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1 **Humus forms as a synthetic parameter for ecological investigations. Some examples in**
2 **the Ligurian Alps (North-Western Italy)**

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7
8 **Abstract**

9 In the Ligurian Alps, a wide range of site conditions that influence soil development and may
10 affect humus variability are present. In this work, we wanted to evaluate the potentialities of
11 humus forms as a synthetic indicator of both chemical properties of the humic episola and site
12 conditions in the upper Tanaro Valley (NW Italy). Vegetation affected the C/N ratio of the least
13 transformed organic horizons, but the effect disappeared in mineral ones, where the pH was
14 related to the soil parent material. All terrestrial humus forms were found in the area and their
15 distribution well reflects the interactions between vegetation, lithology, elevation that shape soil
16 properties and affect the degradability of litter and its actual degradation by microorganisms
17 and soil fauna. Humus forms were thus able to capture the ecological conditions, providing
18 additional information with respect to soil classifications.

19 **Highlights**

- 20 • The Ligurian Alps represent a transition between the Mediterranean and the temperate
21 climate.
- 22 • All humus systems are present and Amphis are relatively abundant
- 23 • Humus forms reflect the interaction between site and soil conditions

- 24 • Humus forms were able to capture the ecological variability and synthesize it in a single
25 parameter

26

27 Keywords: forest cover, soil parent material, climate, soil organic matter

28

29 **1. Introduction**

30 In the Ligurian Alps, the Mediterranean and temperate climatic regimes merge, giving rise to
31 unique environmental conditions in the geographical Alpine area. Vegetation distribution
32 reflects micro-environmental conditions, shaped by the influence of marine breezes,
33 atmospheric humidity and thick, though often transient, snow cover during wintertime
34 (Jefferson, 2011). In a relatively small area, soils vary from poorly developed Regosols to
35 desaturated Alisols, from Podzols to Terra Rossa soils, depending on present or past climatic
36 conditions, geomorphology, vegetation and lithology and their interactions (Catoni et al., 2016;
37 D'Amico et al., 2015).

38 Humus forms are useful and inexpensive indicators of the complex interactions between the
39 soil forming factors (such as climate, vegetation, relief, and geology) and the soil environment
40 (Ponge et al., 2014). Vegetation has indeed a direct effect on litter degradability and
41 transformations (e.g. Bonifacio et al., 2008), while climate and parent material have a major
42 influence on soil biological and microbiological activity (e.g. Ponge et al., 2011). The description
43 of humus forms may thus help in elucidating ecological conditions in complex environments
44 adding therefore to the information provided by soil classifications.

45 The aim of this work is therefore to show how the humus forms can be used as a synthetic
46 indicator of environmental variable interactions in a valley of the Ligurian Alps.

47

48 **2. Materials and Methods**

49 The upper Tanaro Valley, at the border between Piemonte and Liguria Regions, in Italy, was
50 the object of an extensive soil survey in the last years, that encompassed the villages of Ormea,
51 Briga Alta, Caprauna, Garessio and Triora, with an area of approximately 280 km². Thanks to
52 a low anthropogenic pressure and a generally low altitude, the area is mainly covered by
53 forests. The most common forest species is beech (FS, *Fagus sylvatica* L.), covering around
54 30% of the forest surface. Chestnut (CS, *Castanea sativa* Mill.), Scots pine (PS, *Pinus sylvestris*
55 L. or *Pinus montana* Mill.) and hornbeam-ash associations (FO, *Fraxinus ornus* L. and *Ostrya*
56 *carpinifolia* Scop) represent approximately 10-15% of forest surface each, while a lower
57 percentage of the area (around 5%) is occupied by larch (LD, *Larix decidua* Mill) and silver fir
58 (AA, *Abies alba* Mill.) forests.

59 Twenty sites were selected as examples amidst a much larger (70) number of observations to
60 describe humus forms that represent the most common forest cover and lithology types in the
61 area. Seven sites were under FS, 4 under PS, 3 under CS, 2 in LD- and FO-dominated sites,
62 and 1 under AA. From the geological point of view, all sites were located on either the Ligurian
63 Briançonnais domain (quartzite or metamorphic quartzitic porphiroids, QTZ, or limestone-
64 dolostone, LIM) or the Helminthoides Flysch units (FLY). The sites range in elevation from 800
65 to 1730 m a.s.l. At all sites, pits were opened and soil profiles were described, analyzed and
66 classified according to the WRB (IUSS Working Group WRB, 2014). Humus forms were
67 described following Zanella et al. (2011).

68 The C and N contents of all samples from the humic episolum were analyzed with an element
69 analyzer (NA2100, CE Instruments, Rodano, Italy) and pH was determined in water.

70 Differences in chemical properties related to vegetation or parent material were evaluated
71 through analysis of variance (oneway ANOVA) using IBM SPSS Statistics 23. In case of
72 significance of the ANOVA model, differences among groups were assessed through the
73 Duncan test.

74 Table 1 provides a summary of the site characteristics and soil types at sampling points.
75

76 **3. Results and Discussion**

77 Despite the variability in site factors, the pH values had a quite narrow range, particularly in the
78 OL and OF horizons (from 5.1 to 6.5), while the variability increased in the mineral horizons of
79 the episolum (from 4.8 to 7.3, Table 2), where a significant effect of soil parent material was
80 found (7.3 ± 0.99 on LIM and 4.84 ± 0.96 on QTZ, $p < 0.01$). In the OL horizons, the C contents
81 did not differ significantly with vegetation types ($p = 0.268$), but a forest cover effect was visible
82 in the N contents ($p < 0.05$), with the lowest values under pine (Table 2), and consequently in
83 the C/N ratio ($p < 0.01$). The highest C/N ratio in OL layers was found under Scots pine (60.6),
84 but it was above 40 also in fir (48.2) and beech (42.3). The effect of vegetation was less visible
85 in OF and OH horizons, where only the C/N ratio was significantly different ($p < 0.01$ in OF and
86 $p < 0.05$ in OH, Table 2), and almost disappeared in the mineral horizons ($p = 0.047$). This is in
87 agreement with the complexity of the system controlling organic matter and its interactions with
88 the mineral phase in the soils of the area that sharply affect its degradability (Catoni et al.,
89 2016).

90 All Humus systems were found in the study area without, as expected, any clear dependence
91 on vegetation cover nor on soil parent material as single influencing variables (Table 3). Amphis

92 were common, in agreement with the diffusion of this humus form in Italy pointed out by
93 Andreetta et al. (2016).

94 In the case of Scots pine stands (PS), humus forms illustrated quite well the interaction between
95 vegetation and lithology: the low degradability of pine litter, related to its low N contents,
96 originated Pachyamphi forms on limestones, where a higher pH favored biological activity. At
97 the same elevation, a Dysmoder developed on quartzitic rocks (Figure 1) and, where higher
98 elevation added to the poor degradability of pine litter and acidity of the parent material, a
99 Hemimor formed (Figure 2). Humus forms thus mirrored the variability of ecological conditions
100 when the lack of specific pedogenic processes and the limited soil development originated soils
101 belonging to the same WRB group (Cambisols on both LIM and QTZ at around 1200 m, Table
102 1). The potentiality of humus forms as ecological indicators of interactions between site and soil
103 properties was emphasized in the beech stands (FS, Figure 3a). Amphi forms were present on
104 limestones where a good biological activity was coupled with the low degradability of beech
105 litter. Biological activity allowed the development of biomacro A horizons and Leptoamphi
106 humus forms at the lowest elevation (830 m a.s.l.), while biomeso A were present at 1200-1400
107 m, with Eumesoamphi and Pachyamphi forms (Figure 3b). Beech litter is well known for having
108 a high lignin/N content, coupled with relatively low contents of basic cations and N (Jacob et
109 al., 2010; Lagenbruch et al., 2012), and its ability to acidify the soil may be even comparable to
110 that of conifers (Augusto et al., 2002). This effect was clearly visible from humus forms in the
111 study area: Podzols with well developed E horizons were found in beech stands on quartzite,
112 where humus belonging to the Mor system were present. Similar situations were observed in
113 the chestnut stands (CS), with the shift from Oligomull and Eumesoamphi (at ~ 900-1000 m
114 a.s.l.) to Hemimoder (1100 m a.s.l.) with increasing elevation and acidity of the soil parent

115 material. In forests belonging to the hornbeam-ash associations (FO), humus forms seemed to
116 reflect more the litter characteristics than other site or soil factors, such as lithology or soil pH.
117 At 800-900 m, Amphiforms with biomacro A horizons were present both on calcareous and
118 acidic rocks, with only slight differences in OH thickness. Larch forests (LD) were used as
119 pasture in the study area, particularly in the past, and were thus characterized by abundant
120 grass cover. The high degradability of herbaceous litter, coupled with limestones, was likely the
121 determinant factor for the occurrence of Mull forms, despite the high elevation of the two sites
122 (e.g. 1640 and 1670 m). At approximately the same elevation, on the same parent material, a
123 Hemimoder humus developed under silver fir (AA) (Table 3).

124 The interactions among site factors are summarized in Figure 4, where a clear gradient towards
125 less biologically active humus forms with increasing climatic or soil fertility limitations is visible.

126

127 **4. Conclusions**

128 In the Ligurian Alps, the distribution of humus form seems to be shaped by the concomitant
129 action of vegetation, lithology, and elevation that drives the degradability of litter and affects its
130 actual decomposition by microorganisms and soil fauna. Although in some cases one of the
131 factors dominates, more frequently humus forms well reflect the complex interactions between
132 site and soil factors. Humus forms represent therefore a synthetic and inexpensive indicator for
133 the interpretation of ecological conditions in the forest ecosystems of the Ligurian Alps.

134

135 **5. Acknowledgements**

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138

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172

173 Table 1. Forest cover, lithology, elevation and soils at sampling points

Vegetation [†]	Lithology [‡]	Soil types
PS	LIM	Folic Cambisol (1200 m)
	FLY	Cutanic Alisol (1320 m)
	QTZ	Haplic Cambisol (1230 m), Ortsteinic Albic Podzol (1730 m)
FS	LIM	Calcic Chernozem (840 m), Cutanic Luvisol (1230 m), Haplic Cambisol (1410 m)
	FLY	Haplic Regosol (1310 m)
	QTZ	Albic Podzol (1300 m), Haplic Regosols (1020, 1240 m)
CS	FLY	Haplic Regosols (880, 1030 m), Cutanic Luvisol (970 m)
	QTZ	Cutanic Escalic Luvisol (1100 m)
LD	LIM	Haplic Cambisol (1640 m), Haplic Regosol (1670 m)
AA	LIM	Haplic Regosol (1610 m)
FO	LIM	Calcic Kastanozem (800 m)
	QTZ	Haplic Cambisol (890 m)

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175 † PS: *Pinus sylvestris* L. or *Pinus montana* Mill.; FS: *Fagus sylvatica* L.; LD: *Larix decidua* Mill. associated with
 176 grassland; AA: *Abies alba* Mill., FO: *Fraxinus ornus* L. and *Ostrya carpinifolia* Scop. association; CS: *Castanea*
 177 *sativa* Mill.

178 ‡ FLY: Helminthoides Flysch Unit; LIM: limestone and/or dolostone; QTZ: quartzite or porphiroids.

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Table 2. Chemical characteristics of the horizons of the humic episola (average \pm standard deviation) in the different forest sites. Different letters indicate significant differences among vegetation types ($p < 0.05$, Duncan test)

		n	pH	C	N	C/N
				g kg ⁻¹	g kg ⁻¹	
PS[†]	OL	3	5.1 \pm 0.3	463.3 \pm 40.2	7.8 \pm 1.1 b	60.6 \pm 12.6 a
	OF	3	5.5 \pm 0.7	356.6 \pm 91.9	10.8 \pm 2.2	32.6 \pm 2.2 a
	OH	3	5.2 \pm 1.2	327.4 \pm 50.0	9.6 \pm 1.8	34.3 \pm 1.5 a
	A or E	4	5.2 \pm 1.7	60.7 \pm 23.2	2.2 \pm 1.1	29.5 \pm 8.7 a
FS	OL	7	5.7 \pm 0.4	435.6 \pm 28.0	10.6 \pm 1.9 ab	42.3 \pm 7.6 b
	OF	7	6.1 \pm 0.6	366.2 \pm 67.7	13.4 \pm 1.7	27.2 \pm 2.0 b
	OH	4	6.2 \pm 1.1	266.0 \pm 66.0	11.7 \pm 2.1	22.7 \pm 3.5 b
	A or AE	7	5.9 \pm 1.4	62.4 \pm 37.9	3.8 \pm 2.5	17.8 \pm 4.3 ab
CS	OL	4	4.9 \pm 0.6	454.0 \pm 17.2	13.0 \pm 2.0 a	36.0 \pm 5.7 b
	OF	3	5.8 \pm 0.2	255.0 \pm 59.0	11.4 \pm 3.0	22.5 \pm 0.8 c
	OH	1	5.9	262.7	10.0	26.3
	A	4	4.8 \pm 0.6	24.5 \pm 6.4	1.8 \pm 1.1	17.6 \pm 9.0 ab
LD	OL	2	5.5 \pm 1.0	340.4 \pm 173.9	12.4 \pm 1.4 a	26.9 \pm 11.1 b
	OF	1	5.6	359.7	14.8	24.4
	A	2	5.9 \pm 0.4	81.3 \pm 3.8	5.9 \pm 0.9	13.8 \pm 1.5 b
AA	OL	1	6.5	416.9	8.7	48.2
	OF	1	6.1	258.3	8.6	30.1
	A	1	7.2	82.7	3.2	25.9
FO	OL	2	5.8 \pm 0.4	426.2 \pm 13.2	13.7 \pm 3.3 a	32.1 \pm 6.8 b
	OF	1	6.3	372.6	14.3	26.1
	OH	1	7.1	349.1	16.3	21.4
	A	2	7.1 \pm 1.1	35.4 \pm 19.7	2.8 \pm 2.2	14.7 \pm 4.5 b

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184 † PS: *Pinus sylvestris* L. or *Pinus montana* Mill.; FS: *Fagus sylvatica* L.; LD: *Larix decidua* Mill. associated with
185 grassland; AA: *Abies alba* Mill., FO: *Fraxinus ornus* L. and *Ostrya carpinifolia* Scop. association; CS: *Castanea*
186 *sativa* Mill.

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189 Figure 1: Dysmoder under Scots pine on acidic parent material

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194 Figure 2: Hemimor in pine forest at high elevation



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196 Figure 3: A beech stand at 1200 m a.s.l in the Ligurian Alps (a) with *Pachiamphy* humus form
197 (b)



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201 Figure 4: Distribution of humus forms in the Ligurian Alps under the influence of vegetation,
 202 lithology and elevation. Vegetation types have increasing C/N ratio from left to right, site
 203 conditions become harsher from top to bottom and, for each species, with increasing color
 204 saturation. Number in parentheses are pH and C/N ratio of the mineral horizon.

205

	LD		FO		CS		FS		AA		PS		
elevation (m asl)	LIM		LIM	QTZ	FLY	QTZ	LIM	FLY	QTZ	LIM	LIM	FLY	QTZ
800			EumeA (7.9-11.5)				LeptoA (8.1-14.8)						
900				LeptoA (6.3-17.9)	OliMu (5.7-11.3)								
1000					EumeA (4.4-10.9)				DysMu (5.7-14.8)				
1100						HeMd (4.6-18.0)							
1200							PachyA (7.4-15.4)		HeMd (4.6-16.9)		PachyA (7.7-22.0)		DysMd (4.2-42.0)
1300								OliMu (5.7-15.7)	HuMor (4.1-26.9)			HeMd (4.8-25.9)	
1400							EumeA (5.4-19.0)						
1500													
1600	OliMu (6.2-12.7)									HeMd (7.2-25.8)			
1700	DysMu (6.1-15.7)												HeMor (4.0-28.0)

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207 PS: *Pinus sylvestris* L. or *Pinus montana* Mill.; FS: *Fagus sylvatica* L.; LD: *Larix decidua* Mill.
 208 associated with grassland; AA: *Abies alba* Mill., FO: *Fraxinus ornus* L. and *Ostrya carpinifolia*
 209 Scop. association; CS: *Castanea sativa* Mill. - FLY: Helminthoides Flysch Unit; LIM: limestone
 210 and/or dolostone; QTZ: quartzite or porphiroids – OliMu: Oligomull, DysMu: Dysmull, LeptoA:
 211 Leptoamphi, EumeA: Eumesoamphi, PachyA: Pachyamphi, HeMd: Hemimoder; DysMd:
 212 Dysmoder; HuMor: Humimor, HeMor: Hemimor

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