 63 % mit Nord- und 52 % mit Südexposition (Abb. 1). Im Enchyträen-Modell werden bei Nordexposition deutlich mehr Moder-Indikatoren prognostiziert (verbreitet mehr als 40 % Differenz zum Anteil an Mull-Indikatoren), bei Südexposition werden deutlich mehr Mull-Indikatoren vorhergesagt (verbreitet mehr als 10 % und z. T. mehr als 40 % Differenz zum Anteil an Moder-Indikatoren) (Abb. 2). Gemäß der Unsicherheitsanalyse sind die Prognosen besonders bei stark konkaven bzw. konvexen Geländeformen (Tal- und Rippenstrukturen) mit Vorsicht zu betrachten (Abb. 3).

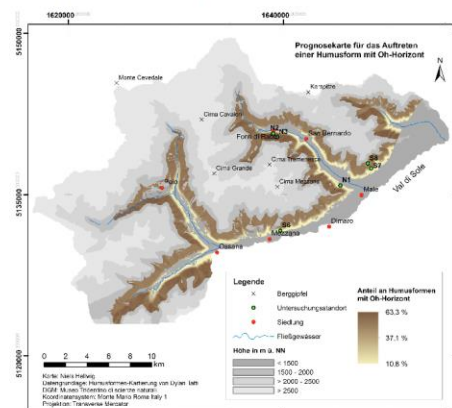


Abb. 1: Prognose für die Verbreitung von Humusformen mit Oh-Horizont

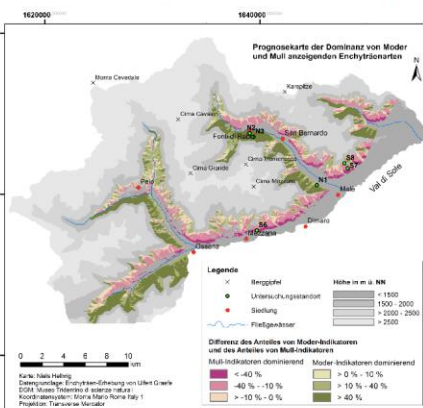


Abb. 2: Prognose für die Verbreitung von Enchyträengesellschaften

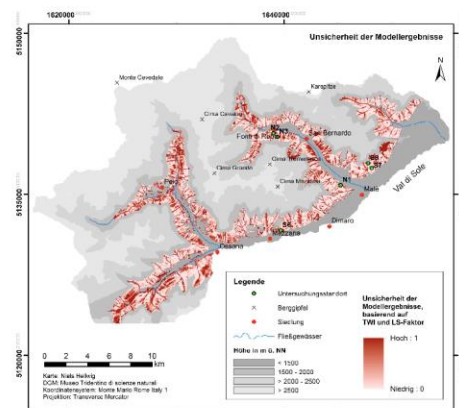


Abb. 3: Unsicherheit der Prognosen in Abhängigkeit von TWI und LS-Faktor

Untersuchungsgebiet und Standorte für die Datenerhebung

Das Untersuchungsgebiet (Abb. 4) umfasst die Waldbestände an den Hängen zweier italienischer Alpentäler. Betrachtet werden sechs Standorte (je drei verschiedene Höhenlagen in Nord- und Südexposition). Der vorherrschende Bodentyp ist Podsol (stärkere Ausprägung bei Nordexposition und größerer Höhe), Ausgangssubstrate sind überwiegend Paragneis und Orthogneis. Die dominierenden Baumarten sind *Larix decidua* und *Picea abies*.

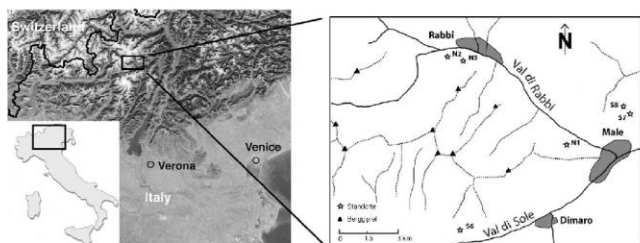


Abb. 4: Untersuchungsgebiet und Standorte in der Provinz Trentino (verändert nach Egli et al. 2006)

Literatur

- Breiman, L., Friedman, J. H., Olshen, R. A., Stone, C. J. (1984): Classification and regression trees. Wadsworth, Belmont.
- Egli, M., Mirabella, A., Sartori, G., Zanelli, R., Bischof, S. (2006): Effect of north and south exposure on weathering rates and clay mineral formation in Alpine soils. *Catena* 67, 155-174.
- Graefe, U., Schmelz, R. M. (1999): Indicator values, strategy types and life forms of terrestrial Enchytraeidae and other microannelids. *Newsletter on Enchytraeidae* 6, 59-67.
- Shi, X., Long, R., Dekett, R., Philippe, J. (2009): Integrating Different Types of Knowledge for Digital Soil Mapping. *Soil Science Society of America Journal* 73, 1682-1692.

Material und Methoden

Pro Standort wurden Humusformen und Enchyträen unter verschiedenen Ausprägungen der Krautschicht mit je drei Replikaten untersucht (insgesamt $n = 30$). Die Flächenanteile dieser Ausprägungen werden abgeschätzt und als Gewichtungen in der Modellierung verwendet. Die Prognose der Anteile an Enchyträen, die Moder- bzw. Mull-Humusformen anzeigen, basiert auf Indikatorwerten zur Lebensform von Enchyträenarten (Graefe & Schmelz 1999). Daten zu Höhe und Hangexposition liegen in einem 10x10-m-Raster vor (Abb. 5). Prognostiziert werden die Verbreitung von Oh-Horizonten sowie Moder- und Mull-Indikatoren als prozentuale Wahrscheinlichkeiten. Die Modellierung nutzt mit dem CART-Algorithmus (Breiman et al. 1984) erzeugte Entscheidungsbaume, deren Struktur ausschlaggebend ist für Fuzzy-Membership-Funktionen, die mit dem Tool ArcSIE (Shi et al. 2009) implementiert werden. Die Unsicherheiten der in ArcMap abgeleiteten Prognosekarten werden mit dem Topographic Wetness Index (TWI) und LS-Faktor (aus Hanglänge und Hangneigung) bewertet.

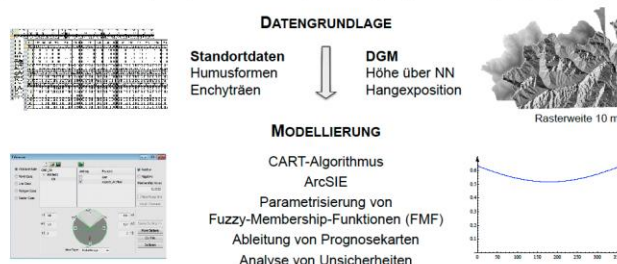


Abb. 5: Überblick über die angewendeten Methoden

Finanziert durch:



In Kooperation mit:



D. RÉSUMÉS DE CONFÉRENCES

D.1 VEGETATION AS BIOINDICATOR OF DECOMPOSITION IN A HIGH MOUNTAIN FOREST, ITALIAN ALPS ; 46TH ANNUAL MEETING OF THE ECOLOGICAL SOCIETY OF GERMANY, AUSTRIA AND SWITZERLAND

Abstract to be submitted to GFÖ 2016, Session “Forests – structures, dynamics, diversity”, Chair: Christian Ammer

Vegetation as bioindicator of decomposition in a high mountain forest, Italian Alps

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In high mountain forests, environmental conditions are very heterogeneous. Thus, decomposition processes show a high spatial variability, manifested in patterns of humus forms. Information on these patterns is often scarce, because field data on humus forms is difficult to obtain in high mountains. Our aim is to identify robust and time-efficient methods to use vegetation parameters as indicators of humus forms.

In the project “DecAlp” (“Effect of climate on coarse woody debris decay dynamics and incorporation into the soils of forested Alpine areas”), forests were studied in the Province of Trentino on siliceous parent material between ca. 900 and 2200 m a.s.l. They are dominated by Norway spruce and European larch. Vegetation relevés and humus forms were recorded at 153 plots. The vegetation parameters tested for their suitability as indicators of humus forms comprise mean Landolt indicator values of the various vegetation layers as well as structural parameters.

Mean Landolt indicator values for reaction as well as for humus, in both cases based on all herb layer species, show closest correlations with humus forms. Also, aggregated cover values of certain plant species groups within the herb layer (e.g. herbs excluding grasses and ferns; Ericaceae) display a close relationship with humus forms. Partly, these parameters can quickly be determined in the field without the need for detailed species identification. Hence, the use of vegetation data has the potential to increase our knowledge on spatial patterns of decomposition.

D.2. GIS-BASIERTE MODELLIERUNG VON HUMUSFORMEN UND ENCHYTRÄEN IN ZWEI ITALIENISCHEN ALPENTÄLERN ; JAHRESTAGUNG DER DEUTSCHE BODENKUNDLICHE GESELLSCHAFT, AG HUMUSFORMEN

Tagungsbeitrag zu: Jahrestagung der DBG, AG Humusformen

Titel der Tagung: Unsere Böden – Unser Leben

DBG, 5.-10. September 2015, München

Berichte der DBG (nicht begutachtete online Publikation)

<http://www.dbges.de>

GIS-basierte Modellierung von Humusformen und Enchyträen in zwei italienischen Alpentälern

Niels Hellwig¹, Ulfert Graefe², Dylan Tatti³, Kerstin Anschlag¹, Jean-Michel Gobat³, Gabriele Broll¹

Zusammenfassung

In einem Gebiet in den norditalienischen Alpen (Val di Sole / Val di Rabbi, Trentino) werden bodenökologische Zusammenhänge und Prozesse untersucht. Daten über Humusformen und die Enchyträengesellschaft liefern wertvolle Informationen zum Abbau der organischen Substanz. Ziel war die Entwicklung eines räumlichen Modells zur Erstellung von Prognosekarten für die Verbreitung von Oh-Horizonten und Enchyträen, klassifiziert in Moder- und Mull-Indikatoren gemäß ihrem arttypischen Lebensraum.

Mithilfe von Entscheidungsbäumen und Fuzzy-Logik werden Zugehörigkeitsfunktionen formuliert, die die Zusammenhänge des Auftretens von Humusformen und Enchyträenarten mit den Umweltvariablen Höhenlage und Hangexposition beschreiben und mit dem Software-Tool ArcSIE verarbeitet werden. Die Ergebnisse zeigen eine gute Übereinstimmung zwischen dem Auftreten von Oh-Horizonten und dem Vorkommen

von Moder-Indikatoren. Moderartige Humusformen finden sich überwiegend an höher gelegenen nordexponierten Lagen, mullartige Bedingungen dominieren an tiefer gelegenen südexponierten Standorten. Das Konzept der Fuzzy-Logik hat sich als geeignet für die Erstellung eines Modells im Hinblick auf die Fragestellungen herausgestellt, da dieses die Abbildung der hohen lokalen Variabilität in den Zersetzungsbedingungen ermöglicht.

Schlüsselwörter: Upscaling, Oh-Horizont, Entscheidungsbaum, Fuzzy-Logik, ArcSIE

Fragestellung

Im Rahmen des D.A.CH.-Projektes "Effect of climate on coarse woody debris decay dynamics and incorporation into the soils of forested Alpine areas" (DecAlp) werden bodenökologische Zusammenhänge und Prozesse untersucht. Daten über Humusformen und die Zusammensetzung der Enchyträengesellschaft liefern Informationen zum Abbau der organischen Substanz. Ziel war die Entwicklung eines räumlichen Modells für die montane Stufe (1100 m bis 1800 m ü. NN) zur Erstellung von Prognosekarten für die Verbreitung von Oh-Horizonten und Enchyträen, klassifiziert in Moder- und Mull-Indikatoren entsprechend ihrem arttypischen Lebensraum.

Folgende Fragen sollen beantwortet werden:

- Welche Auswirkungen haben die Höhe und die Hangexposition auf die Ausbildung von Oh-Horizonten und auf das Vorkommen von Enchyträenarten?
- In welchem Verhältnis kommen Enchyträenarten vor, die als Indikatoren für Auflage-Humusformen (Moder-Indikatoren) und für Mineralboden-Humusformen (Mull-Indikatoren) klassifiziert werden können?
- Inwiefern stimmen die Gebiete mit einem hohen prognostizierten Vorkommen von Moder-Indikatoren mit den Flächen überein, die in der Prognose einen hohen Anteil an Oh-Horizonten aufweisen?

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- Wie ist die Aussagekraft der Modelle einzuschätzen? Wie groß sind die Unsicherheiten der Prognose?

Untersuchungsgebiet und Standorte für die Datenerhebung

Das Untersuchungsgebiet befindet sich im Nordwesten der autonomen Provinz Trentino (Italien) und umfasst die an den Hängen gelegenen Waldbestände in den beiden Alpentälern Val di Sole und Val di Rabbi (Abb. 1). Für die Datenerhebung werden sechs Standorte betrachtet (auf je drei verschiedenen Höhen zwischen 1100 m und 1800 m ü. NN, jeweils in nördlicher und südlicher Hangexposition). Der vorherrschende Bodentyp ist Podsol (stärkere Ausprägung bei Nordexposition und größerer Höhe), Ausgangssubstrate sind überwiegend Paragneis und Orthogneis. Die dominierenden Baumarten sind Lärche (*Larix decidua*) und Fichte (*Picea abies*).

Material und Methoden

An jedem Standort wurden sowohl für die Untersuchung der Humusformen als auch der Enchyträen jeweils drei Replikate für verschiedene Ausprägungen der Krautschicht aufgenommen (insgesamt $n = 30$). Die Flächenanteile dieser Ausprägungen wurden abgeschätzt und als Gewichtungen für die zugehörigen Daten zu Humusformen und Enchyträen in der Modellierung verwendet.

Die Prognose der Anteile an Enchyträen, die Moder- bzw. Mull-Humusformen anzeigen, basiert auf Indikatorwerten zur Lebensform von Enchyträenarten (Graefe & Schmelz 1999). Für die Modellierung auf Landschaftsebene liegen Informationen zu Höhe und Hangexposition in einem 10x10-m-Raster vor.

Prognostiziert werden die Verbreitung von Oh-Horizonten sowie Moder- und Mull-Indikatoren als prozentuale Wahrscheinlichkeiten. Die Modellierung nutzt mit dem CART-Algorithmus (Breiman et al. 1984) erzeugte Entscheidungsbäume, deren Struktur ausschlaggebend ist für Fuzzy-Membership-Funktionen, die mit dem Tool ArcSIE (Shi et al. 2009) implementiert werden.

Die Unsicherheiten der in ArcMap abgeleiteten Prognosekarten werden mit den Reliefparametern Topographic Wetness Index (TWI) und LS-Faktor (zur Beschreibung des Erosionspotentials aus Hanglänge und Hangneigung) bewertet.

Ergebnisse

Die Prognosen für den Anteil an Humusformen mit Oh-Horizont variieren zwischen etwa 11 % und 63 %. Auf mittleren Höhen (ca. 1200 m bis 1400 m) zeigen sie einen deutlich ansteigenden Trend mit der Höhe. Oberhalb davon liegen die Prognosen bei Nordexposition mit etwa 63 % höher als bei Südexposition mit etwa 52 %. Im Enchyträen-Modell wird bei Nordexposition ein Vorkom-

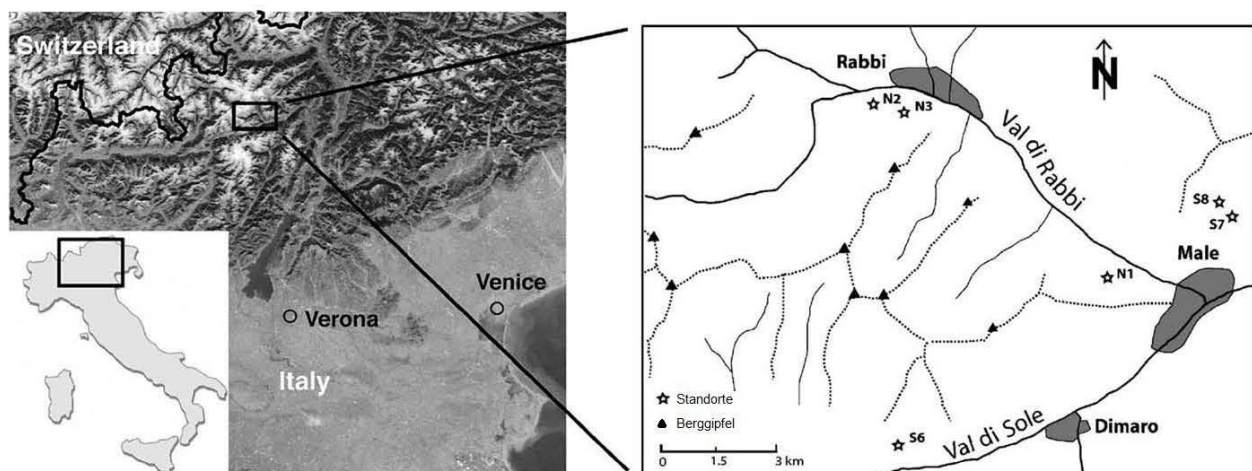


Abb. 1: Untersuchungsgebiet und Standorte der Datenerhebung (verändert nach Egli et al. 2006)

men von überwiegend Moder-Indikatoren vorhergesagt: Bis zu 86 % aller Enchyträen gehören zu den Moder-Indikatoren, der prognostizierte Anteil an Mull-Indikatoren erreicht dagegen ein Minimum von etwa 11 %. Bei Südexposition dominieren laut Prognose Mull-Indikatoren: Ihr Anteil an allen Enchyträen liegt bei bis zu 67 %, während der Anteil an Moder-Indikatoren nahe 0 % liegt. Gemäß der Unsicherheitsanalyse sind die Prognosen besonders bei stark konkaven bzw. konvexen Geländeformen (Tal- und Rippenstrukturen) mit Vorsicht zu betrachten.

Schlussfolgerungen

- Die Prognosen stellen die Abhängigkeit der Zersetzungsprozesse von Höhe und Hangexposition heraus.
- Die Flächen der modellierten Verbreitung von Oh-Horizonten und den zugehörigen Enchyträenarten zeigen deutliche Übereinstimmungen:
 - (1) Die höchsten Anteile an Oh-Horizonten finden sich an höher gelegenen Standorten mit Nordexposition, am wenigsten Humusformen mit Oh-Anteil ergaben die Modelle für niedrige Höhen.
 - (2) Als Moder-Indikatoren klassifizierte Enchyträenarten dominieren an nord-exponierten Hängen, an südexponierten Hängen überwiegen als Mull-Indikatoren klassifizierte Arten, vor allem bei geringerer Höhenlage.
- Fuzzy-Logik hat sich als geeignetes Mittel zur Modellierung von Indikatoren für Dekompositionsmerkmale erwiesen.
- Bei Modellierung auf Landschaftsebene auf der Basis einer geringen Menge an Untersuchungsstandorten helfen Entscheidungsbäume bei der Aufdeckung der Einflüsse von Umweltfaktoren.
- Die Fuzzifizierung der Ergebnisse der Entscheidungsbaumanalyse ermöglicht ein kontinuierliches Modell, ist aber mit Unsicherheiten entsprechend der Datenglage verbunden.

Danksagung

Die vorgestellten Untersuchungen sind Teil des D.A.CH.-Projektes DecAlp. Dieses wird finanziert durch die nationalen Forschungsfonds DFG (Deutsche Forschungsgemeinschaft), FWF (Fonds zur Förderung der wissenschaftlichen Forschung) und SNF (Schweizerischer Nationalfonds).

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