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Can ecoindicators be a tool to reduce and understand complexity of plant communities?

Abstract

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In this study we consider the use of ecoindicators to explain the complex relationships between vegetation and humus in forest ecosystem from all the Italian Peninsula. In particular we concentrate the study on the rarely applied indicators of Rogister's: RxN and R/N, that would represent the humus quality of soil. They are derived from the Ellenberg Indicator Values (EIV), R and N (R = Reaction, N = Nutrients). The aim of the study was to test their effectiveness to distinguish vegetation types and to define meaningful gradients related to humus quality (forms). The focus on the role of humus is justified by the fact that it is a direct result from the interaction between the type of soils and the components of ecological communities of which the plants are playing the primary role. We considered a dataset of 789 forest vegetation relevés (489 obtained from a data base and 300 made by us) and 847 species that we described by all the EIV and by the two Rogister indicators (RO). We grouped the relevés in 9 vegetation types according to the dominance of the most important and common tree species of Italy (1. *Quercus suber*, 2. *Q. ilex*, 3. *Q. pubescens*, 4. *Q. cerris* and *Q. cerris-Q. Frainetto*, 5. *Carpinus betulus*, 6. *Fagus sylvatica*, 7. *Picea abies*, 8. *Abies alba*, 9. Hygrophilous woodlands with *Salix* spp., *Populus* spp., *Fraxinus oxycarpa* and *Alnus glutinosa*) and we have used the evenness of the eigenvalues of the similarity matrices (Eλ), obtained by EIV and RO to test the separation between the 9 types. Eλ proved that the two Rogister's indexes resulted more predictive than EIV. The analysis of the collected humus forms in the field confirms that the Rogister's indicators are effective to identify the functionality of the humus forms and proves their correspondence with vegetation types: the Amphi humus is dominating in evergreen Mediterranean forests, Moder in mixed deciduous forests, Mull in *Fagus sylvatica/Carpinus betulus* and in hygrophilous forests, Mor in boreal forests.

Key words: Italian forests, Rogister Model, Humus, Vegetation.

This we know
That all things are related
like blood
that unifies a family.
Everything that happens to the Earth
it happens to the sons and daughters of the Earth.
Man does not weave the weft of life;
in it he is only a thread.
Whatever it does to the weft,
man does it to himself.

Chief Seattle

Initial Remarks

The study of complexity as well as of ecoindicators is much loved by Sandro Pignatti, who has never been satisfied with the mere classification of species and communities, searching in systems theory explanations and insights for the plant ecology. So, starting from single elements of a whole set, like species getting to flora and then to vegetation, he pursued an often innovative and courageous thought, that at least part of the academic world has found it difficult to recognize and admit. On the other hand, in the development of human thought, especially in the scientific field, the transitions to new paradigms have entailed considerable challenges and efforts. So, we hope to please our teacher and friend Sandro with this contribution trying to combine the two topics.

Introduction

The history of bioindication is quite recent. Johnson & al. (1992) assessed the definitions on this topic mainly in relation to water and air pollution. However, Pignatti (1988) considers its origin at the beginning of phytosociology, when Braun-Blanquet (1926) and Ellenberg (1963) foresaw the development of a multi-methodological analysis of vegetation based on the knowledge of the ecology and morphology (functional traits) of the species. So, following Pignatti (1988;1994a, b, 1995, 2001a), the life forms as well as the chorological types, represented the first bioindicators of climate and geographical distribution of the vegetation types. Ellenberg (1974-1979) considered directly the relationships between species and the ecological factors and developed his consolidated bioindication model that represented a starting point for the studies to calibrate the six indicator values [light (L), temperature (T), continentality (K), soil moisture (F), reaction (R), nitrogen (N)] with respect to the measures directly done on soil and climate physico-chemical parameters (Schaffers & Sýkora 2000; Pignatti & al. 2001b; Diekmann & Dupré 1997; Testi & al. 2008-2009, 2012). Many scientists, who have dealt with this issue, have made a lot of physical and chemical measurements to validate the model and to assign reliable indicator values to each species of the floras in different temperate European countries (Zarzycky 1984; Borhidi 1995; Hill & al. 2000; Böhling & al. 2002; Pignatti & al. 2005).

One of the most useful application of the Ellenberg Indicator Values (EIV) are the eco-maps, that can be used as powerful tools to monitor the changes of vegetation in function of the changes of the main ecological factors (Austin & Gaywood 1994; Testi & al. 2006; Fanelli & al. 2007). Mapping EIV instead species or communities, is a sort of "quantum jumping" which would show the states of ecological factors of plant communities in a given time. In this respect the following question would arise: "May we reduce and understand the ecosystem complexity just shifting from the description of plant communities by a floristic matrix, very rich in species, to a matrix with few ecological variables that describe the species in terms of their indicator values with respect the climate and the soil main factors?".

In this paper we try to answer to this question by concentrating our study on two composite indicators proposed by Rogister (1978): RxN (Reaction x Nutrient) and R/N (ratio between Reaction and Nutrient). He correlated the description of forestry vegetation types from Belgium based on EIV with their humus quality types and discovered that the com-

posite index RxN can be considered an indicator of humus quality, while the ratio R/N can be considered an indicator of nitrogen availability (Rogister 1978; Godefroid & al. 2005; Muys & Granval 1997). We show in Fig. 1 how the ordination of Rogister (1978) of the forestry vegetation types of Belgium reflects the forms of humus as the results of the climate-soil-vegetation interactions.

As shown in Fig. 1, the classification developed by Rogister (1978) recognises six humus types, ordered along ranges of the humus indexes RxN on axis *x*. This composite index shows a negative correlation with the ratio R/N (nitrogen availability) placed on axis y: 1) Mor (humus index RxN 6.4); 2) Moder (6.4-14.4); 3) transition zone Moder/Mull (14.4-18.2); 4) Acid Mull (18.2-23.0); 5) Typical Mull (23.0-27.5); 6) Basic Mull (27.5-36). The six classes correspond to those given by the Biogeoclimatic Ecosystem Classification in British Columbia (Wilson & al. 2001).

We think that the work of Rogister has been overlooked, because, notwithstanding it showed to be useful by offering significant tools to foresters to forecast growth and production of trees and to select the most suitable tree species for given sites (Aertsen & al. 2012), it was published in Flemish. Another obstacle in the application of the two indices could be certainly due to a limited knowledge about the humus forms, particularly in the Mediterranean environment (Andreetta & al. 2013).
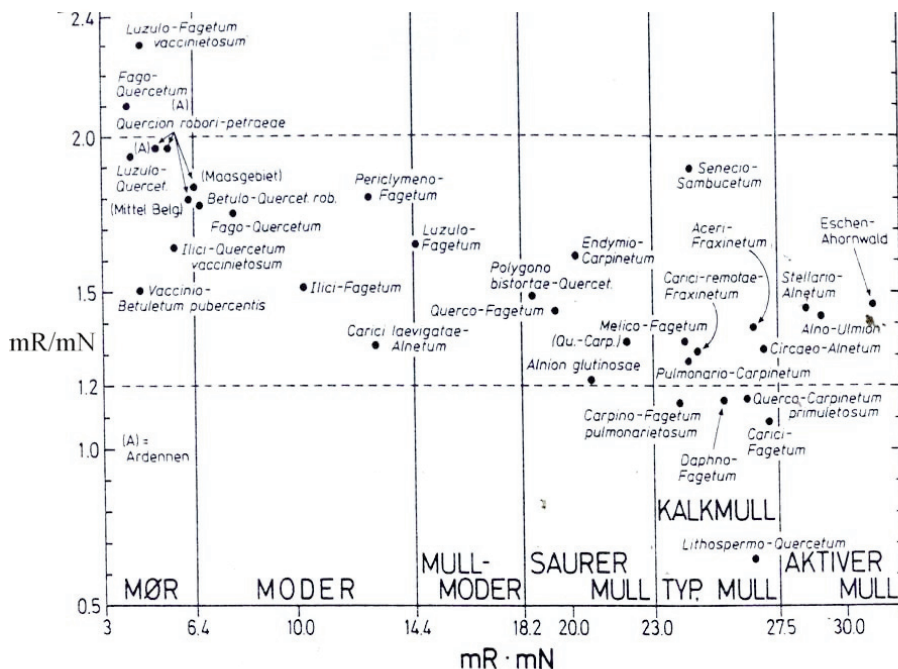

Fig. 1. Rogister's diagram (1978) referred to the ordination of forest vegetation in Belgium: humus forms and correspondent vegetation types are distributed along the *x,y* coordinates represented by values of humus quality-RxN and Nitrogen availability-R/N indexes.

The high correlation between measured parameters of soil and humus and the two Rogister's indices have been already shown in previous studies (De Nicola & al. 2014, 2015, 2018), here we offer the results of a study dedicated to test the performance of the Rogister's indices in terms of predictivity with respect vegetation classification (Pausas & Feoli 1996; Feoli & Ganis 2019 and references therein) with the aim to improve the knowledge of the plant-climate-soil interactions that would had produced the major humus forms: Mor, Moder, Mull and Amphi (Wilson & al. 2001; Ponge 2003) in the Italian forests.

Data and Methods

Data

Vegetation data

We have considered a set of 489 relevés of Italian forest already stored in the database "EVSItalia Database Habitat of Italy" (De Sanctis & al. 2012), EVA project repository (European Vegetation Archive; Chytrý & al. 2016) and 300 relevés done *ex novo* in sampling areas of central-southern Italy for a synchronic study of soil/humus and vegetation, in the course of International Projects of Forest Service in Abruzzo-Molise (Life Project on Habitat Conservation within the framework *Nature2000*), ISPRA (European Project PROFORMIOMED "Promotion of residual forestry biomass in the Mediterranean Basin") and Castelporziano Presidential Estate (Rome) for a long-term Project of Environmental Monitoring.

Such a set of 789 relevés is distributed in almost all the Italian regions (Fig. 2) and represents the 39 plant associations reported in Table 1. The nomenclature of the associations follows Mucina & al. (2016). The relevés were extracted by the program Turboveg (Hennekens & Schaminée 2001).

Soil-Humus data

We have collected the soil-humus data for each of the 300 new phytosociological relevé in Tuscany, Latium, Abruzzo, Campania. Others 100 descriptions of soil samples, that find correspondence with the considered forest types, have been obtained from literature (Bernier & Ponge 1994; Bonanomi & al. 2010; Bonifacio & al. 2011; Andreetta & al. 2013). The soil-humus samples are classified considering the sequence and morphological characteristics of organic (OL-litter, OF-fragmented, OH-humic) and/or organo-mineral (A) horizons, including morphological evidence of biological activity and structures (Zanella & al. 2011; Jabiol & al. 2013).

We have done the physico-chemical analyses according to the methods adopted by the Italian Society of Soil Science (Società Italiana della Scienza del Suolo 1985) and by the USDA Soil Survey Staff (Soil Survey Staff 1975, 1993, 1998).

Fig. 2. Distribution in Italy of the forest types classified on the basis of 789 relevés: 489 derived from the Database "EVSItalia Database Habitat of Italy" and 300 done *ex novo*.

EIV and Rogister's indices data

We have described each of the 847 species found in the relevés by its ecological indicator values (EIV) of Ellenberg (1974-1979) revised by Pignatti (2005). The mean EIV [light (L), temperature (T), continentality (K), soil moisture (F), reaction (R), nitrogen (N)] were calculated for each relevé by the program Turboveg using the cover data of the species. From the indices of reaction (R) and nutrients (N) we have calculated the indices of Rogister: RxN and R/N.

Table 1. List of the 39 plant associations extracted from the 789 relevés of Database. For each association the correspondent forest type was reported by progressive number.

Associations	Forest types
Carici halleranae-Quercetum suberis Beccarisi, Biondi, Casavecchia, Ernandes, Medagli, Zuccarello 2010	1
Viola dehnhardtii-Quercetum suberis Bacchetta, Bagella, Biondi, Farris, Filigheddu, Mossa 2004	1
Galio scabri-Quercetum suberis Rivas-Martìnez, Biondi, Costa, Mossa 2003	1
Cytiso villosi-Quercetum suberis Testi, Lucattini, Pignatti 1982	1
Viburno-Quercetum ilicis (Br.-Bl. 1936) Riv. Mart. 1975 *suberetosum* Br.-Bl. 1936	1
Genisto aristatae-Quercetum suberis Brullo 1984	1
Viburno-Quercetum ilicis Br.-Bl. (1915) 1936 em. Riv.-Mar. 1975	2
Rhamno alaterni-Quercetum ilicis Brullo et Marcenò 1985	2
Pistacio lentisci-Quercetum ilicis Brullo et Marcenò 1984	2
Asplenio onopteris-Quercetum ilicis (Br.-Bl. 1936) Rivas-Martínez 1975	2
Cyclamino repandi-Quercetum ilicis Riv.-Mart., Cantò, Fernàndez-Gonzàles, Sànchez-Mata 1995	2
Fraxino orni-Quercetum ilicis Horvatic 1956 (1958)	2
Rusco aculeati-Quercetum ilicis Biondi, Gigante, Pignatelli, Venanzoni 2002	2
Roso sempervirentis-Ouercetum pubescentis Biondi 1986	3
Peucedano cervariae-Quercetum pubescentis Allegrezza, Baldoni, Biondi, Taffetani, Zuccarello 2002	3
Querco cerridis-Betuletum pendulae Biondi et al. 1998 agrostietosum monteluccii	4
Echinopo siculi-Quercetum fra inetto Blasi et Paura 1995	4
Physospermo verticillati – Quercetum cerridis Ubaldi, Zanotti, Puppi, Speranza et Corbetta in Ubaldi 1995	4
Coronillo emeri-Quercetum cerridis Blasi 1986	4
Asaro-Carpinetum betuli Lausi 1964	5
Cardamino Kitaibelii-Fagetum sylvaticae Ubaldi et al. ex Ubaldi 1995	6
Lathyro veneti-Fagetum sylvaticae Biondi, Casavecchia, Pinzi, Allegrezza, Baldoni 2002	6
Staphyleo pinnatae-Fagetum sylvaticae Ubaldi et Speranza ex Ubaldi 1995	6
Polysticho aculeati-Fagetum sylvaticae Feoli et Lagonegro 1982	6
Aquifolio-Fagetum Gentile 1969	6
Homogyno sylvestris-Piceetum Exner in Poldini & Bressan 2007	7
Luzulo nemorosae-Piceetum (Schmidt et Gaisberg 1936) Br.-Bl. Et Sissingh in Br.-Bl. Et al. 1939	7
Laburno alpini-Piceetum Zupancic 1999	7
Rhodothamno chamaecisti-Piceetum Poldini in Poldini & Bressan 2007	7
Senecioni cacaliastri-Piceetum Poldini in Poldini & Bressan 2007	7
Petasito paradoxi-Piceetum Zupancic 1999	7
Cardamino pentaphylli-Abietetum Mayer 1974	8
Anemono trifoliae-Abietetum Exner in Poldini & Bressan 2007	8
Cirsio erisithalis-Abietetum albae Biondi et al.-2007	8
Pulmonario apenninae-Abietetum albae Allegrezza & Biondi 2008	8
Populetum albae (Br.-Bl. 1931) Tchou 1948	9
Salicetum albae Issler 1926	9
Aro italici-Alnetum glutinosae Gafta & Pedrotti 1995 *betuletosum pendulae*	9
Carici remotae-Fraxinetum oxycarpae Pedrotti 1970 corr. 1992	9

Chorological data

We have calculated an average index of Mediterranean climate, MI, for each forest type by the ratio between Steno+Eurimediterranean and Eurasiatic chorotypes by using the program Turboveg.

Data Analysis

The 789 relevés of the 39 associations (Table 1) described by EIV and Rogister's indices have been ordered in an ordination scattergram according to the two Rogister indices (RO). To test the predictivity of the indicator values EIV and the two RO

indices with respect to vegetation classification, the relevés have been grouped into 9 main vegetation types of forests according to the dominance of the main species of trees (Mucina 2016; Pignatti 1998), one of them include all the azonal hygrophilous woodlands (Table 1):

1. *Quercus suber*, 2. *Quercus ilex*, 3. *Quercus pubescens*, 4. *Quercus cerris and Q.cerris-Q. frainetto*, 5. *Carpinus betulus*, 6. *Fagus sylvatica*, 7. *Picea abies*, 8. *Abies alba*, 9. Hygrophilous woodlands with *Salix* spp., *Populus* spp., *Fraxinus oxycarpa* and *Alnus glutinosa.*

For doing the predictivity analysis we have considered two data matrices, one where the relevés are described by RxN and R/N and the one where the relevés are described by the 6 EIV. In both cases the relevés have been compared by the cosine as similarity function (Orloci 1978) after standardization of the indices. In this way we have obtained a similarity matrix 789x789 based on RO ($\mathbf{S}$(RO)) and a similarity matrix 789x789 based on EIV ($\mathbf{S}$(EIV)). To compare the predictivity of the Rogister indices (RO) with that of EIV with respect to the classification of the relevés in 9 vegetation types, we have calculated the evenness of the eigenvalues (Eλ) (Feoli & Ganis 2019) of the similarity matrices ($\mathbf{S}$(RO)) and ($\mathbf{S}$(EIV)). The method tests the significance of Eλ by a permutation technique (Pillar & Orlòci 1996). To identify the factors responsible for the ecological differences between the 9 vegetation types we have calculated the correlation between the indices (EIV and RO) and the fuzzy sets corresponding to the 9 vegetation types as shown by Feoli & Ganis (2019). The fuzzy sets have been obtained by averaging the similarity the relevés have within and between the 9 groups of relevés corresponding to the vegetation types (Feoli & Zuccarello 1986). The index of Mediterraneity (MI) has been correlated with the other indices by using the average values they have in the 9 types. The matrices of correlation between the indices using the average values in the 9 types and using the all values of the 789 relevès have been compared by Mantel's test (Mantel 1967).

In order to facilitate the interpretation of the results of the ordination based on the two RO indices in terms of syntaxonomy, we have considered the correspondence of the 9 vegetation types, except for the hygrophilous vegetation type-9, with syntaxonomic classes as follows:

Quercetea ilicis including *Quercus suber-1* and *Q. ilex-2* forests;

Quercetea pubescentis including *Quercus pubescens-3* and *Q. cerris-4*;

Carpino-Fagetea including *Carpinus betulus-5*, *Fagus sylvatica-6*, *Abies alba*-8;

Vaccinio-Picetea including *Picea abies-7;*

Hygrophilous including forest type-9.

For each of these 5 classes we have superimposed one ellipse in the ordination scattergram.

To test if species diversity is correlated with the EIV and Rogister indices (RO) we have calculated the following well known indices of diversity: Species richness, Shannon Index, Eveness, Simpson dominance λ.

Finally, we have grouped the relevés by their humus forms and we have calculated the significance of the separation between the groups by Eλ.

Results

The humus samples, classified in a total of 14 different humus sub-forms, belong to four main stable forms: Mor, Moder, Amphi, Mull, according to the classification of the terrestrial humus (Zanella & al. 2011; Jabiol 2013).

Following Rogister, the main humus forms fit well with the vegetation types along the RxN and R/N axes of the diagram (Fig. 3). Their distribution along the ranges of values is easily recognizable: Mor in *Picea abies* forest type- 7 with the lowest values of RxN and R/N values < 1; Amphi in evergreen Mediterranean forest, *Quercus suber* and *Quercus ilex* forest types (1,2) with low values of RxN as in Mor and higher values of R/N, ranged between 1.3 and 1.4; Moder in *Quercus pubescens* and *Quercus cerris* forest types (3, 4) displaying higher RxN values up to 27.20 and intermediate R/N values ranged between 1.1 and 1.5; Mull in *Carpinus betulus* (5), *Fagus sylvatica* (6) and azonal humid forest types (9) with the highest RxN values and R/N intermediate values. Interestingly, in our dataset *Abies alba* forest type (8) showed the Mull form with the indexes values as in beech forest (Fig. 3, Table 2).
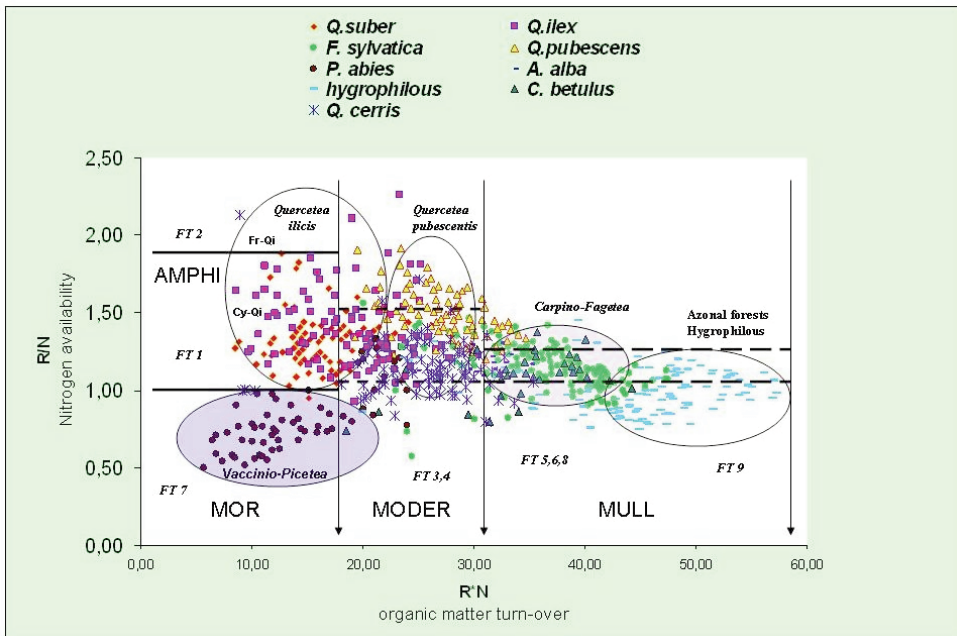

Fig. 3. Diagram of the Italian woodlands according to Rogister: the *x, y* axes were respectively represented by RxN and R/N indexes. The main sociological *syntaxa* and correspondent humus forms are reported along the gradients of the two humus indexes. Number of each Forest Type (FT) are indicated. Two associations of *Quercus ilex* forest are respectively indicated as Fr-Qi (*Fraxino orni-Quercetum ilicis*) and Cy-Qi (*Cyclamino repandi-Quercetum ilicis*). as they are discussed.

Table 2. Average values, standard deviations (StDev) and coefficient of variation (CV) of each of the EIV indicators and RxN and R/N indices.

Average	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	MI
1 Q.suber	16,50	1,31	21,87	2,22	0,74	0,80	21,87	6,12	7,98	2,57	3,27	4,62	3,55	**2,66**
2 Q.ilex	19,14	1,40	17,36	1,92	0,68	0,74	17,36	4,91	8,15	2,46	3,33	5,10	3,71	**1,95**
3 Q.pub	27,20	1,49	25,94	2,39	0,74	0,82	25,94	5,86	6,62	3,21	4,17	6,34	4,28	**0,75**
4 Q.cerris	25,66	1,14	24,09	2,22	0,71	0,78	23,32	5,45	6,89	3,39	4,24	5,37	4,75	**0,98**
5 C.bet	34,70	1,09	29,59	2,54	0,78	0,85	29,59	4,75	5,60	3,75	4,88	6,14	5,64	**0,35**
6 Fagus	36,90	1,14	21,62	1,98	0,65	0,68	21,62	4,20	5,29	3,12	4,95	6,45	5,71	**0,32**
7 Picea	14,00	0,80	24,82	2,36	0,74	0,82	24,82	4,39	3,80	3,87	4,68	3,33	4,14	**0,02**
8 A.alba	30,07	1,15	36,29	2,63	0,73	0,82	36,29	4,39	5,12	3,25	4,95	5,87	5,11	**0,23**
9 hygrophilous	44,87	0,99	19,76	1,97	0,68	0,74	19,24	5,51	5,88	3,86	6,57	6,61	6,77	**0,48**
StDev	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	
1 Q.suber	3,215	0,165	9,307	0,479	0,079	0,096	9,307	0,534	0,397	0,256	0,339	0,544	0,404	
2 Q.ilex	4,810	0,241	5,559	0,417	0,100	0,117	5,559	1,053	0,462	0,247	0,361	0,727	0,630	
3 Q.pub	3,492	0,153	6,566	0,343	0,070	0,061	6,566	0,382	0,508	0,241	0,345	0,379	0,423	
4 Q.cerris	4,785	0,180	8,545	0,502	0,112	0,108	9,360	0,650	0,690	0,570	0,421	0,647	0,600	
5 C.bet	5,586	0,149	13,898	0,510	0,060	0,079	13,898	0,401	0,267	0,249	0,258	0,802	0,440	
6 Fagus	5,206	0,141	8,779	0,640	0,144	0,170	8,779	0,566	0,296	0,377	0,254	0,495	0,620	
7 Picea	4,865	0,196	7,987	0,412	0,076	0,072	7,987	0,382	0,276	0,312	0,369	0,921	0,514	
8 A.alba	3,671	0,100	9,616	0,410	0,070	0,075	9,616	0,260	0,324	0,133	0,107	0,559	0,245	
9 hygrophilous	7,330	0,142	9,940	0,524	0,097	0,122	10,417	0,525	0,672	0,872	1,055	0,724	0,758	
CV	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	
1 Q.suber	0,19	0,13	0,43	0,22	0,11	0,12	0,43	0,09	0,05	0,10	0,10	0,12	0,11	
2 Q.ilex	0,25	0,17	0,32	0,22	0,15	0,16	0,32	0,21	0,06	0,10	0,11	0,14	0,17	
3 Q.pub	0,13	0,10	0,25	0,14	0,09	0,07	0,25	0,07	0,08	0,08	0,08	0,06	0,10	
4 Q.cerris	0,19	0,16	0,35	0,23	0,16	0,14	0,40	0,12	0,10	0,17	0,10	0,12	0,13	
5 C.bet	0,16	0,14	0,47	0,20	0,08	0,09	0,47	0,08	0,05	0,07	0,05	0,13	0,08	
6 Fagus	0,14	0,12	0,41	0,32	0,22	0,25	0,41	0,13	0,06	0,12	0,05	0,08	0,11	
7 Picea	0,35	0,24	0,32	0,17	0,10	0,09	0,32	0,09	0,07	0,08	0,08	0,28	0,12	
8 A.alba	0,12	0,09	0,26	0,16	0,10	0,09	0,26	0,06	0,06	0,04	0,02	0,10	0,05	
9 hygrophilous	0,16	0,14	0,50	0,27	0,14	0,17	0,54	0,10	0,11	0,23	0,16	0,11	0,11	

Along the two axes of Fig. 3, there is a clear overlap between the more thermophile *Quercus cerris* woodlands of central Italy and *Quercus ilex* woodlands, while *Carpinus betulus* forest occupies an intermediate position between *Fagus sylvatica* and *Q. cerris*. The latter is partially overlapping with *F. sylvatica*. The pattern of ordination shows a clear triangular shape, with evergreen Mediterranean forests (*Quercetea ilicis* Br.-Bl- 1952) on the upper left side, mixed deciduous forests (*Quercetea pubescentis* Oberd. 1948; Doing Kraft 1955) in the middle sector between evergreen Mediterranean and deciduous forests of *Carpino-Fagetea* Br.-Bl. & Vlieg. 1937; Jakucs 1960; cool and boreal forests (Class *Vaccinio-Picetea* Br.-Bl. 1939) on the bottom left corner. *Abies alba* woodlands are distributed within the *Fagus sylvatica* cloud of the relevés; azonal humid forests on the right and extreme sector of the diagram.

Synthesizing these results, the RxN showed the highest values in beech forests and in hygrophilous woodlands where Mull forms, with rapid organic matter turn-over, characterize the humus; on the contrary in the Mediterranean sclerophyllous woodlands, such as in boreal Alpine woodlands, values were the lowest in correspondence of the prevalence of Amphi and Mor forms respectively with slow turn-over of organic matter (Fig. 3, Table 2). [*]

The average values, the standard deviations and the variation coefficient of each of the EIV indices and RxN and R/N in the 9 vegetation types are presented in Table 2 (Average, StDev standard deviation, CV coefficient of variation).

The correlation coefficients between the indices are reported in Table 3 according to all the relevés (a) and to the average values in the 9 main vegetation types (b) displayed in Table 1. Mantel test between the two matrices (excluding MI that was considered only as average value for the 9 vegetation types) is highly significant, r= 0.94 p< 0.0001.

A lot of significant correlations emerged: RxN is highly correlated with soil moisture-F, Reaction-R and Nutrients-N indicators (0.81, 0.89, 0.95). R/N is correlated with climatic indicators: temperature T indicator, light L indicator, and MI index by high coefficients values (0.78, 0.50 and 0.61). All EIV, except for R, were correlated with MI. Among the diversity indices, Richness and Species N° were negatively correlated with T indicator and MI (Table 3b).

The separation of the 9 types based only on RxN and R/N indices was 0.816 (in Table 4a), while the separation based on the 6 EIV was 0.576 (in Table 4b). Both the separations were highly significant (p<0.0001) by the permutation test, but the one based on RxN and R/N was superior.

The correlations between fuzzy sets of the 9 vegetation types with all the indices (Table 5), both considering the average values of the 9 types a) and all the data b), showed that the mediterranean (*Q. suber* and *Q. ilex*) and submediterranean (*Q. pubescens* and *Q. cerris*) forest types were correlated with climatic indicators of light-L and temperature-T, while mesophile deciduous forests (*Carpinus betulus* and *Fagus sylvatica)* were correlated with the soil indicators F, R, N as well as with the combined RxN index of humus quality. *Abies alba* type with F indicator, hygrophilous forest type with K, F, N and RxN indices. *Q. suber, Q. ilex* and *Q. cerris* forest types were correlated with MI (Table 5a).

Correlation of R/N nitrogen availability emerged when all the data were considered (Table 5b) with *Q. suber, Q. ilex, Q. pubescens, Q. cerris* types. The mesophile forest types of *C. betulus, Fagus, Abies alba* and hygrophilous woodlands show the same correlation pattern. *Picea abies* forest type shows correlation with continentality-K and soil moisture-F.

Laboratory measurements of total nitrogen -Ntot-, calculated in the different OL, OF, OH, A horizons in previous studies, showed lower values in Mull, where OH horizon is lacking and turn-over faster, against the higher values in Amphi with slower turn-over and consequently nitrogen accumulation in all the horizons (De Nicola & al. 2018). The correspondent index of nitrogen availability R/N showed, actually, coherent values: the narrowest range in Mull against the highest values in Amphi forms (Fig. 3).

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[*] In Appendix we show pictures of some sampling sites that put in evidence the correspondence between the humus forms and vegetation types; the pictures derived from data published concerning the study conducted in the Castelporziano Reserve (De Nicola & al. 2018).

Table 3a, b. Correlation coefficients between RxN and R/N considering all the relevés a) and considering the average values in the 9 main vegetation types b) as indicated in Table 1. In bold the discussed correlations. The Mantel test between the two matrices (by excluding MI) is highly significant r = 0.94 p<0.0001.

a) Correlation on values of all the relevés	R*N	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N
R*N	1,000	-0,218	0,038	-0,064	-0,140	-0,165	0,036	-0,221	-0,325	0,364	0,732	0,849	0,928
R\N	-0,218	1,000	0,054	0,090	0,087	0,080	0,059	0,354	0,579	-0,317	-0,503	0,303	-0,541
Richness	0,038	0,054	1,000	0,834	0,458	0,600	0,976	0,013	-0,174	0,036	0,010	0,111	0,020
Shannon	-0,064	0,090	0,834	1,000	0,852	0,899	0,819	0,136	-0,060	0,029	-0,092	0,017	-0,084
Evenness	-0,140	0,087	0,458	0,852	1,000	0,919	0,456	0,239	0,064	0,038	-0,140	-0,086	-0,154
Simpson	-0,165	0,080	0,600	0,899	0,919	1,000	0,590	0,250	0,062	0,042	-0,146	-0,106	-0,166
Species N°	0,036	0,059	0,976	0,819	0,456	0,590	1,000	0,005	-0,177	0,037	0,007	0,110	0,016
L	-0,221	0,354	0,013	0,136	0,239	0,250	0,005	1,000	0,435	0,029	-0,158	-0,063	-0,313
T	-0,325	0,579	-0,174	-0,060	0,064	0,062	-0,177	0,435	1,000	-0,508	-0,632	-0,052	-0,471
K	0,364	-0,317	0,036	0,029	0,038	0,042	0,037	0,029	-0,508	1,000	0,544	0,198	0,389
F	0,732	-0,503	0,010	-0,092	-0,140	-0,146	0,007	-0,158	-0,632	0,544	1,000	0,436	0,806
R	0,849	0,303	0,111	0,017	-0,086	-0,106	0,110	-0,063	-0,052	0,198	0,436	1,000	0,612
N	0,928	-0,541	0,020	-0,084	-0,154	-0,166	0,016	-0,313	-0,471	0,389	0,806	0,612	1,000

b) Correlation on averages in the 9 Forest types	RxN	R\N	Richness	Shannon	Evenness	Simpson	Species N°	L	T	K	F	R	N	MI
R*N	1,000	-0,156	0,092	-0,131	-0,306	-0,307	0,074	-0,116	-0,227	0,438	0,811	0,880	0,950	-0,485
R\N	-0,156	1,000	-0,142	-0,103	-0,051	-0,048	-0,129	0,502	0,784	-0,774	-0,624	0,317	-0,457	0,614
Richness	0,092	-0,142	1,000	0,929	0,608	0,679	0,999	-0,321	-0,483	0,322	0,164	0,111	0,126	-0,491
Shannon	-0,131	-0,103	0,929	1,000	0,845	0,888	0,932	-0,139	-0,405	0,329	-0,009	-0,090	-0,086	-0,363
Evenness	-0,306	-0,051	0,608	0,845	1,000	0,978	0,614	0,164	-0,146	0,271	-0,180	-0,276	-0,258	-0,052
Simpson	-0,307	-0,048	0,679	0,888	0,978	1,000	0,681	0,161	-0,174	0,294	-0,141	-0,270	-0,257	-0,106
Species N°	0,074	-0,129	0,999	0,932	0,614	0,681	1,000	-0,334	-0,483	0,301	0,144	0,100	0,106	-0,482
L	-0,116	0,502	-0,321	-0,139	0,164	0,161	-0,334	1,000	0,683	-0,263	-0,268	0,073	-0,258	0,637
T	-0,227	0,784	-0,483	-0,405	-0,146	-0,174	-0,483	0,683	1,000	-0,779	-0,625	0,097	-0,444	0,902
K	0,438	-0,774	0,322	0,329	0,271	0,294	0,301	-0,263	-0,779	1,000	0,788	0,082	0,642	-0,821
F	0,811	-0,624	0,164	-0,009	-0,180	-0,141	0,144	-0,268	-0,625	0,788	1,000	0,476	0,928	-0,733
R	0,880	0,317	0,111	-0,090	-0,276	-0,270	0,100	0,073	0,097	0,082	0,476	1,000	0,691	-0,240
N	0,950	-0,457	0,126	-0,086	-0,258	-0,257	0,106	-0,258	-0,444	0,642	0,928	0,691	1,000	-0,629
MI	-0,485	0,614	-0,491	-0,363	-0,052	-0,106	-0,482	0,637	0,902	-0,821	-0,733	-0,240	-0,629	1,000

The comparison between the humus forms obtained by the evenness of the eigenvalues of the similarity matrix calculated by similarity ratio on the basis of the two Rogister indices, reflected the differences among the averages indicator values of the humus forms. The distance between each form was high, with the maximum Eλ value between Amphi and Mull (Table 6). Mor forms were not included in this test since related data came from literature and not from our vegetation relevés and associated humus profiles.

If we consider the ordination of Rogister in Fig. 1, we can note that generally in Belgium forests the RxN range values were lower (Fig. 1) than in Italian ones (Fig. 3), particularly for Mor and Moder humus forms: Mor had the extreme value at 6.4 and Moder at 14.4 in Belgium *vs.* 14 and 27.20 respectively in Italy (see Table 2).

The ordination based on Rogister indices shows a gradient of Mediterraneity (index-MI) from evergreen Mediterranean forests of *Quercetea ilicis* to sub-Mediterranean deciduous *Quercetea pubescentis* forests and to *Carpino-Fagetea*, with the lowest values in boreal *Vaccinio-Picetea* forests and maximum in *Quercus suber* forest type-1 (Fig. 4). In this ordination the type of Azonal hygrophilous woodlands does not follow the general MI gradient.

Table 4. Matrices of within/between similarity of the 9 vegetation types based only on RxN and R/N a) and on the 6 EIV b). The Eveness value of the two matrices (Eλ) is 0.81 (p<0.0001) for the matrix a) and 0.576 for matrix b).

a) Similarity on only R*N and R/N	1 Q.suber	2 Q.ilex	3 Q.pubescens	4 Q.cerris	7 Picea	5 C.betulus	9 Hygrophilous	6 Fagus	8 Abies alba
1 Q.suber	0,907	0,860	0,666	0,572	0,665	0,170	0,111	0,163	0,289
2 Q.ilex	0,860	0,835	0,731	0,527	0,561	0,203	0,146	0,222	0,303
3 Q.pubescens	0,666	0,731	0,935	0,371	0,198	0,340	0,296	0,445	0,367
4 Q.cerris	0,572	0,527	0,371	0,577	0,688	0,453	0,451	0,405	0,483
7 Picea abies	0,665	0,561	0,198	0,688	0,936	0,392	0,389	0,281	0,462
5 C.betulus	0,170	0,203	0,340	0,453	0,392	0,762	0,818	0,767	0,674
9 Hygrophilous	0,111	0,146	0,296	0,451	0,389	0,818	0,876	0,811	0,707
6 Fagus sylv.	0,163	0,222	0,445	0,405	0,281	0,767	0,811	0,795	0,664
8 Abies alba	0,289	0,303	0,367	0,483	0,462	0,674	0,707	0,664	0,591

| b) Similarity on EIV	1 Q. suber	2 Q. ilex	3 Q.pubescens	4 Q.cerris	5 C.betulus	9 Hygrophilous	6 Fagus	8 Abies alba	7 Picea abies
1 Q. suber	0,9586	0,8555	0,6785	0,6723	0,1193	0,2037	0,1470	0,1395	0,3817
2 Q. ilex	0,8555	0,8785	0,5807	0,6191	0,1838	0,2049	0,2952	0,2696	0,3611
3 Q. pubescens	0,6785	0,5807	0,8431	0,5874	0,3876	0,4465	0,3543	0,2918	0,2709
4 Q. cerris	0,6723	0,6191	0,5874	0,6075	0,3919	0,4275	0,3297	0,2984	0,4119
5 C. betulus	0,1193	0,1838	0,3876	0,3919	0,8478	0,7516	0,7633	0,7584	0,5946
9 Hygrophilous	0,2037	0,2049	0,4465	0,4275	0,7516	0,8435	0,6684	0,6159	0,4333
6 Fagus sylvatica	0,1470	0,2952	0,3543	0,3297	0,7633	0,6684	0,8630	0,8481	0,5395
8 Abies alba	0,1395	0,2696	0,2918	0,2984	0,7584	0,6159	0,8481	0,9017	0,7076
7 Picea abies	0,3817	0,3611	0,2709	0,4119	0,5946	0,4333	0,5395	0,7076	0,9443
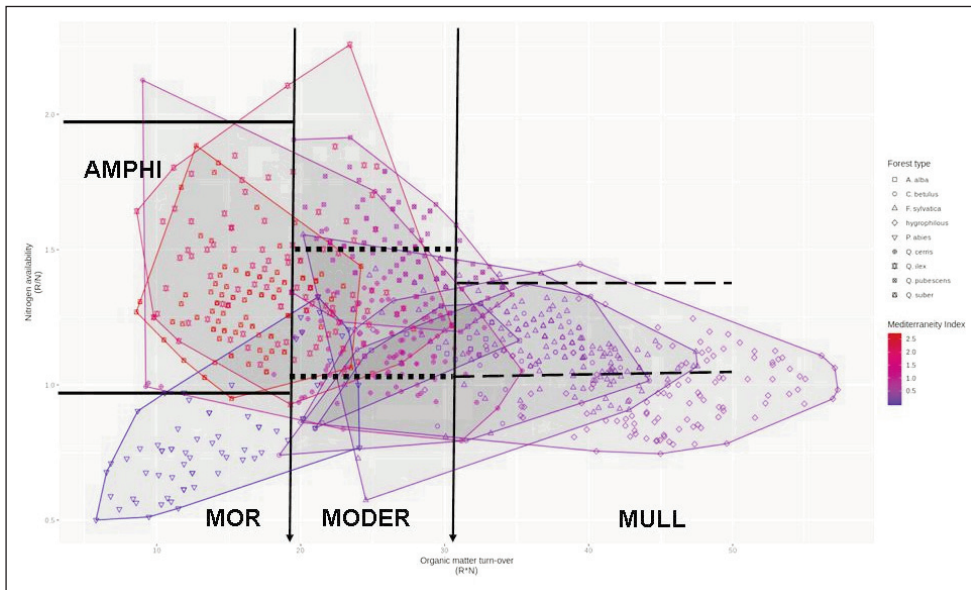
Fig. 4. Diagram of the Italian woodlands according to Rogister in which the phytogeographical gradient expressed by the Mediterraneity index-MI is indicated through a different intensity of colour from the *Quercetea ilicis* Mediterranean forests (red) to boreal *Vaccinio-Picetea* (blue) and *Carpino-Fagetea* (violet). Nine polygons correspondent to the 9 forest types are recognizable.

Table 5a, b. Correlation between fuzzy sets of the 9 vegetation types with the indicator values considering the average values of the 9 types a) and all the data b). In the first case the index of mediterraneity is included.

a) average data	1Q.suberE	2Q.ilexE	3Q.pubE	4Q.cerrisE	5C.betE	6FagusE	7PiceaE	8A.albaE	9HygrE	1 Q.suberE	2 Q.ilexE	3 Q.pubE	4 Q.cerrisE	5 C. betE	6 FagusE	7 PiceaE	8 A.albaE	9 HygrE
L	0,675	0,544	0,853	0,798	-0,626	-0,751	-0,735	-0,831	-0,350	0,454	0,506	0,547	-0,075	-0,473	-0,387	-0,075	-0,491	-0,482
T	0,802	0,830	0,771	0,839	-0,798	-0,741	-0,851	-0,848	-0,608	0,572	0,639	0,705	-0,110	-0,597	-0,484	-0,111	-0,630	-0,608
K	-0,702	-0,822	-0,501	-0,567	0,751	0,537	0,537	0,574	0,745	-0,631	-0,693	-0,718	0,053	0,653	0,548	0,059	0,700	0,665
F	-0,818	-0,873	-0,523	-0,699	0,831	0,725	0,294	0,668	0,925	-0,866	-0,880	-0,627	-0,300	0,875	0,825	-0,295	0,883	0,876
R	-0,419	-0,395	0,148	-0,277	0,438	0,455	-0,504	0,233	0,638	-0,668	-0,548	0,184	-0,935	0,630	0,776	-0,930	0,554	0,609
N	-0,818	-0,833	-0,452	-0,664	0,834	0,760	0,096	0,638	0,961	-0,955	-0,942	-0,540	-0,492	0,954	0,942	-0,485	0,949	0,951
R*N	-0,698	-0,698	-0,220	-0,536	0,715	0,675	-0,172	0,499	0,893	-0,900	-0,839	-0,261	-0,723	0,883	0,939	-0,717	0,847	0,872
R\N	0,616	0,662	0,815	0,600	-0,616	-0,503	-0,811	-0,625	-0,502	0,465	0,594	0,952	-0,485	-0,511	-0,316	-0,489	-0,594	-0,533
Richness	-0,487	-0,485	-0,346	-0,529	0,490	0,488	0,453	0,532	0,327	-0,336	-0,343	-0,252	-0,107	0,337	0,319	-0,105	0,308	0,341
Shannon	-0,285	-0,333	-0,176	-0,306	0,310	0,244	0,429	0,320	0,149	-0,106	-0,121	-0,149	0,039	0,108	0,087	0,039	0,095	0,115
Evenness	0,009	-0,090	0,050	0,049	0,039	-0,106	0,267	-0,021	-0,051	0,151	0,126	-0,034	0,204	-0,149	-0,173	0,201	-0,136	-0,138
Simpson	0,005	-0,097	0,051	0,040	0,040	-0,101	0,280	-0,011	-0,051	0,157	0,130	-0,038	0,215	-0,153	-0,180	0,213	-0,146	-0,143
Species N°	-0,483	-0,477	-0,347	-0,533	0,483	0,489	0,461	0,536	0,312	-0,322	-0,327	-0,232	-0,113	0,323	0,308	-0,111	0,293	0,326
MI	0,866	0,891	0,632	0,832	-0,880	-0,808	-0,608	-0,832	-0,766	0,732	0,757	0,594	0,188	-0,744	-0,685	0,183	-0,752	-0,748

b) all the data	1Q.suberE	2Q.ilexE	3Q.pubE	4Q.cerrisE	5C.betE	6FagusE	7PiceaE	8A.albaE	9HygrE	1 Q.suberE	2 Q.ilexE	3 Q.pubE	4 Q.cerrisE	5 C. betE	6 FagusE	7 PiceaE	8 A.albaE	9 HygrE
L	0,537	0,297	0,744	0,645	-0,468	-0,668	-0,428	-0,702	-0,222	0,409	0,431	0,342	0,026	-0,418	-0,367	0,025	-0,428	-0,423
T	0,769	0,799	0,614	0,810	-0,752	-0,701	-0,703	-0,803	-0,612	0,535	0,567	0,462	0,020	-0,549	-0,478	-0,111	-0,564	-0,554
K	-0,519	-0,663	-0,188	-0,302	0,615	0,294	0,389	0,339	0,568	-0,388	-0,399	-0,280	-0,075	0,393	0,361	-0,072	0,399	0,395
F	-0,758	-0,813	-0,451	-0,663	0,750	0,641	0,241	0,617	0,854	-0,713	-0,716	-0,442	-0,212	0,717	0,680	-0,209	0,716	0,717
R	-0,480	-0,435	0,140	-0,341	0,504	0,510	-0,488	0,312	0,616	-0,598	-0,463	0,233	-0,823	0,555	0,717	-0,821	0,469	0,531
N	-0,792	-0,756	-0,486	-0,643	0,777	0,734	0,034	0,627	0,883	-0,891	-0,889	-0,525	-0,295	0,894	0,856	-0,290	0,890	0,894
R*N	-0,732	-0,697	-0,257	-0,575	0,740	0,709	-0,193	0,551	0,861	-0,858	-0,794	-0,234	-0,575	0,840	0,891	-0,570	0,798	0,829
R\N	0,471	0,481	0,731	0,450	-0,445	-0,384	-0,585	-0,469	-0,422	0,452	0,588	0,869	-0,493	-0,500	-0,288	-0,497	-0,583	-0,524
Richness	-0,113	-0,142	0,070	-0,114	0,125	0,109	0,012	0,102	0,108	-0,051	-0,029	0,065	-0,120	0,043	0,072	-0,119	0,026	0,040
Shannon	0,029	-0,025	0,162	0,052	-0,004	-0,052	-0,043	-0,057	0,003	0,050	0,065	0,094	-0,053	-0,056	-0,032	-0,053	-0,066	-0,058
Evenness	0,143	0,072	0,194	0,186	-0,112	-0,189	-0,060	-0,186	-0,080	0,126	0,127	0,077	0,038	-0,128	-0,120	0,038	-0,127	-0,127
Simpson	0,162	0,083	0,220	0,207	-0,128	-0,212	-0,068	-0,208	-0,092	0,155	0,153	0,084	0,059	-0,156	-0,151	0,059	-0,155	-0,155
Species N°	-0,116	-0,141	0,063	-0,122	0,126	0,116	0,022	0,111	0,101	-0,047	-0,022	0,079	-0,130	0,039	0,071	-0,130	0,020	0,035

Table 6. Complement Euclidean distances among the sampled humus forms Amphi, Moder, Mull. Jaccard similarity ratio was completely significant.

Average	RxN	R\N	SD	RxN	R\N	CV	RxN	R\N	Min	RxN	R\N	Max	RxN	R\N
AMPHI	20.75	1.31	AMPHI	4.12	0.17	AMPHI	0.20	0.13	AMPHI	10.64	1.04	AMPHI	27.84	1.81
MODER	26.41	1.23	MODER	3.66	0.20	MODER	0.14	0.16	MODER	18.14	0.84	MODER	35.38	1.72
MULL	34.09	1.17	MULL	5.64	0.14	MULL	0.17	0.12	MULL	18.50	0.74	MULL	47.45	1.56
	>			max.in	max.in		max.in	max.in						
	max. in			Mull	Moder		Amphi	Moder		>	<		>	<
	Mull	<												

Discussion

The soundness of RO is supported by the fact that the indices are highly correlated with measured parameters of soil and humus as was found in previous studies (De Nicola & al. 2014, 2015); furthermore, the separation of the 9 vegetation types in the ordination space given by the RxN and R/N indices (Table 4a) is higher (Eλ=0.816) than that based on the 6 EIV of Ellenberg (Eλ = 0.576) (Table 4b). This proves that the two RO indices are more predictive that the 6 EIV with respect the classification of the Italian forests in the 9 vegetation types.

The ordination of the relevés of the Italian woodlands based on the Rogister indices displayed a significant distribution pattern along the RxN and R/N axes (Fig. 3). From this ordination it is evident that nitrogen availability is indeed one of the most crucial soil factor influencing structure and eco-physiology of the vegetation (Anas & al. 2020). So, nevertheless the litter of both *Picea abies* cool forest and *Quercus ilex/Quercus suber* thermophile forest is composed by evergreen leaves and therefore the turn-over of organic matter is slowed down, nitrogen availability is higher in the sclerophillous woodlands where we find the Amphi humus form.

This evidence was supported by the quantity of the total nitrogen –Ntot- measured in the different organic and organo-mineral horizons of the soil/humus compound (De Nicola & al. 2018). This result is consistent with Callesen & al. (2007) who found a positive relationship between total soil N pools and both temperature and precipitation in forests of north and central Europe. By following the RxN gradient, we can see that the relevés of *Quercetea pubescentis* (deciduous forests) are characterized by higher values of this index with respect to Amphi forests of *Quercetea ilicis* (Fig. 3). This is due to the faster organic matter turn-over in Moder humus forms that can be explained by climate factors like (1) the heavy rainfall that favours the intensity of leaching, nutrient losses and thus topsoil impoverishment (Turner & al. 2010), and (2) lower temperatures at higher altitude, that slow down the organic matter turnover (Roe 2005), as in the case of the mountain *Q. cerris* woodlands of our dataset.

From floristic and phytosociological point of view *Quercetalia/Quercetea pubescentis* forests are very diversified, but the soil indicators here utilized, suggest that they would have the same structure and dynamic of the soil/humus system.

In correspondence with the highest RxN values (> 30), we have found continental and cooler woodlands of *Carpino-Fagetea* where the organic matter turn-over is the fastest in Mull humus forms, without OH horizon (Ponge 2003). The same humus dynamic concerns azonal humid forests distributed on the extreme pole of the RxN gradient.

The other index R/N showed a rather small range of values in all the forest types with humus Mull (Fig. 3): this pattern is confirmed by the measurements of the chemical parameter Ntot that displays lower quantity in OF+OH+A horizons than in Amphi Mediterranean forests (De Nicola & al. 2018).

The influence of climate to define the Mull forms can be understood by considering the stimulatory influence of temperature on most chemical processes, in particular those involved in organic matter decomposition (Aerts 1997) and mineral weathering (Turner & al. 2010). The heat beside offering benefits to the activity of cold-blooded animals (Briones & al. 2010), is also influencing positively the invertebrates involved in mull-forming (Zhang & al. 2008), at least in the absence of any drought limitations (Cortez 1998) as it happens in hygrophilous forest type.

It is, moreover, remarkable that the ordination of the Italian forest types along the Rogister axes is well supported by their relationships with climatic and soil factors, expressed by the fuzzy set correlation output (Table 5a, b): mediterranean and sub-mediterranean woodlands of *Quercetea ilicis* and *Quercetea pubescentis*, linked to climatic indicators and to nitrogen availability in the soil-R/N, were separated from mesophile deciduous woodlands of *Carpino-Fagetea* correlated with soil (F,R,N) and humus-RxN indicators (Table 5a, b).

By examining the gradients related to Rogister's indexes, we can detect a discrimination of Italian woodlands at a broader scale, but also we can find discrimination at the level of associations (Fig. 3). In this respect the following three points deserve to be put in evidence:

A. The two main *Quercus ilex* associations in Italy (Biondi & al. 2003) are the supramediterranean *Fraxino orni-Quercetum ilicis* (Horvatic 1939) Horvatic 1958, and mesomediterranean *Cyclamino repandi-Quercetum ilicis* Riv.-Mart., Cantó, Fernández-González & Sánchez-Mata 1995, the former with many deciduous species and affinities with *Quercetalia pubescentis*. In the ordination scattergram *Fraxino-Quercetum* (Fr-Qi) is located in correspondence of higher values of R/N, and *Cyclamino-Quercetum* (Cy-Qi) in correspondence of lower values of R/N. The former association in fact has a higher nitrogen availability-N and higher pH-R (Biondi & al. 2003).

B. Woodlands with *Abies alba*, are completely included within the cloud of the relevés of *Fagus sylvatica* , in correspondence with low R/N and high RxN values. Actually, these relevés belong to the belt of *Fagion sylvaticae* in central-southern Apennines of Abruzzo and Molise (Abbate 1990; Rovelli 2008) on moist soils and humus Mull with fast organic matter turn-over. Humus is in fact a Mull form and not Mor, like in the other coniferous forest with *Picea abies* all characterized by Mor humus form with low organic matter turn-over.

C. Beech forests at Apennines lower altitudes overlapped with rich *Quercus cerris* woodlands with *Carpinus betulus* on eutrophic soils. These woodlands showed intermediate R/N values. Typical beech woodlands referred to *Fagion* (Boublik & al. 2007) are in correspondence with higher R/N values (Fig. 3).

Therefore, at a broader scale the four sociological classes including the Italian woodlands analyzed (except for the azonal humid vegetation), completely fit with the four main humus forms -Mor, Amphi, Moder, Mull- (Fig. 3) giving support to humus theory (Ponge 2003).

In summary we can conclude that according to the ordination given by the two humus indexes (RO) we can see that along the RxN and R/N gradients, like for the Belgium forest vegetation (Fig. 1), we can recognize the following sequence of correspondences between vegetation and humus (Fig. 3):

1. *Quercetea ilicis* evergreen Mediterranean woodlands fit with Amphi, a twin humus form showing both characters of Mull (crumby organo-mineral horizon) and Moder (accumulated organic humus), due to a seasonal alternation between phases of high and low biological activity in strongly seasonal Mediterranean environments.

2. *Vaccinio-Picetea* boreal woodlands on Mor forms with slow transformation and accumulation of undecayed plant debris, with a sharp transition to the mineral soil.

3. *Quercetea pubescentis* sub-mediterranean and mesophile woodlands, distributed in fact between *Quercetea ilicis* and *Carpino-Fagetea* forests, fit with Moder humus with a velocity of litter transformation by litter-dwelling animals and fungi intermediate between Amphi and Mull.

4. *Carpino-Fagetea* woodlands on moist soils correspond to humus Mull with fast organic matter turn-over, characterized by a higher nutrient release per unit time, even if all forms would have equal turn-over rates. Here, in fact, the organic layers, accessible to earthworms, disappeared rapidly replaced by well transformed organic matter, integrated in well structured, thick and rich in nutrients A horizon (Klinka & al. 1990; De Nicola & al. 2018).

5. Azonal vegetation of hygrophilous *Alnus glutinosa, Fraxinus oxycarpa, Salix* and *Populus* spp. woodlands showed the highest RxN values on the extreme sector of the gradient: here soil water regime - from very moist up to flooded soils - was well supported by the correlation between RxN with soil moisture-F indicator (*coefficient* = 0.8 in Table 3b).

These ordered correspondences confirm that RxN is indeed an index of humus overall functionality as the result of the total interactions between humus and vegetation (De Nicola & al. 2013).

Along the R/N- nitrogen availability gradient the evergreen forest types were well discriminated. The boreal *Picea abies* relevés are separated from the *Quercus ilex/Q.suber* mediterranean forest due to the differences in nitrogen availability that in Amphi humus is

higher than in Mor where low temperatures slow down the litter decomposition, and consequently N release (Turner & al. 2010). R/N resulted in fact correlated with temperature-T indicator (*coefficient* = 0.8) and with Mediterranean Index-MI (0.6) (Table 3b). Higher temperatures in the Mediterranean Amphi forests help the process of nitrogen plant availability (R/N) where Ntot tends to accumulate in OF+OH+A horizons.

In Italian woodlands ordination the correspondences found between the four vegetation classes and the four main humus forms confirmed that vegetation and humus are both dependent by climate that influences the water and nutrient cycles. These influences are well evident by comparing the ordinations of Italy and Belgium forests. In Belgium there aren't the Amphi Mediterranean forms and boreal coniferous woodlands of *Vaccinio-Picetea*; therefore, RxN range for Mor and for Moder forms was lower than in Italy. Climate of Belgium is typically middle-European, characterized by the dominance of mesophile deciduous vegetation on moist eutrophic soils and Mull humus forms with fast organic matter turn-over (Wilson & al. 2001; Godefroid & al. 2005).

In the Italian woodlands we found that, among the humus forms, the maximum distance was between Amphi and Mull (Table 6) distributed in fact on the opposite limit of the RxN gradient in Fig. 3. This is due to the Mediterraneity acting as a powerful constrain for soil and vegetation diversity *versus* the greater homogeneity of Central-European forests (Pignatti 1998).

On the basis of the results we can assume that humus is a fundamental component of soil- vegetation interaction, supporting the study of Ponge (2013) on this topic.

Conclusion

The spatial pattern of the relevés in the ordination scattergram given by the two indices of Rogister and the high correlation between these two indices and the data collected on humus in the field, confirm that the information content in the species combinations of plant communities can be summarized by ecological indicators, so the complexity related to a great number of species, that produces an ecological space of many dimensions, can be reduced efficiently to few dimensions. We have shown that the reduction of the space defined by 847 species and 789 relevés into a space defined by only two indices (RO), that actually are respectively different combination of only two indicators, i.e. R (Reaction) and N (Nutrients), does not limit the information regarding the mutual position of vegetation types in the ecological multidimensional space. The predictivity of both EIV and RO is statistically significant, however RO show to be even more predictive than EIV (Eλ for RO=0.816 for EIV=0.576).

We can conclude that our question "Can ecoindicators be a tool to reduce and understand complexity of plant communities?" can have a YES answer providing a good support to the Pignatti's (1996; 2003) views.

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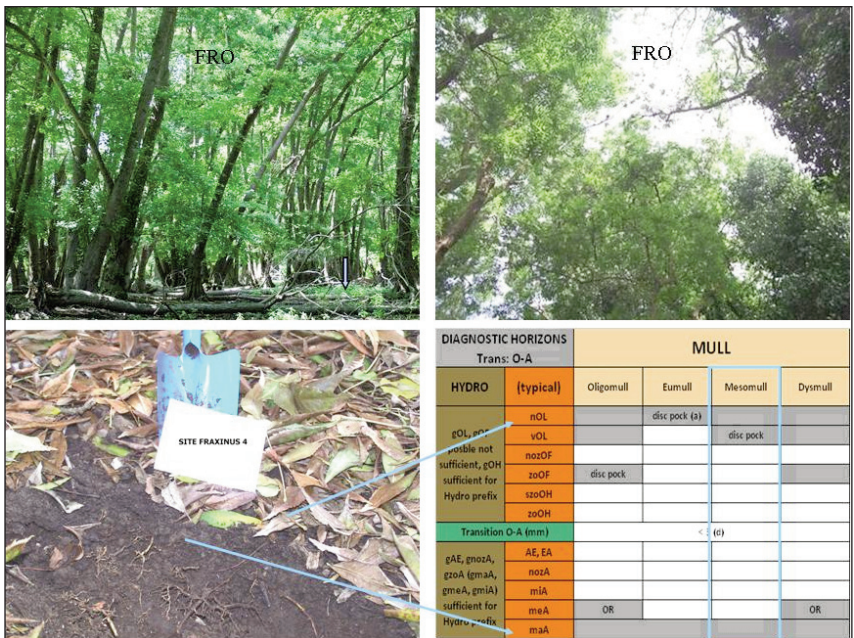*Corresponding author. E mail: annatesti934@gmail.com

APPENDICES

APP. Fig. 1. *Viburno-Quercetum ilicis* (QI) on Amphi humus form (*Quercus ilex* Forest Type 2 in this article).
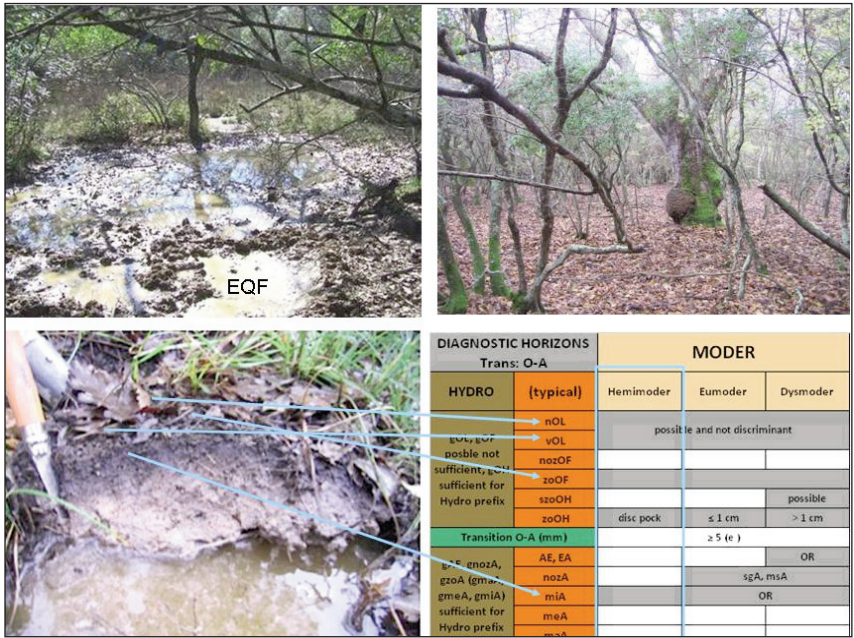
APP. Fig. 2. *Echinopo siculi-Quercetum frainetto* (EQF) on Moder humus form (*Quercus cerris* Forest Type 4 in this article).

APP. Fig. 3. *Carici remotae-Fraxinetum oxycarpae* (FRO) on Mull humus form (Hygrophilous Forest Type 9 in this article).