

## Structure and diversity trends at *Fagus* timberline in central Italy

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**Abstract:** Structure and diversity trends ( $\beta$ -diversity and species richness) across the *Fagus sylvatica* timberline in the central Apennines were investigated. Twenty-three belt transects were laid out across the upper forest line in the Simbruini Mountains. Number of species, plant cover, and height of different layers were recorded in each quadrat. The moving split-window method was used to detect ecological discontinuities across beech timberlines. We show how  $\beta$ -diversity changes along timberlines and we put forward some hypotheses about the possible dynamics of these transitions. Four models resulted from the analysis of  $\beta$ -diversity trends: two  $\beta$ -diversity peaks indicated a transition where shrubs, mainly *Juniperus communis* ssp. *alpina*, (two high peaks) or beech scrub (two small peaks) formed a mantle that could allow forest expansion. One high  $\beta$ -diversity peak referred to an anthropo-zoogenic boundary maintained by disturbance, without the presence of a mantle. A little peak indicated a gradual transition at the upper potential timberline limit where beech forest had lost its typical floristical composition and structural characteristics.

**Nomenclature:** Pignatti (1982).

### Introduction

Timberlines are widely studied boundaries (Di Castri and Hansen 1992), since they are found in many parts of the world and in a great variety of environments: wet timberlines occur along the margin of bogs and swamps, cold ones in arctic and alpine environments and dry ones under steppe and savanna-like conditions (Forman and Moore 1992).

In the mountains of Europe, coniferous forests often reach the upper forest line and the transition zones along boundaries may be wide and gradual (Crawford 1989, Körner 1998). In the Apennines, the Pre-Alps and Eastern Alps (Italy), the Cantabrian chain (northern Spain) and the Dinaric chain (Balkan peninsula), beech forests reach the timberline and make contact with high-mountain dwarf shrublands or grasslands through narrow transition zones (Diaz Gonzalez and Fernandez-Prieto 1994, Bertovic and Lovric 1992, Ferrari and Piccoli 1997, Stanisci et al. 1998).

In the past twenty years, alpine timberlines were studied from the biogeographical and physiological points of view (e.g., Körner 1998, Baig and Tranquillini 1980, Anfodillo et al. 1998). Moreover, the subalpine belt has been analysed as a paleoecological indicator of past forest-line oscillations (e.g., Huppe and Pott 1993, Cherubini et al. 1996) and as an indicator of climatic changes (e.g., Edouard et al. 1991, Holtmeier 1993, Schlüssel and Theurillat 1996).

Available data on Apennine timberlines concern the phytosociology of high-mountain communities (e.g., Avena and Blasi 1980, Biondi et al. 1999, Blasi et al. 1990, Dowgiallo et al. 1998, Stanisci 1997). Until the fifties, high-mountain woody vegetation was largely cut and burned to create pasturelands above the timberline (Marchesoni 1957, Bertolani-Marchetti 1984). The progressive decrease of sheep-raising that followed led to the recovery of woody plants in these pastures. Moreover, recent bioclimatic researches (Blasi 1996) showed that the

**Table 1.** Description of boundary types at timberline in Simbruini Mountains.

PHYSIOGNOMY	SYNTAXONOMY	HABITAT
Beech forest \ <i>Daphne oleoides</i> & <i>Juniperus alpina</i> shrubland	<i>Fagion sylvaticae</i> \ <i>Daphno oleoidis-Juniperion alpinae</i>	Mainly on southeastern slopes with soils rich in debris (altitude 1750-1850 m)
Beech forest \ <i>Carex kitaibeliana</i> & <i>Avenula praetutiana</i> grassland	<i>Fagion sylvaticae</i> \ <i>Seslerion apenninae</i>	Steep slopes close to ridges with rendzina soils (1850 m)
Beech forest \ <i>Festuca dimorpha</i> & <i>Heracleum pyrenaicum</i> scree vegetation	<i>Fagion sylvaticae</i> \ <i>Linario-Festucion dimorphae</i>	Foot of scree slopes (1850 m a.s.l.)
Beech forest \ <i>Nardus stricta</i> & <i>Festuca italica</i> grassland	<i>Fagion sylvaticae</i> \ <i>Festucion macratherae</i>	Gentle slopes with deep leached soils (1700-1820 m)
Beech forest \ <i>Brachypodium genuense</i> dry grassland	<i>Fagion sylvaticae</i> \ <i>Brachypodenion genuensis</i>	Quite steep slopes with soils rich in debris (1675-1810 m)

subalpine and alpine belts in Italian mountains are rising and timberlines thus may change in composition and spatial distribution.

The aim of this study was to analyse structure and diversity trends ( $\beta$ -diversity and species richness alias  $\alpha$ -diversity) across the *Fagus sylvatica* timberline in the central Apennines, in order to make some hypotheses about the possible dynamics of these transitions.

### Study area

Data were collected in the Simbruini Mts. (central Italy), which are on the west side of the central Apennines, between Lazio and Abruzzo Regions (13° 20' N, 41° 50' E); the highest peak is Mt. Viglio (2156 m). The substrate consists mainly of tectonized Mesozoic limestone. Major geomorphological reliefs are gentle slopes, rocky ridges, glacial cirques, rockfaces, scree and gullies. There is no high altitude weather station but extrapolation of data obtained at Subiaco, Fiuggi, Mt. Guadagnolo, and Balze di S. Lucia indicate high rainfall (up to 1500 mm/year) and a mean annual temperature of 5-6 °C, with no dry season (Blasi 1994). The vegetation is mainly *Fagus sylvatica* forest with timberlines extending to a 200 m altitude range, from about 1700 m in old cut areas, to 1900 m in well-preserved zones (Stanisci et al. 1998). In previous studies, five boundary types were identified through cluster analyses (Stanisci et al. 1995, 1998). The physiognomic, syntaxonomic and habitat features are summarised in Table 1.

In other parts of the central Apennines, the beech forest, at timberline, also contacts other shrub communities:

*Pinus mugo* thickets, *Vaccinium myrtillus* & *V. gaultierioides* heaths, and *Rhamnus alpina* & *Berberis vulgaris* scrubs (Biondi et al. 1999, Blasi et al. 1990, Pedrotti 1982, Stanisci 1997). These communities are considered the most well-preserved vegetation of the subalpine belt in central Italy. In the Simbruini Mts., the low richness of shrub communities at the forest line is mainly due to the narrow subalpine belt and past intense grazing by sheep and cows. Nowadays, the shrubland consists of pioneer *Juniperus communis* ssp. *alpina* and *Arctostaphylos uva-ursi* var. *crassifolia* communities with *Rhamnus alpina*, *Rosa pendulina*, *Rubus idaeus* and *Lonicera alpigena* in the mantle of the beech forest.

### Data and methods

We identified 23 sampling sites as representatives of different physical environments and vegetation types at the timberline. In each site, a belt transect (comprising 1m × 1m quadrats) was laid out across the upper forest line. Transect length varied from 14 to 38m, depending on slope morphology and structural features of timberline. The number of species, plant cover (according to the Braun-Blanquet scale), and percentage cover and total height of different layers were recorded in each quadrat. Species richness and  $\beta$ -diversity were calculated for each transect. The moving split-window method (Webster and Wong 1969) was used to detect ecological discontinuities across transects obtained. Dissimilarity between attribute values (plant cover) in each split-window was calculated as squared Euclidean distance (SED). Various measures can be used, but SED is the most common (Johnston et al. 1992): it is quantitative (based on the number and abun-

dance of species in two adjacent half-windows) and generally agrees well with field observations (Wierenga et al. 1987). High SED peaks indicate wide variations in species composition at the edges (abrupt transitions), as reported in Di Castri and Hansen (1992) whereas gradual transitions are indicated by lower peaks. Similar peaks were found using different window widths (2, 3, 4 units) but only results for 3 units are shown.

**Results and discussion**

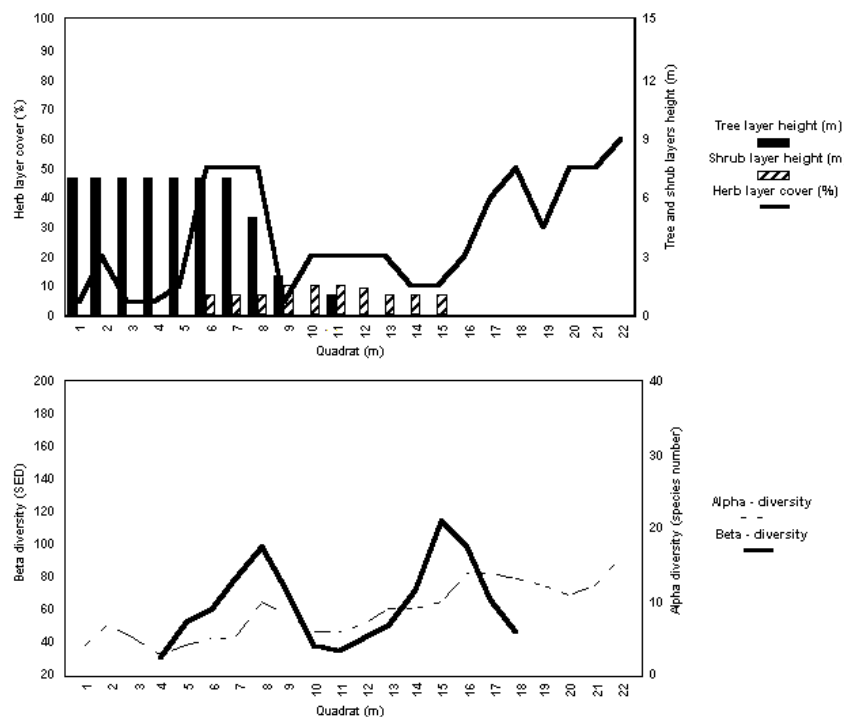
Transition zones were described by analysing  $\beta$ -diversity, species richness and vegetation layers in each transect. According to the main trends of  $\beta$ -diversity curves, the 23 transect could be grouped into two main patterns: one model showed two  $\beta$ -diversity peaks and the other just one peak. In the first case, a well characterised transition with a shrubby forest edge was identified, but in the second case the transition was abrupt, probably due to disturbance. The dynamical significance seems to be that where a shrubby transition (mantle) is present the timberline may move towards higher altitudes, whereas if no shrubby transition occurs, then timberline movement is blocked by disturbance.

These two major patterns can be divided into four transition types as described below.

1. Transition between beech forest and juniper-shrubland: two  $\beta$ -diversity peaks correspond to

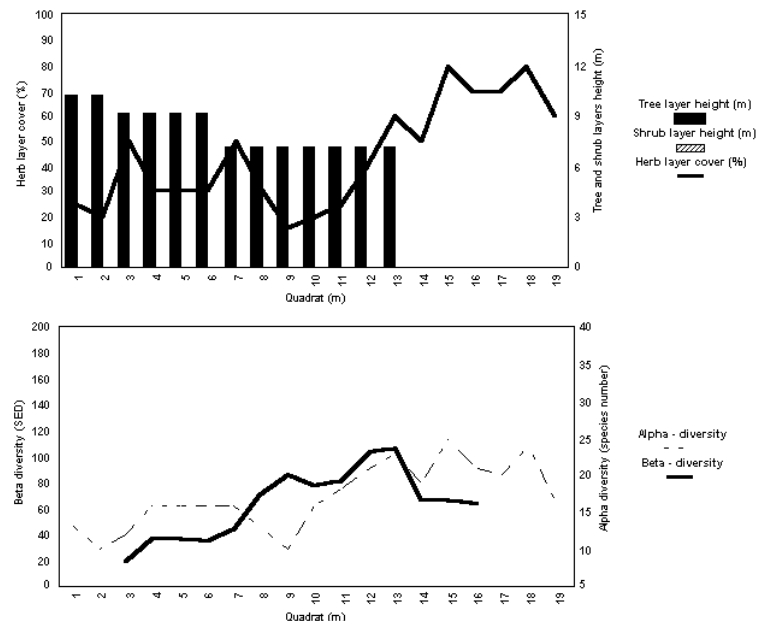
a transition zone with a mantle where *Juniperus communis ssp. alpina* is the dominant species. The distance between the peaks indicates that the mantle is about 8 m wide. Herbaceous cover is low in the juniper mantle and greater in the forest and in open shrubland of the endemic alliance *Daphno oleoidis-Juniperion alpinae* (Fig. 1). The mantle is rich in woody species, such as *Arctostaphylos uva-ursi* var. *crassifolia*, *Rosa pendulina*, *Rubus idaeus* and young specimens of *Acer pseudoplatanus*, *Sorbus aucuparia* and *S. aria*. *Fagus sylvatica* seedlings are also common, suggesting that the beech forest could spread towards higher altitudes.

2. Transition between beech thicket and *Carex kitaibeliana*-grassland: two small  $\beta$ -diversity peaks reveal a structural change in the last 5-7m before the grassland, where *Fagus sylvatica* suckers become shrub-like forming a mantle. This often occurs at boundaries between beech forest and *Carex kitaibeliana* grassland (*Seslerion apenninae*) and between beech forest and dry *Brachypodium genuense* grassland (*Brachypodenion genuensis*). Species richness increases towards the forest edges reaching a maximum in the grassland plots (Fig. 2). Here the only shrub in the mantle is beech and it could be hypothesized that beech forest may spread slowly to higher altitudes.

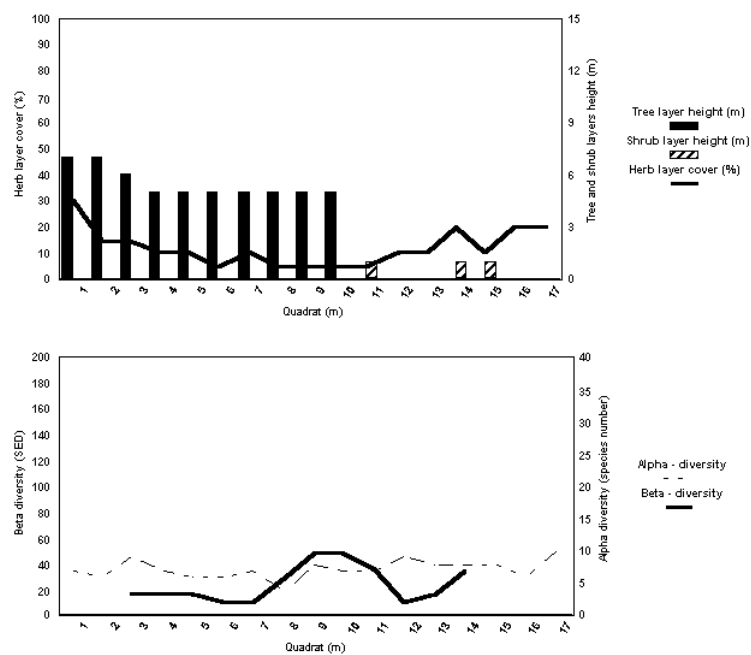


**Figure 1.** Structural (tree and shrub layers height and herb layer cover) and diversity ( $\alpha$  and  $\beta$ -diversity) trends in the beech forest / juniper shrubland transition.

**Figure 2.** Structural (tree and shrub layers height and herb layer cover) and diversity ( $\alpha$  and  $\beta$ -diversity) trends in the beech thicket / *Carex kitaibelliana* grassland transition.



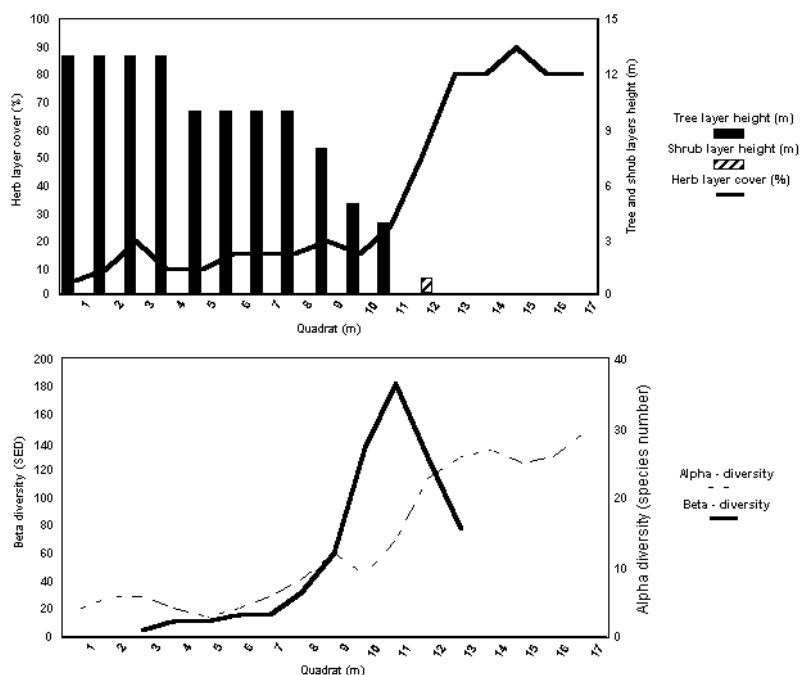
**Figure 3.** Structural (tree and shrub layers height and herb layer cover) and diversity ( $\alpha$  and  $\beta$ -diversity) trends in the beech patches / scree community.



3. Transition between beech patches and scree community: the  $\beta$ -diversity curve is weakly peaked with the lowest mean values. Species richness varies little throughout the sampled area, as does herbaceous cover. The number of species is low with a high floristic similarity between scree vegetation and beech forest. In fact, the timberline pattern is a mosaic formed by scree community (*Festucion dimorphae*) and stunted beech individuals up to 4-5 m tall (Fig.

3). Forest edges are irregular and seem to have reached their upper potential limit.

4. Transition between beech forest and grazed grassland: the  $\beta$ -diversity curve shows one high peak at the forest line, revealing a sharp difference in floristic composition. This often occurs at boundaries between beech forest and *Nardus stricta* grassland (*Festucion macratherae* alliance) and between beech forest and dry *Brachypodium genuense* grassland (*Brachypodion*



**Figure 4.** Structural (tree and shrub layers height and herb layer cover) and diversity ( $\alpha$  and  $\beta$ -diversity) trends in the beech forest / grazed grassland transition.

*genuensis* alliance). Species richness increases from 5 to 30 species towards grassland, and a similar trend may be observed in herbaceous cover (Fig. 4). The timberline is abrupt and the tree layer is often quite high (around 15-20m) at the edge. Nowadays such timberlines are found about 100-200m below the climatic forest line, on gentle slopes with deep soil. Here the beech forest is blocked by disturbance but may expand to its potential upper limit if grazing decreased.

Regarding species richness, the comparison of our  $\beta$ -diversity trends at the beech timberline with published data for forest edges at lower altitudes (e.g., Dierschke 1974, Matlack 1994, Luczaj and Sadowska 1997) confirmed the decrease in species number on the wooded side of the forest edge and an increase in species richness of shrubs and trees on the external side of edge (see forest/shrubland transition). It can be assumed that where natural or antropo-zoogenic disturbance at timberline is heavy, no shrub positive edge effect occurred.

**Conclusions**

The combined analysis of  $\beta$ -diversity, species richness and vegetation layers proved to be effective for defining diversity and structural models of transition zones at *Fagus sylvatica* timberlines in the central Apennines.

$\beta$ -diversity analysis based on the ‘moving split window’, used here for the first time to analyse timberlines,

was found useful for identifying ecological discontinuities along transitions. The four transition models summarise the different patterns of *Fagus sylvatica* at the upper forest line in the western part of the central Apennines. Two  $\beta$ -diversity peaks indicated a transition where shrubs (two high peaks) or beech scrub (two small peaks) formed the mantle that could allow forest expansion. One high  $\beta$ -diversity peak without mantle referred to an anthropo-zoogenic boundary maintained by disturbance. A little peak indicated a gradual transition at the upper potential timberline limit where beech forest had lost its typical floristical and structural composition and was quite similar to the neighbouring grassland.

**References**

Anfodillo, T., S. Rento, V. Carraro, L. Furnaletto, C. Urbinati and M. Carrer. 1998. Tree water relations and climatic variations at the alpine timberline: seasonal changes of sap flux and xylem water potential in *Larix decidua* Miller, *Picea abies* L. Karst and *Pinus cembra* L. *Annales des Sciences Forestieres* 55 (1-2): 159-172.

Avena, G. C. and C. Blasi. 1980. Carta della vegetazione del Monte Velino (Appennino abruzzese). C.N.R. Aq/1/35. Roma.

Baig, M.N.W. and W. Tranquillini. 1980. The effects of wind and temperature on cuticular transpiration of *Picea abies* and *Pinus cembra* and their significance in dessication damage at the alpine timberline. *Oecologia* 47: 252-256.

Bertolani-Marchetti, D. 1984. Dall’Appennino campano alle Serre Calabre - Cenni palinologici e paleoclimatici. *Biogeographia* 10: 67-87.

Bertovic, S. and A.Z. Lovric. 1992. Übersicht der Vegetation Kroatiens nach neueren Untersuchungen. *Tuexenia* 12: 29-48.

- Blasi, C. 1994. Fitoclimatologia del Lazio. *Fitosociologia* 27: 151-175.
- Blasi, C. 1996. Un approccio fitoclimatico allo studio dei cambiamenti climatici in Italia. *S. It. E. Atti* 17: 39-43.
- Blasi, C., A. Stanisci, G. Abbate and M.P. Gigli. 1990. Syntaxonomy and chorology of the *Vaccinium myrtillus* L. communities in the Monti Reatini (central Italy). *Giorn. Bot. Ital.* 124 (2-3): 259-279.
- Biondi, E., S. Ballelli, M. Allegrezza, F. Taffetani, A. R. Frattaroli, J. Guitian and V. Zuccarello. 1999. La vegetazione di Campo Imperatore (Gran Sasso d'Italia). *Braun-Blanquetia* 16: 53-116.
- Cherubini, P., P. Piuksi and F.H. Schweingruber. 1996. Spatiotemporal growth dynamics and disturbances in a subalpine spruce forest in the Alps: a dendroecological reconstruction. *Can. J. For. Res.* 26: 991-1001.
- Crawford, R.M.M. 1989. *Studies in Plant Survival*. Blackwell, London.
- Di Castri, F. and A.J. Hansen. 1992. The Environment and Development Crises as Determinants of Landscape Dynamics. *Ecological studies - Landscape Boundaries* 92: 3-19. Springer, New York.
- Diaz Gonzalez, T.E. and J.A. Fernandez-Prieto. 1994. El paisaje vegetal de Asturias: Guía de la excursión. *Itinera Geobotanica* 8: 5-235.
- Dierschke, H. 1974. Saumgesellschaften im Vegetations- und Standortsgelände an Waldrändern. *Scripta Geobot.* 6: 1-246.
- Dowgiallo, G., G. Rossi and M. Tomaselli. 1998. Vegetation and soil diversity in the areas above timberline of the Tuscan-Emilian Apennines (Northern Italy). *Écologie* 29: 159-162.
- Edouard, J.L., L. Tessier and A. Thomas. 1991. Limite supérieure de la forêt au cours de l'Holocène dans les Alpes Françaises. *Dendrochronologia* 9: 125-142.
- Forman, R. and P. Moore. 1992. Theoretical Foundations for Understanding Boundaries in Landscape Mosaics. *Ecological studies - Landscape Boundaries* 92: 236-259. Springer-Verlag, New York.
- Holtmeier, F.K. 1993. Timberlines as indicators of climatic changes: problems and research need. In: B. Frenzel (ed.), *Solifluction and Climate Variation in the Holocene*. Paläoklimaforschung 9: 211-222. Stuttgart, Jena, New York.
- Huppe, J. and R. Pott. 1993. Man-induced changes at the alpine timberline of the Val Fanga (Silvretta, Switzerland and their reflection in pollen diagrams (preliminary report). In: B. Frenzel B. (ed.), *Solifluction and Climate Variation in the Holocene - Paläoklimaforschung* 9: 211-222. Stuttgart, Jena, New York.
- Körner, C. 1998. A re-assessment of high elevation timberline positions and their explanation. *Oecologia* 115: 445-459.
- Johnston, C.A., J. Pastor and G. Pinay. 1992. Quantitative methods for studying landscape boundaries. *Ecological studies - Landscape Boundaries* 92: 107-128.
- Luczaj, L. and B. Sadowska. 1997. Edge effect in different groups of organisms: vascular plant, bryophyte and Fungi species richness across a forest-grassland border. *Folia Geobot. Phytotax.* 32: 343-353.
- Marchesoni, V. 1957. Storia climatico-forestale dell'Appennino Umbro-Marchigiano. *Ann. Bot. (Roma)* 25: 459-497.
- Matlack, G.R. 1994. Vegetation dynamics of the forest edge-trends in space and successional time. *J. Ecol.* 82: 113-123.
- Pignatti, S. 1982. *Flora d'Italia*. Edagricole, Bologna.
- Rivas-Martinez S. 1995. Clasificación bioclimática de la Tierra. *Folia Botanica Madritensis* 16: 1-15.
- Schlüssel, A. and J.P. Theurillat. 1996. Synusial structure of heathlands at the subalpine/alpine ecocline in Valais (Switzerland). *Revue Suisse de Zoologie* 103: 795-800.
- Stanisci, A. 1997. Gli arbusteti altomontani dell' Appennino centrale e meridionale. *Fitosociologia* 34: 1-45.
- Stanisci, A., A. Acosta, P. Fortini, D. Lavieri and C. Blasi. 1998. I contatti e le transizioni al limite superiore del bosco sui monti Simbruini-Ernici (Italia centrale). *Rev. Valdôtaine. Hist. Nat., Supplément* 52: 249-254.
- Webster, R. and I.F.T. Wong. 1969. A numerical procedure for testing soil boundaries interpreted from air photographs. *Photogrammetria* 24: 59-72.
- Wierenga, P.J., J.M.H. Hendrickx, M.H. Nash, J.A. Ludwig and L.A. Daugherty. 1987. Variation of soil and vegetation with distance along a transect in the Chihuahuan Desert. *J. Arid. Environ.* 13: 53-63.