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NEMORAL DECIDUOUS FORESTS UNDER CLIMATIC EXTREMES – PHYTOSOCIOLOGICAL STUDIES ALONG CLIMATIC GRADIENTS IN SW ROMANIA

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Abstract: *Based on studies on stand structure, plant community composition and tree ecology across a climate gradient in western Romania from beech-dominated to oak-dominated forests, we are investigating how climate warming in 50-60 years would affect forest ecosystem structure, the vitality of important tree species, and the provision of energy wood from nemoral broad-leaved forests. The aim is to identify and characterize the tipping-points from mesic-hygrophilous, dark shady deciduous forests of Fagetalia sylvaticae to thermophilous, light deciduous forests of Quercetalia pubescenti-petraeae forests by using data from the Romanian Forests Vegetation Database. We applied non-metric multidimensional scaling, and indicator species analysis to evaluate ecologically three groups of relevés: (1) beech dominated forests, (2) mixed oak-hornbeam forests and (3) thermophilous oak dominated forests. We analysed spatial distribution of high order syntaxa, degree of warm thin terms of mean Ellenberg indicator values and number of thermophilous species, site differentiation in terms of altitude, aspect, temperature and precipitation. Our findings indicate that the gradient analysis could be performed on transects starting from 600 m downhill to 200 m, representing gradients of decreasing mean annual precipitation (from 800 to 600 mm), increasing temperature (+2-3°C) and increasing risk of drought stress as a proxy for climate warming. We proposed the following selection criteria: (i) near-natural deciduous forests; (ii) coherent and widely undisturbed woodland areas; (iii) sufficient elevational sequences; (iv) intermediate level of hygrotope (soil moisture*

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regime) and trophotope (soil nutrient regime); (v) same slope aspect (south-eastern direction); and (vi) sufficient distance (50-60 km) to each other.

Key words: *species niche, nemoral forests, climatic gradients, multiplicative regression, indicator species.*

1. Introduction

In the context of predicted climate warming, planning strategies in forestry need evidences for the capabilities of species to react to environmental changes, as climate or species competition. One approach is to substitute space for time, i.e. to analyse the relation of species to environment along gradients of temperature and/or species composition. Studies on species or habitat niche models [1, 6, 17, 22] indicate the opportunity and offer tools to explore such complex relationships. Due to the site influence on water availability for plants, the climate favourability has to be checked on so-called euclimatopes – gentle slopes or flat terrain with no influence of flooding or groundwater, with non-carbonated soils [23].

In Romania, as in all countries of temperate Europe, the forests are dominated by deciduous broadleaved species, among which beech (31% of forested area) and oaks prevail (16%)(NFI 2006). The oaks are represented by 5 (9) native taxa – *Quercus petraea* (incl. *Q. dalechampii*, *Q. polycarpa*), *Q. robur* (incl. *Q. pedunculiflora*), *Q. cerris*, *Q. frainetto*, *Q. pubescens* (incl. *Q. virgiliana*) [18-19]. Mixed deciduous forests in western Romania are particularly very complex in terms of composition of the tree layer [2-3]. Beside oaks, three lime species (*Tilia tomentosa, T. cordata, T. platyphyllos*), European hornbeam (*Carpinus betulus*), seldom Oriental hornbeam (*C. orientalis*), maples (*Acer platanoides, A. campestre, A. pseudoplatanus, A. tataricum*), European ash (*Fraxinus excelsior*), and elms (*Ulmus glabra, U. minor*) can occur in the species rich mixed forests.

The NEMKLIM project focuses on deepening the understanding of the effects through increasing summer heat and drought on forests in the nemoral zone. Background of the project is the presumption that dominant tree species of the Central European (sub) mesophytic beech and oak - hornbeam forests (so-called "competitor" species) reach their dry climatic limits in western Romania [5, 24]. At the margins (rear edges) of their occurrence these competitor species develop drought-adapted ecotypes, which have advantages in a summer-drier and warmer climate. In transition zones (ecotones) they are frequently associated and subsequently replaced by more drought-tolerant (“stress-resistant”) species of the Pannonian-Balkan oak mixed forests [7, 21]. Based on the modelling project "Margins" (margins.ecoclimatology.com) decisive bioclimatic variables in western Romania were identified as analogous to a future climate predicted in about 50 years for large parts of central Germany [14-16]. The region exhibits an altitudinal climatic gradient simulating the increasing summer heat and drought, as predicted in the climatic scenarios for large parts of the hilly and mountainous regions of Germany [7].

The aim of this study is to identify and characterize the tipping-points from mesic-hygrophilous, dark shady deciduous forests of *Fagetalia sylvaticae* to thermophilous, light deciduous forests of *Quercetalia pubescenti-petraeae* by using data from the Romanian Forests Vegetation Database. Information on the response of forests in western Romania to climate and weather events will be used to adapt forest management decisions for German woodland in the future.

2. Material and Methods

The research area was chosen in western Romania on 110x210 km, following ETRS-LAEA grid with cell size of 10 km^2. Phytosociological data was extracted from the Romanian forest vegetation database [9]. As selection criteria we used: (1) tree layer dominated by one or several nemoral species of *Fagus sylvatica*, *C. betulus*, *Tilia spp.*, *Quercus spp.* (2) quantitative records of species abundances (excluding relevés with presence-absence values), (3) non-flooded vegetation (excluding units of Alnion), (4) near natural vegetation (excluding stands dominated by exotic tree species), (5) relevés in mature stage (excluding relevés without tree layer). The resulting matrix contains 1111 relevés x 634 species (Figure 1). Available information for each releve are: species composition, vertical structure (tree, shrub, herb, regeneration layers), layers cover, site parameters (altitude, exposition, slope angle), geographic coordinates (with accuracy between 10 m -30 km), syntaxa [2]. Database preparation was processed in JUICE software [20].

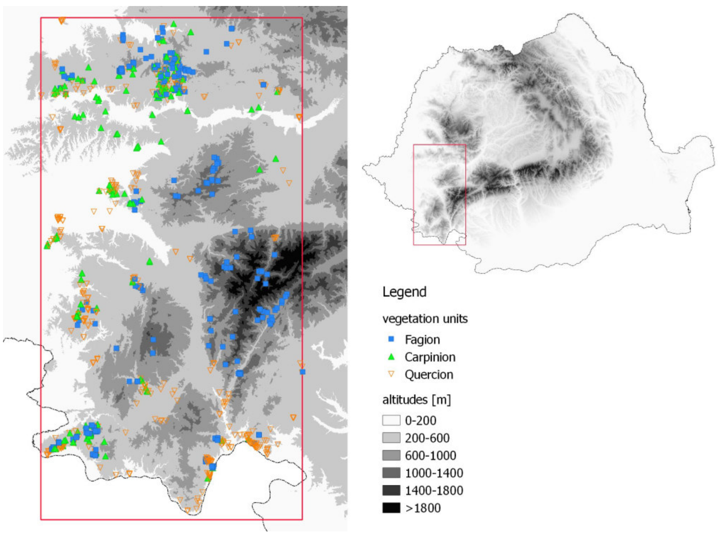

Fig. 1. Forest relevés distribution in south-western Romania

Indicator values of species were extracted from Sârbu et al. (2013), and unweighted averages were calculated for relevés. Climatic parameters were extracted from the WorldClim database [8]. Species ecological niches were drawn by non-parametric multiplicative regression (NPMR), which has the premises that: “the response variable has a physiologically-determined maximum, species respond simultaneously to multiple ecological factors, the response to any one factor is conditioned by the values of other factors, and that if any of the factors is intolerable then the response is zero" [11]. The analysis was performed using HyperNiche software [13], with the settings of Gaussian local mean and quantitative data.

Gradients in species composition and homogeneity of main vegetation units (alliances) were explored by non-metric multidimensional scaling (NMDS) [10], in PC-ORD software [12]. To reduce the variability induced by surveyors, data was transformed as follow: square root of abundance values, deletion of juveniles' records, deletion of species with frequency lower than 3, merging of tree layers.

Indicator species analysis [4] was applied to evaluate the fidelity of species to multi-factorial environment, expressed by vegetation alliances. We consider three major vegetation units that define a multidimensional ecological space: (1) mesic and cold forests, dominated by beech (*F. sylvaticas*) (*Symphyto cordati-Fagion*), (2) mesic and warm forests composed of oaks, hornbeam, limes (*Lathyro hallersteinii-Carpinion*, *Tilio-Acerion*), (3) dry and warm forests dominated by oaks (*Quercion frainetto, Quercion petraeae*). In this study *Carpino-Fagetum* was assigned to *Fagion*, despite its conventional assignment to *Carpinion*.

3. Results

NMDS ordination of forest communities shows a good delineation of major vegetation units (Figure 2).

Coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space (Bray-Curtis) are: R^2=0.517 for Axis 1, R^2=0.182 for Axis 2.

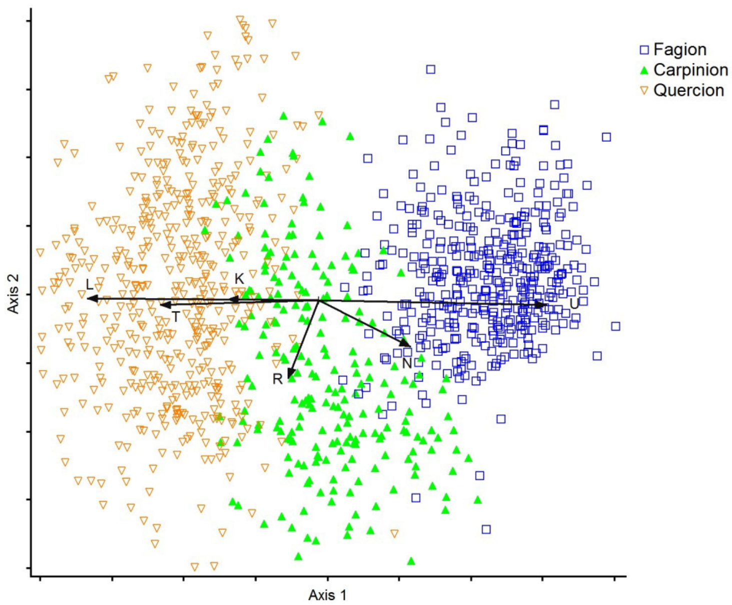

Fig. 2. NMDS ordination of forest communities in western Romania, in relation to mean Ellenberg values (L – light, T – temperature, K – continentality, U – soil water, R – soil reaction, N – nutrients)

The variation in species composition and syntaxa differentiation are best explained by light (R^2=0.805 with axis 1), humidity (R^2=0.792 with axis 1), temperature (R^2=0.550with axis 1), soil reaction (R^2=0.271with axis 2).

Best indicator species for these units are listed in Table 1. Their number increases from beech (18 species) to oak forests (34 species).

Analysis of species niche (Figures 3 and 4) reveals that beech and Hungarian oak are confined to two opposite biomes.

Table 1

Indicator values of species towards vegetation units, as resulted from database analysis. Only species with Ind. Val. > 10.0 are shown. Thermophilous species are in bold. The number of indicator species and thermophilous species increase from beech to oak forests

Vegetation unit	Indicator species
Symphyto-Fagion (401 relevés)	*Fagus sylvatica (87.5), Galium odoratum (36.7), Dryopteris filix-mas (30), Lamiastrum galeobdolon (25.5), Oxalis acetosella (24.8), Dentaria bulbifera (23.7), Festuca drymeia (22.9), Athyrium filix-femina (20.2), Rubus hirtus (17.3), Mycelis muralis (17.1), Luzula luzuloides (16.3), Polystichum aculeatum (15.8), Mercurialis perennis (14.8), Asarum europaeum (14.2), Dentaria glandulosa (11.8),Phyllitis scolopendrium (11.3), Epilobium montanum (10.8), Acer pseudoplatanus (10.7)*
Lathyro-Carpinion (225 relevés)	*Carpinus betulus (66.1), Viola reichenbachiana (29.9), Prunus avium (24.9),* ***Cornus mas*** *(23.2), Acer campestre (20.2), Melica uniflora (20), Stellaria holostea (19.5), Pulmonaria officinalis (19.2), Euphorbia amygdaloides (17.6), Lathyrus vernus (17.1), Galium schultesii (17.1), Glechoma hederacea (16.9),* ***Tilia tomentosa (15.5),*** *Carex pilosa (14.2), Geranium robertianum (14), Primula vulgaris (13.7),* ***Tamus communis (13.6),*** *Tilia platyphyllos (13.3), Hedera helix (13.1), Ranunculus auricomus (12.7), Sanicula europaea (12.2), Carex sylvatica (11.9), Cornus sanguinea (11.8), Ajuga reptans (10.6), Symphytum tuberosum (10.5), Polygonatum multiflorum (10.5)*
Quercetalia pubescentis (485 relevés)	***Quercus cerris (51.6),*** *Poa nemoralis (40.2), Dactylis glomerata (39),* ***Fraxinus ornus (37.8)****,* ***Quercus frainetto (36.5),*** *Quercus petraea (34.7), Crataegus monogyna (30.7),* ***Carpinus orientalis (27.3),*** *Veronica chamaedrys (26.9), Brachypodium sylvaticum (26.5),* ***Lychnis coronaria (25.6),*** *Vincetoxicum hirundinaria (25.5), Lathyrus niger (25), Clinopodium vulgare (24.5), Trifolium medium (23.3), Festuca heterophylla (22.9), Tanacetum corymbosum (21.9), Genista tinctoria (21.2), Campanula persicifolia (20.3),* ***Potentilla micrantha (19.8),*** *Fragaria vesca (19.1), Ligustrum vulgare (18.7), Euphorbia cyparissias (18.5), Buglossoides purpurocaerulea (18), Sedum maximum (16.8), Lembotropis nigricans (16.6), Pyrus pyraster (16.4), Rosa canina (16.4), Veronica officinalis (15.2), Silene viridiflora (15.1), Cruciata glabra (14.8), Geum urbanum (14.6), Chamaecytisus hirsutus (13.7), Rubus canescens (12)*

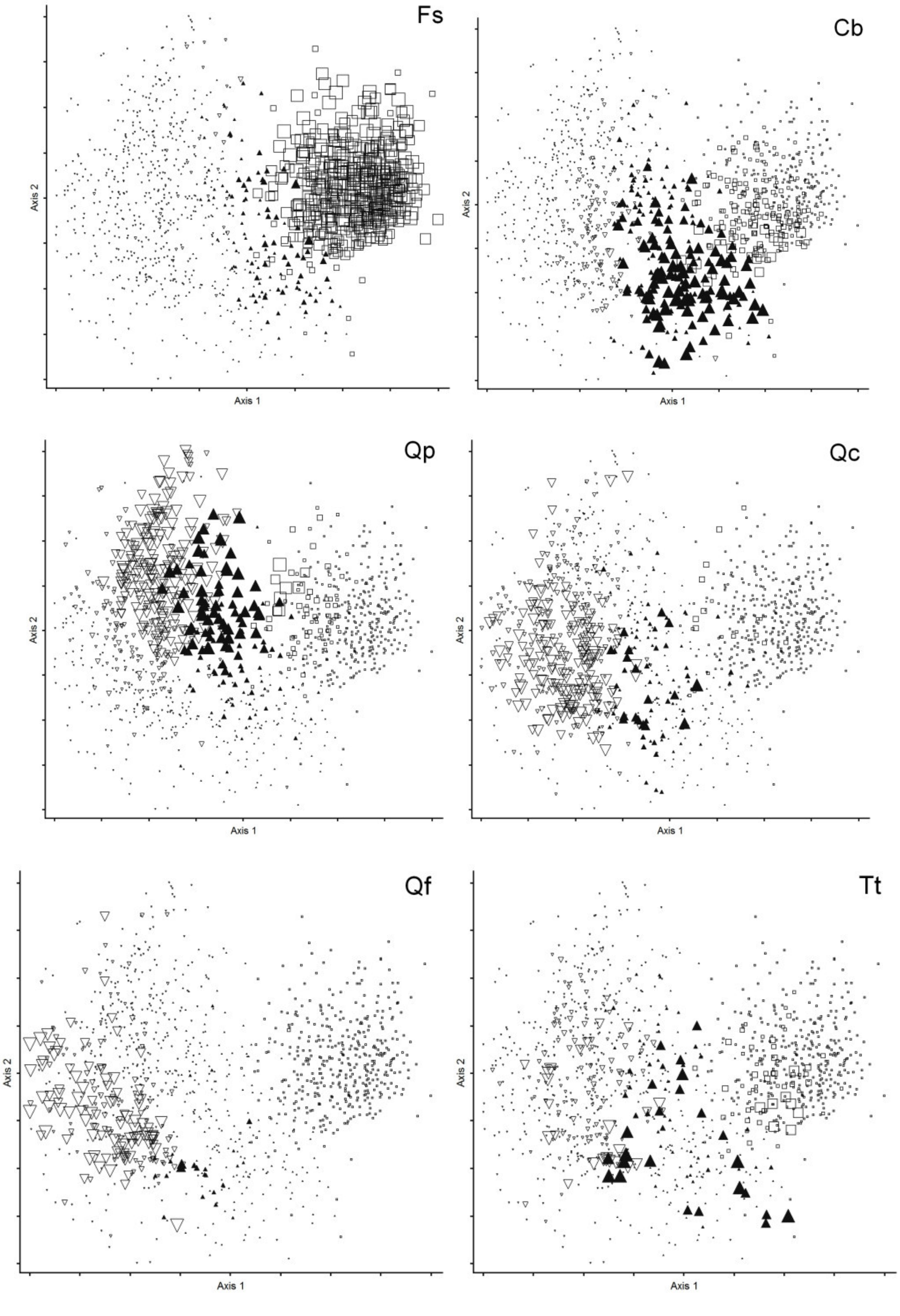

Fig. 3. Abundance domains of beech (Fs), hornbeam (Cb), sessile oak (Qp),Turkey oak (Qc), Hungarian oak (Qf) and silver lime (Tt) on NMDS ordination. Symbol size is proportional with species abundance, and symbol codes correspond to alliances as in Figure 2

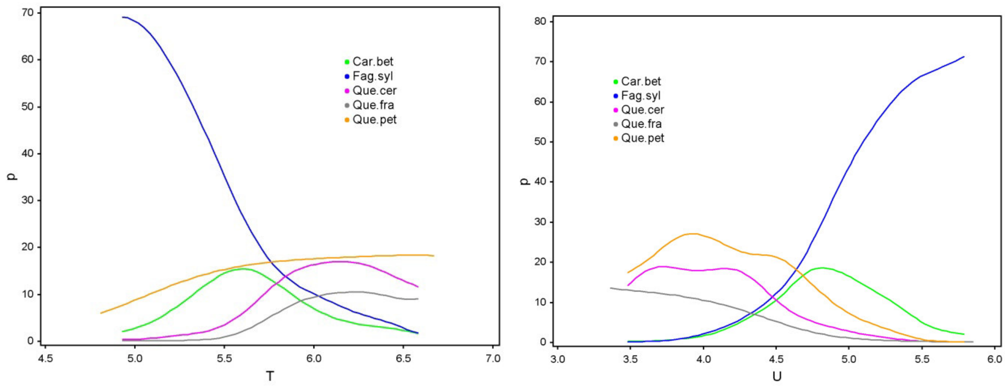

Fig. 4. Response curves of main tree species in western Romania in relation to mean indicator valuesfor temperature (T) and soil humidity(U)

Due to higher negative correlation between humidity and light or temperature, the thermo-hydric gradient may be expressed with the sequence of tree species: beech, hornbeam, silver lime, sessile oak, Turkey oak, Hungarian oak. Ecotonal transition from beech or *Fagion* impression to mesic oak forests of *Lathyro hallersteinii-Carpinion* starts with admixture of hornbeam, wild-cherry, silver lime and other thermophilous herb and shrub species (Table 1).

In terms of site determinants, there is a reciprocal influence of altitude and exposition, which is visible, both to warm demanding species and beech (Figure 5).

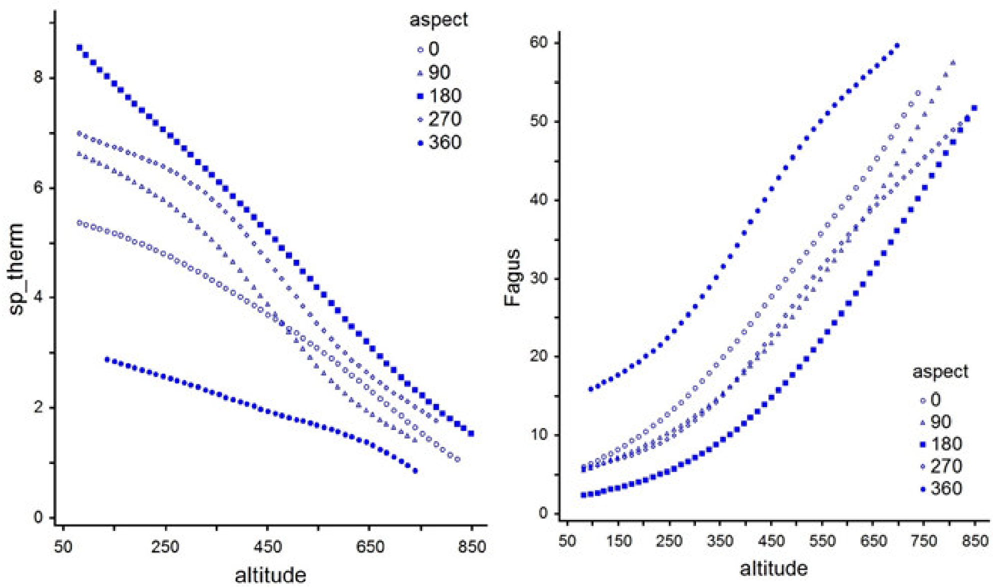

Fig. 5. The effect of altitude and aspect (degrees from N) on the number of thermophilous species (sp_therm) and beech dominance

At altitudes below 500(550) m beech could not become dominant on southern or south-western slopes, whereas at higher altitudes, as the water availability increases, the effect of solar radiation cease to be a limiting factor for beech. As the phytosociological data is expressed in terms of Braun-Blanquet scale, with coarse abundance amplitude, we decided that the score 3 (=cover between 26 and 50%) could express a high competition of beech that leads to *Fagion* forests. Thus, modelled niche of beech in Figure 5 indicates that on sunny slopes beech may exceed 25% cover at altitudes higher than 600 m. For thermophilous taxa, this is a known pattern – decreasing of their number with altitude, but it worth attention that the aspect plays a key role even at lower altitudes (150-100 m). This suggests a significantly distinct microclimate, potentially favourable for mesic species.

4. Discussion

Due to poor data on spatial position of relevés in the existing database, the use of climatic data derived from releve's location and WorldClim grids may induce considerable bias in the analysis. Thus, indirect estimate of environmental gradients, based on indicator values of species became a safer alternative for an overview for vegetation-climate interaction.

Gradients on water availability can be explored on relatively short altitudinal sequence, due to changes in slope and aspect. The zonal beech forest biomes (euclimatopes) start at approx. 550 m a.s.l., though such forests may occur on shady slopes down to 150 m. The above findings indicate that the ecotonal transition between beech and oak-hornbeam forests should be studied in south-western Romania on gentle slopes near 550 m. The gradient analysis could be performed on transects starting from 600 m downhill to 200 m, representing gradients of decreasing mean annual precipitation (from 800 to 600 mm), increasing temperature (+2-3°C) and increasing risk of drought stress as a proxy for climate warming. We proposed the selection criteria: (i) near-natural deciduous forests; (ii) coherent and widely undisturbed woodland areas; (iii) sufficient elevational sequences; (iv) intermediate level of hygrotope (soil moisture regime) and trophotope (soil nutrient regime); (v) same slope aspect (south-eastern direction); and (vi) sufficient distance (50-60 km) to each other. After applying the stratification criteria we selected (1) Munții Zarandului, (2) Munții Poiana Ruscă, and (3) Munții Almăjului.

Ecotonal transition from the *Fagion* to the *Carpinion*is associated with increasing drought stress, as indicated by mean U-values.

In contrast to the NFI survey the phytosociological database also provides the species composition of the forest field layer. Nevertheless, its preferential sampling does not guarantee to reveal the real climatic gradients on a local scale but for analysis on regional scales this effect diminishes. Other issues that may affect results accuracy are differences of sampling skills between surveyors, some inaccurate records of species cover and uneven records on tree seedlings.

5. Conclusions

Analysis of forest communities in western Romania indicates a close relation between tree and herb layer composition. The gradient of temperature is not strictly bound to latitude, since other factors like orography and relief openness may interfere. The use of mean Ellenberg values allowed to explore thermo-hydric gradients and to define the range of euclimatopes for beech forests and transition drivers to mesic-dry communities. The best predictor for tipping points is the soil water availability, which is better reflected by the mean indicator value for soil humidity (Ellenberg's U), and consequently by stress tolerant species. Comparing with the annual mean precipitation derived from DEM, this parameter incorporates the amount of precipitation but also soil water capacity and evapotranspiration.

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