The vegetation of Greek fir (*Abies cephalonica* Loudon) forests on the Oxia - North Vardousia mountain system, central Greece, in relation to drought

Thesis submitted in partial fulfilment of the requirements of

the degree Doctor rer. nat. of the

Faculty of Forest and Environmental Sciences,

Albert-Ludwigs-Universität

Freiburg im Breisgau, Germany

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Freiburg im Breisgau, Germany
2012

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Date of thesis' defence: 11/06/2012

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Acknowledgments

Many people have contributed to the completion of this work, from the very beginning to the last day of the submission. Without the help of all of them this thesis would have still been an unaccomplished dream. First of all I have to thank my two supervisors Albert Reif and Kostas Theodoropoulos, two wonderful persons that I had the good luck to meet in my life. Thanks to Kostas, my mentor over the first years of my scientific steps, I came into contact with the field of phytosociology. Thanks to Albert I did a step further into the field of vegetation ecology. I am grateful to both of them for their scientific support but I am also deeply indebted for all their non scientific help, whenever I need it. Albert I still owe you a luxurious dinner...

I feel extremely grateful to Stefanie Gärtner for her crucial support at the beging and at the end of my PhD. Her critical spirit was always a good advisor. I should gratefully acknowledge Nikos Alexandris for helping a lot with the climatic analysis. His very good knowledge about GIS and his passion for the free/open source world made me see the things from another point of view, more open and more free. Grateful thanks are due to the following people for their help in my field work: Bernd Künemund, Rodrigo Vargas, Cristabel Durán, Osvaldo Vidal and Carl Höcke. I would like to acknowledge the help of Stefanie Gärtner, Rodrigo Vargas, Hendrik Stark, Juana Palma, David Forrester and Nathan Briggs for checking and correcting parts of my manuscript. Special thanks to Günter Gottschlich for verifying or identifying specimens of the difficult genus *Hieracium* and Michael Lüth for identifying all the bryophytes. I would also like to express my gratitude to Christina Petschke for her guidance and help during the soil analysis in the Institute of Soil Science and Forest Nutrition in Freiburg. I'm thankful to Giorgos Karetsos for helping me to find all the maps that I needed for my study area.

I would like to thank the committee of the IKYDA exchange program for covering some travel expenses related to my data collection.

I should not forget to thank Carolin Arheidt, the person that convinced me to leave my country and come to Germany to start there my PhD. Charalambos Neophytou and Fotis Xystrakis, my good Greek friends and fellow travelers for many years, with whom I spend nice moments and I shared their enthusiasm for life and science. And of course all my friends and colleagues from the Institute of Silviculture with whom I spend a lot of time, discussing and exchanging thoughts, ideas and experiences during these four and a half years of my stay in Freiburg. Special thanks to Cristabel Durán, my Bürokollegin with whom I shared my working place all these years, in a nice and friendly atmosphere, and Jan Bannister for his positive aura.

To my parents Agamemnon and Katerina I owe really a lot, for being always there ready to support me whenever my financial situation was problematic.

Last but not least, I owe a great debt of gratitude to Juana Palma, for sharing so many things in our personal and professional life, and for the psychological support during the really hard and exhausting last weeks of our work.

Abstract

Background: Greek fir (*Abies cephalonica* Loudon) is the dominant tree species in the mountainous regions of southern and central Greece. Greek firs grow in a typical montane Mediterranean climate that is characterized by a dry and warm summer period. In such water-controlled ecosystems, drought is an important abiotic factor in competition processes, the structure and composition of plant communities, and plant species survival. The Oxia - North Vardousia mountain range is one of the most extensive areas in Greece with well-preserved montane Mediterranean Greek fir forests. Nevertheless, almost no information is available about the plant communities and the synecology of these forests.

Aims: This study aimed to describe the Greek fir forest vegetation of the flysch area in Oxia - North Vardousia mountain range in relation to drought. It also applied and compared two different methodological approaches for the quantification of drought. The quantification of the most important environmental thresholds for the occurrence of the different forest vegetation units were also assessed.

Methods: Two methods were used to quantify the drought: a humidity/aridity index (HI), which incorporates only the climatic components of drought (climatic drought); a more complete, water balance, method that includes, additionally, the soil components of drought (site drought). The spatial quantification of drought for the whole study area was assessed with the use of HI. The HI was calculated for different time periods and the values for the vegetation period were used for the stratification of the study area. Geostatistical methods were used for the spatial prediction of temperature and precipitation, and a GIS-based model for the calculation of solar irradiation. For the estimation of reference potential evapotranspiration ($\mathrm{PET}_{\mathrm{ref}}$) an empirical equation was chosen after a careful evaluation of its performance.

The description of fir forest vegetation was based on floristic, structural and abiotic parameters recorded in 45 relevés. For the sampling the area was stratified based on the climate conditions during the vegetation period, and the locations of the plots in each stratum were randomly selected. The soil hydraulic properties were derived from soil profiles and laboratory analysis of undisturbed soil samples. Vegetation relevés were classified with cluster analysis and vegetation units were defined and compared with existing published relevés from central Greece. Gradient analysis was performed with the use of non-metric multidimensional scaling. The vegetation pattern was analyzed with several drought-related variables and other abiotic and biotic variables. Classification trees were used to determine the most important environmental factors and to quantify their limits between the *Abies* forest vegetation units.

Results: Two forest communities (*Crepis fraasii* - *Abies cephalonica* comm. and *Sanicula europaea* - *A. cephalonica* comm.), including four subtypes, were identified within the *Abietion cephalonicae* alliance, related to a drought gradient. The *Crepis fraasii* - *Abies cephalonica* comm. occupied the driest side of the gradient, in contrast to *Sanicula europaea* - *A. cephalonica* comm. which occupied the moister sites. The syntaxonomy and nomenclature of those units was discussed as well as their affinities with other *Abies* vegetation units from central Greece. Humidity index followed by potential evapotranspiration were found to be the most important variables for the discrimination of the two forest communities. The *Crepis fraasii* - *Abies cephalonica* comm. occurs when HI is ≤ 0.26 for the four driest months or when PET is > 1034.3 mm for the growth period. For values of HI > 0.26 or PET ≤ 1034.3 mm the *Sanicula europaea* - *A. cephalonica* comm. occurs. Among the subtypes there were no significant differences in terms of water availability. Their differentiation could be partly explained by abiotic (aspect, slope, cover of exposed rocks) and biotic (canopy cover, humus depth, litter cover) variables which are mainly influencing the micro-climatic and edaphic conditions. The method for the estimation of $\mathrm{PET_{ref}}$ that gave the best results was the Abtew empirical equation.

Conclusions: The community patterns of the *Abies* forest vegetation in the study area reflect a major differentiation between mesophytic and xerophytic *Abies* forests along a gradient of decreasing drought. The humidity index appears to be the most suitable variable to express the meso-climatic drought conditions in the Greek fir forests of the study area. The threshold values of HI and $\mathrm{PET_{ref}}$ can be used for the prediction of the occurrence of the two forest communities. In a finer scale, the influence of drought on the floristic composition and structure of the Greek fir forests is weak. Other micro-site factors and historic events seem to play a higher role in further differentiating the two plant communities. The Abtew empirical equation performed best under the mediterranean climate conditions for the estimation of $\mathrm{PET_{ref}}$. It is, therefore, recommended for similar applications in regional or local scales in the fir forests of central Greece.

Zusammenfassung

Hintergrund: Die Bergregionen in Süd- und Zentralgriechenland werden von der Griechischen Tanne (*Abies cephalonica* Loudon) dominiert. Griechische Tannen wachsen im typisch mediterran montanen Klima, welches durch trockene und warme Sommer charakterisiert ist. In diesen Waldökosystemen ist Trockenheit ein wichtiger abiotischer Faktor, der die in Konkurrenzprozesse beeinflusst, der Struktur und Zusammensetzung von Pflanzengesellschaften steuert und für das Auftreten bestimmter Pflanzenarten verantwortlich ist. Der Oxia - Nord Vardousia Gebirgeskomplex, ist das Gebiet mit einen der größten und am besten erhaltenen Vorkommen von mediterran montanen Wäldern mit Griechische Tanne. Bisher existiren keine Arbeiten über die Pflanzengesellschaften und die Synökologie dieser Wälder.

Ziele der Arbeit: 1) Beschreibung der Vegetation der Griechischen Tannenwälder des Flyschgebietes im Oxia - Nord Vardousia Gebirgskomplex in Abhängigkeit von Trockenheit. 2) Der Vergleich von zwei verschieden methodischen Ansätzen zur Bestimmung von Trockenheit. 3) Definition von Schwellenwerten der wichtigsten Umweltfaktoren, die das Auftreten der Pflanzengesellschaften dieser Waldformation bestimmen.

Methoden: Zwei Methoden wurden verwendet um Trockenheit zu quantifizieren: ein Humiditäts/Ariditäts Index (HI), der nur die klimatischen Komponenten von Trockenheit beschreibt (klimatische Trockenheit), und die umfassendere Wasserhaushaltsbilanzmethode, die zusätzlich die bodenbürtigen Komponenten der Trockenheit integriert (Standortstrockenheit). Für die räumliche Beschreibung der Trockenheit über das gesamte Untersuchungsgebiet wurde der HI genutzt und für verschiede Zeiträume errechnet. Geostatistische Methoden wurden verwendet für die räumliche Zuordnung von Temperatur und Niederschlag, und ein GIS- basiertes Model für die Kalkulation der Einstrahlung. Für die Schätzung der potentiellen Evapotranspirationsreferenz ($\mathrm{PET_{ref}}$) wurden empirische Modelle verwendet.

Die Beschreibung der Tannenwälder basiert auf floristischen, strukturellen und abiotischen Daten von 45 Aufnahmen. Das Untersuchungsgebiet wurde anhand von klimatischen Bedingungen während der Vegetationsperiode stratifiziert, innerhalb jedes Stratums wurden die Aufnahmepunkte zufällig ausgewählt. Die hydraulischen

Eigenschaften wurden anhand von Bodenprofilen und Laboranalysen von ungestörten Bodenproben ermittelt. Die Vegetationsaufnahmen wurden mithilfe von Clusteranalysen klassifiziert und in der Literatur Vegetationseinheiten zugeordnet, die für Zentralgriechenland beschrieben sind. Mithilfe von Nichtmetrischer Multidimensionaler Skalierung wurde die Vegetation ordiniert. Die Vegetation wurde mithilfe verschiedener trockenheitsindizierender und anderer biotischer und abiotischer Variablen analysiert. Classification trees wurden verwendet, um die Umweltfaktoren mit den stärksten Einflüssen auf die Vegetation auszuwählen und die Schwellenwerte zwischen den verschieden Tannenwaldgesellschaften zu bestimmen.

Ergebnisse: Zwei Waldgesellschaften (*Crepis fraasii - Abies cephalonica* Gesellschaft und *Sanicula europaea - A. cephalonica* Gesellschaft) mit vier Ausbildungen wurden innerhalb der *Abietion cephalonicae* Allianz wurden ausgeschieden. Sie repräsentieren einen Trockenheitsgradienten. Die *Crepis fraasii - Abies cephalonica* Gesellschaft kommt am trockensten Ende des Gradienten im Kontrast zu der *Sanicula europaea - A. cephalonica* Gesellschaft am feuchteren Ende vor. Die syntaxonomische Einordnung und Nomenklatur der Vegetationseinheiten und ihre Beziehung zu anderen Tannengesellschaften in Zentralgriechenland wird diskutiert. Der HI, gefolgt von der potentiellen Evapotranspiration, waren die wichtigsten Umweltfaktoren für die Differenzierung zwischen den beiden Waldgesellschaften. Die *Crepis fraasii - Abies cephalonica* Gesellschaft kommt dann vor, wenn der HI während der vier trockensten Monate des Jahres 0.26 unterschreitet oder wenn die potentielle Evapotranspiration > 1034.3 mm für die Vegetationsperiode erreicht. Im Bereich von $\mathrm{HI} > 0.26$ oder $\mathrm{PET} \leq 1034.3$ mm tritt die *Sanicula europaea - A. cephalonica* Gesellschaft auf. Die Wasserversorgung differenziert nicht signifikant zwischen den Ausbildungen. Deren Differenzierung kann in Teilen durch abiotische Standortsunterschiede (Exposition, Hangneigung, exponierter Fels) und zum Teil aufgrund biotischer Faktoren (Überschirmung, Humusmächtigkeit, Streudeckung) erklärt werden da diese das Mikroklima und die edaphischen Bedingungen beeinflussen. Die beste Schätzmethode für $\mathrm{PET}_{\mathrm{ref}}$ war das empirische Model von Abtew.

Schlussfolgerungen: Das Vegetationsmuster der Tannenwaldgesellschaften im Untersuchungsgebiet reflektiert die Differenzierung zwischen mesophytischen und xerophytischen Tannenwaldgesellschaften entlang des Trockenheitsgradienten. Der HI stellte sich als der Faktor heraus, der am besten die mesoklimatischen Trockenheitsbedingungen in den Griechischen Tannenwäldern im Untersuchungsgebiet beschreibt. Die Schwellenwerte von HI und $\mathrm{PET}_{\mathrm{ref}}$ können genutzt werden, um das Auftreten der beiden Waldgesellschaften vorherzusagen. Eine genauere Differenzierung in die vier Ausbildungen kann nicht aufgrund der Trockenheit erklärt werden. Andere mikrostandörtlichen Faktoren und historische Ereignisse scheinen einen

stärkeren Einfluss auf die weitere floristische Differenzierung der beiden Pflanzengesellschaften zu haben. Das empirische Model von Abtew erziehlt unter den mediterranen Klimabedingungen die beste Schätzung von PET_{ref} und wir empfehlen es für ähnliche Anwendungen auf regionaler und lokaler Skala in Tannenwäldern in Zentralgriechenland.

Περίληψη

Η κεφαλληνιακή ελάτη (*Abies cephalonica* Loudon) αποτελεί το κυρίαρχο δασικό είδος των ορεινών περιοχών της κεντρικής και νότιας Ελλάδας. Αναπτύσσεται σε περιοχές με ορεινό-μεσογειακό κλίμα, που χαρακτηρίζονται από μια ξηρή και θερμή θερινή περίοδο. Σε αυτού του είδους τα οικοσυστήματα, η ξηρασία αποτελεί ένα πολύ σημαντικό αβιοτικό παράγοντα που επηρεάζει τον ανταγωνισμό μεταξύ των ειδών και των ατόμων του ίδιου είδους, τη δομή και τη σύνθεση των φυτοκοινωνιών και την επιβίωση των φυτών. Η οροσειρά της Οξυάς και των Βορείων Βαρδουσίων αποτελεί μια από τις πιο εκτεταμένες περιοχές του ελληνικού χώρου με καλά διατηρημένα ελατοδάση. Παρόλα αυτά, σχεδόν καμία πληροφορία δεν είναι διαθέσιμη για τις φυτοκοινωνίες και τη συνοικολογία των δασών αυτών.

Σκοπός: Σκοπός της παρούσας διατριβής ήταν η περιγραφή της βλάστησης των δασών της κεφαλληνιακής ελάτης που φύονται επί φλύσχη στην οροσειρά Οξυάς-Βορείων Βαρδουσίων και η συσχέτισή τους με την ξηρασία. Στόχος ήταν επίσης η εφαρμογή και σύγκριση δύο διαφορετικών μεθοδολογικών προσεγγίσεων για την ποσοτικοποίηση της ξηρασίας. Τα όρια των σημαντικότερων περιβαλλοντικών παραμέτρων, που επηρεάζουν την εξάπλωση των διαφόρων δασικών φυτοκοινωνιών της ελάτης, αξιολογήθηκαν και ποσοτικοποιήθηκαν.

Μεθοδολογία: Δύο μέθοδοι χρησιμοποιήθηκαν για τη ποσοτικοποίηση της ξηρασίας: ένας δείκτης υγρασίας/ξηρασίας (HI), ο οποίος ενσωματώνει μόνο τις κλιματικές συνιστώσες της ξηρασίας; και μια μέθοδος υδατικού ισοζυγίου, η οποία ενσωματώνει επιπρόσθετα τις εδαφικές συνιστώσες της ξηρασίας. Για τη χωρική πρόβλεψη των κατακρημνισμάτων και της θερμοκρασίας του αέρα χρησιμοποιήθηκαν γεωστατιστικές μέθοδοι και μέθοδοι γραμμικής παλινδρόμησης, ενώ για τον υπολογισμό της προσπίπτουσας ηλιακής ακτινοβολίας χρησιμοποιήθηκε το μοντέλο r.sun, βασισμένο σε ένα σύστημα γεωγραφικών πληροφοριών. Για την εκτίμηση της δυνητικής εξατμισοδιαπνοής ($\mathrm{PET}_{\mathrm{ref}}$) επιλέχθηκε, μετά από προσεκτική αξιολόγηση, μια εμπειρική μέθοδος (εξίσωση του Abtew).

Η περιγραφή της βλάστησης των ελατοδασών βασίστηκε στη συλλογή χλωριδικών, δομικών και αβιοτικών δεδομένων από 45 δειγματοληπτικές επιφάνειες που πάρθηκαν με τυχαία στρωματομένη δειγματοληψία. Για τη στρωμάτωση της περιοχής έρευνας χρησιμοποιήθηκε η κλιματική ξηρασία. Ο προσδιορισμός των υδατικών σταθερών του εδάφους πραγματοποιήθηκε σε αδιατάρακτα εδαφικά δείγματα που πάρθηκαν από τις 45 εδαφοτομές που πραγματοποιήθηκαν σε όλες τις δειγματοληπτικές επιφάνειες. Οι επιφάνειες ταξινομήθηκαν με μια μέθοδο ανάλυσης ομάδων (cluster analysis) με σκοπό τη διάκριση των μονάδων βλάστησης. Οι διακριθείσες φυτοκοινωνίες περιγράφηκαν και συγκρίθηκαν με δημοσιευμένες δειγματοληψίες (relevés) από την κεντρική Ελλάδα. Έμμεση ταξιθέτηση (indirect ordination) των επιφανειών με τη μέθοδο της μη-μετρικής πολυδιάστατης κλιμακοποίησης (non-metric multidimensional scaling) εφαρμόστηκε με σκοπό τη μελέτη της διαβάθμισης της βλάστησης (gradient analysis). Για την ερμηνεία της διαβάθμισης της βλάστησης διάφορες συνιστώσες της ξηρασίας καθώς και άλλες βιοτικές και αβιοτικές παράμετροι χρησιμοποιήθηκαν. Για τον προσδιορισμό των σημαντικότερων περιβαλλοντικών παραμέτρων και την ποσοτικοποίηση των οριακών τους τιμών, για τις διάφορες δασικές φυτοκοινωνίες, εφαρμόστηκε η μέθοδος της δενδρικής ταξινόμησης (classification tree).

Αποτελέσματα: Δύο δασικές φυτοκοινότητες διακρίθηκαν (*Crepis fraasii* - *Abies cephalonica* κοινότητα και *Sanicula europaea* - *A. cephalonica* κοινότητα) κατά μήκος της διαβάθμισης της έντασης ξηρασίας. Οι φυτοκοινότητες, που περιλαμβάνουν τέσσερις υποτύπους, εντάχθηκαν στη συνένωση *Abietion cephalonicae*. Η *Crepis fraasii* - *Abies cephalonica* κοινότητα εμφανίζεται στους ξηρότερους σταθμούς, σε αντίθεση με τη *Sanicula europaea* - *A. cephalonica* κοινότητα που καταλαμβάνει τις πιο υγρές θέσεις. Η συνταξινομική θέση και η ονοματολογία των μονάδων βλάστησης συζητήθηκε, καθώς και η σχέση τους με άλλες μονάδες βλάστησης από το χώρο της κεντρικής Ελλάδας. Ο δείκτης υγρασίας/ξηρασίας, και η δυνητική εξατμισοδιαπνοή αποδείχτηκαν οι πιο σημαντικές παράμετροι για τη διάκριση των δύο δασικών φυτοκοινοτήτων. Η *Crepis fraasii* - *Abies cephalonica* κοινότητα εμφανίζεται σε θέσεις όπου οι τιμές του δείκτη υγρασίας/ξηρασίας είναι ≤ 0.26 κατά τη διάρκεια των τεσσάρων ξηρότερων μηνών ή όπου η δυνητική εξατμισοδιαπνοή ξεπερνά τα 1034.3 mm κατά τη αυξητική περίοδο. Αντίθετα, η *Sanicula europaea* - *A. cephalonica* κοινότητα εμφανίζεται σε θέσεις οπου ο δείκτης ξηρασίας είναι > 0.26 ή όπου η δυνητική εξατμισοδιαπνοή δεν ξεπερνά τα 1034.3 mm. Μεταξύ των υποτύπων δεν παρατηρήθηκαν σημαντικές διαφορές όσων αφορά τη διαθέσιμη υγρασία. Η διαφοροποίησή τους θα μπορούσε να αποδοθεί, εν μέρει, σε αβιοτικές (έκθεση, κλίση, κάλυψη εδάφους με πέτρες και βράχια) και βιοτικές παραμέτρους (κάλυψη κομοστέγης, βάθος δασικού τάπητα, κάλυψη ξηροφυλάδας) οι οποίες επηρεάζουν το μικροκλίμα και τις εδαφικές συνθήκες.

Συμπεράσματα: Η εξάπλωση των δασικών φυτοκοινωνιών της κεφαλληνιακής ελάτης στην περιοχή έρευνας αντικατοπτρίζει μια βασική διαφοροποίηση σε ξηροφυτικά και μεσοφυτικά ελατοδάση κατά μήκος της διαβάθμισης της έντασης ξηρασίας. Ο δείκτης υγρασίας εμφανίζεται ως η καταλληλότερη περιβαλλοντική παράμετρος για την

έκφραση των μεσο-κλιματικών συνθηκών ξηρασίας στα ελατοδάση της περιοχής έρευνας. Οι οριακές τιμές του δείκτη υγρασίας (HI) και της δυνητικής εξατμισοδιαπνοής ($\mathrm{PET_{ref}}$) μπορούν να χρησιμοποιηθούν για την πρόβλεψη της χωρικής κατανομής των δύο βασικών φυτοκοινοτήτων. Η εμπειρική εξίσωση του Abtew έδωσε τα καλύτερα αποτελέσματα στην εκτίμηση της $\mathrm{PET_{ref}}$ και γι'αυτό το λόγο συνιστάτε η χρήση του σε παρόμοιες εφαρμογές τοπικής κλίμακας στα ελατοδάση της κεντρικής Ελλάδας.

1. Introduction

Fir (*Abies* spp.) forests are an ecologically and economically important and widespread landscape component in the mountains of Greece (especially in southern and central Greece) with a total cover of 543 300 ha (16.17 % of the total forested area of the country and 38 % of the coniferous forests of Greece)[a]. The total growing stock of fir (47 406 000 m^3) is the biggest among all forest tree species in Greece and the annual net increment (798 000 m^3) the third after black pine and beech (Albanis et al., 2000).

1.1. Morphological and genetic variation of the fir populations in Greece

Extensive morphological-anatomical (Mattfeld, 1927, 1930; Panetsos, 1975; Mitsopoulos and Panetsos, 1987; Fady et al., 1991) and biochemical studies (Mitsopoulos and Panetsos, 1987; Fady et al., 1992; Fady and Conkle, 1993; Scaltsoyiannes et al., 1999; Parducci et al., 2001) have shown the existence of considerable variation in a number of traits, both among and within fir populations in Greece. Some traits, particularly the needle apex shape and sharpness, the pubescens of the twigs and the number of stomata on the upper side of the needle, seem to change along a north-south and east-west gradient (Mitsopoulos and Panetsos, 1987; Fady et al., 1991). According to Fady et al. (1991), this clinal pattern of variation "*is the result of a probable superimposition of two opposed phenomena: the increasing introgression of Abies alba towards the north, and the adaptation of stands to increasing drought towards the south*".

According to Mattfeld (1927, 1930) and Mitsopoulos and Panetsos (1987), the fir forests in Greece consist of populations belonging to the species *Abies cephalonica*, introgressed with *A. alba* genes in the south, hybrid populations (*A.* x *borisii-regis* Mattf.) being an intermediate state between *A. cephalonica* and *A. alba* in central Greece, and hybrid populations dominated by *A. alba* traits in the north. Recent

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[a] The Greek forest inventory does not distinguish among the different species of *Abies*.

studies on the genetic variation of Greek fir populations, based on isozyme and molecular markers, have shown that the so called “hybrid” populations of central and northern Greece can not be distinguished from the “pure” populations of southern Greece (Scaltsoyiannes et al., 1999; Fady and Conkle, 1993; Drouzas, 2000).

Although significant morphological variation exist in the fir populations of central Greece (Künemund, 2008; Unpublished material), for the purposes of the present study it was considered that all fir trees of the study area are belonging to the species *Abies cephalonica* (Greek fir). The term Greek fir will be used from now on for all the fir populations of southern Greece (Peloponnisos) and the southern part of central Greece (Sterea Ellas) as far north as to the Mt. Timfristos.

1.2. Biogeography and evolution of the fir populations in Greece

The genus *Abies* Mill. appeared in the Paleocene of the Cenozoic 65 million years ago (Stebbins, 1977). The discovery of *Abies* fossils confirms the presence of the genus in the Mediterranean during the Miocene (Liu, 1971). There is evidence of a unique ancient ancestor of all northern Mediterranean firs which occurred in the Aegean area during the Miocene (Fady et al., 1992; Scaltsoyiannes et al., 1999).

Long-term geological changes in the Mediterranean basin led to geographical isolation of several plant populations (Linares, 2011). At the same time climatic changes (Messinian climatic crisis, summer droughts, Pleistocene glaciations) put plant communities under selective pressure which promoted local adaptations and genetic differentiations among them (Suc, 1984; Linares, 2011). During the Pliocene the ancient fir ancestor was divided into two groups, one on the Balkan Peninsula and the other in Asia Minor (Fady et al., 1992). From the Asia Minor group evolved *Abies alba*, *A. nordmanniana, A. bornmuelleriana* and *A. equi-trojani.* From the Balkan group originated *A. cephalonica* (Fady et al., 1992). According to Scaltsoyiannes et al. (1999) the central area between the two groups remained occupied by the same ancient ancestor from which the above two fir groups originated.

During the last glacial period (90 - 12 thousand years ago), *Abies alba* migrated to the South and became restricted to refugia in the Mediterranean area until it started again its colonization towards central Europe. This southern migration of *A. alba* must have led to gene exchange with *A. cephalonica* contributing to the origin of their natural hybrid *A. x borisii-regis* (Mattfeld, 1930; Mitsopoulos and Panetsos, 1987; Fady et al., 1992). According to Scaltsoyiannes et al. (1999) hybridization and back-crossing during the last glacial period involved not only the above two species but also the ancient ancestor mentioned before.

It is still under discussion whether two or three different species were involved in this secondary contact, which led to the currently parapatric complex of *Abies alba*, *A. cephalonica* and *A. x borisii-regis* (Liepelt et al., 2010; Scaltsoyiannes et al., 1999). It is also not clear if *A. x borisii-regis* should be considered as a natural hybrid, a separate species or simply a subgroup of *A. cephalonica* (Fady and Conkle, 1993; Drouzas, 2000).

1.3. Ecology of Greek fir (*Abies cephalonica* Loudon)

Greek fir can be found on a variety of bedrocks, including gneiss, serpentine, flysch, schist, limestone and dolomite, without showing any preference on a specific soil type (Schütt, 1994). Nevertheless, Barbéro and Quézel (1976) mentioned that forms of Greek fir closer related to *Abies x borisii-regis* can be found more often on deep soils originated from flysch, in contrast to typical forms of *A. cephalonica* which occur mainly on limestone.

The natural altitudinal distribution of Greek fir ranges from 400 m to 2300 m a.s.l. The mean annual precipitation vary from 500 mm, in the lower altitudinal limits of SE Greece, to more than 2 500 mm in the west part of the Pindos mountain range (Gouvas and Sakellariou, 2011). Most of the precipitation occurs in late autumn and during the winter season. This zone, although receiving abundant precipitation during autumn and winter, may suffer from severe summer drought (Aussenac, 2002), which can be very intense during extreme years. During the summer period (June - September) the precipitation is reduced to less than 100 mm (Gouvas and Sakellariou, 2011). Drought is particularly severe on shallow soils with reduced water holding capacity. The crucial limiting factor for the growth of Greek fir is the soil moisture (Schütt, 1994). In such water-controlled (i.e., water stressed) ecosystems, soil moisture is the most important resource affecting vegetation structure and composition (Rodriguez-Iturbe et al., 2001).

Similarly wide is the range of the mean annual temperature (3 - 15 °C), the mean temperature of the coldest month (-4.4 - 5.4 °C) and the mean temperature of the warmest month (12.3 - 23.1 °C) (Gouvas and Sakellariou, 2011). The extreme temperatures that Greek fir can survive, are 41 °C as absolute maximum temperature and -18 °C as absolute minimum (Schütt, 1994). The same author reports an average number of 63 frost days per year. *Abies cephalonica*, although it is considered to be one of the most frost sensitive circum-Mediterranean fir species, it rarely suffers from frost damage and only if the temperature falls below -15 °C (Schütt, 1994).

All circum-Mediterranean fir species are characterized by highly sensitive stomatal regulation in response to water stress (Aussenac, 1980; Descroix, 1981; Bouachrine, 1985; Guehl et al., 1989, 1991). According to Aussenac (2002), *Abies cephalonica* exhibits the best adaptation among all circum-Mediterranean firs, by a very efficient "strategy" to avoid drought. During drought, the water potential of the trees begins to fall and a partial control of transpiration occurs. As the drought becomes more severe the transpiration stops completely (Aussenac, 1980). The dry period in the vegetation belt of the *Abietion cephalonicae* (i.e., where Greek fir and Black pine grows) can last up to 5 months and the maximum climatic water deficit that Greek fir can resist during this period is 200 mm (Gouvas and Sakellariou, 2011).

1.4. Aim and objectives

Oxia - North Vardousia is a typical and representative mountain range of central Greece with complex terrain, which creates a mosaic of sites and habitats. The dominant vegetation type of the study area, like in most of the mountains of central Greece, is the Greek fir forest. Drought (aridity) is an important climatic feature of those mountainous ecosystems, but its influence on the floristic composition and structure of Greek fir forests is not yet well known. It has been suggested that water availability is the crucial factor governing the floristic variation in the mountain coniferous forests of southern Greece (Bergmeier, 2002). In the present study it is hypothesized that drought is a major environmental parameter that differentiates the Greek fir forest communities of the study area. The aim of this study is to understand the role of drought in the floristic differentiation of Greek fir (*Abies cephalonica* Loudon) forests on the Oxia - North Vardousia mountain range. A contribution to a better understanding of the synecology of Greek fir forests, in relation to water availability, will help to protect and preserve these vulnerable mountain coniferous forests.

In order to address the above hypothesis and the aim of the study, two particular objectives were established:

1. **Quantification of drought intensity in the study area**

The first objective of this study is to quantify drought intensity in the different *Abies* forest sites of the study area. In order to achieve this, two approaches were used:

- In the first approach (**climatic index**) the climatic components of drought were used and combined in a form of a “humidity/aridity index”. The “index” approach was applied for the spatial quantification of drought in the whole study area. This information was used in order to stratify the study area (according to the drought intensity) and also to calculate the drought intensity in each plot.
- In the second approach (**water balance**) both climatic and edaphic components of drought were combined with the use of a more complete and therefore accurate method (water balance model). Since this method requires information on soil properties, it was not applicable for the whole study area, due to lack of accurate soil maps. Therefore, the water balance approach was used only for the plot-specific quantification of drought intensity.

2. **Description and analysis of the Greek fir forest vegetation in the study area**

Except of a few relevés published by Barbéro and Quézel (1976), almost nothing is known about the fir forest vegetation of the study area. The second objective of this study is to explore the floristic composition, define the syntaxonomy and explain the synecology of the fir forests of the study area. An ecological and phytosociological investigation would provide:

- valuable information about the vegetation patterns, the floristic differentiation and the plant communities of the Greek fir forests in the study area.
- the means to test the hypothesis that water supply is an important environmental factor that regulates the floristic variation and community differentiation of the Greek fir forests in the study area.

In addition, a comparison of the different components of drought would provide information about their importance in predicting the occurrence of the plant communities.

1.5. The Oxia - North Vardousia mountain system

1.5.1. Physical geography

The Oxia - North Vardousia mountain system is located in the southern part of central Greece (Sterea Ellas), extending between 38.66 ° N and 38.95 ° N latitude and 21.84 ° E and 22.15 ° E longitude (Figure 1.5.1). It is delineated by the rivers Sperchios and Inachos to the north, Krikelopotamos to the west, Evinos to the south and Kranorema to the east. It occupies an area of 414 km^2 and is surrounded by many high mountains all above 2000 m height.

The Oxia - North Vardousia mountain system consists of three mountain ranges which start from the highest peak Saradena (1923 m) and extend into three different directions. The first range (Kokalia), extending from south-east to north-west, consists of a smooth mountain ridge at 1700 m elevation. It ends, in the north, to the mountain pass Raches Timfristou through which it is connected to Mt. Timfristos. The second range (Kokinias) extends from north-east to south-west in its first part but it changes direction to more or less north-south until it ends at the river Evinos. These two ranges form the main range of Mt. Oxia. The third range (North Vardousia) extends west-east and is formed by a succession of summits between 1600 and 1800 m (Pirghos, Milia, Omalo, Pirghaki). To the east and south-east it is connected to the high mountains of Iti and South & West Vardousia through a pass.

1.5.2. Geology

The geology and the soils of the Oxia - North Vardousia mountain system are shaped mainly by flysch, a sequence of early Tertiary, non-calcareous sedimentary rocks, which erodes easily. Flysch consists of sandstone, graywacke, shale and coarse conglomerates. At the eastern part of North Vardousia and around the Kokinias summit, Jurassic limestones occur in small extent. Small areas are covered by screes, coarse slope or terrace deposits, consisting of limestone or greywacke material (Kallergis et al., 1970).

1.5.3. Climate[b]

Oxia - North Vardousia has a typical mediterranean climate with wet, cool winters and dry, warm summers. Nevertheless, there are large local differences in climate due to the complex terrain and variation in topography. January is the coldest month with mean temperature between -3.3 °C and 11.7 °C. The warmest month is July with mean temperature between 17.6 °C and 32.7 °C. The mean temperature of the vegetation period (April - October) ranges between 12.6 °C and 27.7 °C. Frost occurs from November to March on the south facing slopes or in lower altitudes and from October to May on slopes with north orientation or higher elevation. Most of the precipitation occurs from October to April. Summer rains are few and mostly in the form of thunderstorms. The average precipitation during the four driest months

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[b] The description of the climate of the study area is based on Bouras (1985) and on the results of the climatic analysis of the present study.

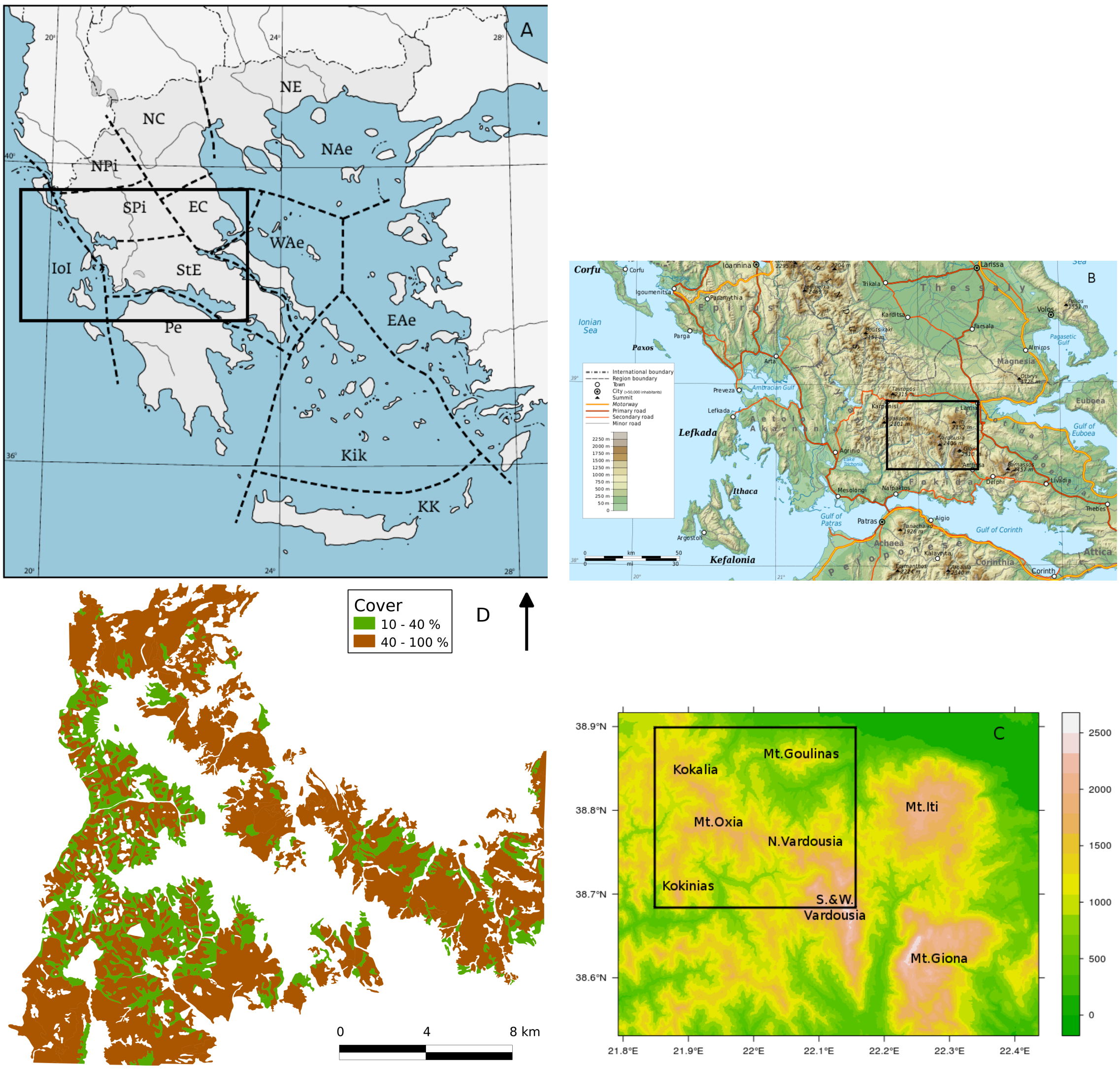

Figure 1.5.1.: A: Map of Greece devided into phytogeographical regions (Strid and Tan, 1997) (StE = Sterea Ellas, Pe = Peloponissos, EC = East Central, SPi = South Pindos). B: Map of central Greece (Wikipedia), including the three phytogeographical regions of StE, EC and SPi. C: Central Sterea Ellas (SC part of central Greece). On the upper left part of the map is located the mountain range of Oxia - North Vardousia. This area was used for the spatial prediction of the climatic variables. D: The study area.

of the year (June - September) varies from 92 mm, in the lowest elevations (~250 m), up to 191 mm in the highest elevations (~1900 m). Snowfall is common during winter time, especially on the higher elevetions, with the maximum number of snowfall days in January. During autumn and spring snowfall is rare but not exceptional. There is a permanent snow cover for several months and patches of snow locally may remain until June (Bouras, 1985).

1.5.4. Vegetation[c]

Following the studies of Ozenda (1975) and Quézel et al. (1985), the vegetation of the Oxia - North Vardousia mountain complex can be divided into five altitudinal vegetation zones:

1. the thermo-mediterranean (up to c. 500 m),
2. the meso-mediterranean (500 - 900 m),
3. the supra-mediterranean (900 - 1400 m),
4. the montane-mediterranean (1400 - 1750 m)
5. the oro-mediterranean (1750 - 1923 m).

Although the above zones have been verified by several authors for the mountains of Sterea Ellas (Karetsos, 2002; Dimitrellos, 2005; Vlachos, 2006), they still constitute a rough generalization of the real vegetation distribution, which tends to vary in a more mosaic-like and topography-dependent pattern.

Deciduous oak forests and scrubs, formed mainly by *Quercus frainetto*, occur on the lower slopes of the mountains (thermo- and lower meso-mediterranean zone), especially in the north-west part of the region. Well-developed forests of *Castanea sativa* can be found locally in the supra-mediterranean zone, but their naturalness is doubtful because the species is widely cultivated in Greece.

The most extensive vegetation type of the region is the montane coniferous forest of *Abies* which covers 44.6 % of the area[d]. The fir forest appears in the middle and upper part of the meso-mediterranean zone (600 - 900 m), but is reaching its optimum distribution in the supra-mediterranean zone (900 - 1400 m). In the montane-mediterranean zone, the *Abies* forest occurs in mixture with meadows, forest clearings and pastures. The timberline has been retreated into this zone probably due to fires and grazing in the past.

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[c] The description of the vegetation is based on personal observations.

[d] The total cover of *Abies* forests was measured after the digitization of the orthophotographs of the study area.

Above the timberline (c. 1750 m), different types of subalpine plant communities occur. Those include low-growing shrubs like *Juniperus communis* subsp. *nana*, *J. communis* subsp. *hemisphaerica*, *Daphne oleoides* and species of *Rosa*, snowbed meadows on smooth and gentle slopes, grasslands of *Nardus stricta* and *Festuca* species on acidic soils and spiny, cushion-like dwarf shrub vegetation with *Astragalus creticus* subsp. *rumelicus*.

The southernmost limit of *Fagus sylvatica* and *Quercus petraea* distribution in Greece occurs in this area. According to many authors, Mt. Oxia contains the northernmost limit for the occurrence of the xerophytic forests of the endemic Greek fir (*Abies cephalonica* Loudon) (Mattfeld, 1930; Quézel et al., 1985; Mitsopoulos and Panetsos, 1987; Schütt, 1994).

1.6. Study area

The study area is located on the Oxia - North Vardousia mountain system. It includes all fir forests that occur on flysch sites of Mt. Oxia and the northern part of Mt. North Vardousia. Flysch is the dominant bedrock on the Oxia - North Vardousia mountain system. The rest of the few sites with different kind of bedrocks (mainly limestone) were excluded from the analysis. The aim for that was to keep the geological substrate the same among all the studied sites. A preliminary study showed that the floristic composition between sites of similar climatic conditions but with different geological substrates (flysch - limestone), differ significantly. Since the study focuses mainly on the climatic influence on vegetation, it was considered as desirable to try to minimize the influence of other environmental factors (bedrock). Fir forests were defined as forested areas in which *Abies cephalonica,* alone or in mixture with other tree species (*Quercus frainetto* or *Fagus sylvatica*), covers at least 10 % of the surface[e]. From mixed stands only those dominated by *A. cephalonica* were chosen.

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[e] According to the new Greek legislation a land with at least 15 % of tree cover is considered forest. The orthophotomaps that were used in this study in order to delineate the forested area are based on the old Greek legislation in which the limit for the definition of forest was 10 %.

2. Quantification of drought intensity

2.1. Overview

This chapter concerns the assessment of the climatic and soil variables for the quantification of drought intensity in the study area. The definition of drought is given and the two methodological approaches used to conduct the analysis are presented. All the terms, concerning the concept of drought, that were used in this study are explained. The assessment of each component of the analytical procedure for the quantification of drought is presented. This includes:

- the evaluation of all available radiation models for the estimation of $\mathrm{PET_{ref}}$
- the spatial prediction of the basic climatic variables (air temperature, precipitation and solar radiation)
- the calculation of $\mathrm{PET_{ref}}$
- the assessment of soil variables

All the previously assessed variables are combined for the spatial and point-specific quantification of drought intensity. Finally (section 2.10), the methods and the results used for the quantification of drought intensity are discussed. The pros and cons of the methods are briefly presented and their utility is evaluated.

2.2. Definition of drought

Drought is a relative term which reflects the lack of water. There are two basic concepts of drought: a) one that considers the phenomenon as a temporary aberration of climate (meteorological anomaly), *"characterized by a prolonged and abnormal moisture deficiency"* (Palmer, 1965), and b) another that considers "*the degree to which a climate lacks effective, life-promoting moisture*" (AMS)[1]. The later definition refers to drought as a permanent feature of the climate which is also called

aridity. This “seasonal” drought, as Thornthwaite (1947) called it, occurs in climates that have well-defined rainy and dry seasons. Although the term drought, in the strict sense of the word, refers to the first definition, in this work it will be used with the same meaning as aridity.

Drought is closely related to **precipitation effectiveness** which is the “*portion of total precipitation used to satisfy vegetation needs*” (AMS)[1]. This actual availability of precipitation that can be used by plants, is a complex environmental factor which consists of climate and soil factors. If the available amount of water (from precipitation and soil moisture) in a region is not enough to cover the water loss caused by runoff, evaporation and transpiration, then drought occurs. From the above definitions can be easily deduced that the main climatic factors governing drought are precipitation (P) and evapotranspiration (ET).

According to Wallén (1967) there are three main approaches that can be used to quantify drought: 1) the classical approach, 2) the index approach and 3) the water balance approach. In the classical approach a simple climatic factor is used for the calculation of drought. Using this approach the first assessments of drought were based on precipitation and/or temperature (Wallén, 1967). In the second approach two or more climatic elements are used in a form of an index in order to define boundaries among different degrees of drought. Tuhkanen’s (1980) review on climatic parameters and indices in plant geography includes many of these indices. Wallén (1967) mentioned that drought should be preferably expressed in terms of a relation between precipitation and evapotranspiration:

$$\mathrm{I_d} = f(P, \mathrm{ET}) \tag{2.2.1}$$

where $\mathrm{I_d}$ is the drought index.

An index with the form of Equation 2.2.1 has a physical meaning and incorporates the two main factors influencing drought.

In order to achieve a more complete understanding of drought, not only the two main factors (precipitation, evapotranspiration) but also other secondary factors have to be considered. These secondary factors are:

1. the amount of water stored in the soil that can be used by plants, called available soil water storage capacity (ASWSC)
2. the amount of water that leaves a site, without being evaporated or transpired, called runoff (R)
3. the distinction between actual and potential evapotranspiration (AET and PET respectively).

This leads to the third approach for the estimation of drought and to the use of a water balance model (Thornthwaite and Mather, 1955; Wallén, 1967; Stephenson, 1998), which incorporates all these elements:

$$\text{Drought} = f(\text{AET}, \text{PET}, P, \text{ASWSC}, R) \tag{2.2.2}$$

2.3. Analytical procedure for the quantification of drought intensity

For the quantification of drought intensity in this study two approaches were used; a) an index approach and, b) a water balance approach. The first approach (index approach) aims at the spatial quantification of drought intensity for the whole study area and its stratification by determining the boundaries among areas of various degrees of drought intensity. It aims also at the subsequent point-specific quantification of drought intensity at each sample unit (site). The second approach aims only at the point-specific quantification of drought intensity at each sample unit (site).

The second approach would have been the best to be used in both cases, if information about the soil parameters had been available. It was not possible to get this kind of information before the sampling in the study area and therefore, the simplest index approach was used for the stratification.

2.3.1. Humidity index

For the spatial quantification of drought intensity in the whole study area, a modified version of Transeau's humidity index (HI) was used (Gärtner et al., 2008). The HI was calculated as the ratio of precipitation (P) to reference potential evapotranspiration (PET_ref, the definition is given in subsubsection 2.3.2.1) for the vegetation period:

$$\text{HI} = \frac{P}{\text{PET}_\text{ref}} \tag{2.3.1}$$

This humidity index seems to be suitable for comparing climatic water balance between different sites and regions (Gärtner et al., 2008). The estimated values of the HI were used afterwards for the stratification of the study area and the subsequent point-specific quantification of drought intensity at each vegetation sample unit.

In order to quantify the drought intensity by means of HI, a Geographical Information System (GIS) was used in a sequence of steps (Figure 2.3.1). Climatic data from weather stations (subsection 2.5.1) and digital elevation data from a Digital Elevation Model (DEM) (subsubsection 2.5.2.1) were combined and a spatial prediction of drought intensity was achived with an accuracy of 90 m. At the begining, the basic climatic components (solar radiation, air temperature and precipitation) were spatially predicted (section 2.5). Afterwards, the two first components (solar radiation and air temperature) were used for the spatial estimation of reference potential evapotranspiration ($\mathrm{PET_{ref}}$) (section 2.6). Finally, $\mathrm{PET_{ref}}$ and P were compined with the use of Equation 2.3.1 and the climatic drought intensity was assessed for every pixel of the DEM.

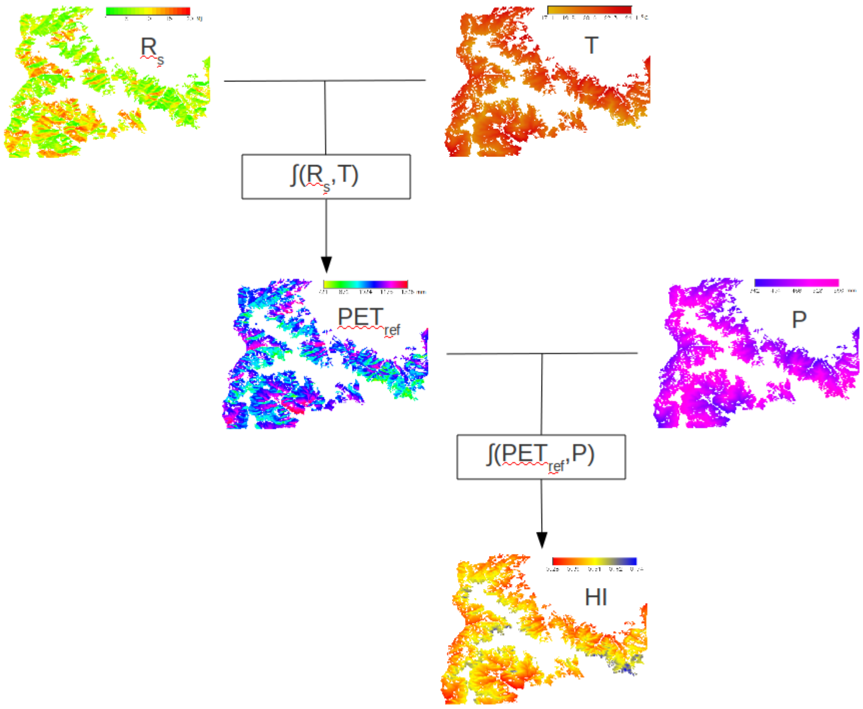

Figure 2.3.1.: Computation scheme of the spatial quantification of drought intensity. R_s: solar radiation, T: air temperature, P: precipitation, $\mathrm{PET_{ref}}$:reference potential evapotranspiration, HI: humidity index.

2.3.2. Water balance

The water balance model, developed by Thornthwaite (1944; 1947; 1948) and revised by Thornthwaite & Mather (1955; 1957), is considered to be the most complete and rational way to describe the abiotic drought properties of a site. Furthermore it is useful for explaining patterns of vegetation on a local scale affected by variations in soils and topography (Stephenson, 1998). For the point-specific quantification of drought intensity a simplified monthly water balance model was used, with **water deficit** (D) as the main output.

The term water deficit, as used here, refers to **climatic water deficit** (D_{climatic}) and must be distinguished from **soil water deficit** (D_{soil}). Climatic water deficit is the evaporative demand of the atmosphere that is not met by available water. It is a measure of how much more water could have been evaporated and transpired from a site covered by a reference crop[a], if sufficient water had been available (Stephenson, 1990). It is the difference between the reference potential evapotranspiration (PET_{ref}) and the reference actual evapotranspiration (AET_{ref}) (for the definitions of PET_{ref} and AET_{ref} see subsubsection 2.3.2.1)(Thornthwaite and Mather, 1955). Soil water deficit is the difference between the **soil water content at field capacity** (θ_{FC}) and its **water content** (θ) at a particular point in time (Stephenson, 1998).

The calculated water deficit indicates directly the physiological drought stress for plants at each site (plot). It is related to the magnitude and length of drought stress; heat stress that cannot be regulated by transpiration; metabolic costs that cannot be met by active photosynthesis; and potential for cell damage or death (Kramer and Kozlowski, 1979; Jones, 1992; Larcher, 2003; Stephenson, 1998).

The guiding principles of the Thorthwaite's water balance model are provided by the three following equations (Willmott et al., 1985; Mintz and Serafini, 1992):

$$\Delta\text{ASWS} = P - \text{AET}_{\text{ref}} - R \tag{2.3.2}$$

$$\text{AET}_{\text{ref}} = \begin{cases} P + \beta \cdot (\text{PET}_{\text{ref}} - P)\,, & P < \text{PET}_{\text{ref}} \text{ and } \text{PET}_{\text{ref}} - P < \text{ASWS} \\ P + \beta \cdot \text{ASWS}, & P < \text{PET}_{\text{ref}} \text{ and } \text{PET}_{\text{ref}} - P > \text{ASWS} \\ \text{PET}_{\text{ref}}, & P \geq \text{PET}_{\text{ref}} \end{cases} \tag{2.3.3}$$

$$R = \begin{cases} P - [\text{AET}_{\text{ref}} + (\text{ASWS}_{\max} - \text{ASWS})]\,, & P > \text{PET}_{\text{ref}} + (\text{ASWS}_{\max} - \text{ASWS}) \\ 0, & P \leq \text{PET}_{\text{ref}} + (\text{ASWS}_{\max} - \text{ASWS}) \end{cases} \tag{2.3.4}$$

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[a] A hypothetical extensive surface of green grass with an assumed height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23 (Allen et al., 1998).

where ASWS is the available soil water storage, $\mathrm{ASWS}_{\mathrm{max}}$ is the maximum available soil water storage in the root zone, P is the precipitation, R is the runoff, $\mathrm{AET}_{\mathrm{ref}}$ is the reference actual evapotranspiration, $\mathrm{PET}_{\mathrm{ref}}$ the reference potential evapotranspiration and β the actual evapotranspiration function. All the above elements of Thornthwaite's water balance model are described with more details next (subsubsection 2.3.2.1).

2.3.2.1. Components of the water balance model

1. **Reference potential evapotranspiration** ($\mathrm{PET}_{\mathrm{ref}}$): The amount of water that could have been evaporated and transpired from a site covered by a reference crop, if that site had been unlimited supplied with water. $\mathrm{PET}_{\mathrm{ref}}$, as is used here, refers to the reference crop evapotranspiration (ET_{o}) as has been defined by Allen et al. (1998). Only climatic factors affect $\mathrm{PET}_{\mathrm{ref}}$, while actual vegetation and soil properties are not considered. $\mathrm{PET}_{\mathrm{ref}}$ is a climatic factor which expresses the evaporating power of the atmosphere at a specific location and time of the year (Allen et al., 1998).
2. **Water supply** (S or P): The amount of liquid water that reaches a site in a given period. It consists of rainfall and snowmelt. Snow is part of precipitation but is not considered part of water supply until it melts (Stephenson, 1990). In this study the water supply is considered equal to **precipitation** (P).
3. **Reference actual evapotranspiration** ($\mathrm{AET}_{\mathrm{ref}}$): The amount of water that could have been evaporated and transpired from a site covered by a reference crop, under the locally prevailing water availability. $\mathrm{AET}_{\mathrm{ref}}$, as is defined here, estimates the simultaneous availability of biologically usable energy and water at a site, independent of actual vegetation (Major, 1963; Rosenzweig, 1968; Stephenson, 1998).
4. **Water surplus or Runoff** (R): The amount of water that leaves a site covered by a reference crop, without being evaporated or transpired. It is a measure of the excess water for the site (Stephenson, 1990).
5. **Available soil water storage** (ASWS): The amount of water stored in the mesopores of the soil potentially usable by plants. It can be expressed in $^{\mathrm{gr}}/_{\mathrm{cm}^3}$ as volumetric water content of fine earth or in mm as amount of water in the root zone after subtracting the volume of soil skeleton content.
6. **Available soil water storage capacity** (ASWSC): The maximum amount of fine earth available water, expressed in $^{\mathrm{gr}}/_{\mathrm{cm}^3}$ or in $^{\mathrm{mm}}/_{10\,\mathrm{cm}}$. It is the difference

between the water content values at **field capacity** (FC) and the **permanent wilting point** (PW).

7. **Maximum available soil water storage** ($\mathrm{ASWS_{max}}$): The ASWSC of the total rooting space, considering the content of coarse materials, expressed in mm or $^{l}/_{m^2}$.
8. **Evapotranspiration function** ($\beta = f(w)$): Is a function that relates the ratio of actual to potential evapotranspiration ($^{\mathrm{AET_{ref}}}/_{\mathrm{PET_{ref}}}$) with the soil wetness w ($^{\mathrm{ASWS}}/_{\mathrm{ASWS_{max}}}$) (Mintz and Serafini, 1992).
9. **Water deficit** (D): The difference between potential and actual evapotranspiration. It refers to the climatic water deficit (Stephenson, 1998).

2.4. Evaluation of radiation-based $\mathrm{PET}_{\mathrm{ref}}$ models

The concept of the reference potential evapotranspiration ($\mathrm{PET}_{\mathrm{ref}}$) was introduced as a means to study the evaporative demand of the atmosphere, independent of crop or vegetation characteristics and soil factors (Allen et al., 1998). Consequently, $\mathrm{PET}_{\mathrm{ref}}$ is a climatic parameter which expresses the evaporative power of the atmosphere and is defined as the evaporative water loss from a site, covered by a hypothetical grass reference crop, with unlimited water supply (Allen et al., 1998).

$\mathrm{PET}_{\mathrm{ref}}$ is a very important parameter not only in hydrological modeling and irrigation planning but also in ecological studies. As a measure of available environmental energy, $\mathrm{PET}_{\mathrm{ref}}$ independently explains the variability in species richness of animals (Currie, 1991). As a basic component of the climatic water balance, $\mathrm{PET}_{\mathrm{ref}}$ is also necessary for the estimation of other biologically meaningful measures of climate, such as actual evapotranspiration and water deficit, both of which are strongly correlated with tree species richness (Currie, 1991) and the distribution of vegetation types (Gärtner et al., 2008; Stephenson, 1990).

The FAO proposed using the Penman–Monteith method as the standard method for estimating $\mathrm{PET}_{\mathrm{ref}}$ (Allen et al., 1998). The basic obstacle to the wide use of this method is the numerous data which are commonly not available at many weather stations. For this reason simplified or empirical temperature or radiation-based equations that require fewer parameters may be used.

Temperature and solar radiation are the most important parameters for the calculation of $\mathrm{PET}_{\mathrm{ref}}$ (Samani, 2000). The above two climatic variables together explain ca. 80 % of the $\mathrm{PET}_{\mathrm{ref}}$ (Jensen et al., 1990). Temperature data are routinely measured and can be accurately interpolated to areas where measurements are not available. Solar radiation data can be estimated with sufficient accuracy by using commonly available meteorological data (Hargreaves and Samani, 1982; Allen, 1997; Meza and Varas, 2000).

The use of a radiation-based instead of a purely temperature-based equation has an advantage in detail-scaled studies over regions with complex terrain. At regional and local scales, topography (relief) is the major factor modifying the distribution of radiation. With the use of a GIS-based model it is possible to consider the terrain features (elevation, slope, aspect, free horizon) and generate solar radiation maps of high accuracy (Hofierka and Šúri, 2002).

These empirical methods are often only valid for the local conditions under which they were derived (Feddes and Lenselink, 1994), or when applied to areas with climatic conditions similar to those for which they were developed (Irmak et al., 2003b).

Several studies show that local or regional calibration of those methods can enhance their performance (Xu and Singh, 2001, 2002; Irmak et al., 2003b; Trajkovic, 2005; Rosenberry et al., 2007). Some authors highly recommend regional calibration in order to obtain reasonable PET$_{\text{ref}}$ estimates in climates different from the ones for which they were developed (Amatya et al., 1995; Irmak et al., 2003a). Furthermore, since the empirical radiation-based methods lack some of the major weather parameters that significantly affect PET$_{\text{ref}}$, their performance requires further investigation (Irmak et al., 2003a).

The objective of this work is to develop and provide feasible methods to estimate the PET$_{\text{ref}}$ under mediterranean climate regimes when lysimeter measurements are not available, or when the use of FAO-56 Penman-Monteith equation is limited. Specific aims are: 1) to group all the available radiation-based equations obtained from the literature into few general models, 2) to adjust (calibrate) the general models to the local conditions under study and 3) to evaluate and compare the performance of the calibrated models.

2.4.1. Materials and methods

2.4.1.1. Study area and climate

Five weather stations, operated by the National Meteorological Service of Greece, were selected for this study. Exact locations are shown in Figure 2.4.1. All five locations, despite their altitudinal difference and their variant distance from the sea, belong to the mediterranean climate with a distinct dry period during the summer (see climate diagrams in Figure 2.4.2). The stations can be further classified into three climatic types (semi-arid, sub-humid and humid) according to their degree of aridity (FAO, 1989; Middleton and Thomas, 1992). There is also considerable variation in the average monthly wind-speed among the different locations, which range from 1.2 m/s (Agrinio, light-windy site) to 4.3 m/s (Karpenisi, moderate-windy site). The mean monthly climatic variables, which were used for the estimation of PET$_{\text{ref}}$ for each of the five stations, are given in Table 2.4.1.

Since measurements of solar radiation were not available for the region, the last one was calculated with the Ångström-Prescot formula

$$R_s = a_s + b_s \cdot \frac{n}{N} \cdot R_a \qquad (2.4.1)$$

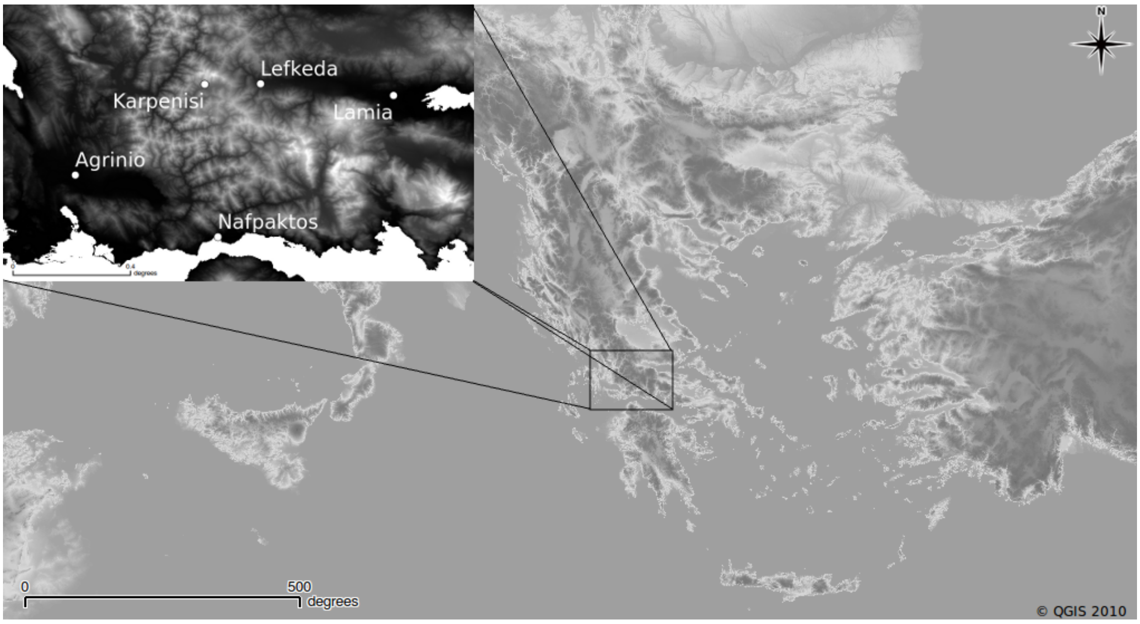

Figure 2.4.1.: Study area and location of the weather stations in central Greece.

which relates solar radiation (R_s) to extraterrestrial radiation (R_a) and relative sunshine duration (n/N) (Martinez-Lozano et al., 1984; Allen et al., 1998). The coefficients a_s and b_s were considered constants for the whole region with values of 0.22 and 0.52 respectively (Glover and McCulloch, 1958; Koutsoyiannis and Xanthopoulos, 1999). The above values are close to the values given by Black et al. (1954) and Flocas (1980).

Table 2.4.1.: Monthly average climatic parameters for the 5 weather stations of the study area.

Month	T_{mean}	T_{min}	T_{max}	u	RH	R_s	R_n	T_{mean}	T_{min}	T_{max}	u	RH	R_s	R_n
	Averaged over 5 years for Nafpaktos (sub-humid with light-windy dry period[b])							**Averaged over 7 years for Agrinio** (humid/light-windy)						
Jan	9.2	4.3	14.1	2.4	71.4	9.2	2.3	7.9	**3.1**	12.8	1.3	76.0	6.4	2.4
Feb	8.8	3.9	13.5	2.1	72.2	12.3	4.7	8.5	3.3	13.7	1.6	73.4	8.9	4.1
Mar	10.8	5.7	15.8	3.0	75.2	16.6	7.9	10.7	5.1	16.3	1.6	71.9	12.5	6.6
Apr	14.8	8.5	21.0	2.3	71.8	23.5	12.4	13.9	7.1	20.6	1.4	67.4	17.4	9.9
May	19.0	12.6	25.3	2.6	69.4	26.9	15.3	18.6	11.7	25.4	1.4	63.7	20.9	12.4
Jun	22.2	15.4	28.9	2.0	63.2	**29.2**	17.1	22.1	14.5	29.6	1.2	58.3	24.9	14.8
Jul	25.5	18.9	32.2	1.7	60.6	28.3	17.0	24.3	15.9	**32.8**	1.0	**56.7**	**26.0**	15.5
Aug	26.4	19.9	**33.0**	1.8	**59.8**	25.3	15.0	24.5	16.3	32.6	0.9	59.4	23.2	13.5
Sep	23.8	17.4	30.3	1.8	60.6	20.7	11.1	22.2	14.0	30.4	0.8	63.4	18.2	9.9
Oct	18.7	13.3	24.2	2.3	65.2	14.4	6.4	17.6	10.6	24.6	0.8	70.3	12.1	5.8

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[b] as dry period are defined the 4 driest months of the year (June-September)

Month	T_{mean}	T_{min}	T_{max}	u	RH	R_{s}	R_{n}	T_{mean}	T_{min}	T_{max}	u	RH	R_{s}	R_{n}
Nov	13.5	8.1	18.8	4.1	71.2	10.5	3.0	12.8	7.2	18.4	1.0	76.6	8.0	3.0
Dec	10.4	**4.2**	16.5	4.4	72.2	9.4	1.4	9.2	3.8	14.6	0.8	76.7	6.2	1.9
Year				**2.5**	**67.7**						**1.2**	**67.8**		
Dry period				**1.8**	**61.1**						**1.0**	**59.5**		
	Averaged over 6 years for Lamia (semi-arid)							**Averaged over 11 years for Lefkada** (sub-humid with gentle-windy dry period)						
Jan	7.9	**3.4**	12.3	2.8	74.3	7.4	2.34	6.2	**2.6**	9.8	3.0	73.0	6.7	2.3
Feb	8.2	4.3	12.0	3.0	77.3	8.2	4.0	6.6	3.0	10.2	3.0	75.8	8.9	4.1
Mar	11.0	6.6	15.4	3.0	73.0	12.0	6.4	10.0	5.8	14.1	3.2	69.4	12.7	6.6
Apr	14.3	8.9	19.6	3.1	68.7	17.0	9.7	13.2	8.1	18.2	3.3	64.0	17.6	9.9
May	19.6	13.8	25.3	3.1	60.8	21.2	12.5	18.4	13.0	23.8	3.3	61.5	21.0	12.5
Jun	24.4	18.1	30.6	3.6	**49.7**	24.8	14.5	22.6	16.6	28.5	3.7	53.8	23.1	14.2
Jul	25.7	19.3	**32.1**	3.2	51.0	**24.7**	14.5	24.4	18.1	**30.8**	3.6	**52.9**	**23.3**	14.2
Aug	25.3	19.0	31.5	2.9	54.3	21.4	12.3	23.8	17.8	29.7	3.5	56.6	20.4	12.2
Sep	22.4	16.1	28.7	2.8	59.2	17.0	9.1	20.9	15.2	26.6	3.2	62.8	16.4	9.0
Oct	17.0	11.9	22.1	2.3	72.7	10.4	5.2	16.0	11.5	20.5	2.5	73.0	11.1	5.3
Nov	11.5	7.5	15.5	2.3	79.2	7.0	2.9	11.1	7.5	14.8	2.4	77.8	7.3	2.8
Dec	8.8	4.8	12.9	2.9	77.5	5.9	1.9	8.2	4.8	11.5	2.8	75.5	5.9	1.9
Year				**2.9**	**66.5**						**3.1**	**66.3**		
Dry period				**3.1**	**53.6**						**3.5**	**56.5**		
	Averaged over 5 years for Karpenisi (humid/moderate-windy)													
Jan	3.8	-0.1	7.6	4.6	67.8	7.5	2.2							
Feb	2.8	**-0.9**	6.5	4.6	70.2	9.0	4.0							
Mar	5.5	1.5	9.5	4.6	72.6	11.8	6.3							
Apr	10.2	5.3	15.2	4.0	61.8	15.0	8.6							
May	14.4	9.1	19.8	4.2	60.0	19.1	11.2							
Jun	17.5	11.7	23.2	4.2	57.0	22.3	13.1							
Jul	20.1	14.4	25.8	4.3	**53.8**	**23.8**	13.7							
Aug	20.2	14.5	**25.9**	4.2	54.6	21.5	12.0							
Sep	17.5	11.8	23.1	4.0	59.0	17.7	9.0							
Oct	13.2	7.6	18.8	4.2	65.8	12.3	5.4							
Nov	8.2	4.3	12.0	4.5	74.4	7.2	2.8							
Dec	5.3	1.7	8.9	4.7	73.4	5.3	1.9							
Year				**4.3**	**64.2**									
Dry period				**4.2**	**56.1**									

T_{mean}: Average daily mean air temperature $\left[{}^{\circ}\mathrm{C}\right]$
T_{min}: Average daily minimum air temperature $\left[{}^{\circ}\mathrm{C}\right]$
T_{max}: Average daily maximum air temperature $\left[{}^{\circ}\mathrm{C}\right]$
u : Average daily mean wind speed $[\mathrm{m/s}]$
RH: Average daily mean relative humidity [%]
R_s: Average daily solar radiation $\left[\mathrm{MJ/m^2 \cdot day}\right]$
R_n: Average daily net radiation $\left[\mathrm{MJ/m^2 \cdot day}\right]$

For the weather stations Lefkada and Nafpaktos, the above formula could not be used because relative sunshine duration data were missing. In this case, solar radiation data were derived from temperature differences using the Hargreaves' radiation formula (Hargreaves and Samani, 1982; Allen et al., 1998):

$$R_s = K_{Rs} \cdot \sqrt{(T_{\max} - T_{\min})} \cdot R_a \tag{2.4.2}$$

The adjustment coefficient K_{Rs} was set to 0.16 for 'interior' stations and 0.19 for 'coastal' stations, following the recommendations of Allen et al. (1998).

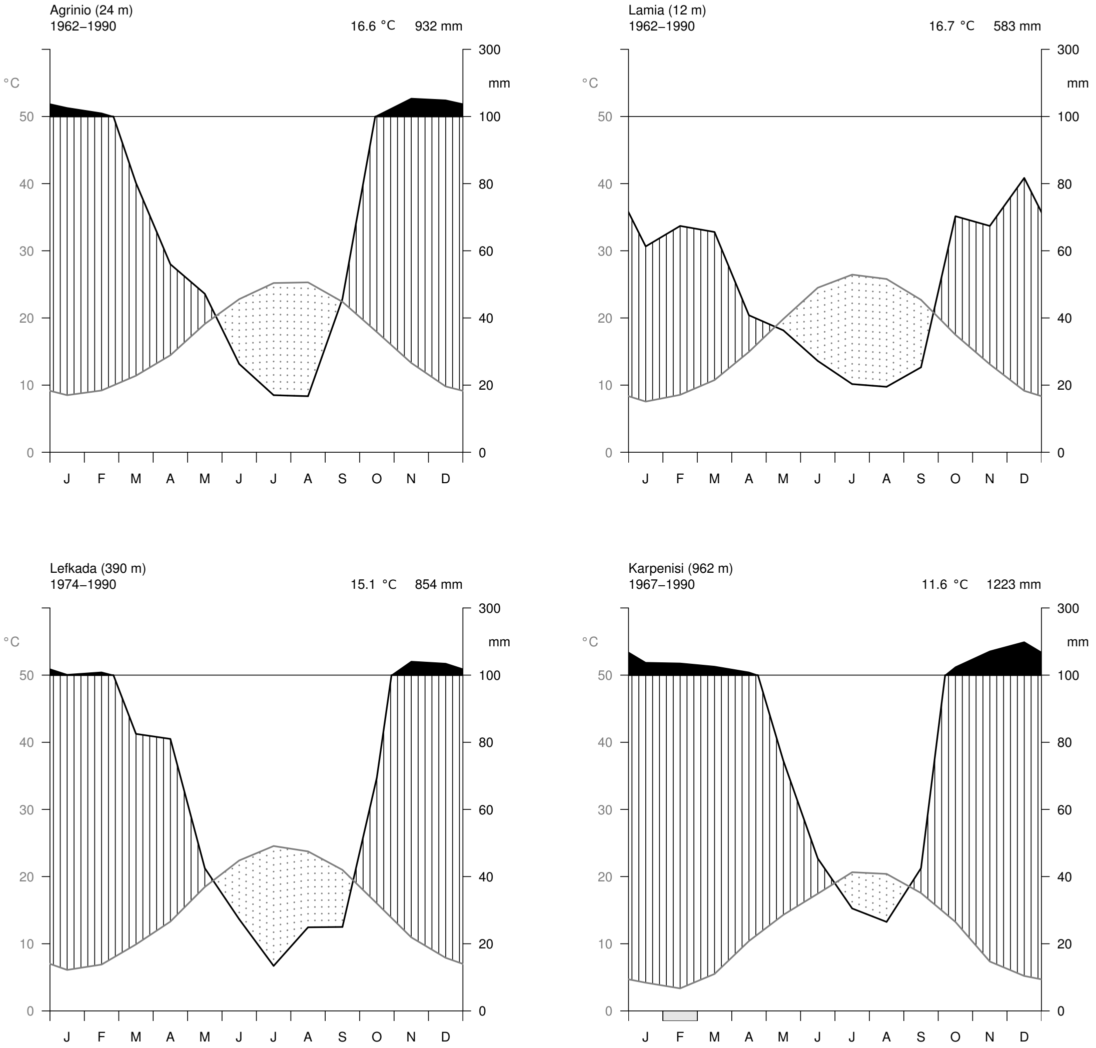

Figure 2.4.2.: Climate diagrams for 4 of the 5 central Greece weather stations.

2.4.1.2. Generalization of radiation-based equations

Several radiation-based equations have been developed and used by different authors for the estimation of $\mathrm{PET_{ref}}$. Some of them also include a temperature factor. All of these equations are based on the energy balance (Jensen et al., 1990) and most of them take the general form:

$$\lambda \cdot \mathrm{PET_{ref}} = C_r \cdot (w \cdot R_s) \tag{2.4.3}$$

or

$$\lambda \cdot \mathrm{PET_{ref}} = C_r \cdot (w \cdot R_n) \tag{2.4.4}$$

where λ is the latent heat of vaporisation (in $^{\mathrm{MJ}}/_{\mathrm{kg}}$), $\mathrm{PET_{ref}}$ is the reference potential evapotranspiration ($^{\mathrm{mm}}/_{\mathrm{day}}$), R_s and R_n are the solar and net radiation respectively (in $^{\mathrm{MJ}}/_{\mathrm{m^2 \cdot day}}$ or $^{\mathrm{cal}}/_{\mathrm{cm^2 \cdot day}}$), w is the temperature and altitude-dependent weighting factor, and C_r is a coefficient depending on the relative humidity and wind speed (Xu et al., 2008).

Seventeen radiation-based equations were selected for comparison in this study (Table 2.4.2). Some of these equations have the same or at least similar form and can be grouped together. The seventeen equations of Table 2.4.2 were finally generalized into seven different forms (general models) (Table 2.4.3). This approach has two advantages (Xu and Singh, 2000): 1) For a specific site, the general form of a model is more important than the constant values that have been derived using meteorological data from different sites; 2) The comparison and the evaluation of the models for a specific site becomes easier.

Table 2.4.2.: Compilation of radiation-based equations with their original coefficients, set into groups of similar forms.

Group	**Equation**	**Reference**	**Developed for**	
			Region	**Climatic conditions**
Christiansen group	Christiansen (1968) $\mathrm{PET_{ref}} = 0.385 \cdot \frac{R_s}{\lambda}$	Hargreaves & Allen (2003)	-	-
	Calibrated Christiansen $\mathrm{PET_{ref}} = K \cdot \frac{R_s}{\lambda},\ 0.52 \leq K \leq 0.54$	Abtew (1996)	South Florida	Warm humid
Jensen-Haise group	Jensen-Haise $\mathrm{PET_{ref}} = (0.025 \cdot T_{\mathrm{mean}} + 0.08) \cdot \frac{R_s}{\lambda}$	Jensen & Haise (1963)	Western USA	Semiarid to arid

Group	**Equation**	**Reference**	**Developed for**	
			Region	**Climatic conditions**
	Stephen-Stewart (1963) $\mathrm{PET}_{\mathrm{ref}} = (0.0148 \cdot T_{\mathrm{mean}} + 0.07) \cdot \frac{R_s}{\lambda}$	Jensen (1966)	Florida	Warm humid
	Stephens (1965)[c] $\mathrm{PET}_{\mathrm{ref}} = (0.0158 \cdot T_{\mathrm{mean}} + 0.09) \cdot \frac{R_s}{\lambda}$	Jensen (1966)	North Carolina	Warm humid
	Caprio $\mathrm{PET}_{\mathrm{ref}} = \frac{25.4}{10^5} \cdot (1.8 \cdot T_{\mathrm{mean}} + 1) \cdot R_s$	Caprio (1974)	Western USA	Semiarid to arid
	Hargreaves (1975) $\mathrm{PET}_{\mathrm{ref}} = (0.0135 \cdot T_{\mathrm{mean}} + 0.2403) \cdot \frac{R_s}{\lambda}$	Hargreaves & Allen (2003)	Davis California	Semiarid to arid
Makkink group	Makkink (1957) $\mathrm{PET}_{\mathrm{ref}} = 0.61 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_s}{\lambda} - 0.12$	Jensen (1966), Rosenberry et al. (2004)	Netherlands	Cool humid
	Calibrated Makkink $\mathrm{PET}_{\mathrm{ref}} = 0.70 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_s}{\lambda} - 0.12$	Castañeda & Rao (2005)	Southern California	Semiarid to arid
	De Bruin (1981) $\mathrm{PET}_{\mathrm{ref}} = 0.65 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_s}{\lambda}$	De Bruin & Lablans (1998)	-	-
	Hansen $\mathrm{PET}_{\mathrm{ref}} = 0.7 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_s}{\lambda}$	Hansen (1984)	North Germany	Cool humid
Priestley & Taylor	Priestley & Taylor $\mathrm{PET}_{\mathrm{ref}} = 1.26 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_n - G}{\lambda}$	Priestley & Taylor (1972)	-	Humid
	Calibrated Priestley & Taylor $\mathrm{PET}_{\mathrm{ref}} = 1.18 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_n - G}{\lambda}$	Abtew (1996)	South Florida	Warm humid
	Calibrated Priestley & Taylor $\mathrm{PET}_{\mathrm{ref}} = 1.65 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_n - G}{\lambda}$	Berengena & Gavilán (2005)	Southern Spain	Semiarid
Turc	Turc (1961) $\mathrm{PET}_{\mathrm{ref}} = 0.013 \cdot \frac{T_{\mathrm{mean}}}{T_{\mathrm{mean}} + 15} \cdot (R_s + 50)$	Xu et al. (2008)	Western Europe	Humid
Modified Turc	Modified Turc $\mathrm{PET}_{\mathrm{ref}} = 0.012 \cdot \frac{T_{\mathrm{max}}}{T_{\mathrm{max}} + 15} \cdot (R_s + 50)$	Abtew (1996)	South Florida	Warm humid
Abtew	Abtew $\mathrm{PET}_{\mathrm{ref}} = \frac{1}{56} \cdot \frac{R_s \cdot T_{\mathrm{max}}}{\lambda}$	Abtew (1996)	South Florida	Warm humid

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[c] In the original equations of Stephen-Stewart and Stephens the temperature is in ^oF.

$\mathrm{PET_{ref}}$: reference potential evapotranspiration $[\mathrm{mm/day}]$
T_{mean} : mean air temperature $[°\mathrm{C}]$
T_{max} : maximum air temperature $[°\mathrm{C}]$
R_s : solar radiation $[\mathrm{MJ/m^2{\cdot}day}]$, in $[\mathrm{cal/cm^2{\cdot}day}]$ for the Turc, modified Turc and Caprio equations
R_n : net radiation $[\mathrm{MJ/m^2{\cdot}day}]$
G : soil heat flux density $[\mathrm{MJ/m^2{\cdot}day}]$
Δ : slope of saturation vapour pressure curve $[\mathrm{kPa/°C}]$
γ : psychrometric constant $[\mathrm{kPa/°C}]$
λ : latent heat of vaporization $[\mathrm{MJ/kg}]$

Table 2.4.3.: The general radiation-based models.

Method	**General model**	**Original equation**
Christiansen group	$\mathrm{PET_{Chr}} = a \cdot \frac{R_s}{\lambda}$	Christiansen (1968), Abtew (1996)
Jensen-Haise group	$\mathrm{PET_{Jen}} = (a \cdot T_{\mathrm{mean}} + b) \cdot \frac{R_s}{\lambda}$	Jensen & Haise (1963), Stephens-Stewart (1963), Stephens (1965), Caprio (1974), Hargreaves (1975)
Makkink group	$\mathrm{PET_{Mak}} = a \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_s}{\lambda} + b$	Makkink (1957), De Bruin (1981), Hansen (1984), Castañeda & Rao (2005)
Priestley-Taylor	$\mathrm{PET_{Pri}} = a \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_n - G}{\lambda} + b$	Priestley & Taylor (1972), Abtew (1996), Berengena & Gavilán (2005)
Turc	$\mathrm{PET_{Tur}} = a \cdot \left(\frac{T_{\mathrm{mean}}}{T_{\mathrm{mean}} + 15}\right) \cdot (R_s + 50)$	Turc (1961)
Modified-Turc	$\mathrm{PET_{MTur}} = a \cdot \left(\frac{T_{\mathrm{max}}}{T_{\mathrm{max}} + 15}\right) \cdot (R_s + 50)$	Modified Turc (Abtew 1996)
Abtew	$\mathrm{PET_{Abt}} = a \cdot T_{\mathrm{max}} \cdot \frac{R_s}{\lambda}$	Abtew (1996)

2.4.1.3. Calibration and validation of the models

All of the general models from Table 2.4.3 have the form of a linear regression equation, with $\mathrm{PET_{ref}}$ as the dependent variable. The models of Christiansen group, Turc, Modified-Turc and Abtew methods have the form $y = a \cdot x$; the Makkink group and Priestley-Taylor models have the form $y = a \cdot x + b$; and the Jensen-Haise group model has the form $y = a_1 \cdot x_1 + a_2 \cdot x_2$. The calibration of these models was based on the estimation of the slope a and the intercept b of the regression line that best fits the data, according to the least-square property. That means that a and b were estimated so that the sum of the squares of the residuals (observed minus predicted values) was as small as possible.

Several statistical procedures have been developed and proposed by different authors for the evaluation of model performance (validation). For a review of the issue see Willmott (1984), Mayer and Butler (1993) and Bellocchi et al. (2010). According to Legates and McCabe (1999), a complete assessment of model performance should include at least one relative error measure (e.g. d or EF) and one absolute error measure (e.g. MAE or RMSE), together with summary statistics and graphical tools.

For the validation of the calibrated evapotranspiration models, quantitative measures were used, following the procedure that was proposed by Fox (1981) and Willmott (1984). The quantitative measures are presented in Table 2.4.4 and can be subdivided into two groups:

1. The first group includes difference or error measures which are generally derived from the differences (D) between the model-predicted and observed values ($P - O$).
2. The second group includes the slope (a), the intercept (b) and the coefficient of determination r^2 of the least-squares regression between the model-predicted and the observed values.

It is very important that model performance is evaluated on a data set (test set) which is different or independent from the data set used for calibrating the model (training set) (Janssen and Heuberger, 1995). An ideal is to divide data into training and test sets, but if there are too few data to make it reasonable to split them, then the method of K-fold cross-validation can be used (Maindonald and Braun, 2007). In our case, a 12-fold cross-validation approach was used. This means that the data were randomly divided into 12 sets (folds). Each of the 12 sets was used in turn as the test set for the validation of the model that was calibrated before with the remaining 11 sets (training set). The 12 assessments were combined (averaged) to give a measure of the model performance. The analysis was repeated for each model, station and performance measure. For more details on cross-validation see (Stone, 1974; Efron and Tibshirani, 1993). The calibration and cross-validation was performed in *R* programming language with the use of the `bootstrap` package (Tibshirani, 2009) (section A.6.1).

2.4.1.4. Standardized calculations

The best way to test the performance of the above mentioned models is to compare their predictions against lysimeter measurements (Irmak et al., 2003a). As lysimeters are difficult and expensive to construct and their operation and maintenance

Table 2.4.4.: Quantitative measures for the evaluation of model performance.

Performance measures	**Symbol**	**Form**
Mean bias error	MBE	$N^{-1} \cdot \sum_{i=1}^{N} (P_i - O_i)$
Mean absolute error	MAE	$N^{-1} \cdot \sum_{i=1}^{N} \mid P_i - O_i \mid$
Relative Mean absolute error	RMAE	$(\mathrm{MAE}/\bar{O}) \cdot 100$
Variance of the distribution of differences	S_d^2	$(N-1)^{-1} \cdot \sum_{i=1}^{N} (P_i - O_i - \mathrm{MBE})$
Root mean square error	RMSE	$\left[N^{-1} \cdot \sum_{i=1}^{N} (P_i - O_i)^2\right]^{0.5}$
Unsystematic root mean square error	$\mathrm{RMSE_u}$	$\left[N^{-1} \cdot \sum_{i=1}^{N} \left(P_i - \hat{P}_i\right)^2\right]^{0.5}$
Systematic root mean square error	$\mathrm{RMSE_s}$	$\left[N^{-1} \cdot \sum_{i=1}^{N} \left(\hat{P}_i - O_i\right)^2\right]^{0.5}$
Coefficient of efficiency	EF	$1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} (\bar{O} - O_i)^2}$
Index of agreement	d	$1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} \left(\mid \acute{P}_i \mid + \mid \acute{O}_i \mid\right)^2}$
Regression quantities	a, b, r^2	$\hat{P}_i = a \cdot O_i + b$

P_i and O_i are the model-predicted and observed (estimated by the FAO-56 PM equation) value i respectively; $\bar{P}$ and $\bar{O}$ are the predicted and observed means; $\acute{P}_i = P_i - \bar{O}$ and $\acute{O}_i = O_i - \bar{O}$; N is the number of cases ; $\hat{P}_i$ is the fitted value i of an ordinary least-squares simple linear regression between observed (O) and predicted (P) values.

requires special care (Allen et al., 1998), their use is limited and precise $\mathrm{PET_{ref}}$ measurements are rarely available. Since the FAO-56 PM equation was proposed by FAO as the best, it has been extensively used as the standard method for calibrating and/or validating empirical methods (Amatya et al., 1995; Xu and Singh, 2002; Irmak et al., 2003a,b; Vanderlinden et al., 2004; Trajkovic, 2005; Suleiman and Hoogenboom, 2007; Castaneda and Rao, 2005). The FAO-56 PM equation was used as the standard method to estimate daily $\mathrm{PET_{ref}}$ with the following formula, as given by FAO Irrigation and Drainage Paper No.56 (Allen et al., 1998):

$$\mathrm{PET_{FAO}} = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \dfrac{\gamma \cdot 900}{T + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \qquad (2.4.5)$$

where $\mathrm{PET}_{\mathrm{FAO}}$ = reference potential evapotranspiration [$^{\mathrm{mm}}/_{\mathrm{day}}$]; R_n = net radiation at the crop surface [$^{\mathrm{MJ}}/_{\mathrm{m}^2}$]; G = soil heat flux density [$^{\mathrm{MJ}}/_{\mathrm{m}^2}$]; T = mean daily air temperature at 2 m height [°C]; u_2 = wind speed at 2 m height [$^{\mathrm{m}}/_{\mathrm{s}}$]; e_s = saturation vapour pressure [kPa]; e_a = actual vapour pressure [kPa]; $e_s - e_a$ = saturation vapour pressure deficit [kPa]; Δ = slope of saturation vapour pressure curve [$^{\mathrm{kPa}}/_{^\circ\mathrm{C}}$]; γ = psychrometric constant [$^{\mathrm{kPa}}/_{^\circ\mathrm{C}}$]. The computation of all values required for the calculation of $\mathrm{PET}_{\mathrm{ref}}$, was based on the methodology of Allen et al. (1998) for monthly periods. The $\mathrm{PET}_{\mathrm{ref}}$ values obtained from the calibrated radiation-based models (P_i or model-predicted values) were compared against the $\mathrm{PET}_{\mathrm{ref}}$ values calculated by the FAO-56 PM equation (O_i or "observed" values) and the performance of the different models was evaluated. The FAO-56 PM equation was also used for the calibration of models.

2.4.2. Results

2.4.2.1. Calibration of general models

The calibrated coefficients a and b for each model and station are presented in Table 2.4.5. For comparison, the parameter values of the original equations presented in Table 2.4.2 are also shown. A comparison of the original coefficients of the models with the calibrated coefficients shows the differences, dependent on the climate station and the equation used. The calibration of all models that contain only one coefficient (Christiansen group, Turc, modified-Turc and Abtew) showed a similar tendency with a slight reduction of the influence of coefficient a at the stations Nafpaktos and Agrinio, and a slightly larger contribution in the other. For the Christiansen group model there is an exception to the above if we compare the calibrated coefficient with the initial coefficient from Christiansen ($a = 0.385$).

For the other three groups of methods (Jensen-Haise, Makkink and Priestley-Taylor) there were different tendencies depending on the initial coefficient that was used for the comparison.

The calibration of the general models for the Jensen-Haise-group method led to a decrease of the influence of a and an increase of the b coefficient for all weather stations. The decrease of coefficient a was higher in the stations of Nafpaktos and Agrinio which are closer to Hargreaves value. The coefficient a for the other three stations (Lamia, Lefkada and Karpenisi) is closer to the original values of Stephen and Stephen-Stewart equations.

The calibrated Makkink-group model for Nafpaktos station was very similar to the original Makkink equation and for Agrinio to the calibrated Makkink for Southern

Table 2.4.5.: Coefficients of the calibrated general models compared with the coefficients of the original equations.

Method	Parameter	Stations					Coefficients of the original equations
		Nafpaktos	Agrinio	Lamia	Lefkada	Karpenisi	
Christiansen group	*a*	0.460	0.455	0.594	0.586	0.549	0.385, 0.52 - 0.54
Jensen-Haise group	*a*	0.005	0.010	0.016	0.019	0.015	0.0148, 0.0158, 0.025, 0.0135
	b	0.338	0.248	0.246	0.218	0.318	0.07, 0.09, 0,08, 0.2403
Makkink group	*a*	0.631	0.694	0.914	0.933	0.837	0.61, 0.65, 0.7
	b	0.062	-0.141	-0.273	-0.338	0.031	0.12, 0
Priestley-Taylor	*a*	0.964	1.101	1.484	1.431	1.353	1.18, 1.26, 1.65
	b	0.798	0.244	0.148	0.213	0.475	0
Turc	*a*	0.012	0.012	0.016	0.016	0.017	0.013
Modified-Turc	*a*	0.012	0.011	0.014	0.015	0.015	0.012
Abtew	*a*	0.017	0.016	0.022	0.023	0.025	0.018

California climatic conditions. For the other three stations the parameter a had a higher value compared to the original.

The calibrated model of Priestley-Taylor showed also a high variation among the different weather stations. The parameter a for the first two stations (Nafpaktos and Agrinio) was closer to the calibrated value of Priestley-Taylor for South Florida (1.18). The stations Lefkada and Karpenisi were closer to the original value of Priestley-Taylor (1.26) and Lamia is the only station which was closer to the calibrated value of Priestley-Taylor for Southern Spain.

2.4.2.2. Validation and comparison of performance

The evaluation of model performance was conducted in two ways. (1) The Mean Bias Error (MBE) of the models for each month was calculated and presented graphically (Figure 2.4.3). This visual display expresses the seasonal variation of the residuals and provides information regarding the over- or under estimation of PET$_{\text{ref}}$ by the models. (2) A number of quantitative measures were calculated in order to evaluate the overall performance of the models for the whole year (Table 2.4.6, Table 2.4.8, 2.4.9a) and for the vegetation period (April to October) (Table 2.4.7, Table 2.4.8, 2.4.9b). The MBE was excluded from the second part of the analysis because of its poor performance in the overall evaluation of models.

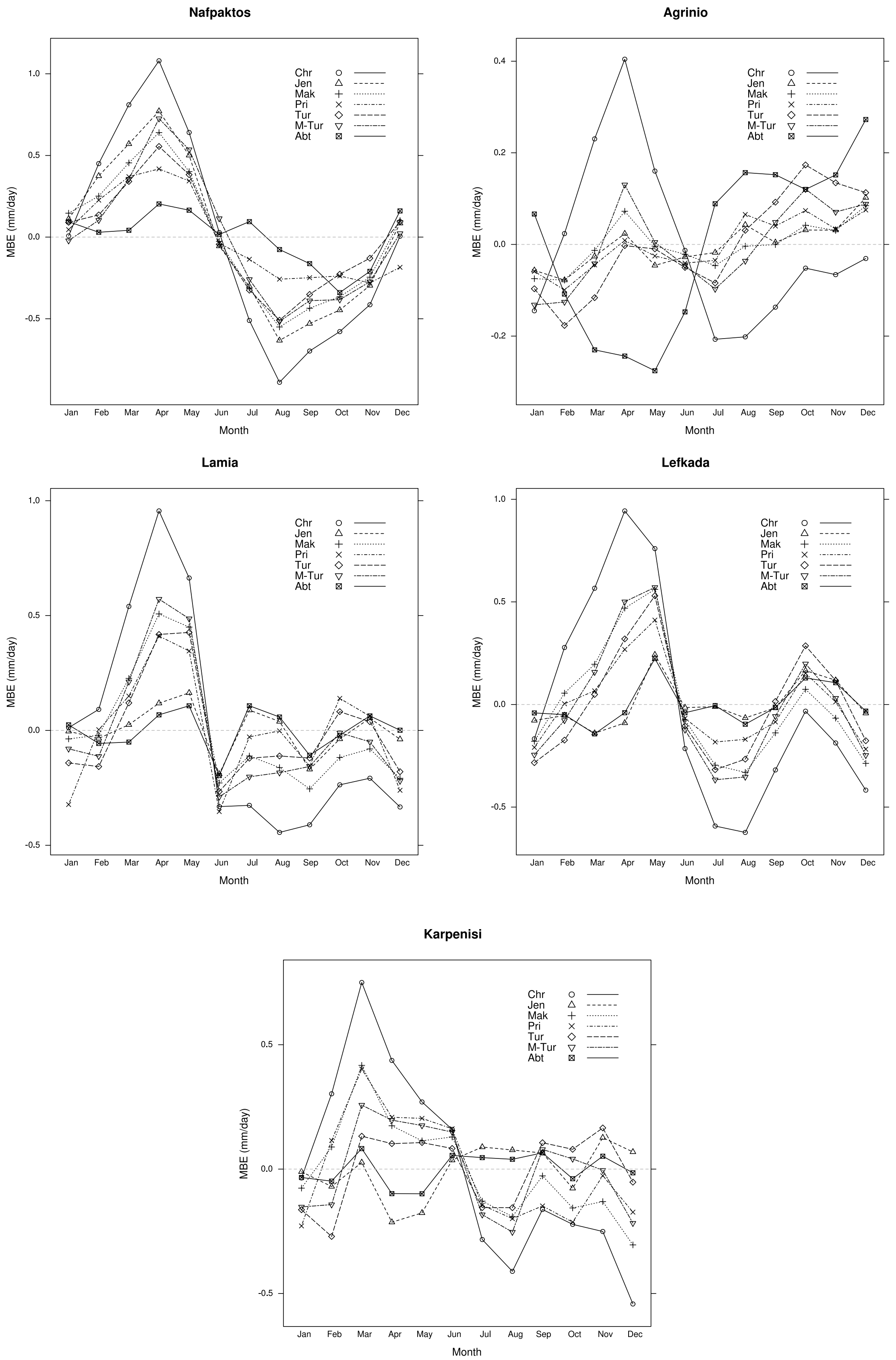

Figure 2.4.3.: Seasonal variation of the Mean Bias Error (MBE) of the calibrated general model in the estimation of PET_{ref}, for the five climate stations of C. Greece.

Table 2.4.6.: Quantitative measures of performance of the calibrated general models in the estimation of PET$_{\mathrm{ref}}$ for the whole year. The calculation was completed for the 5 climate stations of C. Greece. Units of measure are in mm/day with the exception of N, EF and d which are dimensionless. The explanation of the symbols is given in Table 2.4.4.

Model	**Summary univariate measures**					**Difference measures**						
	$\overline{O}$	$\overline{P}$	s_o[a]	s_p[b]	N	MAE	S_d^2	RMSE	$\frac{\mathrm{RMSE_u}}{\mathrm{RMSE}}$	RMSE$_\mathrm{s}$	EF	d
Nafpaktos												
Chr	3.450	3.444	1.817	1.668	60	0.601	0.544	0.732	0.918	0.085	0.835	0.954
Jen	3.450	3.462	1.817	1.713	60	0.583	0.456	0.670	0.942	0.051	0.862	0.962
Mak	3.450	3.455	1.817	1.713	60	0.532	0.379	0.611	0.943	0.042	0.885	0.969
Pri	3.450	3.452	1.817	1.764	60	0.414	0.234	0.480	0.970	0.014	0.929	0.981
Tur	3.450	3.451	1.817	1.726	60	0.505	0.356	0.592	0.950	0.034	0.892	0.971
M-Tur	3.450	3.451	1.817	1.742	60	0.441	0.285	0.530	0.958	0.023	0.914	0.977
Abt	3.450	3.451	1.817	1.783	60	**0.298**	**0.132**	**0.360**	**0.981**	**0.005**	**0.960**	**0.990**
Agrinio												
Chr	2.734	2.732	1.614	1.589	84	0.239	0.079	0.280	0.984	0.003	0.970	0.992
Jen	2.734	2.733	1.614	1.605	84	0.153	0.037	0.192	**0.994**	**0.0004**	0.986	0.996
Mak	2.734	2.733	1.614	1.602	84	0.151	0.037	0.192	0.993	0.001	0.986	0.996
Pri	2.734	2.734	1.614	1.604	84	**0.144**	**0.034**	**0.184**	**0.994**	**0.0004**	**0.987**	**0.997**
Tur	2.734	2.735	1.614	1.601	84	0.163	0.045	0.210	0.992	0.001	0.983	0.996
M-Tur	2.734	2.733	1.614	1.601	84	0.174	0.049	0.220	0.992	0.001	0.981	0.995
Abt	2.734	2.735	1.614	1.594	84	0.221	0.074	0.270	0.989	0.002	0.972	0.993
Lamia												
Chr	3.389	3.386	2.146	2.084	72	0.429	0.266	0.512	0.971	0.015	0.942	0.985
Jen	3.389	3.390	2.146	2.131	72	0.204	0.072	0.266	0.993	0.001	0.984	0.996
Mak	3.389	3.386	2.146	2.119	72	0.262	0.109	0.328	0.988	0.003	0.976	0.994
Pri	3.389	3.388	2.146	2.120	72	0.279	0.130	0.357	0.988	0.003	0.972	0.993
Tur	3.389	3.388	2.146	2.124	72	0.242	0.099	0.312	0.990	0.002	0.979	0.995
M-Tur	3.389	3.386	2.146	2.114	72	0.274	0.119	0.342	0.985	0.003	0.974	0.993
Abt	3.389	3.388	2.146	2.136	72	**0.170**	**0.045**	**0.211**	**0.995**	**0.0004**	**0.990**	**0.998**
Lefkada												
Chr	3.297	3.296	2.004	1.910	132	0.478	0.371	0.606	0.953	0.034	0.908	0.975
Jen	3.297	3.298	2.004	1.985	132	0.224	0.087	0.294	**0.990**	**0.002**	0.978	**0.995**
Mak	3.297	3.296	2.004	1.962	132	0.314	0.164	0.404	0.979	0.007	0.959	0.989
Pri	3.297	3.296	2.004	1.969	132	0.291	0.141	0.375	0.983	0.005	0.965	0.991
Tur	3.297	3.297	2.004	1.968	132	0.297	0.144	0.378	0.982	0.005	0.964	0.991
M-Tur	3.297	3.296	2.004	1.959	132	0.322	0.175	0.417	0.978	0.008	0.956	0.989
Abt	3.297	3.297	2.004	1.982	132	**0.218**	**0.083**	**0.288**	0.989	**0.002**	**0.979**	**0.995**
Karpenisi												
Chr	3.100	3.101	1.758	1.639	60	0.532	0.453	0.667	0.932	0.059	0.854	0.959
Jen	3.100	3.095	1.758	1.700	60	0.337	0.234	0.480	0.966	0.015	0.924	0.980
Mak	3.100	3.092	1.758	1.672	60	0.417	0.293	0.537	0.951	0.028	0.905	0.975
Pri	3.100	3.096	1.758	1.664	60	0.435	0.334	0.573	0.946	0.035	0.892	0.971
Tur	3.100	3.098	1.758	1.684	60	0.376	0.264	0.509	0.958	0.021	0.915	0.977
M-Tur	3.100	3.095	1.758	1.686	60	0.383	0.277	0.522	0.959	0.022	0.910	0.976
Abt	3.100	3.100	1.758	1.702	60	**0.310**	**0.216**	**0.461**	**0.968**	**0.014**	**0.930**	**0.982**

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[a] The standard deviation of the observed variables

[b] The standard deviation of the predicted variables

Table 2.4.7.: Quantitative measures of performance of the calibrated general models in the estimation of PET_{ref} for the vegetation period. The calculation was completed for the 5 climate stations of C. Greece. Units of measure are in mm/day with the exception of N, EF and d which are dimensionless. The explanation of the symbols is given in Table 2.4.4.

Model	**Summary univariate measures**					**Difference measures**						
	$\overline{O}$	$\overline{P}$	s_o	s_p	N	MAE	S_d^2	RMSE	$\frac{RMSE_u}{RMSE}$	$RMSE_s$	EF	d
						Nafpaktos						
Chr	4.726	4.593	1.226	1.119	35	0.673	0.681	0.824	0.876	0.158	0.535	0.859
Jen	4.726	4.627	1.226	1.242	35	0.658	0.584	0.760	0.949	0.058	0.605	0.894
Mak	4.726	4.633	1.226	1.218	35	0.584	0.461	0.676	0.949	0.046	0.687	0.916
Pri	4.726	4.704	1.226	1.167	35	0.391	0.220	0.463	0.949	0.021	0.853	0.960
Tur	4.726	4.652	1.226	1.190	35	0.538	0.407	0.633	0.943	0.045	0.725	0.925
M-Tur	4.726	4.701	1.226	1.112	35	0.477	0.353	0.586	0.905	0.062	0.765	0.932
Abt	4.726	4.712	1.226	1.233	35	**0.256**	**0.104**	**0.317**	**0.993**	**0.001**	**0.931**	**0.983**
						Agrinio						
Chr	3.855	3.848	1.145	1.049	49	0.238	0.083	0.285	0.895	0.016	0.937	0.983
Jen	3.855	3.856	1.145	1.120	49	0.152	0.038	0.192	0.978	0.002	0.971	**0.993**
Mak	3.855	3.860	1.145	1.101	49	**0.148**	**0.037**	**0.191**	0.951	0.004	**0.972**	**0.993**
Pri	3.855	3.867	1.145	1.097	49	0.174	0.046	0.213	0.948	0.005	0.965	0.991
Tur	3.855	3.876	1.145	1.068	49	0.163	0.044	0.209	0.891	0.009	0.966	0.991
M-Tur	3.855	3.873	1.145	1.061	49	0.168	0.046	0.212	0.879	0.010	0.965	0.991
Abt	3.855	3.833	1.145	1.173	49	0.229	0.082	0.284	**0.997**	**0.001**	0.937	0.984
						Lamia						
Chr	4.822	4.803	1.671	1.488	42	0.504	0.352	0.586	0.882	0.076	0.874	0.964
Jen	4.822	4.824	1.671	1.641	42	0.253	0.104	0.319	0.982	0.004	0.963	0.990
Mak	4.822	4.834	1.671	1.553	42	0.310	0.152	0.385	0.912	0.025	0.946	0.985
Pri	4.822	4.873	1.671	1.475	42	0.305	0.159	0.398	0.806	0.055	0.942	0.984
Tur	4.822	4.866	1.671	1.499	42	0.285	0.132	0.362	0.824	0.042	0.952	0.987
M-Tur	4.822	4.853	1.671	1.491	42	0.316	0.162	0.399	0.837	0.048	0.942	0.984
Abt	4.822	4.824	1.671	1.652	42	**0.199**	**0.057**	**0.236**	**0.989**	**0.001**	**0.980**	**0.995**
						Lefkada						
Chr	4.643	4.632	1.521	1.246	77	0.560	0.494	0.699	0.809	0.168	0.786	0.933
Jen	4.643	4.673	1.521	1.441	77	0.265	0.108	0.328	0.934	0.014	0.953	0.987
Mak	4.643	4.681	1.521	1.315	77	0.375	0.222	0.470	0.825	0.071	0.903	0.972
Pri	4.643	4.690	1.521	1.333	77	0.330	0.168	0.410	0.821	0.055	0.926	0.979
Tur	4.643	4.709	1.521	1.264	77	0.361	0.194	0.443	0.726	0.093	0.914	0.974
M-Tur	4.643	4.696	1.521	1.263	77	0.397	0.249	0.499	0.766	0.103	0.891	0.967
Abt	4.643	4.665	1.521	1.450	77	**0.260**	**0.107**	**0.325**	**0.945**	**0.011**	**0.954**	**0.988**
						Karpenisi						
Chr	4.297	4.267	1.335	1.029	35	0.629	0.613	0.772	0.769	0.244	0.656	0.882
Jen	4.297	4.269	1.335	1.255	35	0.458	0.378	0.606	**0.933**	**0.047**	0.788	0.941
Mak	4.297	4.285	1.335	1.107	35	0.537	0.444	0.657	0.827	0.137	0.751	0.922
Pri	4.297	4.279	1.335	1.117	35	0.582	0.517	0.709	0.837	0.151	0.710	0.908
Tur	4.297	4.321	1.335	1.069	35	0.494	0.404	0.627	0.788	0.149	0.773	0.927
M-Tur	4.297	4.327	1.335	1.047	35	0.507	0.436	0.651	0.770	0.173	0.755	0.919
Abt	4.297	4.293	1.335	1.213	35	**0.435**	**0.357**	**0.589**	0.908	0.061	**0.800**	**0.943**

There were no large differences between relative and absolute error measures (Table 2.4.6, Table 2.4.7). The only exceptions were the systematic and unsystematic proportions of RMSE ($\mathrm{RMSE}_{\mathrm{s}}$ and $\mathrm{RMSE}_{\mathrm{u}}$) which in some stations (e.g. Agrinio and Karpenisi in Table 2.4.7) indicated a different model as the best. The a and b parameters of the regressions (Table 2.4.8) also followed the same pattern with the $\mathrm{RMSE}_{\mathrm{s}}$ and $\mathrm{RMSE}_{\mathrm{u}}$. Therefore the use of only one difference measure (e.g. MAE or EF) together with the systematic or unsystematic proportion of RMSE appears to be sufficient for the assessment of the average performance of the models.

All models performed relatively well. The exception is the Christiansen group, which showed high error on the estimation of $\mathrm{PET}_{\mathrm{ref}}$ for most of the months and most of the stations. The Christiansen group model is the only one that uses one parameter (R_s) for the estimation of $\mathrm{PET}_{\mathrm{ref}}$. All the other models use, additionally to the solar radiation, a temperature factor either directly (T_{mean}, T_{max}) or indirectly (Δ).

When modeling the average values for the whole year, the Abtew and Jensen-Haise group models outperformed the other groups for all stations except Agrinio. At the station Nafpaktos, the Abtew model showed the best fit with a Mean Absolute Error (MAE) of 0.298 $^{\mathrm{mm}}/_{\mathrm{day}}$. In Lamia and Karpenisi the results were similar, with the Abtew model providing the best estimates with MAE of 0.17 and 0.31 $^{\mathrm{mm}}/_{\mathrm{day}}$ respectively. In these two stations, the model of the Jensen-Haise group also performed very well, with values for the difference measures very close to the ones of Abtew. In the station of Lefkada the Abtew and Jensen-Haise group models performed similarly, with a MAE of 0.218 and 0.224 $^{\mathrm{mm}}/_{\mathrm{day}}$ respectively.

When modeling the values for the vegetation period, the results were similar to the previous results. The Abtew model had the smallest error. The Jensen-Haise group model followed with a slightly lower performance. The MAE was 0.256 $^{\mathrm{mm}}/_{\mathrm{day}}$ for the station of Nafpaktos, 0.199 for Lamia, 0.260 for Lefkada and 0.435 for Karpenisi. These absolute values were slightly higher when compared with the corresponding annual values due to higher evapotranspiration rates during this period of the year. However, the lower relative MAE (Table 2.4.9) indicates that all models perform better during the vegetation period.

In Agrinio, almost all calibrated models performed well with MAE between 0.144 and 0.239 $^{\mathrm{mm}}/_{\mathrm{day}}$ for both periods of calculation. For the entire year, the most accurate estimations were given by the Priestley-Taylor model followed by the models of the Makkink group and Jensen-Haise group. For the vegetation period, the Makkink group yielded the smallest average error (0.148 $^{\mathrm{mm}}/_{\mathrm{day}}$) and the Jensen-Haise group followed with MAE of 0.152 $^{\mathrm{mm}}/_{\mathrm{day}}$. The Abtew model, although it had the second worst average error (0.229 $^{\mathrm{mm}}/_{\mathrm{day}}$), explained most of the systematic variation in the observed values as indicated with the very low value of $RMSE_s$.

Table 2.4.8.: Regression quantities as additional measures of performance for the calibrated general models in the estimation of PET_{ref}. The terms a and r^2 are dimensionless while b is in units mm/day. The explanation of the symbols is given in Table 2.4.4.

Model	Year						Vegetation period					
	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2
	Nafpaktos			**Agrinio**			**Nafpaktos**			**Agrinio**		
Chr	0.839	0.551	0.835	0.969	0.082	0.970	0.690	1.331	0.571	0.888	0.426	0.939
Jen	0.875	0.443	0.862	**0.987**	**0.034**	0.986	0.819	0.755	0.653	0.964	0.139	**0.971**
Mak	0.887	0.396	0.885	0.985	0.039	0.986	0.840	0.662	0.715	0.948	0.206	0.972
Pri	0.936	0.224	0.929	**0.987**	0.035	**0.987**	0.880	0.544	0.854	0.941	0.239	0.965
Tur	0.897	0.356	0.892	0.983	0.046	0.983	0.836	0.701	0.741	0.919	0.335	0.969
M-Tur	0.916	0.291	0.914	0.982	0.047	0.981	0.794	0.948	0.766	0.912	0.356	0.968
Abt	**0.962**	**0.134**	**0.96**	0.973	0.074	0.972	**0.972**	**0.120**	**0.933**	**0.994**	**0.001**	0.941
	Lamia			**Lefkada**			**Lamia**			**Lefkada**		
Chr	0.943	0.192	0.942	0.908	0.302	0.908	0.833	0.785	0.876	0.729	1.249	0.791
Jen	0.986	0.050	0.984	**0.980**	**0.068**	0.978	0.964	0.178	0.963	0.925	0.377	**0.954**
Mak	0.976	0.079	0.976	0.959	0.134	0.959	0.904	0.473	0.948	0.826	0.846	0.912
Pri	0.974	0.088	0.972	0.965	0.113	0.965	0.861	0.721	0.952	0.848	0.753	0.935
Tur	0.979	0.070	0.979	0.964	0.117	0.964	0.879	0.630	0.959	0.803	0.980	0.935
M-Tur	0.973	0.090	0.974	0.956	0.144	0.956	0.869	0.663	0.949	0.791	1.024	0.907
Abt	**0.990**	**0.032**	**0.990**	0.979	0.069	**0.979**	**0.978**	**0.106**	**0.980**	**0.931**	**0.342**	**0.954**
	Karpenisi						**Karpenisi**					
Chr	0.861	0.432	0.854				0.625	1.580	0.658			
Jen	0.929	0.214	0.924				**0.836**	**0.676**	0.791			
Mak	0.905	0.288	0.905				0.719	1.194	0.752			
Pri	0.894	0.327	0.892				0.705	1.249	0.710			
Tur	0.916	0.258	0.915				0.707	1.283	0.780			
M-Tur	0.915	0.259	0.910				0.685	1.383	0.764			
Abt	**0.933**	**0.208**	**0.930**				0.812	0.801	**0.800**			

2.4.3. Discussion

Only a few studies of modeling PET_{ref} with simple empirical equations were conducted in mediterranean climatic regions, e.g. Spain (Berengena and Gavilan, 2005), Portugal (Teixeira et al., 2008), Morocco (Er-Raki et al., 2004) and Western USA (George et al., 2002; Castaneda and Rao, 2005). An extended evaluation of empirical equations for mediterranean climates in general, and more specifically for Greece, is still lacking. In Greece there are few scientific publications dealing with this topic and their assessment is either restricted to a small region (Xystrakis and

Matzarakis, 2011) or include only a small number of equations (Michalopoulou and Papaioannou, 1991; Alexandris et al., 2006).

Table 2.4.9.: Relative Mean Absolute Error (RMAE) expressed as percent of the observed mean of reference potential evapotranspiration (estimated by the FAO-56 PM equation).

(a) RMAE considering the whole set of data (annual).

	Nafpaktos	Agrinio	Lamia	Lefkada	Karpenisi	Average (%)	Max (%)	Min (%)
Christiansen group	17.4	8.8	12.7	14.5	17.2	14.1	17.4	8.8
Jensen-Haise group	16.9	**5.6**	6.0	**6.8**	10.9	9.2	16.9	5.6
Makkink group	15.4	**5.5**	7.7	9.5	13.4	10.3	15.4	5.5
Priestley-Taylor	12.0	**5.3**	8.2	8.8	14.0	9.7	14.0	5.3
Turc	14.7	6.0	7.2	9.0	12.1	9.8	14.7	6.0
Modified-Turc	12.8	6.4	8.1	9.8	12.4	9.9	12.8	6.4
Abtew	**8.6**	8.1	**5.0**	**6.6**	**10.0**	**7.7**	10.0	5.0
Average (%)	14.0	6.5	7.8	9.3	12.9			
Max (%)	17.4	8.8	12.7	14.5	17.2			
Min (%)	8.6	5.3	5.0	6.6	10.0			

(b) RMAE considering only the values from April to October (vegetation period).

	Nafpaktos	Agrinio	Lamia	Lefkada	Karpenisi	Average (%)	Max (%)	Min (%)
Christiansen group	14.2	6.2	10.4	12.1	14.6	11.5	14.6	6.2
Jensen-Haise group	13.9	**3.9**	5.2	**5.7**	10.7	7.9	13.9	3.9
Makkink group	12.4	**3.8**	6.4	8.1	12.5	8.6	12.5	3.8
Priestley-Taylor	8.3	4.5	6.3	7.1	13.6	8.0	13.6	4.5
Turc	11.4	4.2	5.9	7.8	11.5	8.2	11.5	4.2
Modified-Turc	10.1	4.3	6.6	8.6	11.8	8.3	11.8	4.3
Abtew	**5.4**	6.0	**4.1**	**5.6**	**10.1**	**6.2**	10.1	4.1
Average (%)	10.8	4.7	6.4	7.8	12.1			
Max (%)	14.2	6.2	10.4	12.1	14.6			
Min (%)	5.4	3.8	4.1	5.6	10.1			

The results of the above studies are contradictory. They suggest different empirical equations as the best for areas with semiarid mediterranean climate. For the island of Crete (South Greece), the most appropriate equations are those of Turc and Hansen with a MAE ranging from 0.455 to 0.852 $^{\text{mm}}/_{\text{day}}$ and 0.475 to 0.922 $^{\text{mm}}/_{\text{day}}$ respectively (Xystrakis and Matzarakis, 2011). The Turc equation also provides the best predictions in South California when it compared to the FAO-PM method. However, after the calibration of the equations the Makkink method performs better

(Castaneda and Rao, 2005). The results are similar in California where the original Turc and Makkink equations performs better than Priestley-Taylor (George et al., 2002). The original Makkink equation also performs better in Morocco (Er-Raki et al., 2004). The results are different in South Portugal and Southern Spain where the best results are obtained by Jensen-Haise and Priestley-Taylor methods respectively (Teixeira et al., 2008; Berengena and Gavilan, 2005). After calibration, the Jensen-Haise method has an average MAE of $0.39\,\mathrm{mm}/\mathrm{day}$ for the whole year and $0.43\,\mathrm{mm}/\mathrm{day}$ for the period between April and September (Teixeira et al., 2008). For Southern Spain, the performance of the Priestley-Taylor equation is improved substantially after the local adjustment of the parameter a, with an index of agreement equal to 0.956.

From all these studies we can conclude that there is no single empirical equation that outperforms the others in all cases. The performance of each equation depends on the local climatic conditions and can change from one location to another even if they have the same general climate (e.g. mediterranean).

The adjustment of the general models to the local climatic conditions of central Greece reduced their error, compared to other studies under similar climate in Greece. This can be shown by comparing the results of Xystrakis and Matzarakis (2011) in Crete with the results of the present study in central Greece. Even the models with the highest errors in central Greece outperformed the equations with the lowest errors in Crete. This becomes even more apparent if we look at the comparison between the non-calibrated Priestley-Taylor and Penman equations that Michalopoulou and Papaioannou (1991) did in Greece. For the humid stations (e.g Agrinio) the index of agreement was 0,970 and for the semi-arid stations (e.g. Lamia) 0,886. Both values are lower if we compare them with the results of the present study (0,997 and 0,993 respectively).

The radiation-based equations that have been used in all studies which were carried out in mediterranean climatic regions, belong to four of the seven general models that are presented in the current study. The performance of the Christiansen group, Modified-Turc and Abtew models in mediterranean climates has not been evaluated until now. These equations were originally developed and used in warm and humid wetland environments (Abtew, 1996). Few additional applications are known, including use in humid climatic environments (Xu and Singh, 2000; Melesse et al., 2009). The calibration and evaluation of these models in central Greece revealed the Abtew model as the one with the best overall performance under semi-arid, sub-humid and humid/moderate-windy conditions.

Wind speed seems to play a significant role to the performance of all radiation-based methods that were used in this study. There is a tendency of a progressive increase of average error from the light-windy to the sites with stronger winds. The influence of wind upon PET$_{ref}$ should be further studied in order to provide better interpretation and possible improvement of the methods.

A lack of a complete evaluation of radiation-based methods in mediterranean regions didn't allow, until now, for general recommendations in the use of a preferred method for the estimation of PET$_{ref}$. The present study attempts to fill this gap and to extract some useful information for the use of the most appropriate radiation-based methods in such regions. By taking into consideration all the above remarks the following recommendations can be made:

1. For the semi-arid, sub-humid and humid/moderate-windy mediterranean climates the most appropriate model seems to be the Abtew (Table 2.4.10).
2. If no average daily maximum temperature measurements are available, then a good alternative to the Abtew model, for the three climatic types mentioned before, is the Jensen-Haise group model. The only exception is the sub-humid regions with light-windy dry period (Table 2.4.10).
3. For the humid and light-windy climates, the most accurate estimations give the Priestley-Taylor, Makkink group and Jensen-Haise group models (Table 2.4.10).

Table 2.4.10.: Recommended use of radiation-based methods for the estimation of monthly reference potential evapotranspiration in different mediterranean climatic types.

Method	**Climatic types**				
	semi-arid	sub-humid/ gentle-windy in dry period	sub-humid/ light-windy in dry period	humid/ moderate-windy	humid/ light-windy
Christiansen group					
Jensen-Haise group	✓	✓✓		✓	✓✓
Makkink group					✓✓
Priestley-Taylor					✓✓
Turc					
Modified-Turc					
Abtew	✓✓	✓✓	✓✓	✓✓	

2.4.4. Conclusions

The use of a simple method for the accurate estimation of $\mathrm{PET}_{\mathrm{ref}}$ under mediterranean climatic conditions and complex terrain is essential for applications in regions without available measurements. The radiation-based methods, especially those which also include a temperature factor in their calculations, seem to be a very good choice. The different regional climatic conditions should be considered for the selection of the appropriate equation for modeling evapotranspiration.

The Abtew model should be used in mediterranean climates with semi-arid, subhumid and humid/moderate-windy conditions. Jensen-Haise group, Makkink group and Priestley-Taylor, models are preferable for humid and light-windy conditions.

The extrapolation of the above conclusions and recommendations to other areas with similar climatic conditions should be further examined. Nevertheless, the above empirical methods should not be used without a local adjustment of their parameters a and b. More research is needed to better understand the contribution of the four model terms (T_{max}, T_{mean}, R_s and R_n) of the equations to the predictive accuracy of the methods and their performance in other regions with mediterranean conditions.

2.5. Spatial prediction of climatic variables

2.5.1. Weather stations and climatic data

The area used for the spatial prediction of the three basic climatic parameters was expanded beyond the area of research interest, due to the lack of an adequate number of weather stations inside the study area (Figure 2.5.1). The number of weather stations that were used was 19, operated by four different national services (HNMS[d], PPC[e] MEECC[f], MRDF[g]). All of the stations had available measurements of precipitation, but only 10 of them of temperature (Table 2.5.1, Table Table 2.5.2 on page 53). Most of the climatic data used in this study are publicly available in the repository of ITIA research team of the National Technical University of Athens[2]. Some additional data were collected from Bouras (1985) and Karimbalis (1996).

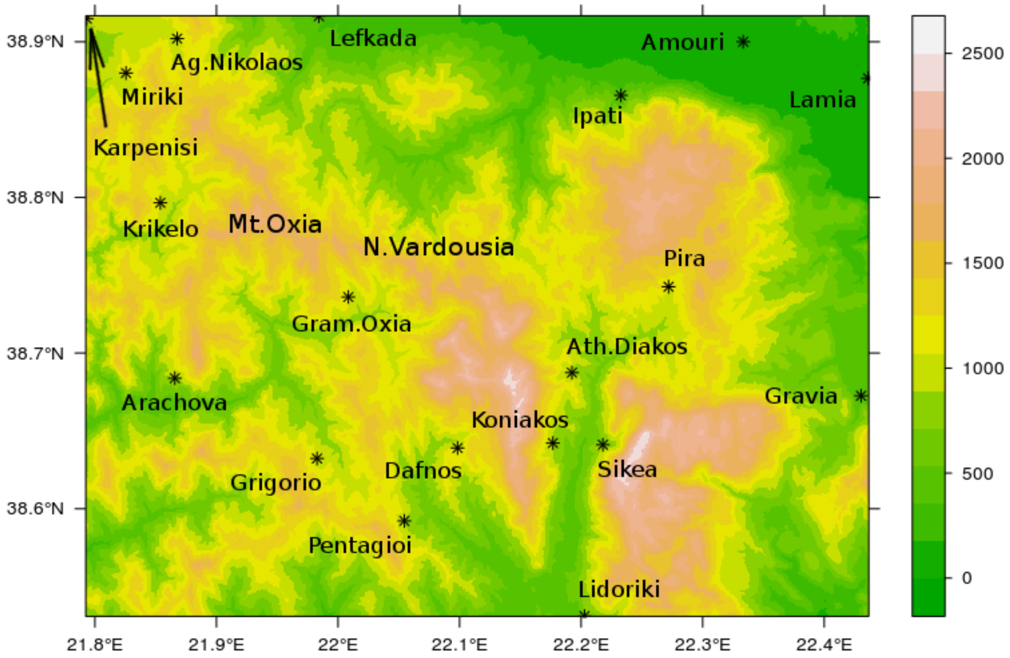

Figure 2.5.1.: The expanded area that was used for the spatial prediction of the climatic variables and the locations of the weather stations used for the spatial prediction of air temperature and precipitation.

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[d] Hellenic National Meteorological Service

[e] Public Power Corporation

[f] Ministry of Environment Energy and Climate Change

[g] Ministry of Rural Development and Food

Table 2.5.1.: Location and observation period for the weather stations of the study area. The coordinates are in decimal degrees (projection system WGS84) and the elevation in meters.

Station	Coordinates		Elevation	Observation period	
	Longitude	Latitude		Precipitation	Temperature
Lamia	22.436	38.877	12	1962 - 1991	1962 - 1990
Amouri	22.333	38.900	50	1965 - 1986	1965 - 1986
Ipati	22.233	38.866	286	1962 - 1991	-
Gravia	22.430	38.673	381	1962 - 1991	-
Lefkada	21.984	38.916	390	1974 - 1990	1973 - 1990
Lidoriki	22.203	38.531	548	1962 - 1991	1975 - 1995
Sikea	22.218	38.641	708	1967 - 1991	-
Ath.Diakos	22.192	38.687	846	1962 - 1991	-
Koniakos	22.177	38.642	875	1967 - 1991	-
Arachova	21.866	38.684	914	1962 - 1991	1972 - 1981
Pentagioi	22.055	38.592	921	1962 - 1991	-
Karpenisi	21.793	38.915	962	1967 - 1991	1982 - 1990
Grigorio	21.983	38.632	1000	1962 - 1991	-
Dafnos	22.098	38.639	1005	1967 - 1991	-
Ag.Nikolaos	21.868	38.902	1012	1962 - 1981	1972 - 1981
Krikelo	21.854	38.797	1067	1962 - 1991	1972 - 1981
Gram.Oxia	22.008	38.736	1107	1962 - 1991	1971 - 1980
Pira	22.272	38.743	1137	1962 - 1991	-
Miriki	21.826	38.880	1155	1962 - 1981	1972 - 1981

2.5.2. Ancillary data and software

Additionally to the climatic information, ancillary data were used for the accomplishment of the present study as well as different software tools. Those were:

2.5.2.1. Digital elevation data

Digital elevation data is a very useful tool for the representation of terrain's surface, by the means of a Digital Elevation Model (DEM), with many applications in physical geography, climatology and ecology. In this study the SRTM elevation data (Far et al., 2007) with resolution of 90 m were used. The original SRTM data, produced and released to the public by NASA[3], contain areas with no information (no-data voids). These original data have been further processed in order to fill in the voids (Jarvis et al., 2008) and are freely available for download (SRTM 90 m Version 4) by the CGIAR Consortium for Spatial Information (CSI)[4].

Table 2.5.2.: Descriptive statistics of the monthly, annual, vegetation and dry period precipitation (mm) and maximum air temperature (°C) data for the 19 weather stations of the study area.

(a) Precipitation data. The last column gives the linear correlation coefficient between precipitation and elevation for each month.

Period	Mean	Median	Standard deviation	Minimum value	Maximum value	Skewness	Kurtosis	Correlation
Jan	162.5	176.0	48.4	61.3	221.2	-0.65	-0.70	0.85
Feb	149.3	156.2	41.8	67.4	211.8	-0.51	-0.72	0.87
Mar	111.7	108.6	29.3	54.6	162.6	-0.06	-0.27	0.78
Apr	86.8	88.8	27.1	40.8	151.4	0.20	0.61	0.76
May	60.1	62.9	16.4	32.4	94.6	-0.03	-0.42	0.84
Jun	39.3	40.2	10.5	23.1	61.3	0.22	-0.61	0.79
Jul	26.7	26.0	8.8	13.4	43.4	0.26	-0.95	0.66
Aug	23.7	24.7	5.4	11.8	34.0	-0.38	0.19	0.67
Sep	35.3	32.6	9.5	19.9	59.0	0.91	0.96	0.67
Oct	107.3	107.7	25.1	63.8	166.2	0.11	0.53	0.72
Nov	171.4	182.3	55.7	67.4	299.6	-0.07	0.86	0.79
Dec	199.0	217.1	63.7	76.2	328.8	-0.35	0.24	0.81
Dry period	125.0	131.5	29.1	73.3	178.2	-0.04	-0.68	0.83
Veg. period	379.2	398.1	91.9	213.9	590.4	0.13	0.28	0.83
Annual	1173.0	1264.3	308.7	583.1	1779.0	-0.51	0.08	0.89

(b) Average maximum air temperature data. The last column gives the linear correlation coefficient between air temperature and elevation for each month.

Period	Mean	Median	Standard deviation	Minimum value	Maximum value	Skewness	Kurtosis	Correlation
Jan	7.4	7.1	2.9	2.5	11.5	-0.07	-0.99	-0.89
Feb	8.5	7.8	2.8	3.7	12.8	0.04	-0.58	-0.90
Mar	11.7	11.4	2.6	7.0	15.2	-0.29	-0.79	-0.84
Apr	15.9	15.1	3.2	10.4	20.1	-0.08	-0.96	-0.89
May	21.4	20.8	3.1	16.2	25.8	-0.02	-0.72	-0.88
Jun	26.2	25.5	3.1	21.9	30.5	0.22	-1.35	-0.92
Jul	28.5	27.4	2.9	23.6	32.3	-0.06	-1.00	-0.88
Aug	27.6	26.3	3.0	22.8	31.6	0.06	-1.27	-0.89
Sep	24.5	24.2	2.9	19.3	28.4	-0.31	-0.76	-0.85
Oct	18.6	18.9	3.0	13.2	22.3	-0.42	-0.69	-0.85
Nov	12.9	12.0	2.9	8.4	17.4	0.37	-0.53	-0.93
Dec	9.2	8.5	2.6	4.9	13.1	0.10	-0.60	-0.91
Dry period	26.7	25.7	2.9	21.9	30.7	0.01	-1.13	-0.90
Veg. period	23.2	22.4	3.0	18.2	27.2	-0.05	-0.93	-0.90
Annual	17.7	16.8	2.9	12.8	21.7	-0.02	-0.82	-0.90

2.5.2.2. Geospatial applications

Two Geographical Information Systems (GIS) were used for the geospatial analysis of climatic information: GRASS-GIS[5] and QuantumGIS[6], both free and open source software.

2.5.2.3. Statistical tools

All the statistical analysis and part of the geospatial analysis of the climatic data was performed in R[7], a programming language and software environment for statistical computing and graphics.

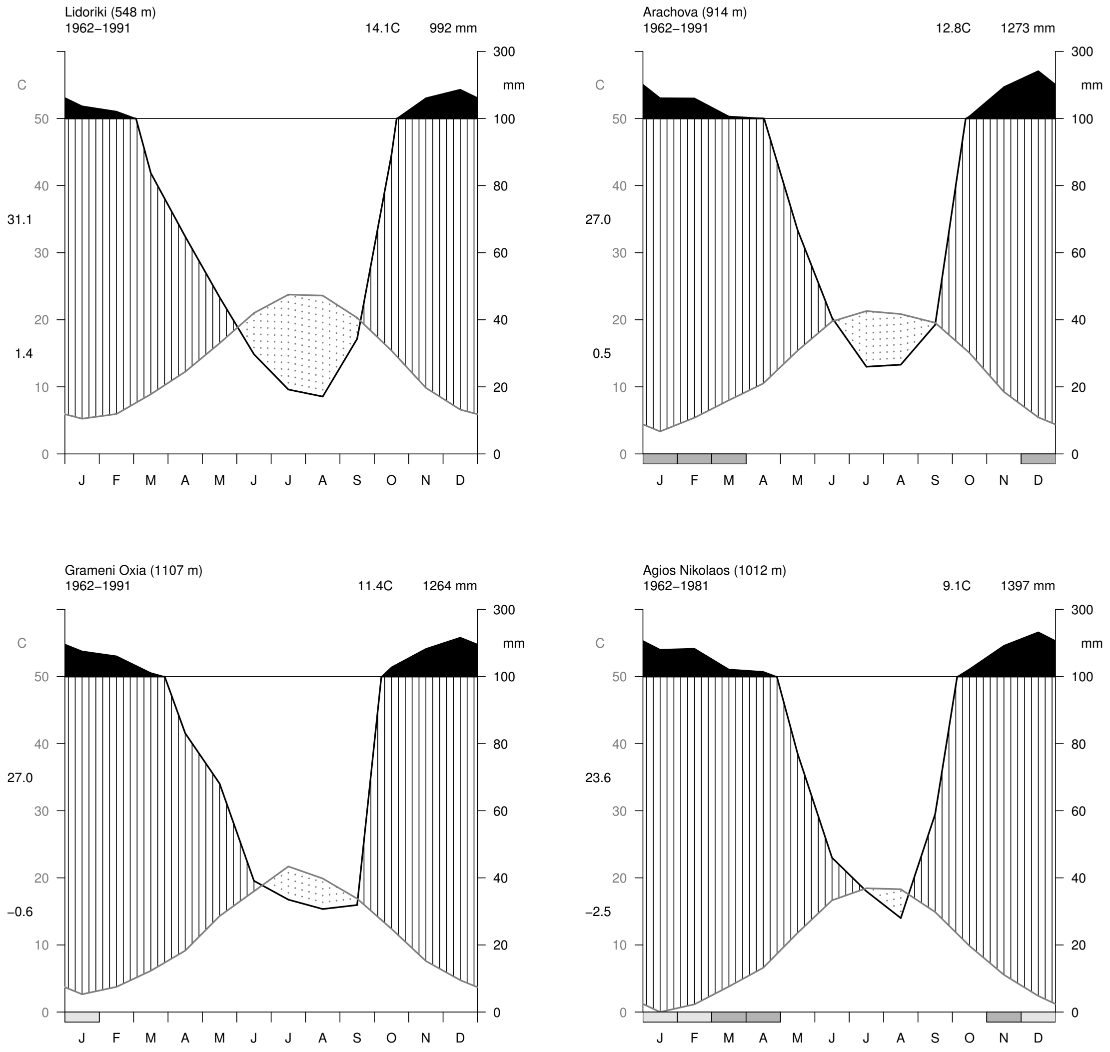

Figure 2.5.2.: Climate diagrams of 4 weather stations, representative of the different climatic conditions of the lower part of the distribution of *Abies* forests in the study area. The annual precipitation, mean annual temperature, mean maximum temperature of the warmest month and mean minimum temperature of the coldest month are shown on the diagrams.

2.5.3. Calculation of solar radiation

At regional and local scales (especially in mountainous regions), topography (relief) is the major factor modifying the distribution of solar radiation (Fu and Rich, 2002; Šúri and Hofierka, 2004). Rorison et al. (1986) showed that at local scales, topography can reduce the amount of annual mean total solar radiation from 6.80 $^{\mathrm{Mj}}/_{\mathrm{m^2 \cdot day}}$ on a slope with southern exposition to 4.89 $^{\mathrm{Mj}}/_{\mathrm{m^2 \cdot day}}$ on a north facing slope. In order to consider the spatial variation of radiation determined by local topography, spatial-based solar radiation models integrated into a geographical information system (GIS) have to be used (Huld et al., 2003; Pons and Ninyerola, 2008).

For the calculation of the monthly mean of daily global (total) irradiation the *r.sun* GIS-based model (Hofierka and Šúri, 2002; Šúri and Hofierka, 2004) was used, which is implemented in the GRASS-GIS. The *r.sun* model is conceptually based on the work undertaken for the development of European Solar Radiation Atlas (ESRA) (Mckenney, 1999; Scharmer and Greif, 2000; Page et al., 2001; Wald et al., 2002). The underlying equations for diffuse radiation implemented in this model reflect especially the European climate conditions.

According to Šúri and Hofierka (2004) the interaction of solar radiation with the atmosphere and earth's surface is determined by three groups of factors:

1. earth's geometry, revolution and rotation
2. terrain (elevation, surface inclination and orientation, shadows)
3. atmospheric attenuation (scattering, absorption) by:
    a) gases (air molecules, ozone, CO_2 and O_2),
    b) solid and liquid particles (aerosols, including non-condensed water),
    c) clouds (condensed water).

The two first groups of factors (1 and 2) can be modeled with high accuracy and the atmospheric attenuation by gases (factor 3a) can be determined with good precision Šúri and Hofierka (2004). The attenuation by solid and liquid particles (factor 3b) is quantified by the Linke turbidity factor (T_L).

Linke turbidity is a measure of the effect of aerosols and water vapor in reducing the transmission of direct solar radiation to the earth's surface under clear sky (AMS)[1]. It describes the optical thickness of the atmosphere relative to a dry and clean atmosphere (Remund et al., 2003) and is very important for the accurate estimation of the clear sky radiation (Ineichen and Perez, 2002).

The monthly averages of the T_L for 4 locations inside the study area were obtained from the PVGIS European solar radiation database[8]. The mean values of these 4 locations were calculated (Table 2.5.3) and used to generate the 12 raster maps of the clear-sky radiation (Figure A.2.2).

The last attenuation factor of solar radiation are the clouds (factor 3c). A great deal of information is required for the theoretical analysis of this factor, including cloud thickness and altitude, position and number of layers along with their optical properties (Satterlund and Means, 1978; Hofierka and Šúri, 2002). Detailed data

Table 2.5.3.: Linke turbidity values used for the calculation of the average monthly clear-sky solar radiation. For each month, the mean values of 4 locations taken from the PVGIS project were used.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Linke turbidity	4.3	4.1	4.4	4.9	5.1	5.3	5.5	5.3	5.3	4.6	4.2	4.1

of this type were not available and therefore the atmospheric attenuation of solar radiation by clouds was not calculated. This means that the “clear-sky” and not the “real-sky” radiation had to be calculated for the region.

The clear-sky radiation can be significantly higher than the real, especially during the winter. This difference between clear and real-sky radiation can be of high importance if the interest is on the absolute values of solar radiation. For this study is not important the exact amount of solar energy reaching the sites but the differences between the different sites. As it was already mentioned in this chapter, at local scale (over distances of hundreds or tens of metres) these differences are mainly caused by the topography, assuming that cloudiness remains more or less the same above a local region. According to Matzarakis and Katsoulis (2006) sunshine does not vary considerably over small distances.

The raster maps of monthly means of daily sums of global irradiation were computed in the following steps:

1. Raster maps of slope, aspect and altitude are first generated from the Digital Elevation Model (DEM)
2. Raster maps of the horizon angle were computed from the DEM. By this the shadowing effect of the topography was incorporated. Eight maps were created for an equal number of azimuthal directions, one every 45 degrees.
3. The ground albedo and the Linke turbidity factors were seted. The ground albedo was considered constant and equal to 0.23. The Linke turbidity values are given in Table 2.5.3.
4. The command `r.sun2` was used in GRASS software to lunch the calculation.

The analysis sequence of clear-sky solar irradiation is shown in Figure 2.5.3. Details about the underlying equations and the computational approach of the *r.sun* model can be found in Hofierka and Šúri (2002); Šúri and Hofierka (2004).

The calculated maps are presented in the Appendix (Figure A.2.2).

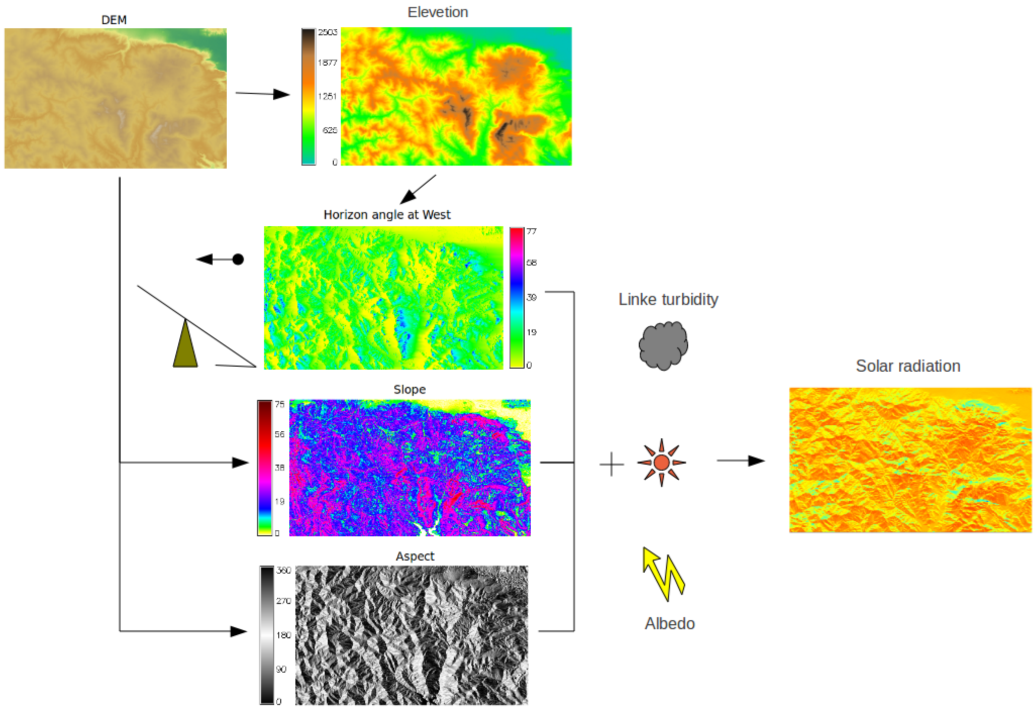

Figure 2.5.3.: Analysis sequence for the calculation of clear-sky solar irradiation. The map of the horizon angle was computed at 8 successive azimuthal directions with an angle step of 45 degrees. The Linke turbidity factor and the ground albedo coefficient were considered constant for the whole region.

2.5.4. Spatial prediction of air temperature and precipitation

According to Matheron (1969), a value of a target variable Z (e.g. air temperature or precipitation) at some location s can be modeled as the sum of the three components of its variation:

$$Z(s) = m(s) + \varepsilon^{'}(s) + \varepsilon^{''} \tag{2.5.1}$$

where $m(s)$ is the deterministic component (trend), $\varepsilon^{'}(s)$ is the spatially correlated random (or stochastic) component and $\varepsilon^{''}$ is the pure noise (partially micro-scale variation, partially the measurement error). This model is often referred as the **universal model of spatial variation** (Hengl, 2009).

Spatial variability of environmental variables is normally a result of the above mentioned deterministic and stochastic processes (natural spatial variation) and additionally the pure inherent noise (mainly measurements errors). The natural spatial variation that appears in a dataset is mainly due to physical processes that can be explained and modeled using a mathematical model called **spatial prediction model**.

Predicting values of a target environmental variable Z (e.g. precipitation) over a whole area of interest is a process based on field samples $z(s)$ (e.g. measurements of precipitation in a number of weather stations) and assumptions regarding the form of the trend of Z ($\hat{m}(s)$, deterministic component) and the interpolated residuals $\hat{e}(s)$ (stochastic component).

$$\hat{z}(s) = \hat{m}(s) + \hat{e}(s) \tag{2.5.2}$$

This is the most generic form of a spatial prediction model, called regression-kriging, and can be graphically represented by the scheme of Figure 2.5.4.

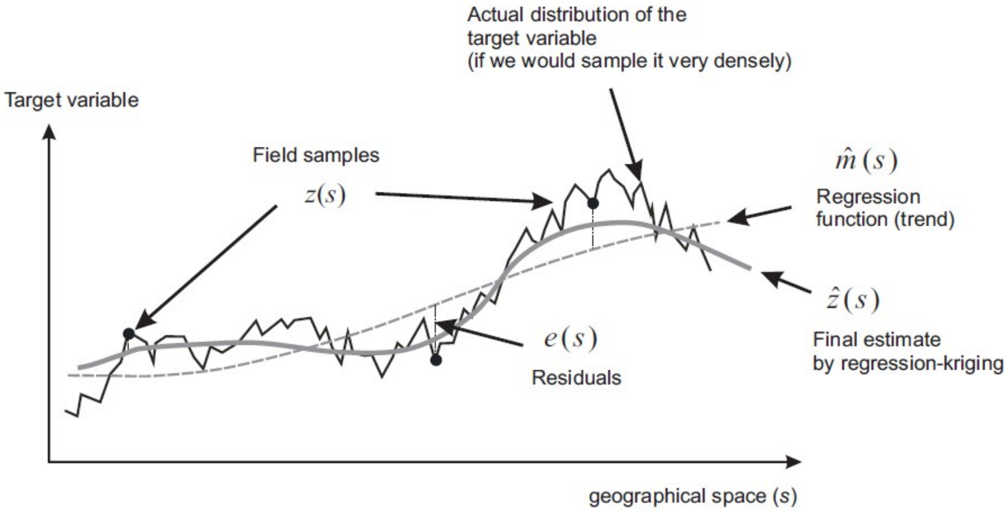

Figure 2.5.4.: Regression-kriging. From Hengl (2007).

The right selection of the most suitable spatial prediction technique (model) is essential in the process of geostatistical mapping. Following a simple decision tree, like the one that was proposed by Hengl (2007)(Figure 2.5.5), one can start from testing the most generic technique and finish with the most appropriate one.

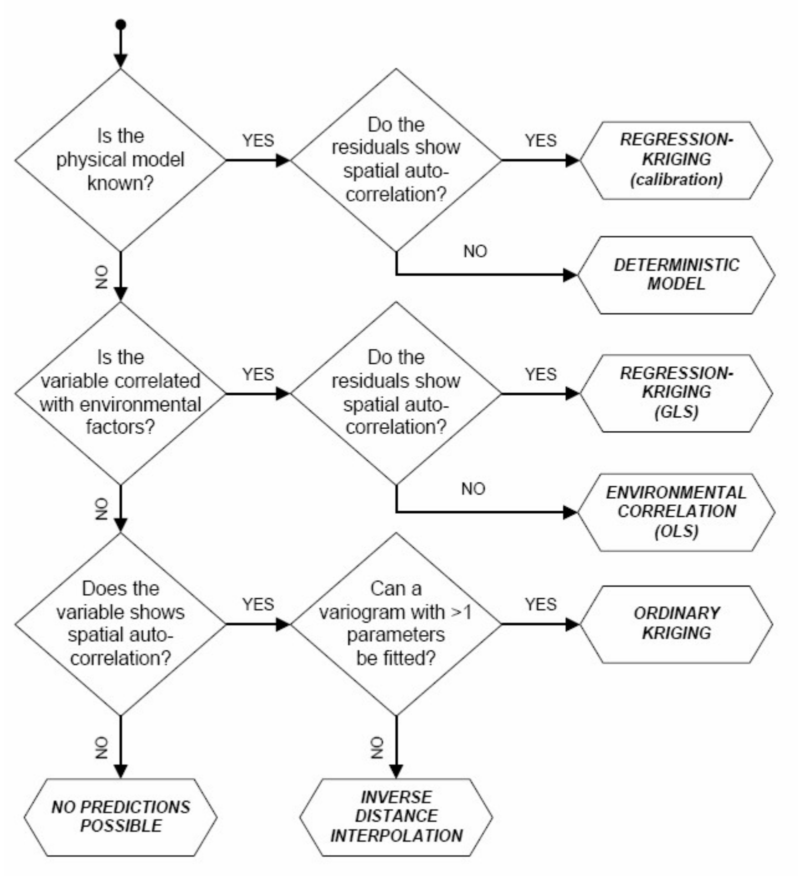

Figure 2.5.5.: Decision tree for selecting a suitable spatial prediction model. From Hengl (2007).

2.5.4.1. Procedure

The computational steps basically follow the general framework for geostatistical mapping of environmental variables described in detail in Hengl (2007). This consists of six steps:

1. Exploratory data analysis - environmental correlation

The two variables of interest (precipitation and air temperature) were checked for possible correlation with other environmental factors. Air temperature is usually well correlated with the elevation, as has been shown in many studies, but for precipitation this is not always true. In this case it was found that a strong correlation occurs between both maximum air temperature - elevetion and precipitation - elevation (Table 2.5.2). The correlation between maximum temperature and elevation was negative and ranged from -0.85 to -0.93. Similarly high but less strong was the correlation between precipitation and elevation. Apart from the three driest months (July - September) the correlation ranged between 0.72 and 0.87 (Table 2.5.2).

2. Regression modeling - trend estimation

The second step was to use the elevation values from the weather stations and fit two linear regression models, one for temperature and another for precipitation. For maximum air temperature, 72 - 87 % of its total variation could be explained by elevation, that accounts for the deterministic part (trend) of the spatial prediction model. The respective proportion for precipitation, apart from the three driest months, was 52 - 76 %.

3. Variogram modeling of residuals - estimating spatial auto-correlation

The residuals of the above linear regression models were further explored, in order to find out whether a spatial auto-correlation among them is present or not. For that, a **variogram cloud** and a **sample (i.q. experimental) variogram** were plotted (Figure 2.5.6). The variogram cloud was obtained by plotting all possible semivariances $\gamma(h_{ij})$ against their distances h_{ij}. **Semivariance** is the half of squared difference of two observations (Bivand et al., 2008):

$$\gamma(h_{ij}) = \frac{1}{2}\left(Z(s_i) - Z(s_j)\right)^2 \qquad (2.5.3)$$

By averaging the variogram cloud values over predifined distance intervals h, and ploting these averaged values against their distances, we obtain the sample variogram.

4. Kriging interpolation of residuals

In those cases where the residuals of the linear regression model showed spatial auto-correlation, an ordinary kriging interpolation of them was performed. With the residuals interpolation, the stochastic part of the spatial prediction model was considered. In order to predict the spatial variation of the residuals, a parametric model had to be fitted to the sample variogram, that had been already calculated in the previous step. The proccedure for fitting the model is described in detail by Bivand et al. (2008). For the residuals variogram of maximum air temperature it was not possible to fit any model. The spatial prediction of temperature was, therefore, made with the linear regression model in which elevetion was the only predictor.

5. Spatial prediction

Once the stochastic part of variation had been estimated, the spatial predictions of the residuals were added to the deterministic part (trend) of variation of the target environmental variable (i.e. precipitation), and the final predictions in areas with no measurements were made. When the correlation between precipitation and elevation is not very strong, the use of ordinary kriging for the spatial prediction of precipitation may give better results than linear regression (Asli and Marcotte, 1995; Goovaerts, 2000). On the other hand, when a strong correlation exist, and the spatial auto-correlation of the residuals is not clear, it might be more usefull to derive the precipitation values directly from the elevetion. All three different cases of the spatial prediction model (Equation 2.5.2) were applied for the calculation of precipitation (ordinary kriging, regression, regression-kriging), and their results were compared before chosing the best.

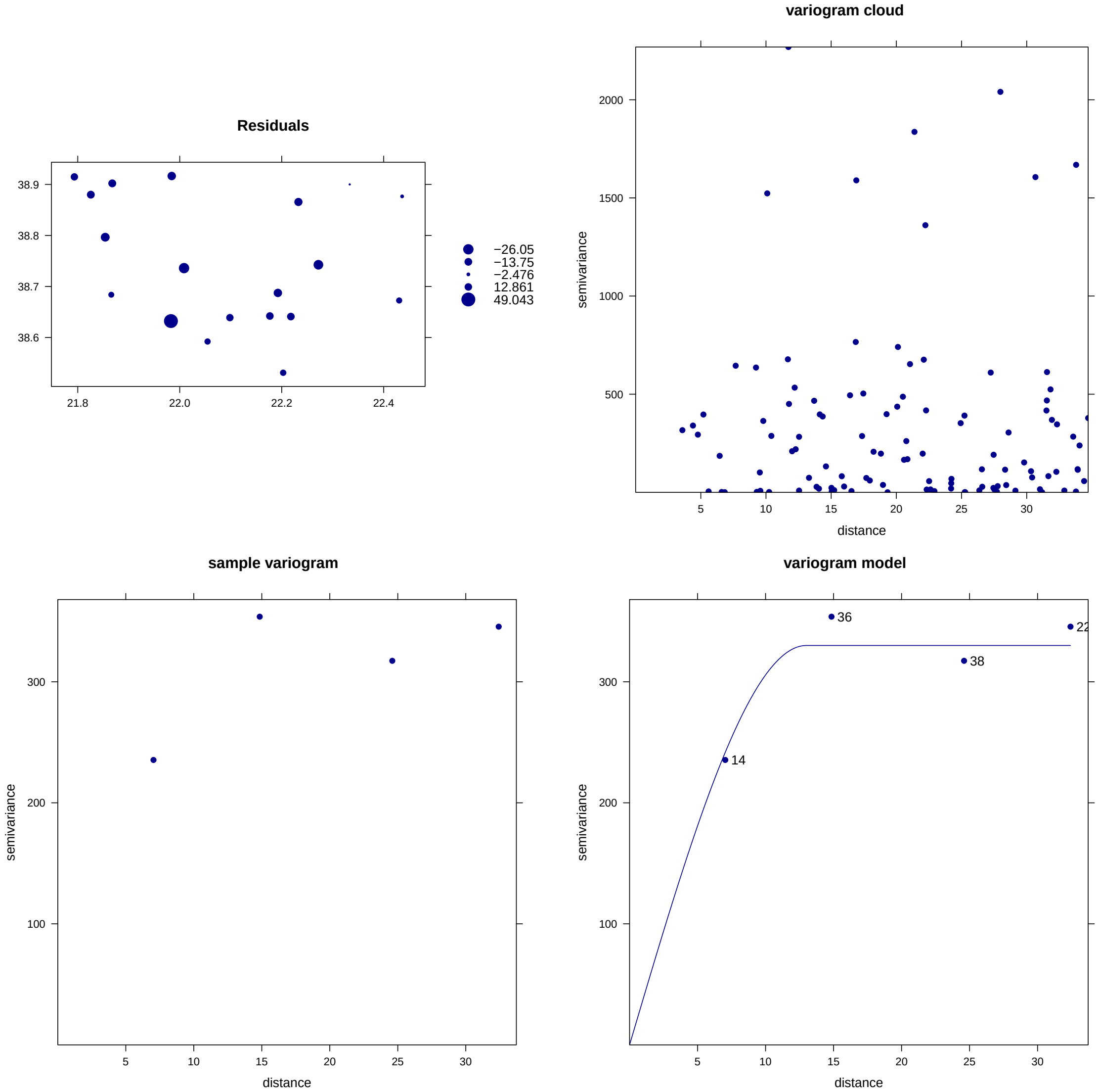

Figure 2.5.6.: Steps of variogram modeling. *Upper left*: location of points (weather stations) with regression residuals of precipitation measurments. *Upper right*: variogram cloud obtained by plotting all possible semivariances against their distancies. *Down left*: sample variogram obtained by averaging the variogram cloud values over predifined distance intervals. *Down right*: the final variogram model fitted into the sample variogram.

6. Evaluation of the performance of the spatial prediction models

The results of the different spatial prediction models were evaluated with the method of leave-one-out cross-validation (Maindonald and Braun, 2007) (subsection 2.4.1). The cross-validation was used to obtain a set of errors[h]. From these errors, quantitative (relative and absolute) error measures were calculated and used for comparing the above prediction models. Those were: the Mean Bias Error (MBE), the Mean absolute error (MAE) and the Index of agreement (d) (Table 2.4.4). The MBE indicates average interpolation bias (average over- or under-estimation by the model) (Willmott and Matsuura, 2006). The MAE and d indicate the absolute and relative average interpolation error respectively.

The comparison of performance of the three spatial prediction models (ordinary kriging, regression, regression-kriging) showed that for most of the months, regression and regression-kriging outperformed ordinary kriging (Figure 2.5.7). Only for the three driest months (July - September) ordinary kriging gave similarly good or even better (i.e. August) results. Regression-kriging performed better for the months January, July, September, November and December. Linear regression performed better for the months February - June and October. Ordinary kriging yield the best results for August (Figure 2.5.7).

Regression and regression-kriging models were selected for the spatial prediction of precipitation and for generating the final monthly precipitation maps. Only for August ordinary kriging was prefered. For the generation of the maximum air temperature maps linear regression models were used for all months, with elevation as predictor. The calculated maps are presented in the Appendix (Figure A.2.1, Figure A.2.3).

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[h] The differences between the model-predicted and observed values. The observed values correspond to the precipitation measurments of the 19 weather stations.

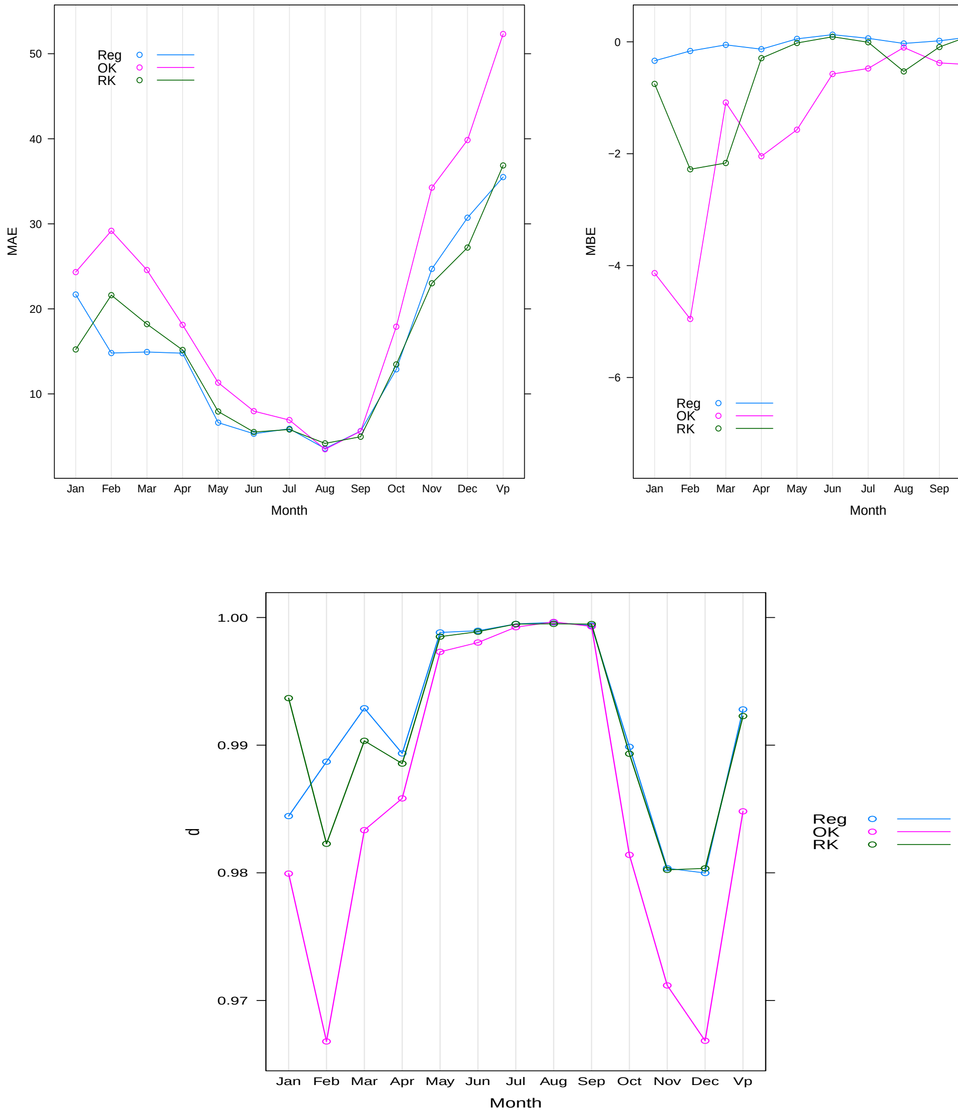

Figure 2.5.7.: Quantitative measures of prediction errors produced by each of the three spatial prediction models (Reg=Regression, OK=Ordinary Kriging, RK=Regression Kriging) for monthly and vegetation period (Vp) precipitation. Mean absolute error (MAE) and Mean bias error (MBE) are expressed in mm. Index of agreement (d) is dimensionless.

2.6. Calculation of $\mathrm{PET}_{\mathrm{ref}}$

Reference potential evapotranspiration is a basic element of the water balance model and one of the most difficult to calculate. The evaluation of the radiation-based equations in central Greece (section 2.4) showed that the best option for the estimation of $\mathrm{PET}_{\mathrm{ref}}$ in the mountainous area of Oxia - N. Vardousia was to use the Abtew equation (Table 2.4.3). The Abtew equation requires measurements or estimations of maximum air temperature ($T_{\max}$) and solar radiation (R_s). The interpolated values of $T_{\max}$ (Figure A.2.1) and R_s (Figure A.2.2) in the study area were extracted for the 45 plots/sites and the monthly average daily $\mathrm{PET}_{\mathrm{ref}}$ was calculated for each of them (Table A.1.5). These values were multiplied by the number of the days of each month in order to obtain the monthly values of $\mathrm{PET}_{\mathrm{ref}}$ (Table A.1.6).

2.7. Soil hydraulic properties

2.7.1. Water retention

The relation between soil water content (θ) and the energy state of the soil water is fundamental for the characterization of the hydraulic properties of a soil (Dane and Hopmans, 2002a). This relation is called **water retention curve** (WRC) or **pF-curve** (Figure 2.7.1). The energy state of the soil water is the result of pressure and absorptive forces and expresses the strength with which soil particles hold water. It is referred in literature by various terms such as **suction**, **tension**, **capillary pressure** or **matric head** (h_m). The energy state may be expressed either as pressure (Pa, hPa, bar) or as height (cm) of a column with fluid of a given density (usually water).

The water retention curve is not only important for the calculation of the available water capacity of a soil but also for the actual evapotranspiration function (β). For determining the water retention relation, a series of equilibria between water in the soil sample and a body of water at a known potential have to be established. At each equilibrium the volumetric water content (θ) of the soil is determined and paired with a value of water tension (h_m). Each data pair (θ, h_m) is a point on the retention relation (Dane and Hopmans, 2002b).

For the determination of the WRC, undisturbed core samples were obtained from the soil profiles that were made at each site. The soil water content at -60, -300 and -15 000 hPa of soil water tension was measured in the laboratory of the Institute of Soil Science and Forest Nutrition in Freiburg. For the laboratory measurements

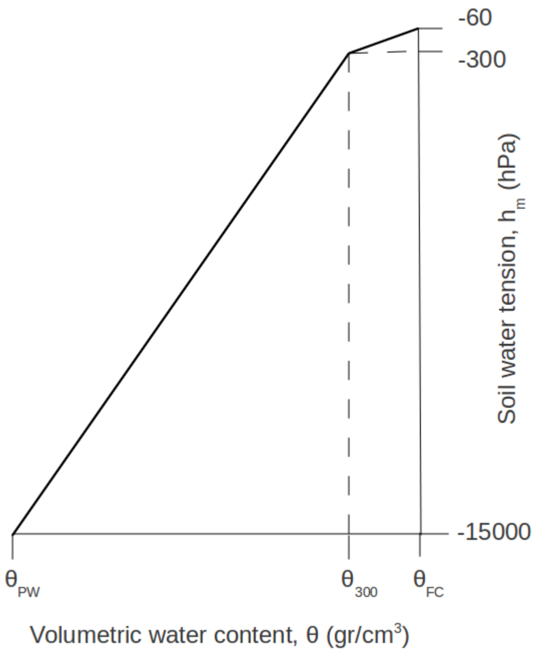

Figure 2.7.1.: Water retension curve.

ceramic suction plates and pressure plate extractors were used (Dane and Hopmans, 2002b).

2.7.2. Available soil water storage capacity

The available water storage capacity of the soil (ASWSC) is an important parameter of the terrestrial water cycle from local (Stephenson, 1988) to global scale (Mintz and Walker, 1993). If the capacity is small and the evaporative demand can not be met by water supply, the AET_{ref} will be reduced to a small fraction of PET_{ref}, after a few days without rainfall. But if the ASWSC is large the AET_{ref} will remain close to PET_{ref} for a relatively long period and the water deficit will be relatively small.

The ASWSC is a constant for any given soil and can be easily obtained by the following equation:

$$\text{ASWSC} = \theta_{\text{FC}} - \theta_{\text{PW}} \tag{2.7.1}$$

where θ_{FC} and θ_{PW} are the soil water content at field capacity (FC) and permanent wilting point (PW) respectively (Figure 2.7.2).

To assess the ASWSC of the total rooting space (ASWS_{max}), the physiological soil depth (rooting depth) and the content of coarse materials (skeleton content) have to

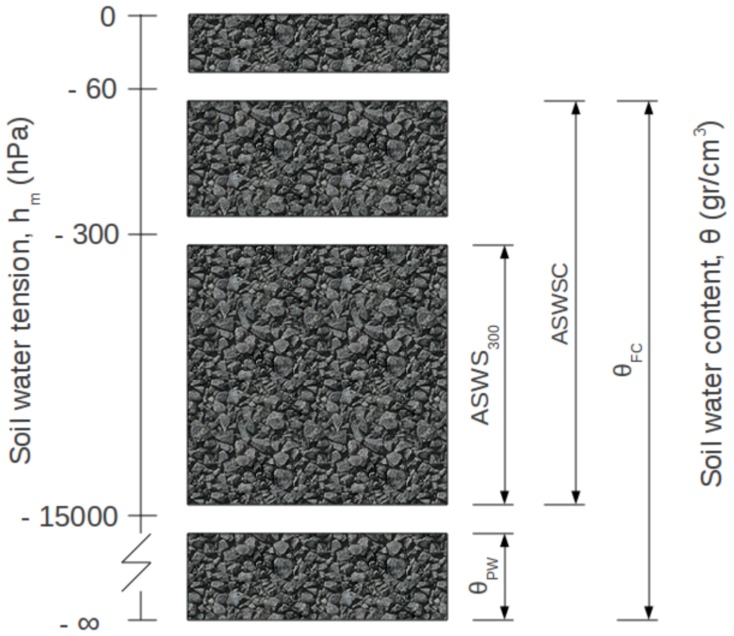

Figure 2.7.2.: Graphical representation of soil water terms.

be considered. The calculation procedure followed the steps suggested by Caspari and Schack-Kirchner (2008).

2.8. Actual evapotranspiration function

The amount of water that reaches a site through precipitation is partly transferred back to the atmosphere to cover its evaporative demand (expressed by PET_{ref}). This vapor transfer back to the atmosphere is performed by AET_{ref}. According to Mintz and Serafini (1992) AET_{ref} can be divided into three components :

1. **interception evaporation**; is the water that evaporates from the surface of the reference crop during and immediately after precipitation events.
2. **soil water evaporation**; is the water directly transferred from the soil to the atmosphere by upward hydraulic diffusion.
3. **crop transpiration**; is the water transferred from the soil to the atmosphere by the plants through transpiration.

When $P \geq \text{PET}_{\text{ref}}$ it is assumed that there is no decrease of water from the soil by transpiration and hydraulic diffusion but only interception evaporation which equals PET_{ref} (Equation 2.3.3). When precipitation is not enough to cover the evaporative demand of the atmosphere ($P < \text{PET}_{\text{ref}}$), transpiration and soil evaporation occurs, removing water from the root zone of the soil (Equation 2.3.3). Mintz and Serafini

(1992) considered separately the above components of $\mathrm{AET_{ref}}$ for their water balance analysis. Although these parameters (transpiration and soil evaporation) are governed by different mechanisms, in this study they were rather considered together for the $\mathrm{AET_{ref}}$ analysis, following the approach of Willmott et al. (1985).

In his initial water balance calculations, Thornthwaite (1948) considered that when $P < \mathrm{PET_{ref}}$, transpiration and soil evaporation equals the excess of $\mathrm{PET_{ref}}$ over precipitation ($\mathrm{PET_{ref}} - P$), independently of the soil wetness. Therefore he set the actual evapotranspiration function as constant and equal to one ($\beta = 1$)(curve A, Figure 2.8.1).

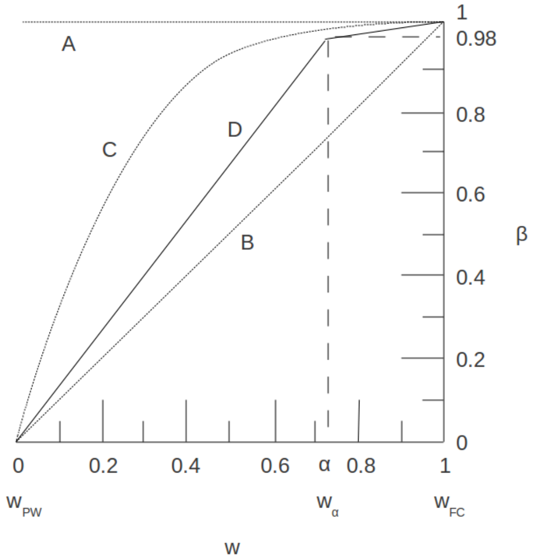

Figure 2.8.1.: The ratio of actual to potential evapotranspiration ($\beta = {}^{\mathrm{AET_{ref}}}/_{\mathrm{PET_{ref}}}$) as a function of the soil wetness ($w = {}^{\mathrm{ASWS}}/_{\mathrm{ASWS_{max}}}$). A: Thornthwaite (1948); B: Thornthwaite and Mather (1955); C: Mintz and Walker (1993); D: Present study

In reality, when $P < \mathrm{PET_{ref}}$ and soil water deficit appears ($\theta < \theta_{\mathrm{FC}}$), $\mathrm{AET_{ref}}$ will decrease, compared to the $\mathrm{PET_{ref}}$ rate, as soil water content is decreased. As the soil water decreases, it becomes more strongly attached to the soil particles and is more difficult to be extracted. Although water is theoretically available until permanent wilting point, water uptake by soil evaporation and reference crop transpiration is reduced considerably before wilting point is reached (Allen et al., 1998).

Thornthwaite and Mather (1955) assumed that the ratio of actual to potential evapotranspiration (β) is a linear function of soil wetness (${}^{\mathrm{ASWS}}/_{\mathrm{ASWS_{max}}}$) and let $\beta = {}^{\mathrm{ASWS}}/_{\mathrm{ASWS_{max}}}$ (curve B, Figure 2.8.1). A third approach was followed by Mintz and Serafini (1992) and Mintz and Walker (1993), which assumed an exponential decrease of β in relation to soil wetness. With their actual evapotranspiration function ($\beta = 1 - e^{-6.8 \cdot (\mathrm{ASWS}/\mathrm{ASWS}_{\mathrm{max}})}$), the $\mathrm{AET}_{\mathrm{ref}}$ is close to $\mathrm{PET}_{\mathrm{ref}}$ over a broad range of soil wetness and it decreases rapidly when ASWS is approximately 40 - 50 % of the $\mathrm{ASWS}_{\mathrm{max}}$ (curve C, Figure 2.8.1). Another compromise between models A and B is the so-called "root constant" (Penman, 1950) or readily available water approach. In this case $\mathrm{AET}_{\mathrm{ref}}$ is assumed to be equal to $\mathrm{PET}_{\mathrm{ref}}$ until the ASWS reaches a critical value (called the "root constant"). Below this point $\mathrm{AET}_{\mathrm{ref}}$ begins to decrease linearly in proportion to the soil wetness (Mohrmann and Kessler, 1959; Alley, 1984; Jamieson et al., 1995; Allen et al., 1998; Laio et al., 2001; Chen et al., 2008).

In this study, an intermediate approach between the C model and the "root constant" approach was used. It was assumed, like in the C model, that $\mathrm{AET}_{\mathrm{ref}}$ will remain close to $\mathrm{PET}_{\mathrm{ref}}$ when the ASWS is still close to the $\mathrm{ASWS}_{\mathrm{max}}$ and it will decrease rapidly after the ASWS reaches a critical point w_α (curve D, Figure 2.8.1). The analytical form of β is:

$$\beta = \begin{cases} b \cdot w, & w < w_\alpha \\ c \cdot w + d, & w \geq w_\alpha \end{cases} \tag{2.8.1}$$

where b, c and d are linear model parameters and w_α the critical soil wetness value below which $\mathrm{AET}_{\mathrm{ref}}$ declines faster. The parameters b, c, d and w_α depend on the water retention curve of the soil (Table 2.8.1). The w_α was calculated for each site from the WRC. It was assumed that w equals w_α when the soil water tension is -300 hPa (Table 2.8.1).

Table 2.8.1.: The relationship among volumetric water content (θ), actual evapotranspiration function (β) and soil wetness (w) for different values of soil water tension (h_m) calculated for plot Nr. 6

	h_m (hPa)	pF	θ (gr/cm^3)	w	β
Field capacity (FC)	- 60	1.8	0.257	1	1
α	- 300	2.5	0.207	w_α	0.984
Permanent wilting point (PW)	- 15 000	4.2	0.040	0	0

Note: PF is the logarithm of the h_m; for the values a and w_a see Figure 2.8.1.

The soil property values for the studied sites are given in (Table 2.8.2).

Table 2.8.2.: Soil property values for the studied sites (plots), including the water retention curve (WRC) values, the available soil water (ASW) characteristics and the model parameters of actual evapotranspiration function (β).

plot	WRC values			ASW characteristics			Parameters of β			
	$(^{gr}/_{cm^3})$			$(^{gr}/_{cm^3})$	(cm)	(mm)	(dimensionless)			
	θ_{FC}	θ_{300}	θ_{PW}	ASWSC	rooting depth	ASWS_{max}	w_α	b	c	d
6	0.257	0.207	0.040	0.218	100	129.9	0.767	1.284	0.069	0.931
9	0.293	0.257	0.031	0.262	100	101.3	0.863	1.140	0.117	0.883
10	0.292	0.234	0.030	0.262	100	249.1	0.780	1.262	0.073	0.927
14	0.336	0.249	0.019	0.317	58	121.9	0.724	1.360	0.058	0.942
15	0.313	0.258	0.025	0.287	100	160.6	0.811	1.213	0.085	0.915
21	0.346	0.306	0.033	0.314	72	160.1	0.870	1.131	0.123	0.877
25	0.315	0.253	0.042	0.273	100	65.7	0.771	1.276	0.070	0.930
26	0.288	0.246	0.044	0.244	44	52.5	0.828	1.188	0.093	0.907
27	0.349	0.306	0.034	0.315	100	297.6	0.862	1.142	0.116	0.884
28	0.310	0.230	0.030	0.280	30	33.1	0.715	1.377	0.056	0.944
29	0.260	0.204	0.020	0.239	36	49.1	0.766	1.284	0.069	0.931
30	0.285	0.214	0.032	0.254	100	140.1	0.720	1.366	0.057	0.943
31	0.220	0.184	0.014	0.206	75	52.6	0.824	1.194	0.091	0.909
33	0.292	0.234	0.030	0.292	100	76.7	0.780	1.262	0.073	0.927
34	0.318	0.260	0.026	0.298	35	54.2	0.800	1.231	0.080	0.920
35	0.331	0.220	0.032	0.207	50	100.4	0.630	1.561	0.043	0.957
36	0.224	0.153	0.017	0.270	27	43.1	0.659	1.494	0.047	0.953
37	0.291	0.235	0.021	0.187	51	87.9	0.791	1.245	0.077	0.923
38	0.220	0.180	0.033	0.244	44	25.9	0.787	1.250	0.076	0.924
39	0.292	0.234	0.030	0.262	20	6.3	0.780	1.262	0.073	0.927
40	0.264	0.216	0.020	0.244	100	151.1	0.803	1.225	0.082	0.918
41	0.251	0.199	0.019	0.232	51	39.2	0.775	1.270	0.071	0.929
42	0.296	0.226	0.023	0.273	48	52.2	0.743	1.324	0.063	0.937
43	0.267	0.227	0.045	0.222	63	37.5	0.819	1.201	0.089	0.911
44	0.360	0.285	0.056	0.304	50	103.0	0.754	1.306	0.065	0.935
46	0.314	0.285	0.044	0.270	39	29.2	0.894	1.101	0.151	0.849
47	0.262	0.225	0.023	0.238	39	55.8	0.847	1.162	0.105	0.895
48	0.321	0.249	0.022	0.299	72	152.7	0.759	1.297	0.067	0.933
49	0.297	0.218	0.029	0.267	100	179.5	0.703	1.399	0.054	0.946
50	0.335	0.281	0.052	0.283	100	206.8	0.809	1.217	0.084	0.916
51	0.292	0.234	0.030	0.262	100	123.3	0.780	1.262	0.073	0.927
52	0.317	0.266	0.032	0.285	100	169.9	0.821	1.198	0.090	0.910
55	0.333	0.263	0.026	0.307	100	179.7	0.772	1.274	0.071	0.929
57	0.365	0.262	0.019	0.346	100	174.4	0.702	1.401	0.054	0.946
58	0.301	0.254	0.042	0.259	18	44.4	0.821	1.199	0.090	0.910
59	0.254	0.199	0.034	0.221	100	197.1	0.747	1.317	0.064	0.936
60	0.300	0.248	0.031	0.269	100	202.9	0.807	1.219	0.083	0.917
61	0.292	0.234	0.030	0.262	40	62.3	0.780	1.262	0.073	0.927
62	0.216	0.190	0.030	0.186	100	113.5	0.856	1.149	0.112	0.888
63	0.300	0.233	0.024	0.276	100	176.2	0.758	1.299	0.066	0.934
64	0.250	0.210	0.025	0.225	72	66.3	0.820	1.199	0.089	0.911
65	0.210	0.155	0.018	0.192	43	44.1	0.710	1.386	0.055	0.945
66	0.274	0.211	0.025	0.249	100	178.2	0.745	1.321	0.063	0.937
69	0.292	0.241	0.031	0.261	68	147.2	0.804	1.223	0.082	0.918
70	0.337	0.262	0.039	0.298	33	72.3	0.750	1.313	0.064	0.936

Note: For the explanation of the ASW characteristics see subsubsection 2.3.2.1:
for the WRC values see Table 2.8.1.

2.9. Results

2.9.1. Humidity index values

The spatial quantification of drought intensity was based on the values of Humidity Index (HI), calculated for different time periods (dry, vegetation, growth and annual period). Dry period is the four driest months of the year (June-September). The vegetation period was defined as the period from beginning of May until end of October. The growth period was determined as the period of the year during which the mean temperature remains above 6 °C. It could be shown, that the fir forests of the study area occupy sites with values of HI, for the vegetation period, varying from 0.28 up to 0.74 (Figure 2.9.1). This means that during that period there is no forest stand in the study area (not even in the highest and less dry sites) where precipitation exceeds $\mathrm{PET}_{\mathrm{ref}}$.

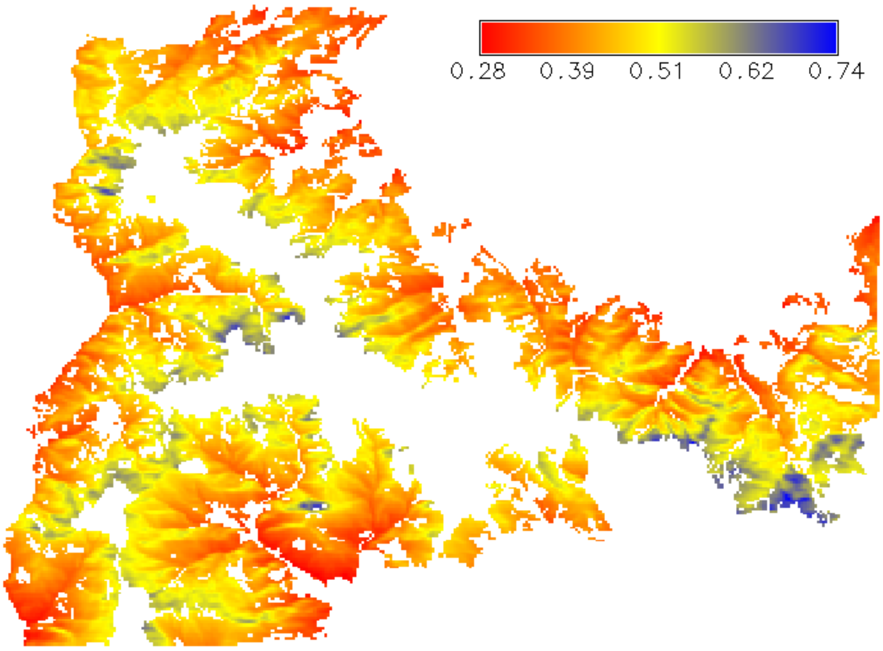

Figure 2.9.1.: Spatially predicted values of the humidity index (HI) in the Greek fir forests of the Oxia - North Vardousia mountain system. The HI was calculated for the vegetation period (April - October).

The values of HI from the spatial quantification of drought intensity were extracted for each of the 45 plots that were used for the vegetation analysis (Figure 2.9.2). These point-specific values are given in Table 2.9.1. The monthly point-specific values of HI for the 45 plots are given in Table A.1.7.

Table 2.9.1.: Humidity Index values (HI) for each studied site (plot).

Plot	HI			
	dry period	vegetation period	growth period	annual period
6	0.24	0.45	0.64	1.25
9	0.21	0.35	0.56	0.95
10	0.23	0.40	0.66	1.11
14	0.30	0.56	0.80	1.58
15	0.23	0.40	0.63	1.06
21	0.28	0.54	0.54	1.50
25	0.27	0.48	0.69	1.35
26	0.26	0.45	0.63	1.21
27	0.26	0.46	0.65	1.24
28	0.19	0.32	0.51	0.86
29	0.20	0.35	0.57	0.95
30	0.22	0.39	0.62	1.05
31	0.22	0.39	0.62	1.03
33	0.21	0.36	0.50	0.93
34	0.22	0.37	0.52	0.98
35	0.21	0.35	0.57	0.91
36	0.20	0.32	0.51	0.81
37	0.21	0.37	0.60	1.01
38	0.20	0.37	0.61	1.06
39	0.20	0.35	0.57	0.97
40	0.21	0.37	0.51	0.99
41	0.23	0.40	0.57	1.09
42	0.21	0.37	0.52	1.00
43	0.29	0.54	0.54	1.53
44	0.29	0.56	0.56	1.63
46	0.21	0.36	0.58	0.98
47	0.20	0.34	0.56	0.95
48	0.24	0.45	0.65	1.30
49	0.25	0.45	0.45	1.23
50	0.20	0.33	0.53	0.88
51	0.29	0.56	0.79	1.56
52	0.27	0.51	0.73	1.44
55	0.29	0.53	0.53	1.49
57	0.29	0.53	0.75	1.50
58	0.29	0.53	0.53	1.47
59	0.32	0.61	0.61	1.70
60	0.31	0.59	0.48	1.64
61	0.29	0.54	0.54	1.54
62	0.30	0.59	0.59	1.72
63	0.35	0.69	0.69	2.04
64	0.29	0.54	0.54	1.55
65	0.29	0.55	0.55	1.59
66	0.29	0.57	0.57	1.66
69	0.28	0.52	0.52	1.47
70	0.28	0.53	0.53	1.49

Note: dry period: the four driest months of the year (June-September);
vegetation period: April to October;
growth period: period with mean temperature $> 6\,^{\circ}\mathrm{C}$

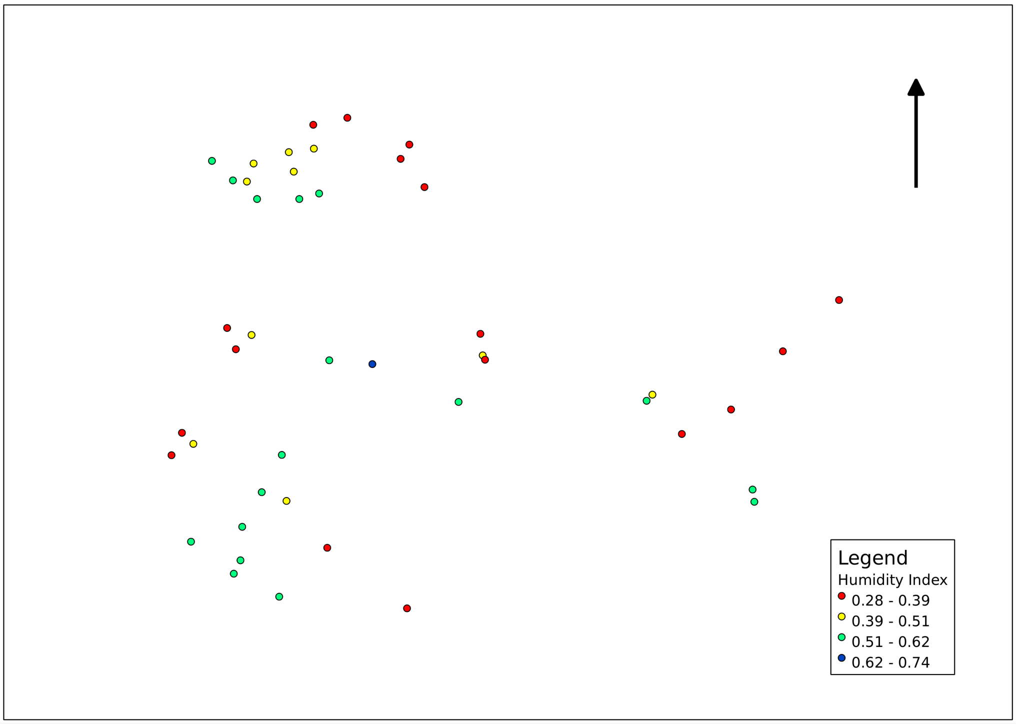

Figure 2.9.2.: Location of the plots with the extracted HI values from the map on Figure 2.9.1. The HI was calculated for the vegetation period (April - October).

2.9.2. Water balance outputs - $\mathrm{AET_{ref}}$ and water deficit

All the components of the water balance model, used in this study, were calculated for a monthly time period. The calculation of the water balance was performed for the soil profiles of the 45 plots that were used for the vegetation analysis. The main results, with high ecological impact (D and $\mathrm{AET_{ref}}$), that were used in the vegetation analysis are presented in Table 2.9.2. Water deficit (D) was used to measure the drought intensity in each site (plot).

Table 2.9.2.: Water balance outputs (AET$_{\text{ref}}$ and D) for each studied site (plot).

Plot	AET$_{\text{ref}}$ (mm)				D (mm)			
	dry period	vegetation period	growth period	annual period	dry period	vegetation period	growth period	annual period
6	177.7	468.1	487.3	564.8	527.3	527.3	527.3	527.3
9	133.3	448.3	533.7	587.4	632.2	653.9	653.9	653.9
10	278.4	604.9	685.7	732.7	485.6	485.6	485.6	485.6
14	228.0	509.7	536.9	620.0	459.8	459.8	459.8	459.8
15	192.6	527.9	618.4	675.6	569.0	569.0	569.0	569.0
21	246.5	521.9	521.9	615.9	442.4	442.4	442.4	442.4
25	157.0	433.5	453.8	531.0	542.0	551.1	551.1	551.1
26	160.1	451.9	483.0	588.0	596.6	627.7	627.7	627.7
27	342.3	665.8	698.1	803.5	418.0	418.0	418.0	418.0
28	124.9	360.7	449.8	507.8	653.5	764.6	764.6	764.6
29	130.5	404.4	489.8	541.8	653.9	721.6	721.6	721.6
30	165.1	486.5	565.6	612.9	581.7	581.7	581.7	581.7
31	138.0	424.9	512.9	567.6	611.8	655.3	655.3	655.3
33	143.5	502.2	556.2	725.7	693.6	727.0	727.0	727.0
34	144.1	470.4	516.6	665.9	674.6	722.4	722.4	722.4
35	138.6	510.7	637.3	730.0	690.4	706.8	706.8	706.8
36	137.3	448.9	605.5	731.9	704.7	813.3	813.3	813.3
37	128.6	431.6	509.4	556.2	616.5	635.6	635.6	635.6
38	130.2	390.0	476.9	531.1	638.2	713.6	713.6	713.6
39	131.5	392.8	504.3	582.3	677.8	786.7	786.7	786.7
40	170.0	547.0	595.9	752.1	646.4	646.5	646.5	646.5
41	147.1	459.1	505.5	649.4	656.7	708.6	708.6	708.6
42	136.9	460.1	508.0	661.6	674.6	725.1	725.1	725.1
43	168.0	435.6	435.6	546.9	535.8	556.1	556.1	556.1
44	204.8	471.8	471.8	561.9	467.4	467.4	467.4	467.4
46	139.2	426.2	539.2	618.6	661.2	742.1	742.1	742.1
47	128.0	393.0	479.1	534.4	633.6	705.1	705.1	705.1
48	198.6	496.1	518.9	604.5	515.4	515.4	515.4	515.4
49	246.8	588.8	588.8	756.8	529.9	529.9	529.9	529.9
50	182.9	547.2	649.8	719.5	620.2	621.1	621.1	621.1
51	209.2	452.1	466.2	524.3	405.2	405.2	405.2	405.2
52	235.5	492.8	505.2	562.4	419.1	419.1	419.1	419.1
55	269.3	548.1	548.1	643.2	425.2	425.2	425.2	425.2
57	259.6	516.3	529.3	587.0	394.9	394.9	394.9	394.9
58	167.4	426.4	426.4	519.1	529.6	549.6	549.6	549.6
59	306.8	557.7	557.7	636.6	336.9	336.9	336.9	336.9
60	310.3	578.2	510.2	668.3	370.5	370.5	370.5	370.5
61	169.9	455.8	455.8	562.4	535.7	535.7	535.7	535.7
62	215.9	464.5	464.5	533.6	431.8	431.8	431.8	431.8
63	294.9	502.5	502.5	550.9	271.6	271.6	271.6	271.6
64	163.5	432.1	432.1	528.9	497.3	497.3	497.3	497.3
65	169.3	438.0	438.0	539.5	526.1	536.9	536.9	536.9
66	280.6	538.2	538.2	618.3	376.5	376.5	376.5	376.5
69	231.3	511.6	511.6	605.2	467.4	467.4	467.4	467.4
70	169.4	447.0	447.0	537.4	526.3	526.3	526.3	526.3

Note: dry period: the four driest months of the year (June-September);
vegetation period: April to October;
growth period: period with mean temperature $> 6\,^{\circ}\mathrm{C}$

2.10. Discussion

The reliability of the data that were used for the quantification of drought intensity, and the methodological limitations, weaknesses and advantages are discussed in the following subsections. Suggestions for future applications and improvements of the methods are also given.

2.10.1. Modeling climatic variables on an uncertain base

Weather stations are usually sparsely distributed and not spatially representative. Most of them are located in flat, open areas of low or medium elevation. In the study area there were no available climatic measurements above 1 200 m, due to the lack of weather stations at these elevations. The only way to make predictions of temperature and precipitation above this altitude is to extrapolate the measurements of the lower elevations. The extrapolation of climatic data in areas where no measurements occur creates an extra uncertainty of the predictions.

High spatial resolution and high quality DEMs[i] are needed to produce high-resolution temperature, precipitation and solar radiation maps. Problems in the quality of the DEM and small resolution could result in errors in slope, aspect, and sky view factor values, all of which can affect solar radiation calculations. Small differences between the DEM-derived and field measured topographic features (slopes, aspects, elevation) were noticed in many cases.

2.10.2. Regression models vs. geostatistical methods for the spatial prediction of precipitation and temperature

Precipitation data are usually spatially dependent (Goovaerts, 2000) and therefore, interpolation techniques that account for this pattern of spatial dependence (e.g. ordinary kriging) are giving good predictions (Vicente-Serrano et al., 2003). Elevation is usually the main topographic determinant for the spatial distribution of precipitation (Goovaerts, 2000; Vicente-Serrano et al., 2003). If elevation is taken into account the spatial predictions of precipitation can be further improved (Goovaerts, 2000; Ninyerola et al., 2000; Moral, 2010).

A moderate to strong correlation was found between precipitation and elevation. This correlation justified the use of the latter (elevation) as the main explanatory variable for the spatial prediction of monthly precipitation. When the correlation

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[i] Digital Elevation Models

was above 0.7, the two spatial prediction models that account for elevation (regression and regression-kriging) performed better than ordinary kriging. This confirms previous findings by Goovaerts (2000) in southern Portugal. The use of regression models (alone or combined with geostatistical methods) has been proved to be advantageous in the prediction of precipitation (Goovaerts, 2000; Ninyerola et al., 2000; Vicente-Serrano et al., 2003; Moral, 2010).

It has been shown that the best results for temperature mapping can be obtained by using regression-based models (Vicente-Serrano et al., 2003). The strong correlation between maximum air temperature and elevation underlined the importance of the latter (elevation) in determining the spatial distribution of the former (temperature) in the study area. The linear regression model, used for the spatial prediction of maximum air temperature, was not combined with a geostatistical interpolation (e.g. kriging) of the residuals. None of the commonly used parametric models (exponential, spherical, Gaussian, Matérn and power models) (Bivard et al. 2008) could be fitted into the variogram. This may indicate that no spatial auto-correlation exists among the residuals (pure nugget effect)(Hengl, 2007). It can also indicate that kriging is not the appropriate interpolation method. Ninyerola et al. (2000) found that *inverse distance squared weighted* interpolation of the residuals could improve the predictions of the multiple linear regression of maximum air temperature in Catalonia. Inverse distance interpolation of the residuals could be an alternative if a linear model could be fitted to their variogram (Hengl, 2007).

Other topographic, geographic and atmospheric factors may also have an important influence on precipitation and maximum air temperature. Gouvas et al. (2009) showed that the use of the elevation observed within a radius of several kilometers around a meteorological station improves the performance of regression equations for the interpolation of precipitation over Greece. Similar results had Vicente-Serrano et al. (2003) in Spain but with the additional use of latitude and distance to the sea. Multiple regression analysis with elevation, latitude, continentality and cloudiness as independent factors gave very satisfactory results in Catalonia (Ninyerola et al., 2000). Different combinations of the above parameters, with the additional use of solar radiation in some cases, gave the best results when compared to other interpolation techniques for the prediction of maximum air temperature (Ninyerola et al., 2000; Gouvas and Sakellariou, 2002; Vicente-Serrano et al., 2003). Future research should consider the use of new independent variables in a form of multiple linear regression. The use of such factors can help to reveal the spatial richness of climate at local scales, especially in mountainous areas and in regions with complex atmospheric influences (Vicente-Serrano et al., 2003).

2.10.3. Solar radiation under overcast conditions

Cloud cover does not vary considerably over small distances. On the other hand, physical shading due to surrounding topographic features (mountains, hills and summits), slope and aspect vary significantly on mountainous regions with complex terrain. This variation can strongly modify the spatial distribution of incoming solar radiation at local scales (Fu and Rich, 2002; Hofierka and Šúri, 2002; Šúri and Hofierka, 2004). The comparison of different sites in a local (meso-) scale can be, therefore, based on the clear-sky solar radiation if the influence of topography (slope, aspect, elevation, sky view factor) is incorporated into the calculation procedure.

Clouds can be a strong attenuation factor and, therefore, it is desirable to include this parameter in studies where the exact amount of potential evapotranspiration (PET) is required. Threshold values of PET and other climatic components of the water balance model (actual evapotranspiration, water deficit) are expected to be overestimated if the clear-sky radiation is used for their estimation.

In the `r.sun` model the real (overcast) radiation can be calculated from the clear-sky values, if the ratio between real and clear-sky global radiation is known. This ratio is called clear-sky index (Hofierka and Šúri, 2002). Very few weather stations have measured data of global radiation. A reliable method is needed for the estimation of clear-sky index in a spatial scale.

2.10.4. Water balance model - assumptions and limitations

A number of simplifying assumptions were made to obtain the calculation scheme for the water deficit and reference actual evapotranspiration. The main approximations in the calculations are the followings:

1. The interception of rain by the grass crop was not taken into account.
2. The snow accumulation and snow-melt was not included in the calculations.
3. It was assumed that actual evapotranspiration function follows a linear pattern.
4. It was assumed that below the permanent wilting point $\mathrm{AET}_{\mathrm{ref}}$ does not occur.
5. Freezing of the soil was not taken into account.
6. The monthly precipitation was equally distributed over all of the days in the month.
7. Crop transpiration and soil water evaporation were not treated separately.

All the above assumptions and simplifications are creating some limitations in the use of the water balance model as a method for the quantification of drought intensity. Apart from that, the main drawback of the method is the use of a monthly step in the calculation procedure of water deficit. The lack of usable daily climatic data did not allow a more fine temporal-scale analysis that could identify possible minor temporal variations in available soil water. Drought events or wet periods shorter than one month will not be reflected in the monthly estimates leading in over- or under-estimations of monthly water deficit. Therefore, it is highly recommended the use of climate data at high temporal resolution (e.g. daily).

Another limitation of the method is that it does not consider the real vegetation in the calculations, but rather a theoretical reference crop. The use of this theoretical crop does not allow to consider differences in vegetation cover that may strongly influence the micro-climatic conditions of a site. These modifications of the climate of a stand are due to the influence of vegetation on precipitation (through interception), wind speed and solar radiation and relative humidity (Schulze et al., 2005). Canopy interception reduces the amount of water that actually reaches the ground. Vegetation cover influencing also the distribution of light and, therefore, the surface temperature. Plant stands also weakens wind and increase relative humidity inside them.

It is obvious that the actual evapotranspiration (AET) calculated from the water balance model, does not correspond to the real AET of the stands but to the theoretical AET of the reference crop. The same is also true for the potential evapotranspiration. All the above mentioned effects of vegetation on site climatic conditions is very difficult to be measured or even estimated. Such an attempt would have made the process too complicate and non operational.

2.10.5. The critical value of soil wetness for the calculation of actual evapotranspiration function

The critical value of soil wetness (w) below which the AET function is changing form (w_α) depends not only on vegetation and soil characteristics (Laio et al., 2001), but also on the magnitude of $\mathrm{PET}_{\mathrm{ref}}$ (Romano and Santini, 2002). Typical values of w_α, commonly used in water balance studies, are 0.5 - 0.65 (Jamieson et al., 1995). These values are small for a period with high $\mathrm{PET}_{\mathrm{ref}}$. As an example, when daily $\mathrm{PET}_{\mathrm{ref}}$ is 7.6 $^{\mathrm{mm}}/_{\mathrm{day}}$, the w_α takes a value of 0.75 - 0.8 (Saxton et al., 2006). In the study area, during the summer period, the daily $\mathrm{PET}_{\mathrm{ref}}$ reached, in many sites, values higher than 7 $^{\mathrm{mm}}/_{\mathrm{day}}$. The w_α was calculated from the water retention curves and equaled the soil wetness at water tension of -300 hPa. These values (Table 2.8.2) are very close to the values of Saxton et al. (2006).

2.10.6. Strength and adequacy of the methods for the quantification of drought intensity

Despite all the above mentioned limitations of the spatial prediction and the water balance models, there are some strong advantages of their use:

- All methods require a small number of input parameters and are easy to use. Their simplicity and adequacy can secure a detailed and operational approach with many potential applications.
- The solar radiation model can be widely applied in topographically diverse terrain and is good at characterizing high spatial and temporal resolution patterns. Solar radiation is the primary input for energy balance, and also the driving force for water balance, therefore, is very important for all of the physical and biological processes in forest ecosystems (Fu and Rich, 2002).
- The climatic models for temperature and precipitation are very good at characterizing high spatial resolution patterns. The use of a Digital Elevation Model with a good resolution is very important if we want to incorporate in the calculation procedure topographic features that may influence these two climatic parameters.
- With the use of regression and regression-kriging models it is possible to make predictions of climate variables in altitudinal zones with no measurements. This requires only a good correlation of the climate variables with the elevation.
- The use of a reference crop for the calculation of potential and actual evapotranspiration, despites its limitations, it gives the opportunity for biologically meaningful comparisons among sites. The use of climatic factors (or combination of them) that have a physiological importance to plants can help to reveal the climatic controls on vegetation distribution (Stephenson, 1998).
- The continued and rapid development of GIS software and techniques will improve their performance and will increase their use in bioclimatic applications. The future development of Digital Elevation Models (DEMs) with resolution finer than 90 m will make feasible the modeling of micro-topographic features over extended areas, big enough for forestry applications.

3. Description and analysis of the Greek fir forest vegetation

3.1. Overview

After the calculation of all the climatic drought-components, which was presented in the previous chapter (chapter 2), the stratification of the study area followed, based on the Humidity Index which compiled all these components of drought into one "drought intensity" value for the vegetation period. This calculation is presented in this chapter (chapter 3). The vegetation and soil assessment in the field followed the stratification of the study area, and the data analysis was conducted afterwards.

At the begining (subsection 3.2.1), a literature review of all fir forest vegetation units that have been described from the western and central part of Sterea Ellas is given. The materials and methods used to assess the vegetation and soil in the field and to analyze the data are presented (section 3.3). The results are also presented together with a partial discussion (section 3.4). Finally a general discussion is taking place (section 3.5).

3.2. Literature review

3.2.1. Fir forest vegetation in Western & Central Sterea Ellas

The phytosociological research of Greek fir forests started in 1964 with Knapp (1964), who described two vegetation units on the island of Kefalonia. Knapp (1964) described the fir forests of the high vegetation belt of the island as *Scillo bifoliae - Abietetum cephalonicae* Knapp 1964 and those of the low vegetation belt as *Cyclamini hederifoli - Abietetum cephalonicae* Knapp 1964[a]. As character species

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[a] The names that Knapp (1964) gave to this associations were: *Abies cephalonica - Scilla nivalis* association and *Abies cephalonica - Cyclamen hederifolium* association respectively. The correct names of the syntaxa resulted according to the International Code of Phytosociological Nomenclature (Weber et al., 2000).

of both associations he mentioned: *Abies cephalonica*, *Scilla nivalis* (= *S. bifolia*), *Cardamine graeca*, *Corydalis densiflora* (= *C. solida* ssp. *incisa*) and additionally for the first association *Freyera pindicola* (= *Geocaryum pindicolum*).

Horvat et al. (1974) assigned those two associations from Kefalonia, together with all fir forests of southern Greece, to the ***Abietion cephalonicae*** alliance, without giving any character species group. The authorship of this alliance name was erroneously credited by Horvat et al. (1974) to Knapp, in spite the fact that the later did not mention in his book any syntaxon name higher than association rank (Bergmeier, 2002).

Barbéro and Quézel (1976) noted that *Abietion cephalonicae* is more a physiognomic rather than a phytosociological unit because of the lack of floristic criteria for its specification. The same authors assigned the fir and black pine forests of southern Greece to the ***Abieti-Pinion*** alliance, which indicates better the floristic relationship between the two forest types. The names *Abietion cephalonicae* and *Abieti-Pinion* have been alternately used since then by several authors and nowadays are considered as synonyms. Following Bergmeier's remarks (Bergmeier, 2002) and for priority reasons, the name *Abietion cephalonicae* Horvat et al. 1974 was adopted here and used to circumscribe the fir forests of southern Greece.

3.2.1.1. *Lilio chalcedonicae - Abietetum cephalonicae*

The *Lilio chalcedonicae - Abietetum cephalonicae* Barbéro & Quézel 1976 was described by Barbéro and Quézel (1976) with 22 relevés from different mountains of Peloponnisos (Parnon, Taygetos, Menalon, Oligirtos, Killini)[b]. Dimopoulos et al. (1996) and Bergmeier (2002) confirmed its presence on Mt. Killini and Mt. Parnon with 11 and 26 relevés respectively. The presence of the association in Sterea Ellas was confirmed for the first time by Karetsos (2002) on Mt. Iti with 18 relevés. Dimitrellos (2005) and Vlachos (2006) described also the association from Mt. Timfristos and Mt. Vardousia with 6 and 7 relevés respectively.

The *Lilio chalcedonicae - Abietetum cephalonicae* was assigned by Barbéro and Quézel (1976) to the *Abieti-Pinion* and in case of the higher syntaxa to the *Quercetalia*(-*ea*) *pubescentis*. The *Lilio chalcedonicae - Abietetum cephalonicae* association circumscribes the fir forests of the Supra- and Montane-Mediterranean vegetation belt (Barbéro and Quézel, 1976; Dimopoulos et al., 1996; Karetsos, 2002). A distinction between the two vegetation belts, based on floristic criteria, was not possible.

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[b] The name that Barbéro and Quézel (1976) gave to this association was: "Association à *Abies cephalonica* et *Lilium heldreichii*". According to Sfikas (1978) the name-giving species *Lilium heldreichii* is a variety of *Lilium chalcedonicum,* whereas Strid and Tan (1991) consider them as synonyms.

The only difference between them, as mentioned by Barbéro and Quézel (1976), seems to be the reduced floristic richness of the Montane-Mediterranean fir forests in comparison to the Supra-Mediterranean fir forests. According to Karetsos (2002); Dimitrellos (2005) and Vlachos (2006) the *Lilio chalcedonicae - Abietetum cephalonicae* occurs on the most humid sites of the fir forests.

3.2.1.2. *Abies cephalonica* - community

Karetsos (2002) was the first who described *Abies cephalonica* - community with 18 relevés from Mt. Iti. Samaras (2007), with 21 relevés, assigned the fir forests of Mt. Goulinas to the same plant community pointing out their floristic affinity with the *Abies cephalonica* community from Mt. Iti. The same name gave Kokmotos (2008) to a plant community of fir forests from eastern Sterea Ellas (Mt. Elikon), without mentioning any relationship with the plant communities from western Sterea Ellas. Karetsos (2002) divided the *Abies cephalonica* community from Mt. Iti up into two groups; one which has close floristic affinity with the *Quercion ilicis* and another one with more floristic elements from the *Quercion confertae* (=*frainetto*). Similar intermediate characteristics appears to have the *Abies cephalonica* community from Mt. Elikon. On Mt. Goulinas the fir forests constitute also a plant community with floristic similarities to the *Lilio chalcedonicae - Abietetum cephalonicae* (subsubsection 3.2.1.1) and the *Trifolio grandiflori - Abietetum borisii-regis* (subsubsection 3.2.1.6).

3.2.1.3. *Abies cephalonica - Lonicera graeca* - community

The first and only description of *Abies cephalonica - Lonicera graeca* community was done by Barbéro and Quézel (1976), with 11 relevés from Mt. Chelmos and Mt. Parnassos. The same authors mentioned the presence of the above community in two more mountains (Killini and Giona), without however presenting any relevés. According to Karetsos (2002), there is no species with the name *Lonicera graeca* in the literature and the name-giving species for this community is probably *Lonicera hellenica*. Barbéro and Quézel (1976) assigned the community to the *Abieti-Pinion* and mentioned that it consist of mixed forest stands between *Abies cephalonica* and *Abies borisii-regis*. The *Abies cephalonica - Lonicera graeca* community occurs in the Montane-Mediterranean vegetation belt (1200 - 1600 m) on north facing slopes with deep soil originated from limestone rocks (i.e. terra rosa) (Barbéro and Quézel, 1976).

3.2.1.4. *Helictotricho convoluti - Abietetum cephalonicae*

Barbéro and Quézel (1976) were the first that described *Helictotricho convoluti - Abietetum cephalonicae* Barbéro & Quézel 1976[c] with 29 relevés distributed through several mountains of Peloponnisos and Sterea Ellas. Several authors have confirmed its presence on the same mountains, like Dimopoulos et al. (1996) for Killini, Bergmeier (2002) for Parnon, Dimitrellos (2005) for Timfristos and Vlachos (2006) for Vardousia. Two new confirmations (not recorded in previous studies) came by Karetsos (2002) and Kokmotos (2008) for Mt. Iti and Mt. Elikon respectively. All the above authors assigned the *Helictotricho convoluti - Abietetum cephalonicae* to the *Quercion ilicis* alliance and *Quercetalia*(*- ea*) *ilicis* order and class respectively. The only exception was Bergmeier (2002) who preferred to assign the association to the *Abietion cephalonicae* alliance and *Quercetalia pubescentis* order.

According to Barbéro and Quézel (1976), the *Helictotricho convoluti - Abietetum cephalonicae* occurs at low elevation (in comparison to the general altitudinal distribution of *Abies*), between 550 and 1250 m. The same conclusion can be also drawn from the relevés of all the other authors who studied this association. In this case the altitudinal distribution of *Helictotricho convoluti - Abietetum cephalonicae* range between (500 -)750 and 1350(- 1480) m (upper part of Meso-Mediterranean and Supra-Mediterranean vegetation belts). The association occurs mainly on limestone and seems to occupy the warmest and driest sites of fir forests.

3.2.1.5. *Quercus ilex - Abies cephalonica* - community

The first reports on the existence of mixed formations between *Abies* and *Quercus ilex* in Greece were from Mattfeld (1927),Regel (1943) and Ganiatsas (1963). The first phytosociological description of mixed stands with *Abies cephalonica* and *Quercus ilex* was done by Barbéro and Quézel (1976) from North Peloponnisos (Mt. Killini and Mt. Oligirtos) and Sterea Ellas (Mt. Vardousia). Barbéro and Quézel (1976) considered those mixed plant communities as a sub-association of *Helictotricho convoluti - Abietetum cephalonicae* (subsubsection 3.2.1.4) and not as a separate association. Dimopoulos et al. (1996) confirmed the presence of those formations on the north and west part of Mt. Killini at an elevation between 700 to 1200 m a.s.l., without however presenting any relevés.

Quercus ilex - Abies cephalonica community was described for the first time by Karetsos (2002) with 17 relevés from Mt. Iti. The community occurs on the NE part of the

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[c] The name that Barbéro and Quézel (1976) gave to this association was: “Association à *Abies cephalonica* et *Helictotrichon convolutum*”. The correct name of the syntaxon resulted according to the International Code of Phytosociological Nomenclature (Weber et al., 2000).

mountain at low elevation (600 - 900 m a.s.l.), just above the formations of *Quercus ilex,* on deep soils derived from limestone colluvium. The *Q. ilex*, together with other floristic elements of *Quercion ilicis*, appears mainly in the understory of the forest. The tree layer is mainly composed of fir trees and only rarely is mixed with scattered individuals of *Q. ilex.*

3.2.1.6. *Trifolio grandiflori - Abietetum borisii-regis*

The *Trifolio grandiflori - Abietetum borisii-regis* Barbéro & Quézel 1976[d] was described by Barbéro and Quézel (1976) with 15 relevés from the mountains of Vardousia, Oxia and Timfristos. According to the same authors the association circumscribes the forests of *Abies x borisii-regis* in the southernmost part of Southern Pindhos (region of Karditsa) and the NW part of Sterea Ellas. Dimitrellos (2005) and Vlachos (2006) confirmed its presence with 14 and 15 relevés from Mt. Timfristos and Mt. Vardousia respectively. Nevertheless, according to Dimitrellos (2005) and Vlachos (2006), the association consists of mixed stands between *Abies x borisii-regis* and *A. cephalonica.* It occurs mainly in the Supra-Mediterranean and Montan-Mediterranean vegetation belt, at elevation between 800 and 1500 m a.s.l., on both flysch and limestone.

3.2.2. Syntaxonomic synopsis

A syntaxonomic synopsis of all Greek fir (including *Abies x borisii-regis*) forest associations and communities that have been described from the mountains of western and central Sterea Ellas is given here:

Class: *Quercetea ilicis* Br.-Bl. ex A. Bolòs 1950

Order: *Quercetalia ilicis* Br.-Bl. ex Molinier 1934

Alliance: *Quercion ilicis* Br.-Bl. ex Molinier 1934

Association: *Helictotricho convoluti - Abietetum cephalonicae* Barbéro et Quézel 1976

Community: *Quercus ilex - Abies cephalonica*

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[d] The name that Barbéro and Quézel (1976) gave to this association was: “Association à *Abies cephalonica* et *Trifolium speciosum*”. The correct name of the syntaxon resulted according to the International Code of Phytosociological Nomenclature (Weber et al., 2000).

Class: *Quercetea pubescentis* Doing-Kraft ex Scamoni et Passarge 1959

Order: *Quercetalia pubescentis* Klika 1933

Alliance: *Quercion confertae* Ht. ex Horvat 1958

Association: *Trifolio grandiflori - Abietetum borisii-regis* Barbéro et Quézel 1976

Alliance: *Abietion cephalonicae* Horvat et al. 1974

Association: *Lilio chalcedonicae - Abietetum cephalonicae* Barbéro et Quézel 1976

Association: *Scillo bifoliae - Abietetum cephalonicae* Knapp 1964

Community: *Abies cephalonica*

Community: *Abies cephalonica - Lonicera graeca*?

Association: *Cyclamini hederifoli - Abietetum cephalonicae* Knapp 1964

3.2.3. Synopsis of the phytosociological research on Greek fir forests

A synopsis of the phytosociological research on Greek fir (including *Abies x borisii-regis*) forests in Peloponnisos (southern Greece) and Sterea Ellas (southern part of central Greece) is given in Table 3.2.1. The synopsis includes information on the authors, the year of the publication, the study area, the number of relevés and the vegetation units that have been described.

Table 3.2.1.: Synopsis of the phytosociological research on Greek fir forests carried out in Peloponnisos and Sterea Ellas.

Author	Year	Region	Nr. of relevés	Vegetation units
Knapp	1964	Cephalonia	1	*Scillo bifoliae - Abietetum cephalonicae*
			1	*Cyclamini hederifoli - Abietetum cephalonicae*

Author	**Year**	**Region**	**Nr. of relevés**	**Vegetation units**
Barbero & Quezel	1976	Peloponnisos (Mt. Parnon, Mt. Taygetos, Mt. Menalon, Mt. Oligirtos, Mt. Killini)	22	*Lilio chalcedonicae - Abietetum cephalonicae*
		Peloponnisos (Mt. Chelmos), Sterea Ellas (Mt. Parnassos)	11	*Abies cephalonica - Lonicera graeca* community
		Peloponnisos (Mt. Parnon, Mt. Killini, Mt. Erimanthos, Mt. Chelmos, Mt. Menalon, Mt. Oligirtos), Sterea Ellas (Mt. Vardousia, Mt. Timfristos)	29	*Helictotricho convoluti - Abietetum cephalonicae*
		Sterea Ellas (Mt. Vardousia, Mt. Oxia, Mt. Timfristos)	15	*Trifolio grandiflori - Abietetum borisii-regis*
Dimopoulos	1993	Peloponnisos (Mt. Killini)	11	*Lilio chalcedonicae - Abietetum cephalonicae*
			17	*Helictotricho convoluti - Abietetum cephalonicae*
Bergmeier	2002	Peloponnisos (Mt. Parnon)	26	*Lilio chalcedonicae - Abietetum cephalonicae*
			37	*Helictotricho convoluti - Abietetum cephalonicae*
			26	*Junipero drupaceae - Abietetum cephalonicae*
Karetsos	2002	Sterea Ellas (Mt. Iti)	18	*Lilio chalcedonicae - Abietetum cephalonicae*
			12	*Helictotricho convoluti - Abietetum cephalonicae*
			18	*Abies cephalonica* community

Author	**Year**	**Region**	**Nr. of relevés**	**Vegetation units**
Karetsos	2002	Sterea Ellas (Mt. Iti)	17	*Quercus ilex - Abies cephalonica* community
Maroulis	2003	Peloponnisos (Mt. Erymanthos)	13	*Orchis provincialis - Abies cephalonica* community
			25	*Geranium lucidum - Abies cephalonica* community
			6	*Helleborus odorus* subsp. *cyclophyllus - Abies cephalonica* community
			16	*Scillo bifoliae - Abietetum cephalonicae*
Dimitrellos	2005	Sterea Ellas (Mt. Timfristos)	6	*Lilio chalcedonicae - Abietetum cephalonicae*
			6	*Helictotricho convoluti - Abietetum cephalonicae*
			14	*Trifolio grandiflori - Abietetum borisii-regis*
Vlachos	2006	Sterea Ellas (Mt. Vardousia)	7	*Lilio chalcedonicae - Abietetum cephalonicae*
			8	*Helictotricho convoluti - Abietetum cephalonicae*
			15	*Trifolio grandiflori - Abietetum borisii-regis*
Samaras	2007	Sterea Ellas (Mt. Goulinas)	21	*Abies cephalonica* community
Kokmotos	2008	Sterea Ellas (Mt. Elikon)	10	*Scillo bifoliae - Abietetum cephalonicae*

Author	Year	Region	Nr. of relevés	Vegetation units
Kokmotos	2008	Sterea Ellas (Mt. Elikon)	17	*Lilio chalcedonicae - Abietetum cephalonicae*
			12	*Geranium lucidum - Abies cephalonica* community
			11	*Abies cephalonica* community
			10	*Helictotricho convoluti - Abietetum cephalonicae*

3.3. Materials and methods

3.3.1. Sampling design and stratification

The stratification of the study area was based on the values of Humidity Index (HI), calculated for the vegetation period. The vegetation period was defined as the period from beginning of April until end of October. The whole study area was stratified into four equal intervals of HI (Figure 3.3.1). The four strata represent forest sites with different drought intensity for the vegetation period. Most of the study area belongs to the three first strata in which precipitation is equal to 28 - 62 % of PET_{ref}. Only few stands, mainly in the highest area of Mt. North Vardousia, belong to the fourth stratum with values of HI more than 0.62 and up to 0.74. The aim of the stratification was the equal distribution of the sampling units (plots) in the whole range of drought intensity.

After the stratification of the study area, a number of locations were randomly selected from each stratum. Each location represents an area of 8 100 m^2, which is the size of a pixel in the Digital Elevation Model used in this study (subsubsection 2.5.2.1). At the center of each location a quadratic plot of 200 m^2 was set and a relevé was recorded. The size of the plot was in accordance with a standard plot size for Mediterranean woodlands, proposed by Chytrý and Otýpková (2003). If the center of the chosen locations was occupied by a forest gap, a road or non-forest vegetation (meadow, scrubland), the plot was moved to the nearest forest stand, by moving systematically every 10 m towards the north and never further than 45 m. Not all of those locations were accessible and therefore, the number of plots was not equal among the different strata. In total, 45 plots were sampled.

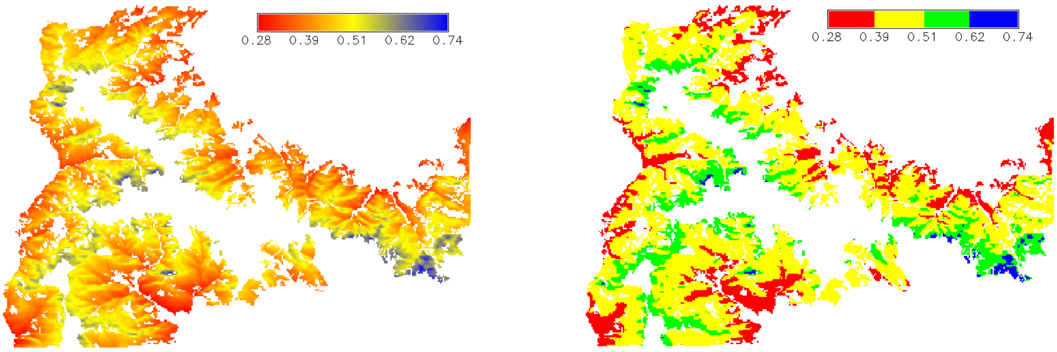

Figure 3.3.1.: Maps of the study area with the Humidity Index (HI) values calculated for the vegetation period (April - October). The map on the right shows the stratification of the area based on the HI.

3.3.2. Data collection

In each plot the species composition (including vascular plants, and lower plants growing on mineral soil or humus) was observed and recorded. Structural information was obtained by defining 4 layers (moss, herb, shrub and tree layer) (Table 3.3.1). For all species and layers, the cover-abundance was estimated using the extended (9-point) Braun-Blanquet scale (Van der Maarel, 2006). The following abiotic and biotic parameters were noted per relevé: geographical coordinates; altitude; inclination; aspect; relief (position of the site and slope form); percentage cover of exposed rocks and litter; humus depth; height and diameter of higher tree inside the plot; percentage cover of the canopy, shrubs, herbs and lower plants.

Table 3.3.1.: Vegetation layers

Layer	Habit		
	mosses	herbs/ferns	woody species
Moss layer	all	-	-
Herb layer	-	all	< 50 cm
Shrub layer	-	-	50 cm - 5 m
Tree layer	-	-	> 5 m

Soil profiles were made in all 45 plots and undisturbed soil samples were collected. One soil sample was collected from each plot from the middle of its soil profile.

For the collection of the soil samples, metal cylinders with a volume of 100 cm^3 were used. Wherever the collection of the samples was difficult (due to the coarse material of the soil), bigger cylinders were used (163 cm^3). For each profile, the rooting depth was measured and the soil skeleton content was estimated. The soil data were used for the calculation of the available soil water storage capacity of each profile (section 2.7), representing the edaphic water availability at each site (plot).

3.3.3. Preparation of the data

3.3.3.1. Plant identification, nomenclature and ecology of the species

All plant specimens that were collected during the field work were dried and stored in the herbarium of Laboratory of Forest Botany-Geobotany in Aristotle University of Thessaloniki, Greece (TAUF). For the identification of unknown specimens, descriptions and identification keys from Flora Europaea (Tutin et al., 1968, 1993), Flora Hellenica (Strid and Tan, 1997, 2002) and Mountain Flora of Greece (Strid, 1986; Strid and Tan, 1991) were used. Supplementary information (photos and illustrations) was provided by a number of Floras: Flora d'Italia (Pignatti, 1982), Flora Reipublicae Popularis Bulgaricae (Jordanov et al., 1995) and Exkursionsflora von Deutschland (Rothmaler, 1995). Additional taxonomic bibliography was used for specific genus: *Arum* (Boyce, 1994), *Allium* (Tzanoudakis, 2000) and *Trifolium* (Zohary and Heller, 1984). Taxa of the *Hieracium* genus were confirmed or identified by G. Gottschlich and all mosses specimens were identified by M. Lüth.

Nomenclature of vascular plants follows, in the given order, Flora Hellenica (Strid and Tan, 1997, 2002), Exkursionsflora für Kreta (Jahn and Schönfelder, 1995), Mountain Flora of Greece (Strid, 1986; Strid and Tan, 1991), Med-Checklist (Greuter et al., 1984) and Flora Europaea (Tutin et al., 1968, 1993). The families of Asteraceae, Poaceae, Campanulaceae and Rosaceae follow the more recent reviews of Greuter (2009); Valdés et al. (2009); Castroviejo et al. (2010); Kurtto (2009) respectively. The nomenclature of Orchids follows Baumann et al. (2006). Nomenclature of mosses follows Hill et al. (2006).

The evaluation of the ecological behaviour of the vascular plants was based on the works of Böhling et al. (2002) and Pignatti (2005).

3.3.3.2. Syntaxonomy and nomenclature of syntaxa

For the characterization of the taxa as diagnostic (character or differential) of syntaxa higher than the Association level (Alliance, Order, Class) a review of all recent bibliography, relative to the topic, was conducted. For the Classes, mainly the work of Mucina (1997) was followed. For the Alliances and the Orders the works of Horvat et al. (1974); Barbéro and Quézel (1975, 1976); Raus (1980); Bergmeier (1990); Dimopoulos et al. (1996); Karetsos (2002); Maroulis (2003); Dimitrellos (2005); Vlachos (2006); Kokmotos (2008) and Samaras et al. (2008) were used.

The nomenclature of the phytosociological units follows Horvat et al. (1974) and Bergmeier and Dimopoulos (2001, 2008), always in accordance with the code of phytosociological nomenclature of Weber et al. (2000).

3.3.3.3. Data exploration and adjustment

A data exploration was performed to detect exceptional cases (outliers) and to reveal the structure of the data. Possible collinearity between environmental variables was also explored and, wherever detected, highly correlated variables were removed. Prior to some analysis the environmental variables were standardized to the norm (normalization) because of their different units. Species original cover-abundance values of the alpha-numeric extended Braun-Blanquet scale were replaced by the 1-9 Ordinal Transform Scale (OTS) proposed by Van der Maarel (1979).

The OTS can be considered as an intermediate (not strong) transformation of species performance, by giving emphasis to both presence and dominance of the species (Van der Maarel, 1979). As has been shown in many studies (Smartt et al., 1976; Jensén, 1978; Van der Maarel, 1979), this intermediate transformation leads to ecologically satisfactory results when applied to classification and ordination techniques, because it gives a higher weight to the common species. This is apparently true in the case of hierarchical classifications of syntaxonomical units at the level of association and alliance (Van der Maarel, 1979).

In order to reduce the noise in the data-set, all rare taxa (occurring in one or two plots) were not included in the analysis.

3.3.3.4. Software

A database was constructed including all the information (biotic and abiotic data). The program `Turboveg` (Hennekens and Schaminée, 2001) was used for importing, storing and organizing the data. For exporting the data from `Turboveg` and importing them into the program `R`, for further analysis, the package `vegdata (Jansen, 2010; Jansen and Dengler, 2010)` was used. For the cluster and gradient analysis the packages `cluster` (Maechler, 2010), `vegan` (Oksanen et al., 2011b) and `labdsv` (Roberts, 2010) were mainly used. The fidelity values were calculated with the package `indicspecies` (De Caceres and Jansen, 2010) and the classification trees analysis was performed with the use of the `party` (Hothorn et al., 2006, 2011a) package.

3.3.4. Climatic variables and soil hydraulic properties

All the climatic parameters, that were used for the quantification of drought intensity (chapter 2), were also used as explanatory variables in the vegetation analysis. These were:

- Maximum air temperature (°C)
- Solar radiation ($^{\mathrm{Mj}}/_{\mathrm{m^2 \cdot day}}$)
- Precipitation (mm)
- Potential evapotranspiration (mm)
- Humidity index (dimensionless)

Additionaly to those parameters some extra climatic variables were calculated:

- Minimum air temperature (°C)
- Mean air temperature (°C)

Except of the above climatic variables, the two climatic-soil components of water balance (actual evapotranspiration and water deficit) and the available soil water storage capacity were also used in the analysis.

3.3.5. Data analysis

3.3.5.1. Classification of forest vegetation

The phytosociological classification of the fir forest vegetation was accomplished in two steps:

1. a cluster analysis of the sites (plots) was conducted and the dendrogram was pruned in the most ecologically meaningful point, in order to obtain the final clusters (groups of sites)
2. the fidelity values of the taxa were calculated in order to define the diagnostic species of each group.

Cluster analysis: Vegetation data were classified based on the floristic composition and cover values. The method used was the **hierarchical agglomerative cluster analysis**. According to McCune and Grace (2002), the agglomerative methods should be preferred over divisive methods because the former are polythetic in comparison to most of the latter that are monothetic. The monothetic approach usually perceived as a drawback because less information is used at each step than with polythetic methods (McCune and Grace, 2002).

Cluster analysis groups the sites (plots) with similar species composition in the same cluster (group). The similarity (or dissimilarity) in species composition between two sites is summarized by a **distance measure** which expresses the floristic distance between the plots. The **Bray-Curtis** distance measure (Bray and Curtis, 1957), also known as *percentage difference* (Odum, 1950; Legendre and Legendre, 1998) or *Sorensen distance* (McCune and Grace, 2002), was chosen for the cluster analysis. The resulting **distance matrix** provides information on the floristic distance between all pairs of plots. The clustering starts by treating each site as a cluster (group) of size 1. The closest two clusters are joined to form a new cluster of size 2. The process continues until one cluster has been formed that contains all the sites.

The Bray-Curtis is a semi-quantitative and asymmetrical distance measure. This means that it can be applied to semi-quantitative data (e.g. species relative abundances) and it skips the double-zeros (the common absences of species from two sites). This last property is generally desirable when applied to community data because the absence of a species from two sites cannot be counted as an indication of resemblance between the two sites (Borcard, 2004).

An other property of Bray-Curtis coefficient is that abundant and rare species contribute equally to the distance between sites. According to (Legendre and Legendre, 1998) this may be desirable when the species abundance data are normally distributed or when the sites under comparison are from mature communities.

The **linkage method** (clustering algorithm) chosen for the classification was the **flexible beta** (Lance and Williams, 1967) with $\beta =$-0.25. Flexible beta is a special case of the general agglomerative clustering model (Lance and Williams, 1967). Flexible beta with $\beta =$-0.25 is an alternative to the Ward's method (Ward Jr, 1963) but, in contrast to the latter, it is compatible with semi-metric distance measures (e.g. Bray-Curtis). Both methods (Flexible beta =-0.25 & Ward's) are space-conserving, which means that properties of the original space are preserved and therefore chaining is avoided.

The results of the cluster analysis that performed to the distance matrix of the plots, were represented by a dendrogram (Figure 3.4.1). The dendrogram clearly

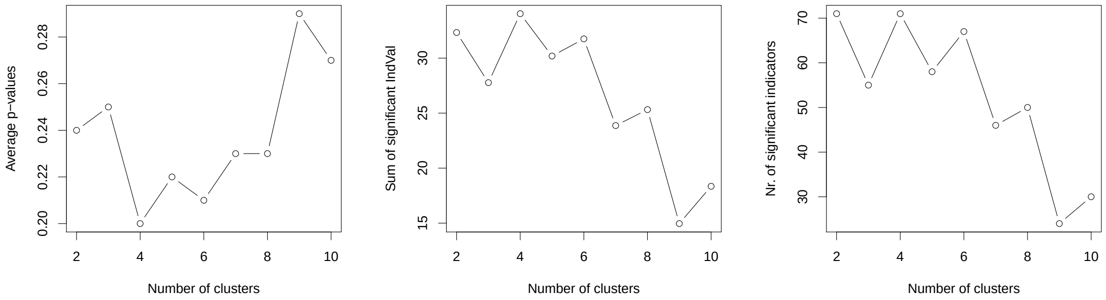

Figure 3.3.2.: Use of Indicator Species Analysis as an objective criterion for pruning the dendrogram. The left diagram shows the changes in p-values from the permutation tests, averaged over the species for each clustering level. The diagram in the middle shows the sum of all significant ($p \leq 0.05$) Indicator Values (IndVal) for each clustering level. The right diagram presents the frequency distribution of the number of the significant indicator species for each clustering level.

illustrates how plots were merged into clusters in a hierarchical sequence of steps. It also shows at which hierarchical level (height) the clusters and the plots inside the clusters were joined together. The different hierarchical levels represent different levels of ecological distance, expressed in this case by Bray-Curtis distance.

The distance matrix was computed with the function `dist` (section A.6.2.1) from the `vegan` package and the clustering performed with the use of function `agnes` (section A.6.2.1) from the `cluster` package.

Pruning the dendrogram: There is no single and widely accepted criterion for pruning a dendrogram derived from a cluster analysis. A quantitative and objective criterion, proposed by Dufrene and Legendre (1997), is to use the sum of the species significant indicator values, or the number of the significant indicator species that are provided from the Indicator Species Analysis (IndVal). The clustering step (grouping level) with the highest sum of indicator values or the highest number of indicator species is considered as the most informative and should be chosen as the optimum number of groups (Dufrene and Legendre, 1997; McCune and Grace, 2002). McCune and Grace (2002) proposed, additionally, the use of average p-values across all species, resulting from the randomization (permutation) tests of IndVal. Dufrene & Legendre's (1997) indicator species analysis was used to define the most informative level in the dendrogram (Figure 3.3.2). The indicator species analysis was performed with the use of `indval` function from the `labdsv` package (section A.6.2.1).

For testing whether there were significant differences among the derived groups and to confirm the cluster selection, two non-parametric procedures were used; **Multi-Response Permutation Procedure** (MRPP) (McCune and Grace, 2002) and **Permutational Multivariate Analysis of Variance** (PERMANOVA) (Anderson, 2001). Both test the hypothesis of no difference between two or more groups of entities. The MRPP algorithm compares the dissimilarities (distances) within- and among-groups and calculates two statistics; delta (δ) and chance-corrected within-group agreement (A). The first is the overall weighted mean of group mean distances and the second, is the proportion of the distances explained by group identity. The PERMANOVA is based on partitioning the sum of squares of inter-point distances divided by the number of points (McCune and Grace, 2002). It calculates a typical ANOVA table showing, among others, a F-statistic. The significance is evaluated by a permutation test. The above non-parametric procedures were applied to test group differences in species composition. The MRPP was performed with the function `mrpp` (section A.6.2.1) and PERMANOVA with the function `adonis` (section A.6.2.1).

The goodness of community classification was also inspected graphically by comparing the groups against external environmental variables (with the use of notched boxplots), and by displaying the clustering groups over the ordination diagram (subsubsection 3.3.5.2). If two boxes' notches do not overlap this is a strong evidence that their medians differ significantly (Chambers et al., 1983). For those variables that such differences were observed, Kruskal-Wallis (1952) non-parametric test was applied. From the visual inspection of notched boxplots of all environmental variables within each group (section A.4), strong evidences for differences between groups A - B and sub-groups A1 - A2 and B1 - B2 were found for several variables (section A.4). The Kruskal-Wallis test confirmed those differences. The boxplots were also used to check for possible site differences between the derived vegetation units and for describing their structure and synecology.

According to Oksanen et al. (2011a), a drawback of MRPP is that is not possible to distinguish weather the difference between two groups is due to their location (difference in means) or due to their spread (difference in within-group distance). The PERMANOVA seems not to suffer from this problem and is considered a more robust alternative to MRPP (Oksanen et al., 2011a).

Diagnostic taxa: Different approaches have been used in vegetation studies for the determination of diagnostic taxa, including traditional (non-statistical) and statistical fidelity measures (Willner et al., 2009). Among them, phi coefficient of association (Φ) has an advantage which makes it preferable to identify vegetation types. It is independent of the size of the data set (Chytrý et al., 2002a). It is, nevertheless, affected (although little) by the relative size of the vegetation units within the data set (Bruelheide, 2000; Chytrý et al., 2002b). An other drawback of the index is that the analysis provides no information on the statistical significance of the fidelity values.

The fidelity values of all species in the data set were calculated using a modification of the Φ index, proposed by Tichý and Chytrý (2006). The modified index equalizes the relative sizes of all vegetation units to calculate a fidelity not affected by the relative size of the target vegetation unit. The Φ index was based on species presence/absence values because they provide more robust estimates of fidelity compared to the cover values (Bruelheide, 2000; Chytrý et al., 2002b and Willner et al., 2009). The statistical significance of the fidelity values was tested with 1000 permutations of the species data (De Cáceres and Legendre, 2009).

For the determination of diagnostic taxa, the fidelity value of each taxon was computed not only for each vegetation unit separately compared to all others in the data set, but also for all possible combinations of units against the remaining units or some of the remaining units (Tsiripidis et al., 2009; De Cáceres et al., 2010). This approach has an advantage if more than one gradient is present in the data set and the taxa respond differently to these gradients. In such a case different group sequences emerge in the vegetation table (Tsiripidis et al., 2009). The function `multipatt` (section A.6.2.1) was used for the analysis.

3.3.5.2. Gradient analysis

In order to reveal and study the structure and underlined patterns (gradients) of the vegetation, another multivariate approach is needed (i.e. ordination). This multivariate approach consists in representing the objects (sites) in a multi-dimensional space with as many dimensions as the number of descriptors (species). Because it is not possible to present graphically such a multi-dimensional space and to understand and interpret such an amount of information, this information has to be reduced. In order to achieve this, an ordination technique has to be used. Ordination (or gradient analysis) reduces the multi-dimensional species space into a space of few dimensions (axis) summarizing the information of the other dimensions. Each of the new dimensions is a synthetic variable representing as much of the original information as possible, by omitting minor factors and noise (redundancy species information) (McCune and Grace, 2002).

Non-Metric Multidimensional Scaling (NMDS) is considered as the most appropriate ordination technique for ecological community data due to its flexibility and robustness (Minchin, 1987; Clarke, 1993; McCune and Grace, 2002). The main advantages of the method according to McCune and Grace (2002) are:

1. It avoids the assumption of normal distribution of the data
2. It avoids the assumption of linear relationships among variables
3. It allows the use of any distance measure (including semi-metric like Bray-Curtis)
4. It preserves the ordering relationships (rank order) among objects
5. Tends to linearize the relationship between distances measured in species space and distances measured in environmental space
6. It relieves the "zero-truncation" problem

The NMDS tries to arrange the objects (sites) along the axis of the reduced species space (which has been defined beforehand) (Figure 3.3.3) such that, the rank-order of the distances of the objects (ordination distances) is as close as possible to the rank-order of the distances in the original space (original distances) (Podani, 2000). Through iteration steps, NMDS is searching for the best position of the objects in the reduced space. The comparison among the rank-order of ordination and original distances is done with the use of **monotone regression** and **stress function** (S). Monotone regression is a non-parametric regression which is constrained to always increase from left to right in a step-function mode (Legendre and Legendre, 1998). Stress function is the goodness-of-fit of the monotone regression (Legendre and Legendre, 1998), informing how efficient is the ordination in preserving the ordering relations among the original distance values (Podani, 2000). The comparison of the original and ordination rank-order distances can be graphically presented with the **Shepard diagram** (Figure 3.3.3).

The analysis follows partly the recommendations of Minchin (1987) which have been implemented into the `R` software by Oksanen et al. (2011a). The steps are:

1. **Choice of distance measure**: an adequate distance measure has to be used in order to give a good rank-order relation between community dissimilarity and gradient distance (Oksanen, 2004). The Bray-Curtis distance is recommended as the best choice (Oksanen, 2004) and it was used also for comparability reasons with the cluster analysis.
2. **NMDS with random starts**: the final result of the computations depends on the starting configuration, therefore is not sure that this will be the best solution (Podani, 2000). The NMDS may be trapped into a very poor local optimum. In order to be sure that the analysis will find the global optimum

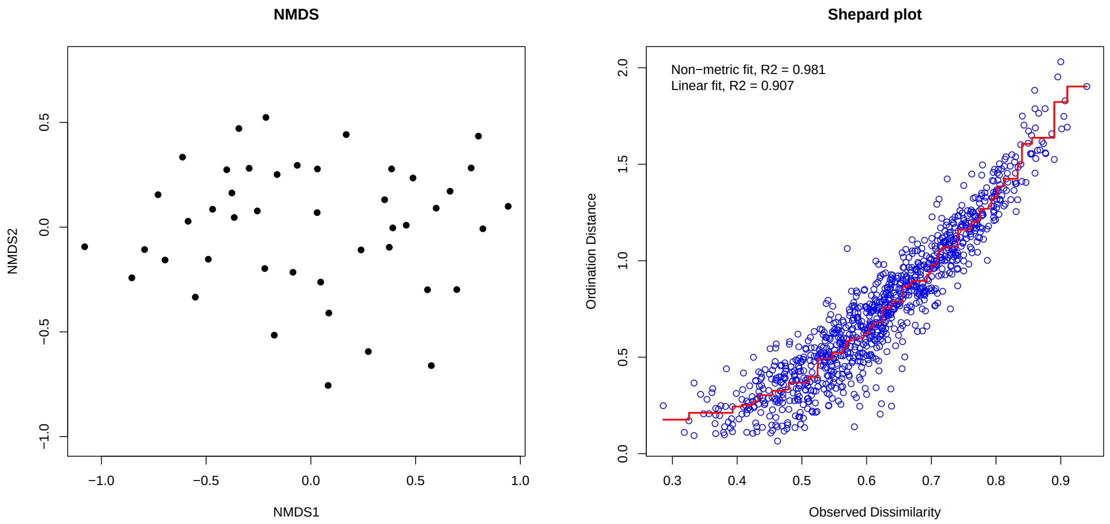

Figure 3.3.3.: Ordination diagram for Non-Metric Multidimensional Scaling (NMDS) (left) and Shepard plot for the NMDS (right). The points in NMDS diagram indicate the sites (plots). In Shepard plot the horizontal axis represents the original Bray-Curtis distances among the plots and the vertical axis the distances obtained by the NMDS configuration.

solution, NMDS must be performed several times from different random configuration and the result providing the lowest stress value has to be maintained (Podani, 2000). Function `metaMDS` run with several random starts and stops either after a certain number of tries (in this case 20), or after finding two similar configurations with minimum stress (Oksanen et al., 2011a).

3. **Centering of the results**: the origin is moved to the average of the axis (Oksanen et al., 2011a).
4. **Rotating of the results**: the configuration is rotated so that the largest variance of site scores will be on the first axis (Oksanen et al., 2011a).
5. **Scaling of the results**: the configuration is scaled so that one unit corresponds to halving of community similarity from the replicate similarity (Oksanen et al., 2011a).
6. **Species scores**: the species scores are calculated as weighted averages of site scores, but the values are expanded so that species and site scores have equal variances (Oksanen, 2010).

Environmental interpretation: For the interpretation of NMDS, environmental information was overlayed (fitted) onto the ordination diagram and the squared correlation coefficient (r^2) of each variable with the ordination was calculated. The significances (p-values) of r^2 were assessed using random permutations of environmental variables. The environmental variables were fitted to the ordination as vectors with the use of function `envfit` (section A.6.2.2) and plotted with the form of an arrow. The method implies a linear relationship between ordination and environment, which may not be always true. Therefore, another method was used additionally, in order to test the linearity assumption of vector fitting. This second approach fits a smooth surface to the ordination by using thinplate splines and plot it with the form of isolines (function `ordisurf`, section A.6.2.2). If the isolines are parallel, equally spaced and perpendicular to the arrow, the response of the environmental variable is really linear and vectors are appropriate (Oksanen, 2010).

3.3.5.3. Classification trees analysis

All the methods discussed previously are focusing on whether the vegetation groups are different or not and in which degree (MRPP, PERMANOVA) or exploring those differences indirectly, by trying to fit the environmental information onto the ordination space (NMDS).

To determine more precisely the relationship between environmental variability and vegetation patterns, and to distinguish which variables differentiate better the groups that have been defined, based on species composition, the classification trees analysis was used (Breiman et al., 1984). A statistical, non-parametric approach of classification trees, called **conditional inference trees** (Hothorn et al., 2006) was implemented through the package `party` (Hothorn et al., 2011a), function `ctree` (subsubsection A.6.2.3).

Conditional inference trees are based on a three step procedure (Hothorn et al., 2011b):

1. They test the global null hypothesis of independence between any of the input variables (in this case the environmental variables) and the response variable (in this case the vegetation types). The procedure stops if the hypothesis cannot be rejected, otherwise the input variable with the strongest association to the response is being selected.
2. They implement a binary split in the selected input variable.
3. The repeat recursively the steps 1 and 2.

The results are represented graphically with a tree-like classification. The association between the response and each of the input variables (step 1) is measured by the p-value of the conditional distribution of test statistics that is used to test the partial null hypothesis of independence between a single input variable and the response

(Hothorn et al., 2011b). The basic advantage of the method in comparison to other classification trees analysis is that, it doesn't require any pruning of the tree or any kind of cross-validation of the results. The size of the tree is determined by the significance level α of the statistical test and the splitting of the selected input variable (step 2) is based on permutations.

3.4. Results and partial discussion

Two major clusters of plots (site groups) could be recognized in the dendrogram. These two groups are represented with the letters A and B (Figure 3.4.1).

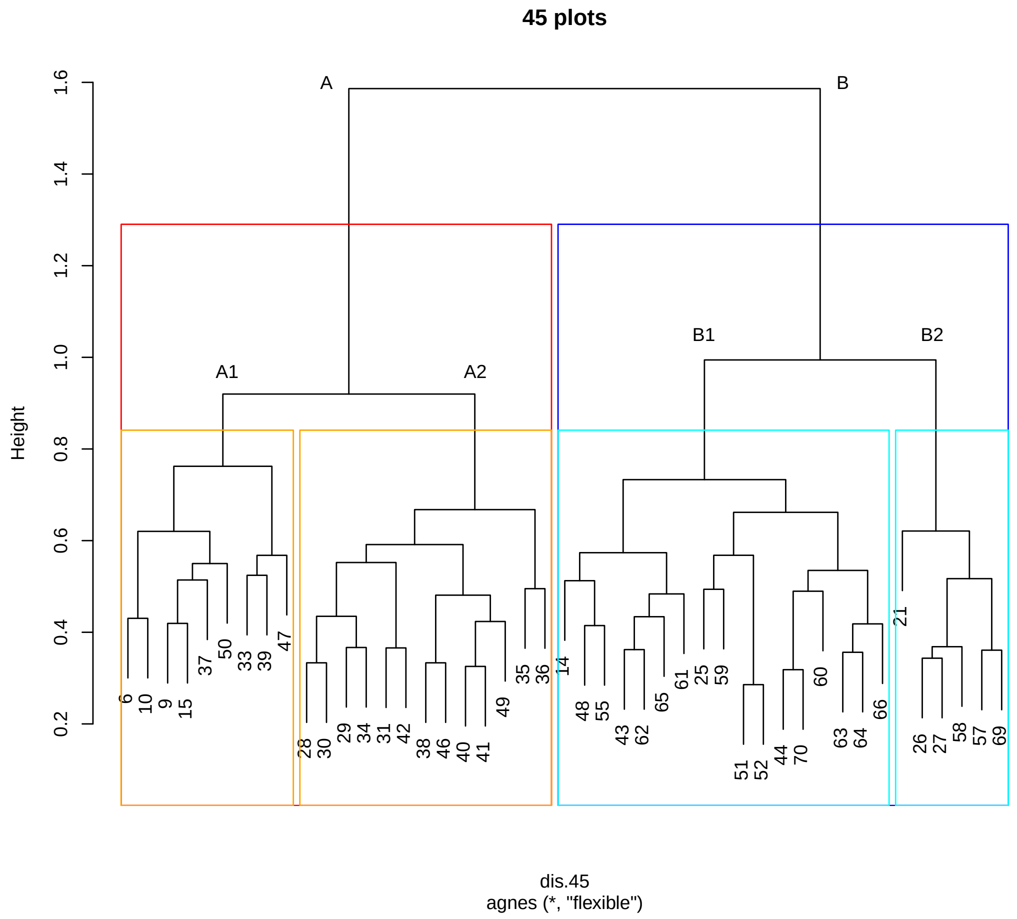

Figure 3.4.1.: Vegetation units - Dendrogram from hierarchical agglomerative cluster analysis of plots (sites) by species matrix. The clustering was performed by using flexible beta ($\beta = -0.25$) method and Bray-Curtis distance. The y axis (Height) is showing at which ecological distances (Bray-Curtis distances) the clusters were formed. The site groups are shown with colored rectangles and different codes. (A1, A2, B1, B2).

All three criteria of the methods used to prune the dendrogram (see section 3.3.5.1) showed that the optimum number of groups is four (Figure 3.3.2). Therefore, the two main groups (A & B) were further divided into four subgroups (A1, A2, B1, B2, Figure 3.4.1). The results from MRPP and PERMANOVA confirmed that groups A-B and sub-groups A1-A2 and B1-B2 differ significantly in species composition, (subsection A.3.1, subsection A.3.2).

The floristic and the underlined ecological gradients were depicted by the ordination diagram of the Non-Metric Multidimensional Scaling (NMDS). For two axis the stress of NMDS was 13.64277, which was considered relatively good, so the two-dimensional configuration was kept as acceptable. The four vegetation types occupied different sectors of the ordination space with a small overlapping only between types A1 and A2. This was an indication of the good separation of the groups because of their difference in species composition (Figure 3.4.2).

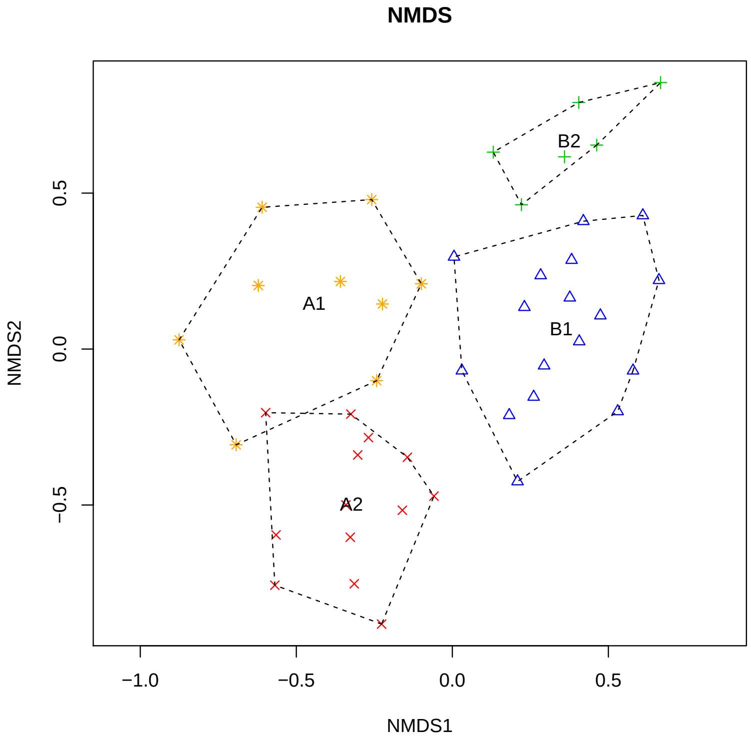

Figure 3.4.2.: Ordination diagram for Non-Metric Multidimensional Scaling (NMDS). The symbols in NMDS indicate site (plot) groups formed by the cluster analysis. The stress is equal to 13.643 and two axis were extracted.

The above analyses showed that two ecologically meaningful and floristically well differentiated plant communities exist in the study area (A & B), including four subtypes (A1, A2, B1, B2). The diagnostic taxa of the two communities and the four subtypes (determined by calculating their fidelity values (section 3.3.5.1)) are presented in the synoptic table (Table 3.4.1). A general description of the vegetation units is given below (subsection 3.4.1). Their syntaxonomic position and their synecology are also discussed.

3.4.1. Vegetation units - syntaxonomy and synecology

3.4.1.1. *Crepis fraasii* - *Abies cephalonica* community

(Table 3.4.1: type A and section A.7)

General appearance: Pure and mixed *Abies cephalonica* forest stands with *Quercus frainetto* and occasionally with *Castanea sativa*. *A. cephalonica* is the only dominant species in the tree layer. The shrub layer is formed mainly by *A. cephalonica*, *Juniperus oxycedrus* ssp. *oxycedrus* and *Q. frainetto*. Many other woody species appear in the shrub layer but with low frequency, most of them being diagnostic elements of *Ostryo-Carpinion* (*Fraxinus ornus*, *Carpinus orientalis* ssp. *orientalis*, *Hippocrepis emerus* ssp. *emeroides* etc.).

Distribution: The community occurs in both Mt. Oxia and Mt. Vardousia, and can be found in the meso-mediterranean and the lower part of the supra-mediterranean zones with its optimum between (690 -) 800 and 1100 (- 1360) m.

Floristic composition: The constant taxa, with frequency higher that 66 %, are given below. The letters inside the square brackets are indicating different layers (t=tree, s=shrub, h=herb) and the numbers inside the parenthesis are showing the frequency (%). With bold are marked the dominant taxa and with an asterisk the constant taxa with diagnostic value. All the diagnostic taxa are given in the synoptic table (Table 3.4.1).

Trees: ***Abies cephalonica*** [t,s,h] (100,95,100), ***Quercus frainetto**** [h] (100);
Shrubs: *Juniperus oxycedrus* ssp. *oxycedrus** [s,h] (86,73);
Herbs: *Aremonia agrimonoides* (68), *Brachypodium sylvaticum* ssp. *sylvaticum* (68), *Campanula spatulata* ssp. *spatulata* (91), *Cardamine hirsuta* (73), *Cerastium brachypetalum* ssp. *roeseri* (73), ***Crepis fraasii**** (82), *Cynosurus effusus* (73), *Dactylis glomerata* (86), *Galium rotundifolium* (82), *Luzula forsteri* (82), *Pilosella piloselloides* ssp. *bauhinii* (68), *Potentilla micrantha* (73), *Satureja vulgaris* ssp. *orientalis* (86), *Silene italica* ssp. *italica* (73), *Thymus longicaulis* ssp. *chaubardii** [h] 77, *Trifolium grandiflorum** (68), *Trifolium physodes* (77), ***Veronica chamaedrys* ssp.**

chamaedryoides (100);
Mosses: *Homalothecium aureum** (82), *Hypnum cupressiforme** (95)

Table 3.4.1.: Synoptic table of the vegetation types of *Abies* forests. Only the diagnostic species are presented, with their fidelity value (Φ) and their statistical significance (p). The frequency values of the taxa, for the vegetation types to which they considered as diagnostic, are given in bold. Woody species occurring in different layers are referred with a letter (t = tree, s = shrub, h = herb). The mosses are referred with the letter m. If a taxon is diagnostic of a higher syntaxon the name of that syntaxon is given before the name of the taxon.

Vegetation type (community)			A		B			
Subtype			A1	A2	B1	B2		
Number of relevés (n = 45)			9	13	17	6		
Number of diagnostic taxa			13	22	5	9		
			frequency (%)				Φ	p
Diagnostic taxa of *Crepis fraasii* - *Abies cephalonica* comm. (vegetation type A)								
A.c.	*Crepis fraasii*		**67**	**92**	6	0	0.778	0.001 ***
Q.c.	*Quercus frainetto*	t	**44**	**23**	0	0	0.451	0.037 *
	Quercus frainetto	s	**56**	**54**	6	0	0.571	0.005 **
	Quercus frainetto	h	**100**	**100**	24	33	0.746	0.001 ***
Q.p.	*Juniperus oxycedrus* ssp. *oxycedrus*	s	**78**	**92**	24	0	0.733	0.001 ***
	Hypnum cupressiforme var. *cupressiforme*	m	**100**	**92**	65	33	0.528	0.005 **
D.-F.	*Thymus longicaulis* ssp. *chaubardii*		**67**	**85**	29	17	0.526	0.010 **
	Homalothecium aureum	m	**67**	**92**	41	17	0.507	0.008 **
Q.c.	*Trifolium patulum*		**44**	**46**	6	0	0.495	0.014 *
	Galium mollugo agg.		**56**	**62**	18	17	0.427	0.045 *
Diagnostic taxa of subtype with *Castanea sativa* (subtype A1)								
Q.p.	*Rosa arvensis*	h	**67**	0	0	0	0.775	0.001 ***
Q.c.	*Scutellaria columnae* ssp. *columnae*		**56**	0	0	0	0.696	0.002 **
Q.p.	*Rubus canescens*	s	**44**	0	0	0	0.612	0.002 **
Q.-F.	*Hedera helix*	s	**33**	0	0	0	0.522	0.004 **
	Hedera helix	h	**56**	15	0	0	0.572	0.004 **
Q.p.	*Viola alba* ssp. *alba*		**56**	0	0	17	0.563	0.004 **
Q.p.	*Cyclamen hederifolium*		**33**	0	0	0	0.522	0.013 *
Q.i.	*Asplenium onopteris*		**44**	15	0	0	0.477	0.023 *
Q.p.	*Platanthera montana*		**33**	0	6	0	0.457	0.018 *
Q.p.	*Ruscus aculeatus*	s	**22**	0	0	0	0.420	0.045 *
	Ruscus aculeatus	h	**33**	8	0	0	0.439	0.029 *

Vegetation type (community)			A		B			
Subtype			A1	A2	B1	B2		
Q.c.	*Castanea sativa*	s	**56**	15	6	17	0.439	0.034 *
Q.p.	*Carex flacca* ssp. *serrulata*		**22**	0	0	0	0.420	0.036 *
	Scabiosa sp.		**22**	0	0	0	0.420	0.050 *
	Trifolium heldreichianum		**22**	0	0	0	0.420	0.047 *
Diagnostic taxa of subtype with *Trifolium grandiflorum* (subtype A2)								
Q.p.	*Trifolium grandiflorum*		22	**100**	0	0	0.870	0.001 ***
	Origanum vulgare ssp. *hirtum*		11	**85**	0	0	0.821	0.001 ***
K.-C.	*Myosotis ramosissima* ssp. *ramosissima*		0	**85**	12	0	0.817	0.001 ***
S.m.	*Anisantha sterilis*		0	**69**	0	0	0.792	0.001 ***
K.-C.	*Trifolium arvense*		0	**69**	6	0	0.746	0.001 ***
C.-M.j.	*Cistus creticus* ssp. *creticus*	h	11	**69**	0	0	0.708	0.001 ***
	Trifolium physodes		44	**100**	29	0	0.658	0.001 ***
T.-B.	*Cerastium brachypetalum* ssp. *roeseri*		33	**100**	47	0	0.637	0.001 ***
D.-F.	*Festuca circummediterranea*		0	**62**	18	0	0.605	0.003 **
T.-B.	*Cynosurus echinatus*		0	**54**	12	0	0.584	0.004 **
K.-C.	*Vicia lathyroides*		22	**77**	24	0	0.579	0.004 **
K.-C.	*Trifolium scabrum*		0	**38**	0	0	0.565	0.003 **
Q.p.	*Trifolium ochroleucon*		0	**46**	12	0	0.520	0.013 *
	Anthyllis vulneraria ssp. *bulgarica*		0	**31**	0	0	0.500	0.013 *
F.-B.	*Chamaecytisus austriacus*		0	**31**	0	0	0.500	0.011 *
Q.p.	*Lathyrus digitatus*		0	**31**	0	0	0.500	0.012 *
	Leontodon tuberosus		0	**31**	0	0	0.500	0.014 *
S.m.	*Torilis arvensis*		0	**31**	0	0	0.500	0.011 *
	Syntrichia ruralis	m	0	**31**	0	0	0.500	0.013 *
A.t.	*Asplenium adiantum-nigrum*		33	**69**	18	0	0.493	0.016 *
	Cota tinctoria ssp. *parnassica*		22	**62**	18	0	0.480	0.021 *
Q.p.	*Hypericum spruneri*		33	**69**	24	0	0.469	0.034 *
A.c.	*Neotinea maculata*		11	**46**	12	0	0.442	0.027 *
Diagnostic taxa of *Sanicula europaea - Abies cephalonica* comm. (vegetation type B)								
T.r.	*Epilobium lanceolatum*		0	23	**88**	**67**	0.663	0.001 ***
F.s.	*Poa nemoralis* ssp. *nemoralis*		11	0	**88**	**50**	0.657	0.001 ***
F.s.	*Sanicula europaea*		33	8	**88**	**83**	0.654	0.001 ***
F.s.	*Viola reichenbachiana x riviniana*		11	0	**47**	**83**	0.624	0.001 ***
Q.p.	*Fragaria vesca*		0	0	**53**	**50**	0.589	0.003 **
	Lapsana communis		11	15	**71**	**67**	0.563	0.004 **
Q.-F.	*Lactuca muralis*		56	46	**94**	**100**	0.526	0.010 **

Vegetation type (community)			A		B			
Subtype			A1	A2	B1	B2		
Q.p.	*Pteridium aquilinum* ssp. *aquilinum*		44	38	**82**	**100**	0.526	0.006 **
Q.p.	*Geum urbanum*		0	0	**35**	**50**	0.521	0.013 *
Q.c.	*Geocaryum capillifolium*		22	15	**76**	**50**	0.452	0.031 *
Diagnostic taxa of subtype with *Silene multicaulis* ssp. *multicaulis* (subtype B1)								
T.r.	*Silene multicaulis* ssp. *multicaulis*		0	8	**82**	0	0.827	0.001 ***
	Rumex acetosella ssp. *acetoselloides*		0	15	**59**	0	0.598	0.004 **
T.r.	*Arabis alpina* ssp. *caucasica*		0	0	**35**	0	0.539	0.008 **
Q.p.	*Myosotis sylvatica* ssp. *cyanea*		56	31	**100**	50	0.480	0.025 *
A.c.	*Arrhenatherum elatius*		11	0	**47**	17	0.420	0.050 *
Diagnostic taxa of subtype with *Rubus hirtus* (subtype B2)								
S.m.	*Geranium robertianum* ssp. *purpureum*		22	8	12	**100**	0.780	0.001 ***
F.s.	*Rubus hirtus*	h	11	0	12	**83**	0.742	0.001 ***
F.s.	*Moehringia trinervia*		0	0	6	**50**	0.600	0.003 **
	Bromopsis riparia		0	0	29	**67**	0.576	0.001 ***
Q.-F.	*Ilex aquifolium*	s	0	0	0	**33**	0.522	0.021 *
T.r.	*Polystichum lonchitis*		0	0	0	**33**	0.522	0.016 *
F.-B.	*Tephroseris integrifolia* ssp. *integrifolia*		0	0	0	**33**	0.522	0.017 *
	Epipactis greuteri ssp. *preinensis*		0	0	18	**50**	0.510	0.009 **
F.s.	*Calamintha grandiflora*		22	0	24	**67**	0.495	0.012 *
Common diagnostic taxa of two or more subtypes								
	Dactylis glomerata		**100**	**77**	**53**	0	0.671	0.001 ***
Q.p.	*Campanula spatulata* ssp. *spatulata*		**78**	**100**	**82**	17	0.657	0.001 ***
Q.p.	*Doronicum orientale*		**44**	**77**	**82**	0	0.588	0.003 **
	Cynosurus effusus		**56**	**85**	**59**	0	0.574	0.003 **
Q.p.	*Juniperus oxycedrus* ssp. *oxycedrus*	h	**56**	**85**	**41**	0	0.526	0.008 **
F.-B.	*Pilosella piloselloides* ssp. *bauhinii*		**56**	**77**	**41**	0	0.506	0.019 *
S.m.	*Cardamine hirsuta*		**33**	**100**	**82**	0	0.747	0.001 ***
	Carlina biebersteinii et *corymbosa*		**22**	**77**	**71**	0	0.634	0.001 ***
	Pilosella hoppeana ssp. *testimonialis*		0	**46**	**29**	0	0.483	0.019 *
	Sedum amplexicaule ssp. *tenuifolium*		0	**46**	**29**	0	0.483	0.017 *
	Sanguisorba minor ssp. *muricata*		0	**31**	**35**	0	0.445	0.045 *
A.t.	*Sedum hispanicum*		0	**38**	**24**	0	0.428	0.041 *

A.c.: Abietion cephalonicae, F.s.: Fagion sylvaticae, Q.c.: Quercion confertae, Q.i.: Quercet(-ea)alia ilicis,

Q.-F.: Querco-Fagetea, C.-M.j.: Cisto-Micromerietea , D.-F.: Daphno-Festucetea, F.-B.: Festuco-Brometea

K.-C.: Koelerio-Corynephoretea, S.m.: Stellarietea mediae, T.-B.: Thero-Brachypodietea,

Q.p.: Quercet(-ea)alia pubescentis, A.t.: Asplenietea trichomanis, T.r.: Thlaspietea rotundifolii

Subtypes: Two subtypes can be distinguished.

The first subtype with *Castanea sativa* (Table 3.4.1: subtype A1) is differentiated by a group of typical semi-shade to semi-light forest plants, most of which are diagnostic of sub-mediterranean thermophilous oak woods (*Quercet(-ea)alia pubescentis*) (Table 3.4.1). *Abies cephalonica* dominates and together with *Castanea sativa, Juniperus oxycedrus* ssp. *oxycedrus* and *Quercus frainetto* are forming a moderately dense shrub layer which covers up to 45 % of the surface (average cover 27 %). Some woody taxa like *Rubus canescens, Hedera helix, Ruscus aculeatus, Quercus petraea* ssp. *medwediewii*, *Q. coccifera* and *Fraxinus ornus,* appear occasionally in the shrub or herb layer. Several other like *Quercus pubescens, Acer campestre, A. monspessulanum* ssp. *monspessulanum*, *Phillyrea latifolia, Prunus cocomilia* et *domestica* ssp. *insititia, Carpinus orientalis* ssp. *orientalis*, *Hippocrepis emerus* ssp. *emeroides*, *Rosa canina, Crataegus monogyna, Tilia rubra* ssp. *rubra* and *Cercis siliquastrum* ssp. *siliquastrum,* are more rare. The subtype is restricted to the mountain range of Oxia and is completely absent from North Vardousia.

The herb layer is dominated mostly by diagnostic taxa of *Quercet(-ea)alia pubescentis* (*Veronica chamaedrys* ssp. *chamaedryoides, Satureja vulgaris* ssp. *orientalis, Luzula forsteri*), following by *Quercion confertae* (*Quercus frainetto*, *Scutellaria columnae* ssp. *columnae*) and *Abietion cephalonicae* (*Abies cephalonica*, *Crepis fraasii*). Two more dominant taxa are *Galium rotundifolium* and *Hieracium bracteolatum* ssp. *reinholdii.* Other constant taxa (frequency > 66 %) but less dominant are: *Aremonia agrimonoides* (100), *Dactylis glomerata* (100), *Potentilla micrantha* (100), *Hypnum cupressiforme* (100), *Brachypodium sylvaticum* ssp. *sylvaticum* (89), *Campanula spatulata* ssp. *spatulata* (78), *Lathyrus laxiflorus* ssp. *laxiflorus* (78), *Rosa arvensis** (67), *Thymus longicaulis* ssp. *chaubardii* (67) and *Homalothecium aureum* (67).

The second subtype with *Trifolium grandiflorum* (Table 3.4.1: subtype A2) is characterized by a big group of low nutrients site indicators. Most of them are semi-light and light-demanding thermophilous plants which are diagnostic of grasslands and other open plant communities (*Myosotis ramosissima* ssp. *ramosissima, Trifolium arvense*, Cistus creticus* ssp. *creticus*, Festuca circummediterranea, Cynosurus echinatus, Vicia lathyroides*, T. scabrum* etc.). These taxa are reflecting not only the structure of the stands but also some site characteristics which differ from the previous subtype. The stands are more open (average cover almost 60 %) and although their altitudinal range does not differ from the previous subtype, they appear more often in south facing and steeper slopes. The subtype is distributed all over the study area.

The shrub layer is formed mainly by *Abies cephalonica* and *Juniperus oxycedrus* ssp. *oxycedrus.* It covers up to 20(- 25) % of the surface with an average of 13 %. *Quercus frainetto* also appears but is less constant and with lower cover values compared to subtype A1. *Castanea sativa* is not an important floristic element of subtype A2, in contrast to subtype A1. Some of the woody species mentioned in the previous subtype (*Quercus pubescens, Carpinus orientalis* ssp. *orientalis, Fraxinus ornus* etc.) occasionally appear also here. In general, the shrub layer is less dense and less reach in species in comparison with the previous subtype.

The herb layer appears less dense, in comparison with the subtype A1, dominated by the taxa: *Abies cephalonica, Crepis fraasii, Quercus frainetto, Juniperus oxycedrus* ssp. *oxycedrus, Trifolium grandiflorum*, Cerastium brachypetalum* ssp. *roeseri*, Campanula spatulata* ssp. *spatulata, Cynosurus effusus, Veronica chamaedrys* ssp. *chamaedryoides* and *Silene italica* ssp. *italica.* Other constant taxa (frequency > 66 %) but less dominant are: *Trifolium physodes** (100), *Cardamine hirsuta* (100), *Homalothecium aureum* (92), *Hypnum cupressiforme* (92), *Galium rotundifolium* (85), *Origanum vulgare* ssp. *hirtum** (85), *Thymus longicaulis* ssp. *chaubardii* (85), *Carlina biebersteinii* et *corymbosa* (77), *Dactylis glomerata* (77), *Doronicum orientale* (77), *Pilosella piloselloides* ssp. *bauhinii* (77), *Satureja vulgaris* ssp. *orientalis* (77), *Sedum cepaea* (77), *Anisantha sterilis** (69), *Asplenium adiantum-nigrum** (69), *Hypericum spruneri** (69), *Luzula forsteri* (69).

Syntaxonomy: The *Crepis fraasii - Abies cephalonica* comm. has many common floristic elements with the association *Trifolio grandiflori - Abietetum borisii-regis* (subsubsection 3.2.1.6). The association was described by Barbéro and Quézel (1976) from the mountains of Oxia, Timfristos and S. Vardousia and confirmed later by Dimitrellos (2005) and Vlachos (2006) for the last two mountains (Timfristos and S. Vardousia). The status of the association is ambiguous and its exact distribution is not known yet, although it appears to be restricted in the N & W part of Sterea Ellas. The small number of relevés that was used by the above authors to describe that association (14 - 15 each) (Table 3.2.1) and the floristically rather inaccurate relevés published by Barbéro and Quézel (1976) are not allowing a fully delineation of the *Trifolio grandiflori - Abietetum borisii-regis.*

Barbéro and Quézel (1976) mentioned as character species of the association the: *Abies x borisii-regis, Trifolium grandiflorum, Trifolium aurantiacum, Luzula forsteri, Helleborus odorus* ssp. *cyclophyllus* and *Cicer montbretii.* The species *Trifolium aurantiacum* and *Cicer montbretii* could not be found in the study area and neither Dimitrellos (2005) nor Vlachos (2006) were able to verify their occurrence on Timfristos and S. Vardousia respectively. Moreover, according to Med-Checklist (Greuter et al., 1989) the species *Cicer montbretii* doesn't exist in Greece at all and probably there was a misidentification by Barbéro and Quézel (1976). The other two species (*Luzula forsteri* and *Helleborus odorus* ssp. *cyclophyllus*) are present in the *Crepis fraasii* - *Abies cephalonica* comm., but they don't show any specific preference to this community. Besides, *Helleborus odorus* ssp. *cyclophyllus* is completely absent from the second subtype (A2) with *Trifolium grandiflorum* (section A.7). Only the species *Trifolium grandiflorum* has a diagnostic value for this subtype (A2) of the community, but is almost absent from the more dense and north facing stands, represented by the first subtype (A1) with *Castanea sativa*.

Barbéro and Quézel (1976); Dimitrellos (2005) and Vlachos (2006) assigned the association *Trifolio grandiflori* - *Abietetum borisii-regis* to the alliance *Quercion confertae*, due to the presence of many diagnostic species of it. Such a designation seems not to be good justified. *Abies* dominated forests of meso-, supra- and montane-Mediterranean zones of central and southern Greece are a distinct forest type of a well defined formation, that of xerophytic coniferous forests and scrub (Bohn et al., 2003). Syntaxonomically, this mediterranean fir forest type has been assigned (together with *Pinus nigra* ssp. *pallasiana* forests of the same region) to the alliance *Abietion cephalonicae* (Horvat et al., 1974; Barbéro and Quézel, 1976; Bergmeier, 2003). Untill an integrated revision of all coniferous forest communities of southern and central Greece take place, it is justified to follow the previous authors and assign all the fir forest communities of the study area to the alliance *Abietion cephalonicae*.

Synecology: The *Crepis fraasii* - *Abies cephalonica* comm. with its two subtypes, is a quite diverse plant community occupying a wide range of sites. The community occurs in the upper, middle and down part of gentle to steep slopes (25 - 90 %) of all expositions (section A.7). The NMDS ordination (Figure 3.4.3, Figure 3.4.4) and the correlations between relevé scores and various abiotic variables (Table 3.4.2) suggest that the first (horizontal) axis reflects a climatic gradient which is mainly caused by elevation. The high correlation between elevation and precipitation and elevation and air temperature (Table 2.5.2), in combination with the long altitudinal width (~900 m) creates a strong ecological gradient. This gradient is better expressed by the combination of the most important climatic parameters (precipitation, air temperature, solar radiation, potential evapotranspiration) in the form of the Humidity Index (HI). The community occupies the left part of this gradient which represents areas with low elevetion and low humidity (Figure 3.4.4).

The second floristic gradient (vertical axis) of the ordination (Figure 3.4.3) is less obviously explained by the available parameters. Along the second axis, the two

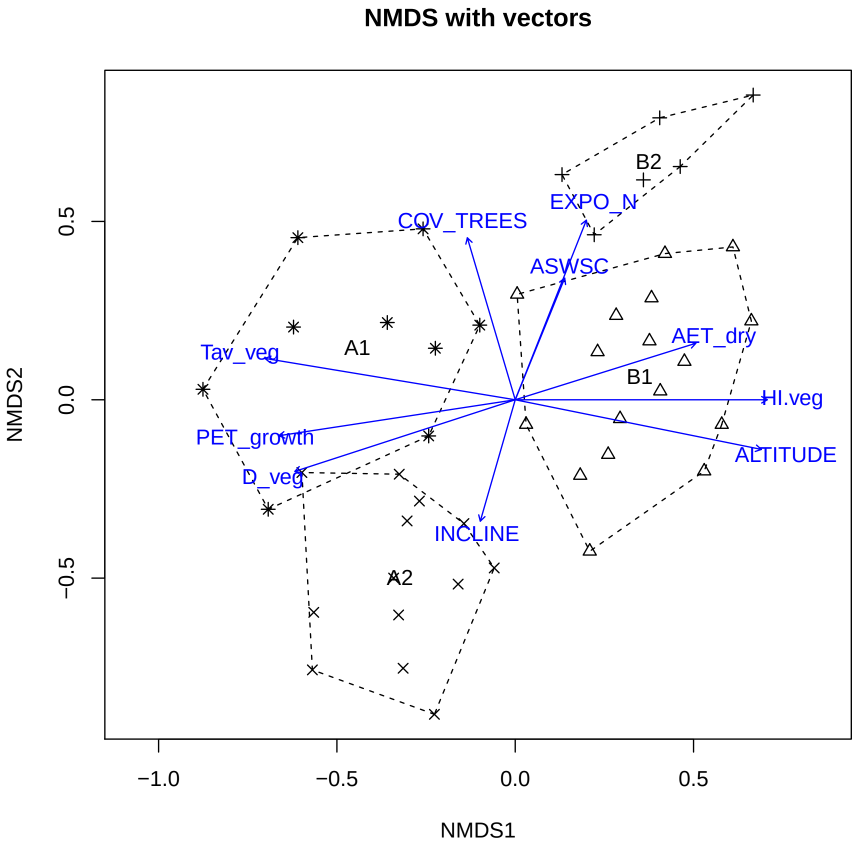

Figure 3.4.3.: Ordination diagram for Non-Metric Multidimensional Scaling (NMDS) and projection of the various environmental variables on the ordination as vectors. The symbols in NMDS indicate site (plot) groups formed by the cluster analysis. The stress is equal to 13.643 and two axis were extracted. The direction and strength of the gradients is represented by the direction and length of the vectors respectively. For the abbreviations of the environmental variables and their coefficients of determination see Table 3.4.2.

subtypes of the *Crepis fraasii - Abies cephalonica* comm. are differentiated and occupying different sectors of the ordination space. Some differences in topography (exposition and inclination), structure of the stands (cover of tree layer) and soil water availability occur between the two subtypes of the community (Figure 3.4.3, Figure 3.4.5 and Figure 3.4.6). These structural, topographic and edaphic changes along the second axis are creating specific micro-climatic conditions that differentiate the two subtypes. Nevertheless, these variables are not strongly correlated with the ordination configuration (Table 3.4.2). This indicates that other parameters, which have not been recorded in this study, are also responsible for this differentiation.

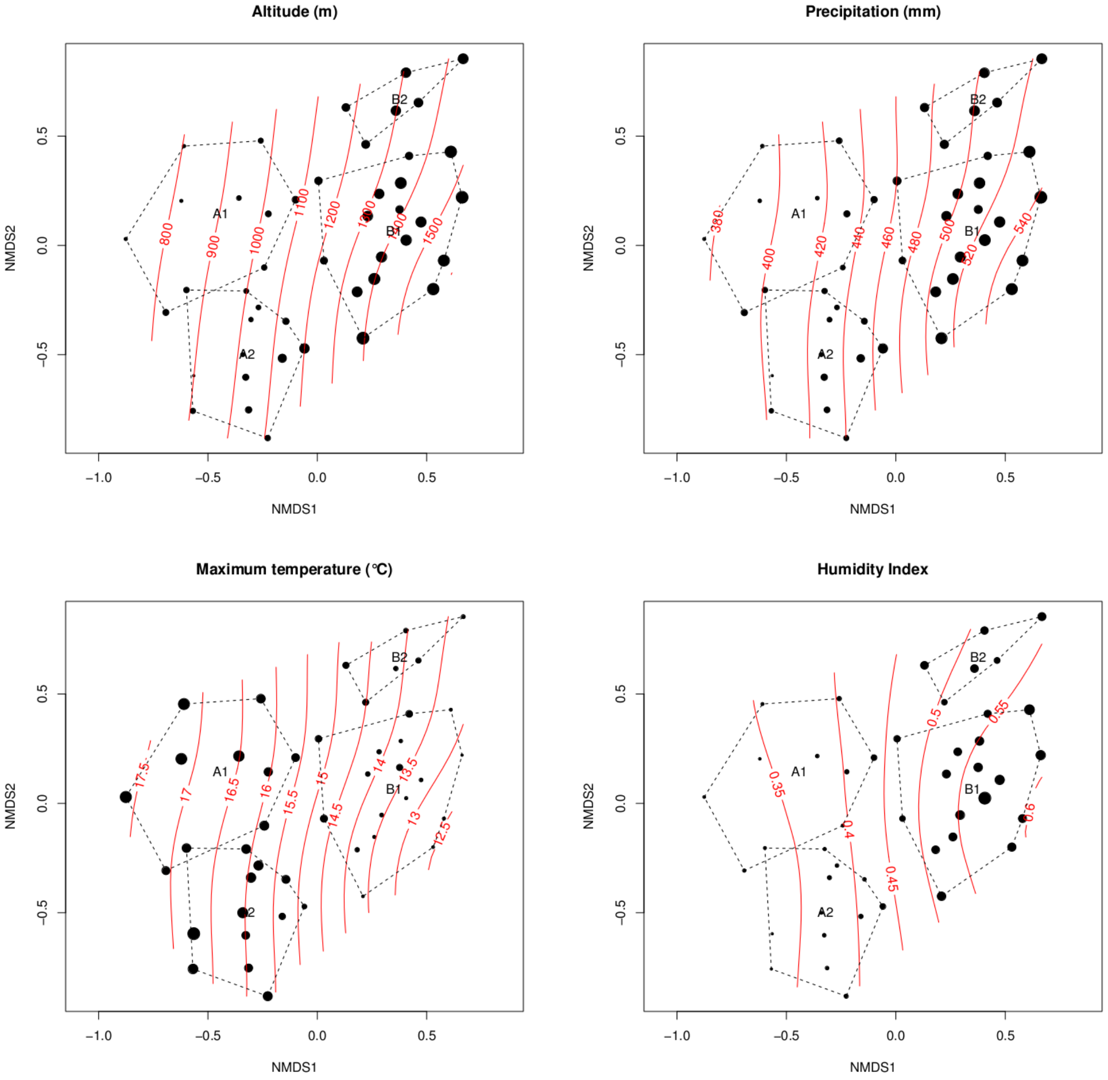

Figure 3.4.4.: Ordination diagrams for Non-Metric Multidimensional Scaling (NMDS) and projection of various environmental variables on the ordination as isolines (contours). The isolines were created using thinplate splines. The different circle sizes indicating different degrees of the environmental variables. The humidity index is dimensionless ranging from 0 (Dry) to 1 (Humid). The Precipitation and the Humidity index were calculated for the vegetation priod. The Maximum temperature was calculated for the whole year.

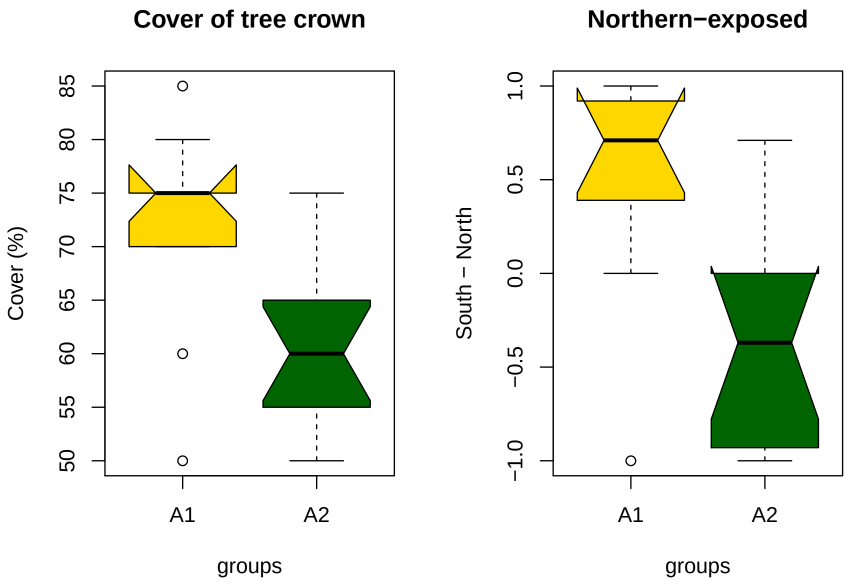

Figure 3.4.5.: Notched boxplots of environmental variables which differ significantly among the sub-groups A1 and A2.

3.4.1.2. *Sanicula europaea* - *Abies cephalonica* community

(Table 3.4.1: type B and section A.7)

General appearance: Pure *Abies cephalonica* forest stands. The shrub layer is formed almost exclusively by *A. cephalonica* and the appearance of other woody species (*Juniperus oxycedrus* ssp. *oxycedrus*, *Castanea sativa*, *Fagus sylvatica* ssp. *sylvatica, Ilex aquifolium*, etc.) is rare.

Distribution: The community can be found on both Mt. Oxia and Mt. Vardousia, without any geographical preference. The altitudinal range of its distribution (1130 - 1580 *m*) appears higher to the previous community, been extended up to lower part of the montane-mediterranean zone and reaching the timberline of the region.

Floristic composition: The constant taxa, with frequency higher that 66 %, are given below. The letters inside the square brackets are indicating different layers (t=tree, s=shrub, h=herb) and the numbers inside the parenthesis are showing the frequency (%). With bold are marked the dominant taxa and with an asterisk the constant taxa with diagnostic value. All the diagnostic taxa are given in the synoptic table (Table 3.4.1).

Trees: ***Abies cephalonica*** [t,s,h] (100,87,96);
Semiprasites: *Viscum album* ssp. *abietis* [t] (87);
Herbs: *Aremonia agrimonoides* (96), *Brachypodium sylvaticum* ssp. *sylvaticum* (83), *Epilobium lanceolatum** (83), ***Galium rotundifolium*** (100), *Geocaryum capillifolium* (70), *Lactuca muralis* (96, *Lapsana communis* (70), *Myosotis sylvatica* ssp. *cyanea* (87), *Poa nemoralis* ssp. *nemoralis** (78), *Potentilla micrantha* (83), ***Pteridium aquilinum* ssp. *aquilinum*** (87), *Sanicula europaea** (87), *Satureja vulgaris* ssp. *orientalis* (78), ***Veronica chamaedrys* ssp. *chamaedryoides*** (100);
Mosses: *Brachythecium velutinum** (78)

Subtypes: Two subtypes can be distinguished.

The first subtype with *Silene multicaulis* ssp. *multicaulis* (Table 3.4.1: subtype B1) is differentiated by a small group of diagnostic taxa. From those taxa, *Myosotis sylvatica* ssp. *cyanea* can be considered as a taxon with a weak diagnostic value. Although it has a constancy of 100 % in subtype B1, is present in all vegetation types of the study area with a relatively high frequency. Most of the dominant taxa in the herb layer are diagnostic of the class/order *Quercet(-ea)alia pubescentis* (*Pteridium aquilinum* ssp. *aquilinum, Myosotis sylvatica* ssp. *cyanea*, Doronicum orientale, Veronica chamaedrys* ssp. *chamaedryoides*). The layer is further formed by *Abies cephalonica, Silene multicaulis* ssp. *multicaulis** and two diagnostic taxa of *Fagion sylvaticae* (*Poa nemoralis* ssp. *nemoralis* and *Galium rotundifolium*). Other constant taxa (frequency $> 66\,\%$) but less dominant are: *Aremonia agrimonoides* (94), *Lactuca muralis* (94), *Potentilla micrantha* (94), *Epilobium lanceolatum* (88), *Sanicula europaea* (88), *Brachypodium sylvaticum* ssp. *sylvaticum* (82), *Campanula spatulata* ssp. *spatulata* (82), *Cardamine hirsuta* (82), *Satureja vulgaris* ssp. *orientalis* (82), *Brachythecium velutinum* (82), *Geocaryum capillifolium* (76), *Lapsana communis* (71), *Carlina biebersteinii* et *corymbosa* (71).

The second subtype with *Rubus hirtus* (Table 3.4.1: subtype B2) is differentiated by a bigger group of taxa. Almost half of these taxa are diagnostic of the class *Querco-Fagetea* (*Ilex aquifolium*) and the alliance *Fagion sylvaticae* (*Rubus hirtus, Moehringia trinervia, Calamintha grandiflora*). Most of the dominant taxa in the herb layer are also diagnostic of these two syntaxa (*Sanicula europaea, Viola reichenbachiana x riviniana, Lactuca muralis, Galium rotundifolium, Aremonia agrimonoides*). Other taxa with high constancy and cover values are: *Abies cephalonica, Pteridium aquilinum* ssp. *aquilinum, Geranium robertianum* ssp. *purpureum** and *Veronica chamaedrys* ssp. *chamaedryoides.* Other constant taxa (frequency $> 66\,\%$) but less dominant are: *Brachypodium sylvaticum* ssp. *sylvaticum* (83), *Rubus hirtus** [h] (83), *Bromopsis riparia** (67), *Calamintha grandiflora** (67), *Epilobium* *lanceolatum* (67), *Lapsana communis* (67), *Lathyrus laxiflorus* ssp. *laxiflorus* (67), *Satureja vulgaris* ssp. *orientalis* (67), *Brachythecium velutinum* (67).

The distribution of subtype B2 is restricted only to the north-west part of the study area, mainly on gentle slopes with north - northeast orientation and very low rockiness.

Table 3.4.2.: The coefficients of determination (r^2) and the significances (p-values) of the environmental variables, after fitting them as vectors onto the ordination. Only the variables with the highest r^2 are shown. The most important variables are in bold. The p-values were assessed using 999 random permutations of the environmental variables.

Variables	Abbreviations	r^2	p-values
Altitude (m)	**ALTITUDE**	**0.8426**	0.001
Inclination (%)	INCLINE	0.2054	0.012
Exposition to the north	EXPO_N	0.4865	0.001
Canopy cover (%)	COV_TREES	0.3944	0.001
Annual solar radiation (Mj/m^2)	Rs_annual	0.2610	0.003
Solar radiation during the growth period (Mj/m^2)	**Rs_growth**	**0.5220**	0.001
Average maximum air temperature ($T_{\max}$) during the dry period (°C)	Tmax_dry	0.8572	0.001
Average $T_{\max}$ during the vegetation period (°C)	Tmax_veg	0.8574	0.001
Average annual $T_{\max}$ (°C)	**Tmax_annual**	**0.8587**	0.001
Average $T_{\max}$ during the growth period (°C)	Tmax_growth	0.5880	0.001
Average minimum air temperature ($T_{\min}$) during the dry period (°C)	**Tmin_dry**	**0.8587**	0.001
Average $T_{\min}$ air temperature during the vegetation period (°C)	Tmin_veg	0.8585	0.001
Average annual $T_{\min}$ (°C)	Tmin_annual	0.8527	0.001
Average $T_{\min}$ during the growth period (°C)	Tmin_growth	0.4391	0.001
Mean air temperature (T_{mean}) during the dry period (°C)	Tav_dry	0.8551	0.001
T_{mean} during the vegetation period (°C)	**Tav_veg**	**0.8562**	0.001
Mean annual air temperature (°C)	Tav_annual	0.8541	0.001
T_{mean} during the growth period (°C)	Tav_growth	0.6235	0.001
Precipitation (P) during dry period (mm)	P_dry	0.8223	0.001
P during vegetation period (mm)	**P_veg**	**0.8516**	0.001
Annual P (mm)	P_annual	0.8251	0.001
P during growth period (mm)	P_growth	0.3847	0.001
Reference potential evapotranspiration (PET$_{\text{ref}}$) during dry period (mm)	PET_dry	0.6601	0.001
PET$_{\text{ref}}$ during vegetation period (mm)	PET_veg	0.6606	0.001
Annual PET$_{\text{ref}}$ (mm)	PET_annual	0.6543	0.001
PET$_{\text{ref}}$ during growth period (mm)	**PET_growth**	**0.7527**	0.001
Humidity index (HI) during dry period	HI_dry	0.8236	0.001
HI during vegetation period	**HI_veg**	**0.8389**	0.001
Annual humidity index	HI_annual	0.8143	0.001
Humus depth (cm)	HUMUS_DEPTH	0.0498	0.350
Available soil water storage capacity (mm)	ASWSC	0.2148	0.004
Reference actual evapotranspiration during dry period (mm)	AET_dry	0.4615	0.001
Water deficit during dry period (mm)	D_dry	0.6902	0.001
Water deficit during vegetation period (mm)	**D_veg**	**0.6956**	0.001

Syntaxonomy: The *Sanicula europaea - Abies cephalonica* comm. has many common floristic elements with the association *Lilio chalcedonicae - Abietetum cephalonicae* (subsubsection 3.2.1.1). The association was first described by Barbéro and

Quézel (1976) from different mountains of Peloponnisos and later confirmed by several authors not only in southern Greece (Peloponnisos) (Dimopoulos et al., 1996; Bergmeier, 2002) but also in central Greece (Sterea Ellas) (Karetsos, 2002; Dimitrellos, 2005; Vlachos, 2006; Kokmotos, 2008). One more community that can be found in central Greece, on the adjacent Mt. Iti, shares also many floristic elements with *Sanicula europaea - Abies cephalonica* comm. This community was described by Karetsos (2002) as *Abies cephalonica* comm. and, as he mentioned, it is closely related to *Lilio chalcedonicae - Abietetum cephalonicae* of the same mountain.

Several taxa have been mentioned as “character species” of the association *Lilio chalcedonicae - Abietetum cephalonicae.* At least some of them should be considered as diagnostic taxa with local value, but among all these species there are at least few, that appear to be constantly faithful to almost all mountains in which the above association exist. These species are *Lilium chalcedonicum* and *Calamintha grandiflora.* In the study area the first species although has been observed, did not appear in any of the plots. The species is growing mainly in forest gaps or at the edges of the forest. Its absence from all the plots of the present study is probably an artifact of the sampling method, since those ecotones where the species occurs (forest gaps and edges) where avoided. The other species (*Calamintha grandiflora*) appears in the study area as diagnostic taxon of the second subtype (B2) with *Rubus hirtus*, even though also occurs (with lower frequency) in the first subtype (B1) with *Silene multicaulis* ssp. *multicaulis.*

The close affinity of the *Sanicula europaea - Abies cephalonica* comm. with the association *Lilio chalcedonicae - Abietetum cephalonicae* of the neighboring Mt. Iti is indicated by their many common diagnostic taxa. Karetsos (2002) is naming as character taxa of the association in Mt. Iti the: *Abies cephalonica, Lilium chalcedonicum, Calamintha grandiflora, Geum urbanum, Silene multicaulis* ssp. *multicaulis, Sanicula europaea and Digitalis ferruginea* ssp. *ferruginea.* From these taxa, *Sanicula europaea* and *Geum urbanum* were found to be diagnostic species of the *Sanicula europaea - Abies cephalonica* comm., *Silene multicaulis* ssp. *multicaulis* diagnostic species of the first subtype (B1) and *Calamintha grandiflora* diagnostic species of the second subtype (B2). The many common constant species between *Sanicula europaea - Abies cephalonica* comm. and the association *Lilio chalcedonicae - Abietetum cephalonicae* of the adjacent mountains Iti and Timfristos is also indicating their close relation. Common floristic elements can be also found between *Sanicula europaea - Abies cephalonica* comm. and *Abies cephalonica* comm. from Mt. Iti as was already mentioned before. These taxa with common diagnostic value are: *Lapsana communis*, *Pteridium aquilinum* ssp. *aquilinum* and *Arrhenatherum elatium.*

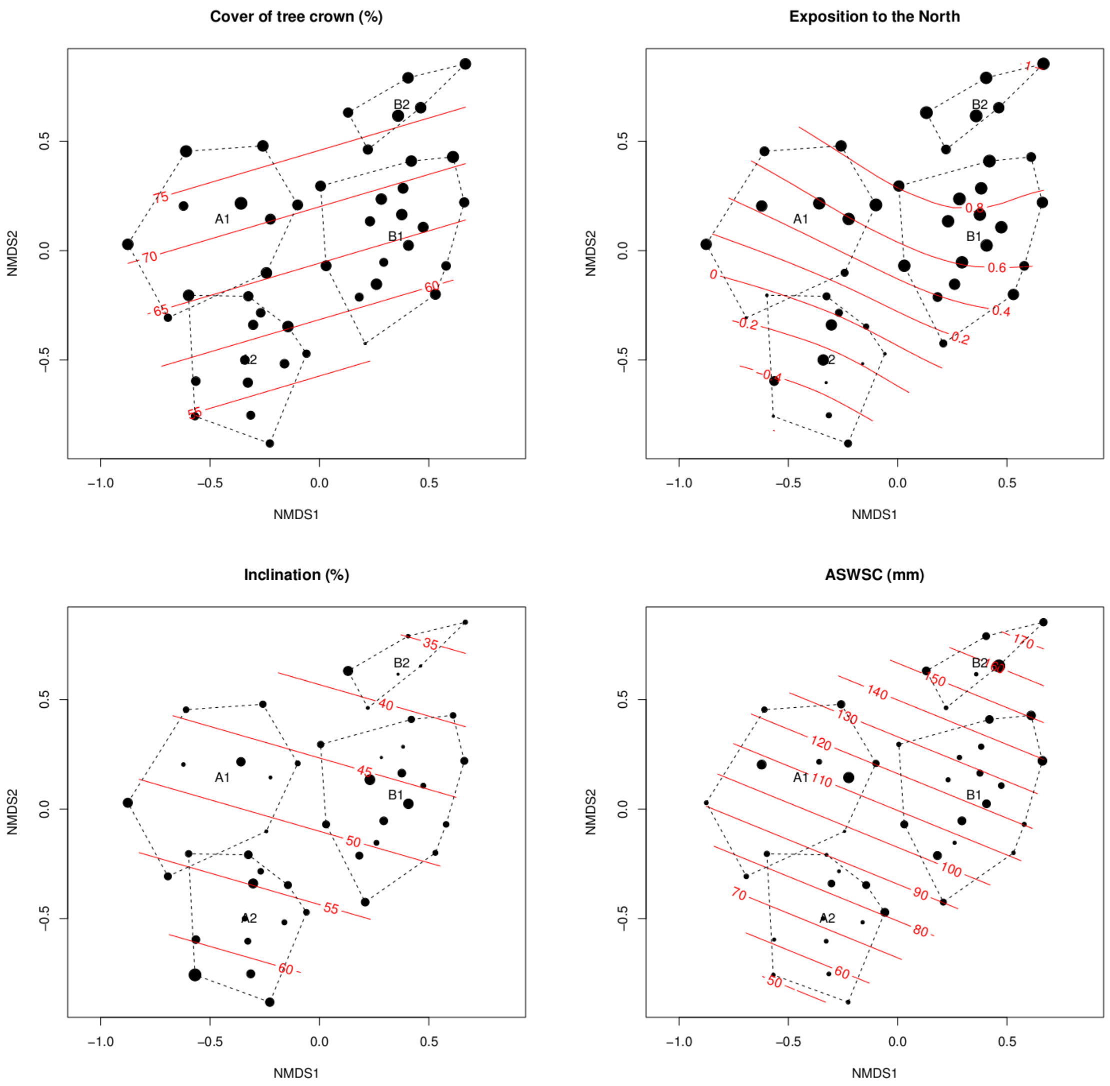

Figure 3.4.6.: Ordination diagrams for Non-Metric Multidimensional Scaling (NMDS) and projection of various environmental variables on the ordination as isolines (contours). The isolines were created using thinplate splines. The different circle sizes indicating different degrees of the environmental variables. The exposition to the North is dimensionless ranging from -1 (South) to 1 (North).

Synecology: The *Sanicula europaea - Abies cephalonica* comm. is restricted to the upper and middle part of, mainly, northern-exposed slopes. It occupies the right part of the ordination diagram along the first axis (Figure 3.4.3). This indicates the more humid conditions of the high-altitude fir forests, in relation to the previous community.

The floristic differentiation of its two subtypes follows the second (vertical) axis of the ordination. This second axis, as mentioned before, is difficult to be explained with the available information. The structural and topographic differentiation that occurred in the case of *Crepis fraasii* - *Abies cephalonica* comm. is not present here. Additionally, the difference in available soil water storage capacity between the subtypes is very small. A characteristic of the subtype with *Rubus hirtus* is the high accumulation of litter on the surface (Figure 3.4.7). The gentle slopes (Figure 3.4.7) in combination with the north and north-east orientation, the high altitude (low temperature) and the relatively close canopy of the stands are slowing down the litter decomposition process. This may suggest a nutrient gradient along the second axis. A similar gradient from nutrient-rich conditions to sites with poor mineralization found Bergmeier (2002) on Mt. Parnon.

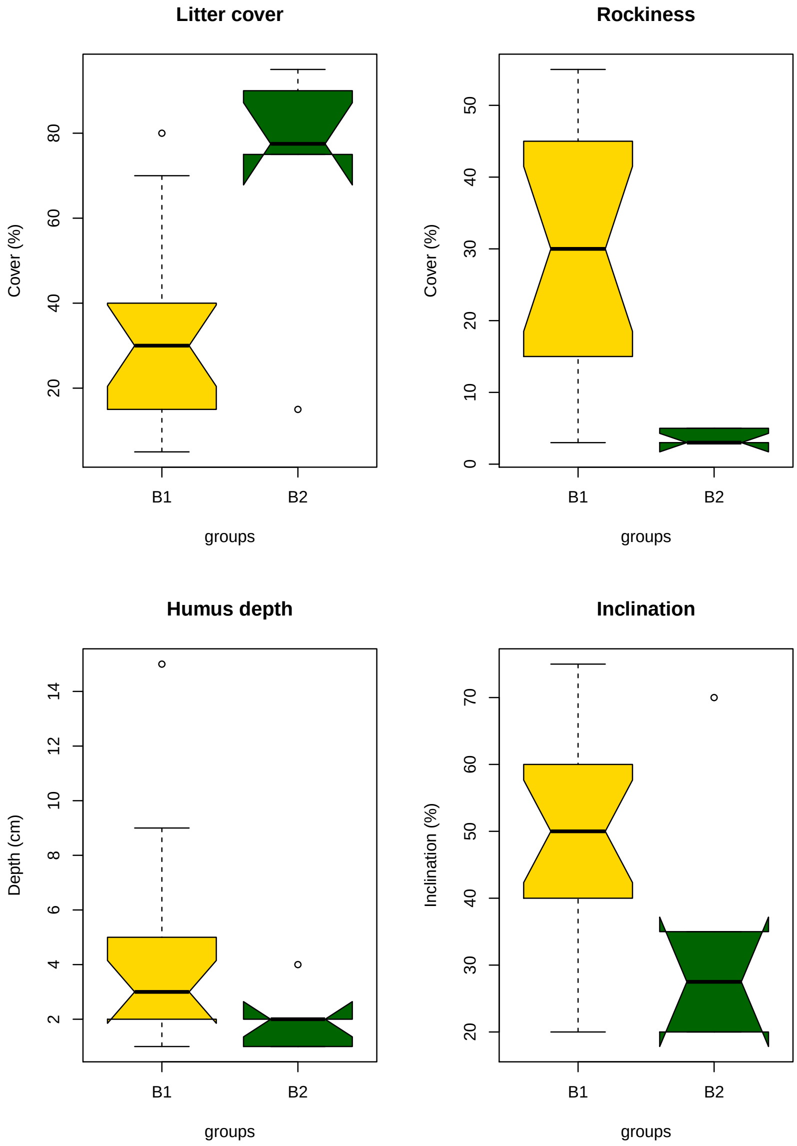

Figure 3.4.7.: Notched boxplots of environmental variables which differ significantly among sub-groups B1 and B2. Rockiness is the cover of exposed rocks and stones. Humus includes the organic topsoil horizons Of and Oh.

3.4.2. Environmental thresholds

The classification tree analysis for the four vegetation types (Figure 3.4.8: Left) divided the plots into two groups based on the Humidity Index during the dry period (HI.dry). The differentiating power of HI.dry was the highest among all environmental variables (p-value < 0.001). The level of significance chosen was $\alpha = 0.05$. The first group (Figure 3.4.8: Left, Node 2) included all the plots in which the humidity index for the dry period was less or equal to 0.26. These were all the plots belonging to *Crepis fraasii* - *Abies cephalonica* community and three plots from *Sanicula europaea* - *Abies cephalonica* community. The second group (Figure 3.4.8: Left, Node 3) included all the plots in which the humidity index for the dry period was higher than 0.26. These were the majority of the plots belonging to *Sanicula europaea* - *Abies cephalonica* community. After the first division of the data-set, non of the environmental variables could further differentiate the plots into smaller groups, so the division stopped and the final classification tree was formed.

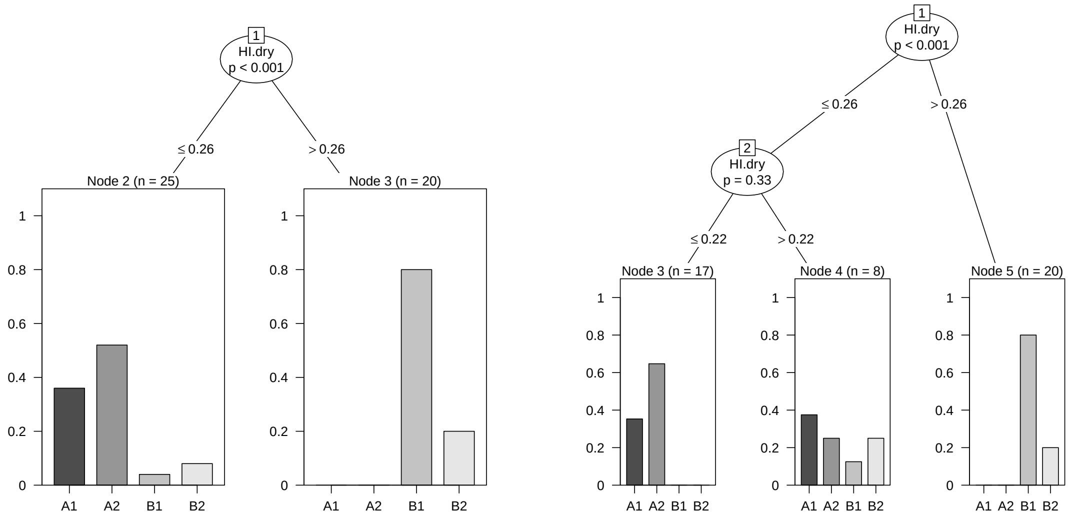

Figure 3.4.8.: Classification trees for the four vegetation subtypes (A1 = *Crepis fraasii* - *Abies cephalonica* comm. subtype with *Castanea sativa*; A2 = *Crepis fraasii* - *Abies cephalonica* comm. subtype with *Trifolium grandiflorum*; B1 = *Sanicula europaea* - *Abies cephalonica* comm. subtype with *Silene multicaulis* ssp. *multicaulis*; B2 = *Sanicula europaea* - *Abies cephalonica* comm. subtype with *Rubus hirtus*) based on the environmental variables. The drought thresholds are indicated namely HI.dry (humidity index during the dry period) *Left*: significance level $\alpha = 0.05$, *Right*: significance level $\alpha = 0.6$. The vertical axis are showing the proportions of each subtype in each division.

In order to check if a further, reasonable, division of the data-set was possible, the level of significance was reduced to $\alpha = 0.6$, and the same procedure was applied again. In this case the classification tree analysis divided the data-set into three groups of plots (Figure 3.4.8: Right). In both levels of division HI.dry was the variable that gave the best split.

In the above analysis, the classification trees resulted in a good separation of the two forest communities (*Crepis fraasii* - *Abies cephalonica* comm. and *Sanicula europaea* - *A. cephalonica* comm.) but not such a good separation of the subtypes was achieved. Therefore, a separate classification trees analysis was applied for each of the two forest communities. The analysis didn't reveal any significant differentiation between the vegetation subtypes based on any environmental variable. Only if the level of significance was reduced to $\alpha = 0.6$ there was a separation of the plots of the two data-sets into two groups in each case (Figure 3.4.9). These groups were corresponding to the vegetation subtypes A1, A2, B1 and B2. In the case of *Crepis fraasii* - *A. cephalonica* comm. (Figure 3.4.9: Left), exposition to the North appeared to be the most important variable for the discrimination between subtype with *Castanea sativa* (A1) and subtype with *Trifolium grandiflorum* (A2). In the case of *Sanicula europaea* - *A. cephalonica* comm. (Figure 3.4.9: Right), rockiness gave the best split between subtype with *Silene multicaulis* ssp. *multicaulis* (B1) and subtype with *Rubus hirtus* (B2).

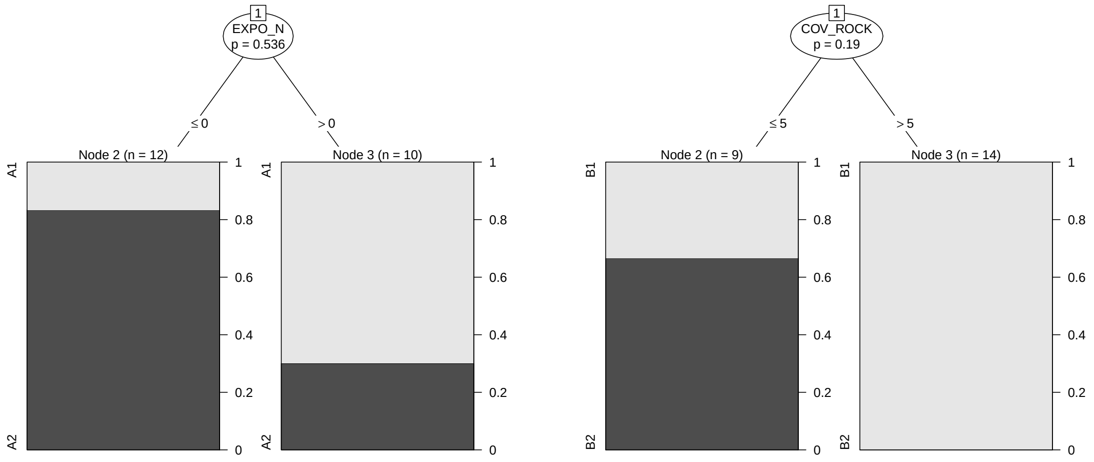

Figure 3.4.9.: *Left*: Classification tree for the two vegetation subtypes of *Crepis fraasii* - *Abies cephalonica* comm. (A1 and A2) based on the environmental variables. *Right*: Classification tree for the two vegetation subtypes of *Sanicula europaea* - *Abies cephalonica* comm. (B1 and B2) based on the environmental variables. Significance level $\alpha = 0.6$. The environmental thresholds are indicated namely EXPO_N (Exposition to the north) and COV_ROCK (cover of exposed rocks).

3.5. General discussion

3.5.1. Syntaxonomy of higher syntaxa

The classification of the fir forests in the study area revealed the existence of two main vegetation types (communities) which can be clearly distinguished, floristically and ecologically: the *Crepis fraasii - Abies cephalonica* comm. (Table 3.4.1: type A) and the *Sanicula europaea - A. cephalonica* comm. (Table 3.4.1: type B). The syntaxonomic status of the two communities and their subtypes in relation to higher-rank syntaxa (higher to the association rank) will be discussed in detail in the following paragraphs.

3.5.1.1. *Crepis fraasii - Abies cephalonica* community

(Table 3.4.1: type A and section A.7)

The number of diagnostic species of the alliance *Quercion confertae* that are present in the first subtype (A1) of the *Crepis fraasii - Abies cephalonica* comm. with *Castanea sativa*, is higher comparing with the other three subtypes (A2, B1, B2). In addition to that, a few diagnostic species of the alliance *Ostryo-Carpinion* and the class *Quercetea ilicis* are also present in this subtype (A1) (Table 3.5.1). This is an indirect indication of its more xerothermic character. A high number of diagnostic species from classes which are indicating low nutrients supply (Mucina, 1997), occur in the subtype with *Trifolium grandiflorum* (Table 3.5.1). Those classes are: *Koelerio - Corynephoretea, Festuco - Brometea, Thero - Brachypodietea and Cisto - Micromerietea.*

The *Crepis fraasii - Abies cephalonica* comm. includes many diagnostic species of the order *Quercetea pubescentis* and its related syntaxa in contrast to the few only species from *Querco-Fagetea* and its related syntaxa. This indicates its close relation to the thermophilous broadleave forests. Indeed, the community is representing the part of the *Abies* forests of the study area which are growing in the lower altitudinal zone of their distribution, some times in mixture with *Quercus frainetto* and *Castanea sativa*. Although *Quercus frainetto* and *Castanea sativa* are present on the tree layer with low cover values and relatively small frequency, they have a very good regeneration.

The presence of *Juniperus oxycedrus* ssp. *oxycedrus* in the shrub layer of *Crepis fraasii - Abies cephalonica* comm., indicates that a degradation (disturbance) took place in the past. This disturbance had a profound effect on the fir forests of the

Table 3.5.1.: Number of diagnostic taxa of the most important higher syntaxa for the different vegetation subtypes. Only the taxa with frequency $\geq 33\,\%$ were counted.

Vegetation type (community)	A		B	
Subtype	A1	A2	B1	B2
Quercetea pubescentis	2	1	1	-
Quercetalia pubescentis	18	16	14	11
Abietion cephalonicae	2	4	2	2
Quercion confertae	8	5	4	5
Ostryo-Carpinion	1	-	-	-
Total	**31**	**26**	**21**	**18**
Querco-Fagetea	4	3	3	4
Fagetalia sylvaticae	2	-	4	9
Fagion sylvaticae	1	1	1	1
Total	**7**	**4**	**8**	**14**
Quercetea ilicis	**2**	**-**	**-**	**-**
K.-C., F.-B., T.-B., C.-M.j.	**4**	**9**	**3**	**2**

K.-C.: Koelerio-Corynephoretea, F.-B.: Festuco-Brometea,
T.-B.: Thero-Brachypodietea, C.-M.j.: Cisto-Micromerietea

meso-mediterranean and the lower part of supra-mediterranean vegetation zone in the study area. The causes of this disturbance can be only speculated, since no historical records are available. Forest fires, grazing and illegal logging would have been quite common in the past. Forest fires are still happening in the thermo-mediterranean zone and some times they are reaching the lower part of fir forest zone. Grazing by sheeps and goats is still occuring in the study area, although it has been decreased the last decades. All these, mainly anthropogenic, factors would have led to a change in the structure and floristic composition of the fir forests or even to their complete destruction. Other taxa, like *Juniperus oxycedrus* ssp. *oxycedrus,* which are more tolerant to the human pressure and more light demanding than *Abies cephalonica*, occupied these degradated areas. Wherever this degradation was not irreversible, *A. cephalonica* regenerated and *Juniperus oxycedrus* ssp. *oxycedrus* remained in the understory of the newly created forests. The presence of many dead shrubs of *Juniperus oxycedrus* ssp. *oxycedrus* in the understory of stands with close canopy supports this theory.

3.5.1.2. *Sanicula europaea* - *Abies cephalonica* community

(Table 3.4.1: type B and section A.7)

The *Sanicula europaea* - *Abies cephalonica* comm. includes less diagnostic species of the order *Quercetea pubescentis* and its related syntaxa in comparison with the *Crepis fraasii* - *Abies cephalonica* comm. (Table 3.5.1). There are also many species of *Querco-Fagetea*, especially in the second subtype (B2) with *Rubus hirtus*. The total number of diagnostic taxa of *Querco-Fagetea* and its related syntaxa (14 taxa) in this subtype is very close to that of *Quercetea pubescentis* (18 taxa). This indicates the less xerothermic site conditions of subtype (B2) with *Rubus hirtus* by comparison with all the other subtypes.

The subtype with *Rubus hirtus* seems to represent the most fertile sites of the Abies forests in the study area. Two indicators of more or less rich in nutrient sites are among its diagnostic species (*Rubus hirtus*, *Moehringia trinervia*).

3.5.1.3. Syntaxonomic synopsis of the fir forests in the study area

Most *Fagetalia* species are absent from the *Abies* forests of the study area. Their understory vegetation is similar to that of oak forests with the presence of many *Quercetalia* species. Therefore, both communities should be classified within the *Quercetalia pubescentis*. A syntaxonomic synopsis is given below:

Class: ***Quercetea pubescentis*** Doing-Kraft ex Scamoni et Passarge 1959

Order: ***Quercetalia pubescentis*** Klika 1933

- Alliance: ***Abietion cephalonicae*** Horvat et al. 1974
- Community: ***Crepis fraasii* - *Abies cephalonica*** comm.
    - Subtype: with ***Castanea sativa***
    - Subtype: with ***Trifolium grandiflorum***
- Community: ***Sanicula europaea* - *Abies cephalonica*** comm.
    - Subtype: with ***Silene multicaulis*** ssp. ***multicaulis***
    - Subtype: with ***Rubus hirtus***

3.5.2. Vegetation units along the drought gradient

Ordination analysis showed that there are at least two main floristic/vegetation and ecological gradients in the study area. The principal vegetation gradient (along the first axis on the ordination diagram) is following the elevation gradient which has a length of almost 900 m. Elevation was highly correlated with the main vegetation gradient but since it does not have any direct ecological or physiological effect on species (Gärtner et al., 2008), other factors were preferred to be used in order to explain the vegetation pattern.

Among them, almost all the climatic components of drought were highly correlated with the vegetation gradient along the first axis. Temperature and precipitation for all but the growth periods (four driest months, vegetation period and year) showed the highest correlations in the ordination. Nevertheless, their differentiating power, assessed by the classification tree, was worse than those from humidity index (HI) and reference potential evapotranspiration ($\mathrm{PET}_{\mathrm{ref}}$). The HI appeared to be the most important variable that separated the two forest communities, followed by the $\mathrm{PET}_{\mathrm{ref}}$ for the growth period.

From the components of soil water balance, only water deficit (D) appeared to have a good correlation with the principal vegetation gradient. The D incorporates the available soil water storage capacity (ASWSC) and the reference actual evapotranspiration ($\mathrm{AET}_{\mathrm{ref}}$) into the calculation of drought intensity, through the soil water balance model. However, it did not improve the explanatory power of drought for the main vegetation pattern.

A principal differentiation of the Greek fir forest vegetation in mesophytic and xerophytic forest stands occurs in the study area. Bergmeier (2002) found the same pattern in the coniferous woodlands of Mt. Parnon in southern Greece (Peloponnisos). He claimed that water supply is the crucial factor that is driving the floristic variation in those forests which, except of *Abies cephalonica*, include also *Pinus nigra* and *Juniperus drupacea*.

This pattern of vegetation differentiation along a gradient of increasing drought must be a common phenomenon which appears in most of the Greek fir forest of southern and central Greece. This is indicated by the wide altitudinal range that these forests occupy in most of the mountains on which they occur (Dimopoulos et al., 1996; Bergmeier, 2002; Karetsos, 2002; Dimitrellos, 2005; Vlachos, 2006). As the results of this study show, this elevation gradient is highly correlated with the basic meso-climatic components of drought; precipitation, $\mathrm{PET}_{\mathrm{ref}}$ and their combination as humidity/aridity index.

3.5.3. Threshold values of the components of drought

The distribution of the *Sanicula europaea - Abies cephalonica* comm. in the study area was limited by increasing drought. Out of all drought-indicating variables, two separated well the forest communities; the humidity index for the four driest months (HI.dry) and the reference potential evapotranspiration for the growth period ($\mathrm{PET_{ref}}$_growth).

The above threshold values of HI.dry and $\mathrm{PET_{ref}}$_growth can be used to predict the occurrence of the two forest communities in the study area. The validity of the prediction model can be assessed by the p-value of the conditional distribution of test statistics that is used to test the partial null hypothesis of independence between the above variables and the vegetation (subsubsection 3.3.5.3). The lower the p-value the better the predicting power of the variable is. The number of misclassification in the final dendrogram can be also used to validate the predictive accuracy of the model.

For both HI.dry and $\mathrm{PET_{ref}}$_growth the p-value was < 0.001 and the number of relevés that were misclassified was 3 (less than 7 % of the total number of relevés). The *Crepis fraasii - Abies cephalonica* comm. occurs when the HI.dry is ≤ 0.26 or when the $\mathrm{PET_{ref}}$_growth is > 1034.3 mm. In reverse, when HI.dry is > 0.26 or $\mathrm{PET_{ref}}$_growth is ≤ 1034.3 mm, the *Sanicula europaea - A. cephalonica* comm. occurs.

Conclusions and outlook

- The Greek fir (*Abies cephalonica* Loudon) forests of the study area consist of two communities: the *Crepis fraasii* - *Abies cephalonica* comm. and the *Sanicula europaea* - *A. cephalonica* comm. These two communities are further subdivided into four subtypes. For a broader synsystematical and syntaxonomical overview there is a need for a syntaxonomic review of all fir forests in Greece. This will relate all fir forest vegetation units to a wider phytogeographical background and give a better understanding of their floristic differentiation.
- The community variation within the *Abies cephalonica* forest vegetation of the study area reflects a principal differentiation between mesophytic and xerophytic fir forest stands. This pattern is driven by meso-climatic factors that are related to elevation. The wide altitudinal range of *A. cephalonica* distribution on the mountain range of Oxia - North Vardousia (almost 900 m) follows a drought gradient that is linked to two main components: Precipitation (P) and reference potential evapotranspiration (PET_{ref}). *A. cephalonica* follows a similar elevation gradient in all mountains of southern and central Greece. This suggests that the pattern from mesophytic to xerophytic vegetation units should be encountered in all Greek fir forests.
- At a finer scale (at the level of stand) factors other than meso-climatic are more important in explaining the floristic differentiation of the *Abies cephalonica* forest communities. Edaphic parameters like available soil water storage capacity (ASWSC) and topographic features like exposition and inclination are related with this secondary vegetation pattern. The division of the two main *Abies* forest communities of the study area into subtypes, reflects the micro-climatic conditions that these factors create. Nevertheless, these factors could only explain a small amount of the total floristic variation that existed at a local scale. Other abiotic parameters (geology, nutrients) as well as biotic parameters (logging, grazing) should also have a significant influence upon vegetation. Local or finer-scale studies in the Greek fir forests should incorporate more detailed soil measurements and, if possible, historic records and management plans.
- The combination of the two main meso-climatic components of drought (P,

PET_{ref}) into a form of humidity/aridity index (HI) improved their differentiating power in relation to the main vegetation units. The HI was a better choice, compared to climatic water deficit (D), in estimating drought at a meso-scale. The inclusion of edaphic components into the calculation of drought did not improve its predictive ability. The use of a simple climatic index, such as the modified Transeau's humidity index, is advisable for meso-scale studies conducted on a given substrate, in this case flysch.

- Two drought-indicating variables (HI and PET_{ref}) separated the two main forest communities very well. The occurrence of these two forest communities can be predicted using the threshold values of HI or PET_{ref}. When HI is ≤ 0.26 for the four driest months or when PET is > 1034.3 mm for the growth period *Crepis fraasii - Abies cephalonica* comm. occurs. On the other hand, if HI > 0.26 or PET ≤ 1034.3 mm then *Sanicula europaea - A. cephalonica* comm. occurs.
- Geostatistical tools have turned out to be very useful for assessing climatic variables at a meso-scale (regional or local scale). Their ability to include topographic features (aspect, slope, sky view factor, altitude) and to incorporate information on the spatial variation of the climatic variables makes them very accurate and reliable in their predictions. For micro-scale studies their implementation is still restricted due to the reduced accuracy of the digital elevation models (DEM), but it can be still used cautiously. The prediction of soil parameters is even more difficult and therefore it is not recommended.
- Reference potential evapotranspiration (PET_{ref}) is one of the most important components of drought, but also very difficult to assess. For reliable and easily implemented estimations of PET_{ref}, two parameters (T, R_s) have to be included in the calculation procedure with the use of an empirical equation. For the study area and the whole WC Sterea Ellas, the Abtew equation appeared to be the best choice for such studies. The use of this equation is recommended for the calculation of PET_{ref} in other *Abies* forests of the region.

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A. Appendix

A.1. Climatic data

Table A.1.1.: Solar radiation (R_s) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	4.92	8.41	14.12	20.40	25.24	27.23	25.94	21.94	16.10	10.23	5.80	4.00	22.80	21.01
9	6.46	10.11	15.54	21.13	25.22	26.92	25.78	22.37	17.23	11.77	7.42	5.46	23.08	21.49
10	6.95	10.90	16.65	22.51	26.84	28.54	27.35	23.77	18.33	12.64	7.98	5.90	24.50	22.85
14	10.04	14.10	19.24	23.94	27.18	28.32	27.41	24.74	20.32	15.49	11.13	8.97	25.20	23.91
15	8.26	12.28	17.61	22.61	26.26	27.59	26.61	23.62	18.94	13.87	9.33	7.17	24.19	22.79
21	7.02	10.94	16.65	22.51	26.88	28.61	27.41	23.80	18.34	12.66	8.05	5.98	24.54	22.89
25	5.65	9.29	14.97	21.06	25.74	27.65	26.39	22.52	16.83	11.06	6.58	4.69	23.35	21.61
26	9.17	13.30	18.77	23.98	27.67	29.03	27.99	24.94	20.07	14.84	10.27	8.08	25.51	24.07
27	10.05	14.30	19.75	24.77	28.27	29.52	28.53	25.64	20.93	15.80	11.20	8.93	26.16	24.78
28	6.56	10.20	15.56	21.08	25.23	26.88	25.74	22.30	17.13	11.81	7.51	5.59	23.01	21.45
29	6.68	10.57	16.30	22.16	26.52	28.23	27.03	23.44	17.99	12.31	7.69	5.65	24.17	22.53
30	6.39	10.05	15.52	21.26	25.63	27.38	26.19	22.58	17.21	11.72	7.34	5.41	23.34	21.71
31	7.61	11.64	17.04	22.12	25.61	26.90	25.96	23.09	18.45	13.27	8.70	6.49	23.60	22.20
33	14.98	19.42	23.87	27.02	28.70	29.05	28.49	27.09	24.09	20.37	16.23	13.82	27.18	26.40
34	12.76	17.15	22.05	25.98	28.39	29.07	28.34	26.37	22.69	18.36	13.97	11.58	26.62	25.60
35	13.93	18.20	22.70	26.11	28.08	28.58	27.94	26.31	23.06	19.19	15.12	12.84	26.47	25.61
36	17.83	22.09	25.50	27.06	27.31	27.00	26.80	26.57	25.04	22.58	19.06	16.72	26.35	26.05
37	5.82	9.35	14.80	20.62	25.08	26.88	25.67	21.98	16.54	11.03	6.73	4.89	22.77	21.11
38	7.50	11.36	16.86	22.34	26.36	27.91	26.81	23.49	18.37	12.98	8.51	6.47	24.14	22.61
39	11.14	15.30	20.28	24.57	27.37	28.30	27.47	25.16	21.14	16.60	12.27	10.04	25.52	24.37
40	13.46	17.72	22.34	25.95	28.11	28.68	28.02	26.25	22.83	18.81	14.64	12.34	26.45	25.52
41	13.99	18.37	23.05	26.63	28.71	29.25	28.60	26.88	23.51	19.45	15.20	12.84	27.06	26.15
42	13.12	17.31	21.92	25.64	27.93	28.58	27.88	26.00	22.46	18.39	14.28	12.04	26.23	25.27
43	9.63	13.74	19.09	24.10	27.62	28.90	27.91	25.00	20.30	15.22	10.74	8.55	25.53	24.15
44	7.02	10.85	16.44	22.19	26.50	28.21	27.04	23.46	18.09	12.53	8.02	6.00	24.20	22.57
46	11.68	15.86	20.68	24.68	27.21	27.99	27.23	25.15	21.39	17.07	12.83	10.56	25.44	24.39
47	6.58	10.17	15.46	20.93	25.05	26.68	25.58	22.17	17.06	11.78	7.51	5.62	22.88	21.32
48	6.18	9.87	15.47	21.35	25.79	27.58	26.38	22.70	17.21	11.58	7.13	5.20	23.47	21.80
49	13.84	18.18	22.90	26.62	28.83	29.44	28.75	26.93	23.42	19.27	15.04	12.72	27.13	26.18
50	8.62	12.73	18.03	22.97	26.40	27.62	26.65	23.85	19.26	14.25	9.73	7.51	24.35	23.00
51	3.98	6.89	12.08	18.08	22.95	25.08	23.77	19.69	14.05	8.57	4.68	3.26	20.65	18.89
52	3.28	6.28	12.12	18.91	24.24	26.50	25.10	20.70	14.43	8.21	3.97	2.59	21.68	19.73
55	6.72	10.61	16.37	22.32	26.79	28.57	27.35	23.66	18.11	12.36	7.73	5.67	24.42	22.74
57	3.56	6.74	12.60	19.28	24.53	26.75	25.37	21.03	14.85	8.67	4.31	2.79	22.00	20.07
58	6.37	10.28	16.17	22.29	26.87	28.70	27.46	23.67	17.99	12.09	7.38	5.33	24.46	22.72
59	6.23	9.92	15.49	21.33	25.77	27.58	26.37	22.69	17.22	11.63	7.19	5.25	23.46	21.80
60	8.02	12.13	17.84	23.45	27.54	29.12	27.99	24.61	19.37	13.82	9.11	6.91	25.27	23.70
61	9.18	13.31	18.82	24.10	27.85	29.25	28.20	25.10	20.16	14.87	10.28	8.09	25.67	24.22
62	4.49	8.05	14.00	20.56	25.65	27.76	26.42	22.21	16.13	9.98	5.38	3.57	23.13	21.24
63	3.11	5.57	10.96	17.56	23.02	25.41	23.99	19.44	13.23	7.36	3.59	2.67	20.52	18.57
64	6.97	10.64	15.91	21.28	25.29	26.89	25.78	22.45	17.41	12.20	7.93	6.00	23.13	21.61
65	8.83	12.91	18.44	23.79	27.63	29.08	28.01	24.83	19.83	14.49	9.91	7.74	25.43	23.95
66	5.65	9.28	14.97	21.10	25.80	27.71	26.46	22.57	16.85	11.06	6.58	4.69	23.40	21.65
69	6.30	10.20	16.08	22.20	26.80	28.64	27.39	23.60	17.91	12.02	7.31	5.26	24.38	22.65
70	6.08	10.02	16.05	22.24	26.84	28.68	27.44	23.64	17.93	11.93	7.08	5.07	24.42	22.67

Table A.1.2.: Maximum temperature (T_{max}) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	5.3	6.2	10.0	13.2	19.4	24.4	26.2	25.5	22.2	16.4	10.8	7.8	24.6	21.1
9	7.1	8.0	11.5	15.3	21.3	26.2	28.1	27.4	24.1	18.3	12.7	9.3	26.4	22.9
10	5.5	6.4	10.2	13.5	19.7	24.6	26.5	25.8	22.5	16.7	11.1	8.0	24.8	21.3
14	2.4	3.4	7.6	9.9	16.6	21.5	23.4	22.7	19.4	13.6	8.0	5.4	21.8	18.2
15	5.8	6.7	10.4	13.8	19.9	24.9	26.7	26.0	22.7	17.0	11.3	8.2	25.1	21.6
21	3.0	3.9	8.1	10.5	17.2	22.1	24.0	23.3	20.0	14.2	8.6	5.9	22.3	18.7
25	4.5	5.4	9.3	12.3	18.6	23.6	25.4	24.8	21.4	15.7	10.0	7.1	23.8	20.3
26	4.3	5.2	9.2	12.1	18.5	23.4	25.3	24.6	21.3	15.5	9.9	7.0	23.6	20.1
27	3.8	4.8	8.8	11.5	18.0	23.0	24.8	24.1	20.8	15.0	9.4	6.6	23.2	19.6
28	7.6	8.6	12.0	15.9	21.8	26.7	28.6	27.9	24.6	18.8	13.2	9.7	26.9	23.5
29	6.5	7.5	11.0	14.6	20.7	25.6	27.5	26.8	23.5	17.7	12.1	8.8	25.8	22.3
30	6.2	7.1	10.7	14.2	20.3	25.3	27.1	26.4	23.1	17.3	11.7	8.5	25.5	22.0
31	6.0	6.9	10.6	14.0	20.2	25.1	27.0	26.3	23.0	17.2	11.6	8.4	25.3	21.8
33	5.3	6.2	10.0	13.2	19.5	24.4	26.3	25.6	22.3	16.5	10.9	7.8	24.6	21.1
34	5.2	6.2	10.0	13.1	19.4	24.4	26.2	25.5	22.2	16.4	10.8	7.7	24.6	21.0
35	5.7	6.6	10.4	13.7	19.9	24.8	26.7	26.0	22.7	16.9	11.3	8.1	25.0	21.5
36	6.3	7.2	10.8	14.3	20.4	25.4	27.2	26.6	23.2	17.5	11.8	8.6	25.6	22.1
37	6.7	7.7	11.2	14.9	20.9	25.8	27.7	27.0	23.7	17.9	12.3	9.0	26.1	22.6
38	6.0	7.0	10.6	14.1	20.2	25.1	27.0	26.3	23.0	17.2	11.6	8.4	25.4	21.8
39	6.0	6.9	10.6	14.0	20.2	25.1	26.9	26.3	23.0	17.2	11.6	8.4	25.3	21.8
40	5.3	6.3	10.1	13.3	19.5	24.5	26.3	25.6	22.3	16.5	10.9	7.8	24.7	21.1
41	4.4	5.3	9.3	12.2	18.6	23.5	25.4	24.7	21.4	15.6	10.0	7.1	23.7	20.2
42	5.4	6.3	10.1	13.3	19.6	24.5	26.3	25.7	22.4	16.6	11.0	7.9	24.7	21.2
43	2.6	3.6	7.8	10.1	16.8	21.8	23.6	22.9	19.6	13.8	8.2	5.6	22.0	18.4
44	2.8	3.7	7.9	10.3	16.9	21.9	23.7	23.0	19.7	14.0	8.3	5.7	22.1	18.5
46	5.8	6.7	10.4	13.8	20.0	24.9	26.8	26.1	22.8	17.0	11.4	8.2	25.1	21.6
47	7.2	8.1	11.6	15.4	21.4	26.3	28.1	27.5	24.2	18.4	12.8	9.4	26.5	23.0
48	4.9	5.8	9.7	12.7	19.0	24.0	25.8	25.2	21.8	16.1	10.5	7.5	24.2	20.7
49	3.5	4.5	8.6	11.1	17.7	22.7	24.5	23.8	20.5	14.7	9.1	6.3	22.9	19.3
50	7.0	7.9	11.4	15.2	21.1	26.1	27.9	27.3	23.9	18.2	12.6	9.2	26.3	22.8
51	4.3	5.2	9.2	12.1	18.5	23.4	25.3	24.6	21.3	15.5	9.9	7.0	23.6	20.1
52	4.6	5.6	9.5	12.4	18.8	23.8	25.6	24.9	21.6	15.8	10.2	7.3	24.0	20.4
55	3.3	4.2	8.4	10.9	17.5	22.4	24.2	23.6	20.3	14.5	8.9	6.1	22.6	19.0
57	4.3	5.2	9.2	12.0	18.5	23.4	25.2	24.6	21.3	15.5	9.9	7.0	23.6	20.1
58	3.3	4.3	8.4	10.9	17.5	22.5	24.3	23.6	20.3	14.5	8.9	6.2	22.7	19.1
59	2.5	3.4	7.7	9.9	16.6	21.6	23.4	22.8	19.4	13.7	8.1	5.5	21.8	18.2
60	2.1	3.0	7.4	9.5	16.3	21.2	23.1	22.4	19.1	13.3	7.7	5.1	21.4	17.8
61	2.6	3.5	7.7	10.0	16.7	21.7	23.5	22.8	19.5	13.8	8.1	5.5	21.9	18.3
62	2.9	3.8	8.0	10.4	17.1	22.0	23.9	23.2	19.9	14.1	8.5	5.8	22.2	18.6
63	2.6	3.5	7.7	10.0	16.7	21.7	23.5	22.8	19.5	13.7	8.1	5.5	21.9	18.3
64	3.4	4.3	8.5	11.0	17.6	22.5	24.4	23.7	20.4	14.6	9.0	6.2	22.7	19.2
65	2.4	3.4	7.6	9.9	16.6	21.6	23.4	22.7	19.4	13.6	8.0	5.4	21.8	18.2
66	3.0	3.9	8.1	10.5	17.2	22.1	23.9	23.3	20.0	14.2	8.6	5.9	22.3	18.7
69	3.5	4.4	8.5	11.1	17.6	22.6	24.4	23.7	20.4	14.7	9.0	6.3	22.8	19.2
70	3.3	4.3	8.4	10.9	17.5	22.4	24.3	23.6	20.3	14.5	8.9	6.2	22.7	19.1

Table A.1.3.: Minimum temperature (T_{min}) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	-0.8	0.1	2.1	4.5	8.8	12.4	15.1	14.6	11.8	8.1	3.8	1.1	13.5	10.7
9	0.4	1.2	3.1	5.8	10.1	13.8	16.3	15.7	12.9	9.2	5.0	2.2	14.7	12.0
10	-0.7	0.2	2.2	4.7	9.0	12.6	15.2	14.8	11.9	8.2	4.0	1.2	13.6	10.9
14	-2.7	-1.6	0.4	2.6	6.8	10.1	13.2	13.0	10.1	6.4	2.0	-0.6	11.6	8.9
15	-0.5	0.4	2.4	4.9	9.2	12.8	15.4	14.9	12.1	8.4	4.1	1.4	13.8	11.1
21	-2.3	-1.2	0.8	3.0	7.2	10.6	13.6	13.3	10.4	6.7	2.4	-0.2	12.0	9.3
25	-1.3	-0.4	1.6	4.0	8.3	11.7	14.6	14.2	11.3	7.6	3.3	0.6	12.9	10.2
26	-1.5	-0.5	1.5	3.9	8.1	11.6	14.5	14.1	11.2	7.5	3.2	0.5	12.8	10.1
27	-1.8	-0.7	1.3	3.5	7.8	11.2	14.2	13.8	10.9	7.2	2.9	0.3	12.5	9.8
28	0.7	1.5	3.4	6.1	10.5	14.2	16.6	16.0	13.2	9.5	5.3	2.5	15.0	12.3
29	0.0	0.8	2.8	5.4	9.7	13.4	15.9	15.4	12.5	8.8	4.6	1.8	14.3	11.6
30	-0.2	0.6	2.6	5.1	9.4	13.1	15.7	15.2	12.3	8.6	4.4	1.6	14.0	11.3
31	-0.3	0.5	2.5	5.0	9.3	12.9	15.6	15.1	12.2	8.5	4.3	1.5	13.9	11.2
33	-0.8	0.1	2.1	4.5	8.8	12.4	15.1	14.7	11.8	8.1	3.8	1.1	13.5	10.8
34	-0.8	0.1	2.1	4.5	8.8	12.3	15.1	14.6	11.8	8.0	3.8	1.1	13.4	10.7
35	-0.5	0.4	2.3	4.8	9.1	12.7	15.4	14.9	12.1	8.3	4.1	1.3	13.8	11.0
36	-0.2	0.7	2.7	5.2	9.5	13.2	15.7	15.2	12.4	8.7	4.5	1.7	14.1	11.4
37	0.1	1.0	2.9	5.5	9.8	13.5	16.0	15.5	12.7	8.9	4.8	1.9	14.4	11.7
38	-0.3	0.6	2.5	5.0	9.4	13.0	15.6	15.1	12.2	8.5	4.3	1.5	14.0	11.3
39	-0.3	0.5	2.5	5.0	9.3	12.9	15.6	15.1	12.2	8.5	4.3	1.5	13.9	11.2
40	-0.8	0.1	2.1	4.6	8.9	12.4	15.1	14.7	11.8	8.1	3.9	1.1	13.5	10.8
41	-1.4	-0.4	1.6	3.9	8.2	11.7	14.5	14.1	11.3	7.5	3.3	0.6	12.9	10.2
42	-0.7	0.2	2.1	4.6	8.9	12.5	15.2	14.7	11.9	8.1	3.9	1.2	13.5	10.8
43	-2.6	-1.5	0.6	2.7	7.0	10.3	13.4	13.1	10.2	6.5	2.1	-0.4	11.7	9.0
44	-2.5	-1.4	0.6	2.8	7.0	10.4	13.5	13.2	10.3	6.6	2.2	-0.4	11.8	9.1
46	-0.5	0.4	2.4	4.9	9.2	12.8	15.4	14.9	12.1	8.4	4.2	1.4	13.8	11.1
47	0.5	1.2	3.2	5.8	10.2	13.9	16.3	15.8	12.9	9.2	5.1	2.2	14.7	12.0
48	-1.1	-0.1	1.9	4.3	8.5	12.1	14.8	14.4	11.6	7.8	3.6	0.9	13.2	10.5
49	-2.0	-0.9	1.1	3.3	7.6	11.0	14.0	13.6	10.7	7.0	2.7	0.1	12.3	9.6
50	0.3	1.1	3.1	5.7	10.0	13.7	16.2	15.6	12.8	9.1	4.9	2.1	14.6	11.9
51	-1.5	-0.5	1.5	3.9	8.1	11.6	14.5	14.1	11.2	7.5	3.2	0.5	12.8	10.1
52	-1.2	-0.3	1.7	4.1	8.4	11.9	14.7	14.3	11.4	7.7	3.4	0.7	13.1	10.3
55	-2.1	-1.1	0.9	3.2	7.4	10.8	13.8	13.5	10.6	6.9	2.6	-0.1	12.2	9.4
57	-1.5	-0.5	1.5	3.8	8.1	11.6	14.5	14.1	11.2	7.5	3.2	0.5	12.8	10.1
58	-2.1	-1.0	1.0	3.2	7.5	10.8	13.8	13.5	10.6	6.9	2.6	0.0	12.2	9.5
59	-2.7	-1.5	0.5	2.6	6.8	10.2	13.3	13.0	10.1	6.4	2.0	-0.5	11.6	8.9
60	-2.9	-1.8	0.2	2.3	6.6	9.9	13.0	12.8	9.9	6.2	1.8	-0.8	11.4	8.7
61	-2.6	-1.5	0.5	2.6	6.9	10.2	13.3	13.0	10.2	6.4	2.1	-0.5	11.7	9.0
62	-2.4	-1.3	0.7	2.9	7.1	10.5	13.6	13.2	10.4	6.6	2.3	-0.3	11.9	9.2
63	-2.6	-1.5	0.5	2.6	6.9	10.2	13.3	13.0	10.2	6.4	2.1	-0.5	11.7	9.0
64	-2.1	-1.0	1.0	3.2	7.5	10.9	13.9	13.5	10.7	6.9	2.6	0.0	12.2	9.5
65	-2.7	-1.6	0.4	2.6	6.8	10.1	13.2	13.0	10.1	6.4	2.0	-0.6	11.6	8.9
66	-2.3	-1.2	0.8	2.9	7.2	10.6	13.6	13.3	10.4	6.7	2.4	-0.2	12.0	9.2
69	-2.0	-1.0	1.0	3.3	7.5	10.9	13.9	13.6	10.7	7.0	2.7	0.0	12.3	9.6
70	-2.1	-1.0	1.0	3.2	7.4	10.8	13.8	13.5	10.6	6.9	2.6	0.0	12.2	9.5

Table A.1.4.: Precipitation (P) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	191.1	180.3	131.7	104.8	72.0	46.5	31.4	26.1	39.8	123.4	200.5	213.2	143.9	444.0
9	161.9	149.3	111.6	86.8	60.1	39.3	28.6	25.2	40.1	107.2	170.9	192.7	133.2	387.3
10	192.6	176.1	129.0	102.3	70.4	45.5	32.6	25.0	44.3	121.1	202.0	208.1	147.4	441.3
14	260.0	227.9	162.5	132.4	90.3	57.7	37.6	25.0	48.0	148.1	263.4	256.2	168.1	538.9
15	187.4	171.6	126.1	99.7	68.7	44.5	32.2	24.9	44.5	118.8	193.8	208.4	146.1	433.3
21	229.8	215.5	154.5	125.2	85.5	54.8	37.2	26.5	45.3	141.6	239.2	234.2	163.7	516.0
25	212.7	193.3	140.1	112.4	77.0	49.6	35.2	24.7	47.4	130.1	219.4	218.9	157.0	476.4
26	212.8	196.2	142.0	114.0	78.1	50.2	35.7	24.7	49.5	131.6	218.8	222.9	160.1	483.7
27	220.8	203.2	146.5	118.0	80.8	51.9	36.0	24.4	50.0	135.2	225.6	226.3	162.4	496.4
28	145.8	140.5	106.0	81.7	56.7	37.2	25.0	25.9	33.5	102.7	156.2	179.1	121.6	362.6
29	167.4	159.1	118.0	92.5	63.9	41.6	28.0	24.2	36.7	112.3	179.1	183.5	130.5	399.1
30	169.6	165.2	122.0	96.0	66.2	43.0	29.0	27.4	37.1	115.5	180.0	199.9	136.5	414.3
31	168.2	167.8	123.6	97.5	67.2	43.6	29.6	28.0	36.8	116.8	178.2	204.3	138.0	419.5
33	191.4	179.6	131.3	104.4	71.7	46.4	31.3	25.9	39.9	123.0	202.0	211.2	143.5	442.5
34	191.1	180.6	131.9	105.0	72.1	46.6	31.5	26.2	39.8	123.5	200.4	213.6	144.1	444.7
35	181.8	172.7	126.8	100.4	69.1	44.8	28.9	24.9	40.1	119.4	205.5	196.3	138.6	427.5
36	172.7	163.1	120.6	94.8	65.4	42.5	27.8	24.9	38.7	114.4	192.7	193.6	133.9	408.6
37	163.5	155.5	115.7	90.4	62.5	40.8	26.5	24.7	36.6	110.5	183.4	189.6	128.6	392.0
38	199.6	167.3	123.3	97.2	67.0	43.5	25.7	23.4	37.6	116.6	193.2	229.7	130.2	411.0
39	198.4	167.9	123.7	97.6	67.2	43.6	26.6	23.5	37.8	116.9	194.8	230.8	131.5	413.2
40	209.3	178.9	130.8	104.0	71.5	46.2	28.0	23.3	40.2	122.6	200.8	226.4	137.8	435.8
41	227.7	194.6	140.9	113.1	77.5	49.9	31.0	23.7	42.6	130.8	221.0	233.8	147.1	468.4
42	210.5	178.1	130.3	103.5	71.1	46.0	27.7	23.5	39.6	122.2	201.7	227.9	136.9	433.7
43	240.8	224.4	160.2	130.4	88.9	56.8	37.8	25.4	48.0	146.3	262.6	265.4	168.0	533.5
44	245.2	222.2	158.8	129.1	88.1	56.3	37.3	24.5	47.4	145.1	260.5	262.0	165.6	527.9
46	178.9	171.1	125.8	99.4	68.5	44.4	29.8	26.3	38.3	118.6	193.4	234.6	138.8	425.3
47	143.7	147.6	110.6	85.8	59.5	38.9	26.2	27.5	34.0	106.4	173.9	223.3	126.6	378.3
48	220.2	186.6	135.8	108.4	74.4	48.0	29.3	23.6	40.9	126.6	216.7	240.5	141.8	451.3
49	232.1	209.3	150.5	121.6	83.1	53.3	35.4	25.4	44.9	138.4	240.3	251.5	159.0	502.2
50	162.5	151.2	112.9	87.9	60.8	39.7	27.7	25.1	38.9	108.2	176.4	190.0	131.5	388.5
51	201.4	196.3	142.0	114.1	78.1	50.3	34.2	27.4	41.8	131.7	213.9	216.1	153.7	477.5
52	195.7	190.6	138.4	110.8	76.0	48.9	33.2	27.3	41.0	128.7	208.1	212.8	150.5	465.9
55	236.6	213.4	153.1	124.0	84.7	54.3	37.9	24.5	49.7	140.5	243.2	227.9	166.4	515.6
57	207.1	196.5	142.2	114.2	78.2	50.3	34.8	24.4	50.5	131.8	213.6	224.5	160.0	484.1
58	229.4	212.6	152.6	123.5	84.4	54.1	37.2	24.3	51.9	140.1	234.8	230.8	167.4	515.4
59	237.6	227.0	161.9	131.9	89.9	57.5	39.1	28.8	47.0	147.6	253.1	234.3	172.4	541.8
60	244.7	233.4	166.0	135.6	92.4	58.9	40.2	29.0	48.1	150.9	261.4	237.9	176.2	555.0
61	244.0	225.7	161.1	131.1	89.4	57.1	38.1	25.3	48.1	146.9	263.3	264.8	168.7	536.2
62	230.9	219.8	157.3	127.7	87.2	55.8	37.1	26.0	47.2	143.9	259.0	265.4	166.1	524.9
63	253.7	225.8	161.1	131.2	89.5	57.2	38.3	25.4	47.7	147.0	258.4	241.2	168.5	536.1
64	242.4	211.4	151.9	122.9	83.9	53.8	35.2	24.8	45.3	139.5	242.2	238.3	159.1	505.4
65	251.8	227.7	162.4	132.3	90.2	57.6	38.3	25.1	48.3	148.0	265.0	262.8	169.3	539.7
66	245.8	218.4	156.4	126.9	86.6	55.4	36.5	25.0	46.5	143.2	252.8	255.8	163.5	520.1
69	233.2	210.5	151.3	122.3	83.6	53.6	37.5	24.7	48.8	139.1	241.8	225.0	164.5	509.5
70	233.8	212.8	152.7	123.6	84.4	54.1	37.1	24.3	50.6	140.2	237.7	230.4	166.1	514.4

Table A.1.5.: Daily Potential evapotranspiration (PET) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	0.264	0.532	1.439	2.738	5.002	6.773	6.938	5.717	3.651	1.716	0.641	0.317	5.77	4.65
9	0.468	0.829	1.827	3.300	5.472	7.202	7.380	6.249	4.231	2.197	0.958	0.518	6.27	5.15
10	0.391	0.716	1.733	3.089	5.388	7.171	7.385	6.255	4.202	2.153	0.902	0.480	6.25	5.09
14	0.249	0.484	1.499	2.409	4.602	6.227	6.539	5.731	4.021	2.153	0.909	0.495	5.63	4.53
15	0.487	0.841	1.872	3.174	5.343	7.007	7.257	6.278	4.395	2.401	1.080	0.599	6.23	5.12
21	0.216	0.440	1.379	2.419	4.709	6.458	6.702	5.654	3.737	1.835	0.704	0.359	5.64	4.50
25	0.259	0.513	1.428	2.634	4.898	6.659	6.850	5.689	3.684	1.769	0.675	0.341	5.72	4.60
26	0.404	0.712	1.764	2.950	5.216	6.940	7.216	6.258	4.358	2.348	1.036	0.575	6.19	5.04
27	0.395	0.698	1.776	2.910	5.195	6.917	7.219	6.312	4.445	2.425	1.075	0.600	6.22	5.06
28	0.510	0.891	1.899	3.424	5.609	7.334	7.504	6.348	4.298	2.268	1.010	0.555	6.37	5.25
29	0.445	0.804	1.836	3.308	5.596	7.384	7.578	6.409	4.309	2.224	0.949	0.508	6.42	5.26
30	0.401	0.726	1.700	3.081	5.313	7.058	7.243	6.090	4.058	2.074	0.877	0.470	6.11	4.99
31	0.466	0.824	1.844	3.165	5.270	6.894	7.139	6.191	4.324	2.329	1.027	0.555	6.14	5.04
33	0.811	1.235	2.442	3.640	5.700	7.237	7.631	7.070	5.474	3.428	1.799	1.099	6.85	5.74
34	0.682	1.081	2.244	3.483	5.619	7.225	7.575	6.867	5.140	3.079	1.540	0.915	6.70	5.57
35	0.812	1.233	2.401	3.645	5.694	7.238	7.602	6.976	5.334	3.309	1.739	1.066	6.79	5.69
36	1.142	1.625	2.821	3.962	5.696	6.996	7.445	7.199	5.939	4.024	2.303	1.469	6.89	5.89
37	0.400	0.731	1.693	3.129	5.345	7.088	7.250	6.058	3.998	2.016	0.844	0.448	6.10	4.98
38	0.462	0.808	1.829	3.206	5.431	7.162	7.381	6.305	4.309	2.282	1.007	0.555	6.29	5.15
39	0.682	1.082	2.195	3.515	5.630	7.251	7.554	6.744	4.952	2.910	1.448	0.858	6.63	5.51
40	0.734	1.135	2.293	3.510	5.594	7.158	7.518	6.863	5.197	3.172	1.629	0.986	6.68	5.57
41	0.630	1.002	2.184	3.307	5.440	7.022	7.401	6.772	5.128	3.097	1.548	0.924	6.58	5.45
42	0.722	1.117	2.260	3.483	5.573	7.146	7.494	6.809	5.124	3.111	1.596	0.967	6.64	5.53
43	0.260	0.501	1.521	2.485	4.735	6.416	6.718	5.846	4.061	2.149	0.899	0.487	5.76	4.63
44	0.199	0.410	1.329	2.323	4.579	6.302	6.545	5.518	3.642	1.785	0.682	0.348	5.50	4.38
46	0.692	1.090	2.204	3.473	5.542	7.116	7.434	6.692	4.970	2.960	1.488	0.886	6.55	5.46
47	0.483	0.844	1.831	3.293	5.459	7.163	7.347	6.216	4.206	2.211	0.978	0.537	6.23	5.13
48	0.308	0.586	1.528	2.772	5.013	6.754	6.954	5.828	3.838	1.900	0.761	0.396	5.84	4.72
49	0.500	0.829	2.000	3.028	5.206	6.804	7.185	6.543	4.898	2.896	1.397	0.821	6.36	5.22
50	0.615	1.028	2.103	3.556	5.696	7.355	7.598	6.635	4.707	2.643	1.246	0.705	6.57	5.46
51	0.175	0.369	1.134	2.223	4.326	5.994	6.127	4.939	3.050	1.356	0.472	0.232	5.03	4.00
52	0.156	0.358	1.173	2.400	4.652	6.424	6.555	5.263	3.183	1.326	0.413	0.192	5.36	4.26
55	0.226	0.458	1.396	2.476	4.772	6.532	6.767	5.691	3.743	1.827	0.699	0.355	5.68	4.54
57	0.156	0.360	1.182	2.368	4.620	6.391	6.537	5.273	3.222	1.370	0.434	0.198	5.36	4.25
58	0.217	0.449	1.385	2.484	4.800	6.577	6.807	5.706	3.727	1.794	0.671	0.335	5.70	4.56
59	0.158	0.346	1.214	2.160	4.378	6.079	6.307	5.269	3.418	1.623	0.590	0.292	5.27	4.18
60	0.173	0.376	1.340	2.269	4.573	6.307	6.587	5.621	3.770	1.875	0.713	0.362	5.57	4.43
61	0.240	0.475	1.487	2.462	4.753	6.470	6.766	5.849	4.017	2.086	0.852	0.455	5.78	4.63
62	0.134	0.316	1.148	2.186	4.469	6.240	6.432	5.255	3.271	1.435	0.465	0.212	5.30	4.18
63	0.081	0.198	0.866	1.793	3.928	5.620	5.755	4.530	2.634	1.033	0.297	0.150	4.63	3.61
64	0.243	0.471	1.372	2.389	4.535	6.179	6.408	5.425	3.619	1.817	0.726	0.381	5.41	4.34
65	0.220	0.445	1.439	2.397	4.681	6.396	6.686	5.756	3.926	2.016	0.810	0.428	5.69	4.55
66	0.173	0.372	1.238	2.265	4.516	6.253	6.465	5.360	3.433	1.601	0.575	0.281	5.38	4.27
69	0.223	0.458	1.394	2.506	4.820	6.598	6.825	5.716	3.733	1.797	0.673	0.336	5.72	4.57
70	0.207	0.436	1.374	2.476	4.792	6.569	6.798	5.695	3.713	1.767	0.642	0.319	5.69	4.54

Table A.1.6.: Monthly Potential evapotranspiration (PET) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	8.2	14.9	44.6	82.2	155.1	203.2	215.1	177.2	109.5	53.2	19.2	9.8	595.5	995.4
9	14.5	23.2	56.6	99.0	169.6	216.0	228.8	193.7	126.9	68.1	28.8	16.0	638.5	1102.2
10	12.1	20.1	53.7	92.7	167.0	215.1	228.9	193.9	126.1	66.8	27.1	14.9	638.0	1090.5
14	7.7	13.6	46.5	72.3	142.7	186.8	202.7	177.7	120.6	66.8	27.3	15.3	567.2	969.5
15	15.1	23.5	58.0	95.2	165.6	210.2	225.0	194.6	131.8	74.4	32.4	18.6	629.8	1096.9
21	6.7	12.3	42.8	72.6	146.0	193.7	207.8	175.3	112.1	56.9	21.1	11.1	576.8	964.3
25	8.0	14.4	44.3	79.0	151.8	199.8	212.3	176.4	110.5	54.8	20.2	10.6	588.5	984.7
26	12.5	19.9	54.7	88.5	161.7	208.2	223.7	194.0	130.7	72.8	31.1	17.8	625.9	1079.7
27	12.2	19.5	55.1	87.3	161.0	207.5	223.8	195.7	133.3	75.2	32.3	18.6	627.0	1083.8
28	15.8	24.9	58.9	102.7	173.9	220.0	232.6	196.8	129.0	70.3	30.3	17.2	649.4	1125.3
29	13.8	22.5	56.9	99.2	173.5	221.5	234.9	198.7	129.3	68.9	28.5	15.8	655.1	1126.0
30	12.4	20.3	52.7	92.4	164.7	211.7	224.5	188.8	121.8	64.3	26.3	14.6	625.1	1068.3
31	14.5	23.1	57.2	95.0	163.4	206.8	221.3	191.9	129.7	72.2	30.8	17.2	620.1	1080.3
33	25.1	34.6	75.7	109.2	176.7	217.1	236.6	219.2	164.2	106.3	54.0	34.1	672.9	1229.2
34	21.1	30.3	69.6	104.5	174.2	216.7	234.8	212.9	154.2	95.4	46.2	28.4	664.5	1192.8
35	25.2	34.5	74.4	109.4	176.5	217.1	235.6	216.3	160.0	102.6	52.2	33.0	669.1	1217.5
36	35.4	45.5	87.5	118.8	176.6	209.9	230.8	223.2	178.2	124.8	69.1	45.5	663.8	1262.2
37	12.4	20.5	52.5	93.9	165.7	212.6	224.8	187.8	119.9	62.5	25.3	13.9	625.2	1067.2
38	14.3	22.6	56.7	96.2	168.4	214.9	228.8	195.4	129.3	70.7	30.2	17.2	639.1	1103.6
39	21.1	30.3	68.0	105.4	174.5	217.5	234.2	209.0	148.6	90.2	43.4	26.6	660.7	1179.5
40	22.7	31.8	71.1	105.3	173.4	214.7	233.0	212.7	155.9	98.3	48.9	30.6	660.5	1193.5
41	19.5	28.0	67.7	99.2	168.6	210.6	229.4	209.9	153.8	96.0	46.4	28.7	650.0	1167.7
42	22.4	31.3	70.0	104.5	172.8	214.4	232.3	211.1	153.7	96.4	47.9	30.0	657.8	1185.2
43	8.1	14.0	47.2	74.5	146.8	192.5	208.3	181.2	121.8	66.6	27.0	15.1	582.0	991.7
44	6.2	11.5	41.2	69.7	141.9	189.0	202.9	171.1	109.3	55.3	20.5	10.8	563.0	939.2
46	21.4	30.5	68.3	104.2	171.8	213.5	230.5	207.4	149.1	91.8	44.6	27.5	651.4	1168.3
47	15.0	23.6	56.8	98.8	169.2	214.9	227.8	192.7	126.2	68.5	29.3	16.7	635.4	1098.1
48	9.6	16.4	47.4	83.2	155.4	202.6	215.6	180.7	115.1	58.9	22.8	12.3	598.9	1011.4
49	15.5	23.2	62.0	90.8	161.4	204.1	222.7	202.8	146.9	89.8	41.9	25.5	629.7	1118.6
50	19.1	28.8	65.2	106.7	176.6	220.6	235.5	205.7	141.2	81.9	37.4	21.9	661.9	1168.3
51	5.4	10.3	35.2	66.7	134.1	179.8	189.9	153.1	91.5	42.0	14.2	7.2	522.9	857.2
52	4.8	10.0	36.3	72.0	144.2	192.7	203.2	163.2	95.5	41.1	12.4	5.9	559.1	911.9
55	7.0	12.8	43.3	74.3	147.9	196.0	209.8	176.4	112.3	56.6	21.0	11.0	582.2	973.3
57	4.8	10.1	36.6	71.0	143.2	191.7	202.6	163.5	96.7	42.5	13.0	6.1	557.8	911.2
58	6.7	12.6	42.9	74.5	148.8	197.3	211.0	176.9	111.8	55.6	20.1	10.4	585.2	976.0
59	4.9	9.7	37.6	64.8	135.7	182.4	195.5	163.3	102.5	50.3	17.7	9.0	541.2	894.6
60	5.3	10.5	41.6	68.1	141.8	189.2	204.2	174.2	113.1	58.1	21.4	11.2	567.6	948.7
61	7.4	13.3	46.1	73.9	147.3	194.1	209.7	181.3	120.5	64.7	25.6	14.1	585.1	991.5
62	4.1	8.8	35.6	65.6	138.5	187.2	199.4	162.9	98.1	44.5	14.0	6.6	549.5	896.2
63	2.5	5.6	26.8	53.8	121.8	168.6	178.4	140.4	79.0	32.0	8.9	4.7	487.4	774.0
64	7.5	13.2	42.5	71.7	140.6	185.4	198.6	168.2	108.6	56.3	21.8	11.8	552.2	929.4
65	6.8	12.5	44.6	71.9	145.1	191.9	207.3	178.4	117.8	62.5	24.3	13.3	577.6	974.9
66	5.4	10.4	38.4	67.9	140.0	187.6	200.4	166.1	103.0	49.6	17.2	8.7	554.1	914.7
69	6.9	12.8	43.2	75.2	149.4	197.9	211.6	177.2	112.0	55.7	20.2	10.4	586.7	979.0
70	6.4	12.2	42.6	74.3	148.5	197.1	210.8	176.5	111.4	54.8	19.3	9.9	584.4	973.3

Table A.1.7.: Humidity index (HI) values for the plots/sites of the study area.

plot	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Dry period	Veg. period
6	23.35	12.11	2.95	1.28	0.46	0.23	0.15	0.15	0.36	2.32	10.43	21.72	0.24	0.45
9	11.16	6.43	1.97	0.88	0.35	0.18	0.13	0.13	0.32	1.57	5.94	12.01	0.21	0.35
10	15.90	8.78	2.40	1.10	0.42	0.21	0.14	0.13	0.35	1.81	7.46	13.99	0.23	0.40
14	33.65	16.81	3.50	1.83	0.63	0.31	0.19	0.14	0.40	2.22	9.66	16.70	0.30	0.56
15	12.42	7.29	2.17	1.05	0.41	0.21	0.14	0.13	0.34	1.60	5.98	11.22	0.23	0.40
21	34.37	17.50	3.61	1.73	0.59	0.28	0.18	0.15	0.40	2.49	11.33	21.02	0.28	0.54
25	26.52	13.45	3.17	1.42	0.51	0.25	0.17	0.14	0.43	2.37	10.84	20.73	0.27	0.48
26	16.99	9.83	2.60	1.29	0.48	0.24	0.16	0.13	0.38	1.81	7.04	12.51	0.26	0.45
27	18.04	10.40	2.66	1.35	0.50	0.25	0.16	0.12	0.38	1.80	6.99	12.17	0.26	0.46
28	9.22	5.63	1.80	0.80	0.33	0.17	0.11	0.13	0.26	1.46	5.15	10.41	0.19	0.32
29	12.14	7.07	2.07	0.93	0.37	0.19	0.12	0.12	0.28	1.63	6.29	11.65	0.20	0.35
30	13.65	8.13	2.31	1.04	0.40	0.20	0.13	0.15	0.30	1.80	6.84	13.73	0.22	0.39
31	11.63	7.27	2.16	1.03	0.41	0.21	0.13	0.15	0.28	1.62	5.79	11.88	0.22	0.39
33	7.62	5.19	1.73	0.96	0.41	0.21	0.13	0.12	0.24	1.16	3.74	6.20	0.21	0.36
34	9.04	5.97	1.90	1.00	0.41	0.22	0.13	0.12	0.26	1.29	4.34	7.53	0.22	0.37
35	7.22	5.00	1.70	0.92	0.39	0.21	0.12	0.12	0.25	1.16	3.94	5.94	0.21	0.35
36	4.88	3.58	1.38	0.80	0.37	0.20	0.12	0.11	0.22	0.92	2.79	4.25	0.20	0.32
37	13.20	7.60	2.20	0.96	0.38	0.19	0.12	0.13	0.31	1.77	7.25	13.65	0.21	0.37
38	13.95	7.40	2.17	1.01	0.40	0.20	0.11	0.12	0.29	1.65	6.39	13.35	0.20	0.37
39	9.39	5.54	1.82	0.93	0.39	0.20	0.11	0.11	0.25	1.30	4.49	8.68	0.20	0.35
40	9.20	5.63	1.84	0.99	0.41	0.22	0.12	0.11	0.26	1.25	4.11	7.41	0.21	0.37
41	11.66	6.94	2.08	1.14	0.46	0.24	0.14	0.11	0.28	1.36	4.76	8.16	0.23	0.40
42	9.41	5.69	1.86	0.99	0.41	0.21	0.12	0.11	0.26	1.27	4.21	7.60	0.21	0.37
43	29.90	15.98	3.40	1.75	0.61	0.30	0.18	0.14	0.39	2.20	9.74	17.58	0.29	0.54
44	39.82	19.34	3.85	1.85	0.62	0.30	0.18	0.14	0.43	2.62	12.73	24.25	0.29	0.56
46	8.34	5.60	1.84	0.95	0.40	0.21	0.13	0.13	0.26	1.29	4.33	8.55	0.21	0.36
47	9.59	6.25	1.95	0.87	0.35	0.18	0.12	0.14	0.27	1.55	5.93	13.41	0.20	0.34
48	23.05	11.37	2.87	1.30	0.48	0.24	0.14	0.13	0.36	2.15	9.50	19.61	0.24	0.45
49	14.99	9.02	2.43	1.34	0.52	0.26	0.16	0.13	0.31	1.54	5.73	9.88	0.25	0.45
50	8.53	5.25	1.73	0.82	0.34	0.18	0.12	0.12	0.28	1.32	4.72	8.69	0.20	0.33
51	37.07	19.02	4.04	1.71	0.58	0.28	0.18	0.18	0.46	3.13	15.11	30.09	0.29	0.56
52	40.60	19.04	3.81	1.54	0.53	0.25	0.16	0.17	0.43	3.13	16.78	35.78	0.27	0.51
55	33.79	16.65	3.54	1.67	0.57	0.28	0.18	0.14	0.44	2.48	11.60	20.73	0.29	0.53
57	42.82	19.50	3.88	1.61	0.55	0.26	0.17	0.15	0.52	3.10	16.40	36.58	0.29	0.53
58	34.06	16.93	3.55	1.66	0.57	0.27	0.18	0.14	0.46	2.52	11.67	22.22	0.29	0.53
59	48.48	23.42	4.30	2.04	0.66	0.32	0.20	0.18	0.46	2.93	14.29	25.89	0.32	0.61
60	45.75	22.14	4.00	1.99	0.65	0.31	0.20	0.17	0.42	2.60	12.22	21.19	0.31	0.59
61	32.77	16.98	3.49	1.78	0.61	0.29	0.18	0.14	0.40	2.27	10.30	18.77	0.29	0.54
62	55.78	24.86	4.42	1.95	0.63	0.30	0.19	0.16	0.48	3.23	18.55	40.48	0.30	0.59
63	100.91	40.65	6.00	2.44	0.73	0.34	0.21	0.18	0.60	4.59	28.97	51.79	0.35	0.69
64	32.23	16.02	3.57	1.71	0.60	0.29	0.18	0.15	0.42	2.48	11.12	20.17	0.29	0.54
65	36.90	18.28	3.64	1.84	0.62	0.30	0.18	0.14	0.41	2.37	10.91	19.81	0.29	0.55
66	45.88	20.96	4.07	1.87	0.62	0.30	0.18	0.15	0.45	2.89	14.66	29.33	0.29	0.57
69	33.78	16.43	3.50	1.63	0.56	0.27	0.18	0.14	0.44	2.50	11.97	21.57	0.28	0.52
70	36.44	17.42	3.59	1.66	0.57	0.27	0.18	0.14	0.45	2.56	12.33	23.33	0.28	0.53

Table A.1.8.: Climatic data for the weather stations of the study area.

(a) Monthly, annual, vegetation and dry period precipitation (mm) data for the 19 weather stations of the study area.

	Lamia	Amouri	Ipati	Gravia	Lefkada	Lidoriki	Sikea	Ath.Diakos	Koniakos	Arachova	Pentagioi	Karpenisi	Grigorio	Dafnos	Ag.Nikolaos	Krikelo	Gram.Oxia	Pira	Miriki
Jan	61.3	87.7	103.3	124.4	102.0	137.3	202.8	216.8	202.4	161.4	196.1	137.8	205.6	184.3	181.0	216.1	176.0	221.2	170.1
Feb	67.4	79.0	95.2	113.1	109.2	121.4	193.4	156.2	151.2	160.8	191.3	135.8	192.0	179.3	184.0	181.6	161.5	211.8	152.4
Mar	65.6	54.6	88.9	101.4	82.5	83.7	145.5	102.7	106.3	106.8	126.0	126.2	162.6	138.8	122.0	127.1	111.4	161.0	108.6
Apr	40.8	44.4	50.7	57.1	81.0	64.8	96.9	107.4	81.0	100.8	103.4	109.0	151.4	90.4	115.0	88.8	83.1	88.4	94.9
May	36.3	32.4	45.1	38.3	42.5	46.7	62.9	71.3	61.5	66.7	56.3	74.5	94.6	70.7	77.0	69.4	68.1	55.8	71.9
Jun	27.2	26.1	28.2	23.1	27.3	29.7	34.7	52.2	40.2	40.6	40.8	45.4	61.3	52.5	46.0	38.6	39.1	45.3	48.4
Jul	20.3	15.5	16.2	19.3	13.4	19.2	31.8	30.0	38.1	26.0	18.5	30.5	39.5	43.4	36.0	25.0	33.5	27.3	24.5
Aug	19.5	11.8	15.8	21.4	24.9	17.1	24.7	27.4	24.4	26.6	22.5	26.5	27.4	34.0	28.0	21.7	30.7	26.7	19.3
Sep	25.3	19.9	27.6	29.0	25.0	34.3	35.8	31.8	32.6	38.5	36.5	42.5	50.0	30.9	59.0	39.1	31.9	32.2	48.3
Oct	70.3	63.8	102.4	107.1	69.5	89.2	111.3	124.1	78.9	107.7	103.2	124.5	166.2	107.8	123.0	107.7	128.5	126.6	126.0
Nov	67.4	74.2	89.9	121.6	141.1	161.4	182.3	238.9	186.0	194.6	201.0	171.6	299.6	199.4	193.0	207.3	183.4	164.2	179.4
Dec	81.7	76.2	116.9	159.6	135.1	186.9	217.2	272.6	232.3	242.3	237.9	199.1	328.8	177.1	233.0	245.4	217.1	218.9	203.2
Dry period	92.3	73.3	87.8	92.8	90.6	100.3	127.0	141.4	135.3	131.7	118.3	144.9	178.2	160.8	169.0	124.4	135.2	131.5	140.5
Veg. period	239.7	213.9	286.0	295.3	283.6	301.0	398.1	444.2	405.5	406.9	381.2	452.9	590.4	429.7	484.0	390.3	414.9	402.3	433.3
Year	583.1	585.6	780.2	915.4	853.5	991.7	1339.3	1431.4	1234.9	1272.8	1333.5	1223.4	1779.0	1308.6	1397.0	1367.8	1264.3	1379.4	1247.0

(b) Monthly, annual, vegetation and dry period temperature (°C) data for the 10 weather stations of the study area. The mean, average maximum and average minimum values for each period is given.

	Lamia			Amouri			Lefkada			Lidoriki			Arachova			Karpenisi			Ag.Nikolaos			Krikelo			Gram.Oxia			Miriki		
	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.
Jan	11.5	7.6	3.6	11.0	6.6	2.5	9.6	6.1	2.6	9.1	5.2	1.4	6.2	3.6	0.5	7.9	4.2	0.5	2.5	0.2	-2.5	4.7	1.4	-2.0	5.9	2.6	-0.6	5.2	2.5	-0.3
Feb	12.8	8.5	4.3	11.8	7.4	2.9	10.5	6.9	3.3	10.1	6.0	1.8	8.3	5.5	2.5	6.9	3.3	-0.2	3.7	1.3	-1.4	6.5	2.5	-1.5	6.7	3.8	0.8	7.3	4.1	1.0
Mar	15.2	10.7	6.3	14.3	9.8	4.2	14.0	9.9	5.8	14.1	8.9	3.7	11.5	7.7	4.5	9.3	5.5	1.7	7.0	3.9	0.6	10.2	5.2	0.8	10.2	6.2	2.1	11.2	7.1	3.1
Apr	20.1	15.0	9.8	20.1	14.9	7.5	18.5	13.5	8.1	18.2	12.7	6.3	14.6	10.7	6.4	15.5	10.4	5.3	10.4	6.8	2.8	13.3	8.1	3.0	13.3	9.2	5.0	14.7	10.0	5.4
May	25.3	19.9	14.4	25.8	20.4	11.9	24.0	18.5	12.9	23.0	17.3	10.0	20.3	16.0	10.5	19.6	14.3	9.0	16.2	11.8	7.4	19.5	13.5	7.4	19.2	14.3	9.4	21.3	15.5	10.1
Jun	30.4	24.5	18.6	30.5	25.0	16.3	28.5	22.4	16.3	28.2	22.3	13.8	25.8	20.2	13.7	23.2	17.5	11.7	21.9	16.9	11.4	25.1	18.4	11.7	23.4	18.0	12.6	24.9	19.5	14.1
Jul	32.3	26.4	20.6	32.0	26.2	18.0	30.8	24.5	18.3	31.1	25.1	16.4	27.0	21.6	15.6	26.4	20.7	14.9	23.6	18.5	13.3	27.7	21.0	14.2	27.0	20.3	16.4	27.1	21.9	16.7
Aug	31.6	25.8	20.0	31.0	25.2	16.4	29.7	23.8	17.8	30.9	24.3	16.3	26.3	20.9	15.4	26.2	20.4	14.6	22.8	18.3	13.8	26.2	19.7	13.3	24.9	19.9	14.9	26.3	21.2	16.2
Sep	28.4	22.7	17.0	27.5	21.3	13.5	26.7	21.0	15.3	27.3	20.6	13.3	24.8	19.7	14.3	23.2	17.6	11.9	19.3	14.9	10.5	22.0	16.0	10.1	22.5	16.9	11.3	23.6	18.4	13.3
Oct	22.3	17.5	12.7	22.3	16.5	10.2	20.5	16.0	11.5	20.9	15.2	9.9	19.1	14.6	11.0	18.6	13.3	7.9	13.2	9.9	6.5	15.3	10.8	6.0	16.7	12.4	8.1	17.1	13.3	9.4
Nov	17.4	13.1	8.8	17.0	11.5	6.4	14.6	10.9	7.3	14.0	9.7	5.7	12.5	9.5	6.0	11.3	7.4	3.4	8.4	5.6	2.7	11.0	6.6	2.3	11.1	7.6	4.1	11.4	8.2	5.0
Dec	13.1	9.1	5.2	12.7	8.4	3.6	11.3	7.9	4.5	10.3	6.5	2.9	8.3	5.5	2.6	8.7	5.2	1.7	4.9	2.4	-0.1	7.0	3.1	-0.7	8.2	4.8	1.3	7.8	4.9	2.1
Dry period	30.7	24.9	19.1	30.3	24.4	16.1	28.9	22.9	16.9	29.4	23.1	15.0	26.0	20.6	14.8	24.8	19.1	13.3	21.9	17.2	12.3	25.3	18.8	12.3	24.5	18.8	13.8	25.5	20.3	15.1
Veg. period	27.2	21.7	16.2	27.0	21.4	13.4	25.5	20.0	14.3	25.7	19.6	12.3	22.6	17.7	12.4	21.8	16.3	10.8	18.2	13.9	9.4	21.3	15.4	9.4	21.0	15.9	11.1	22.1	17.1	12.2
Year	21.7	16.7	11.8	21.3	16.1	9.5	19.9	15.1	10.3	19.8	14.5	8.5	17.1	13.0	8.6	16.4	11.7	6.9	12.8	9.2	5.4	15.7	10.5	5.4	15.8	11.3	7.1	16.5	12.2	8.0

A.2. Climatic maps

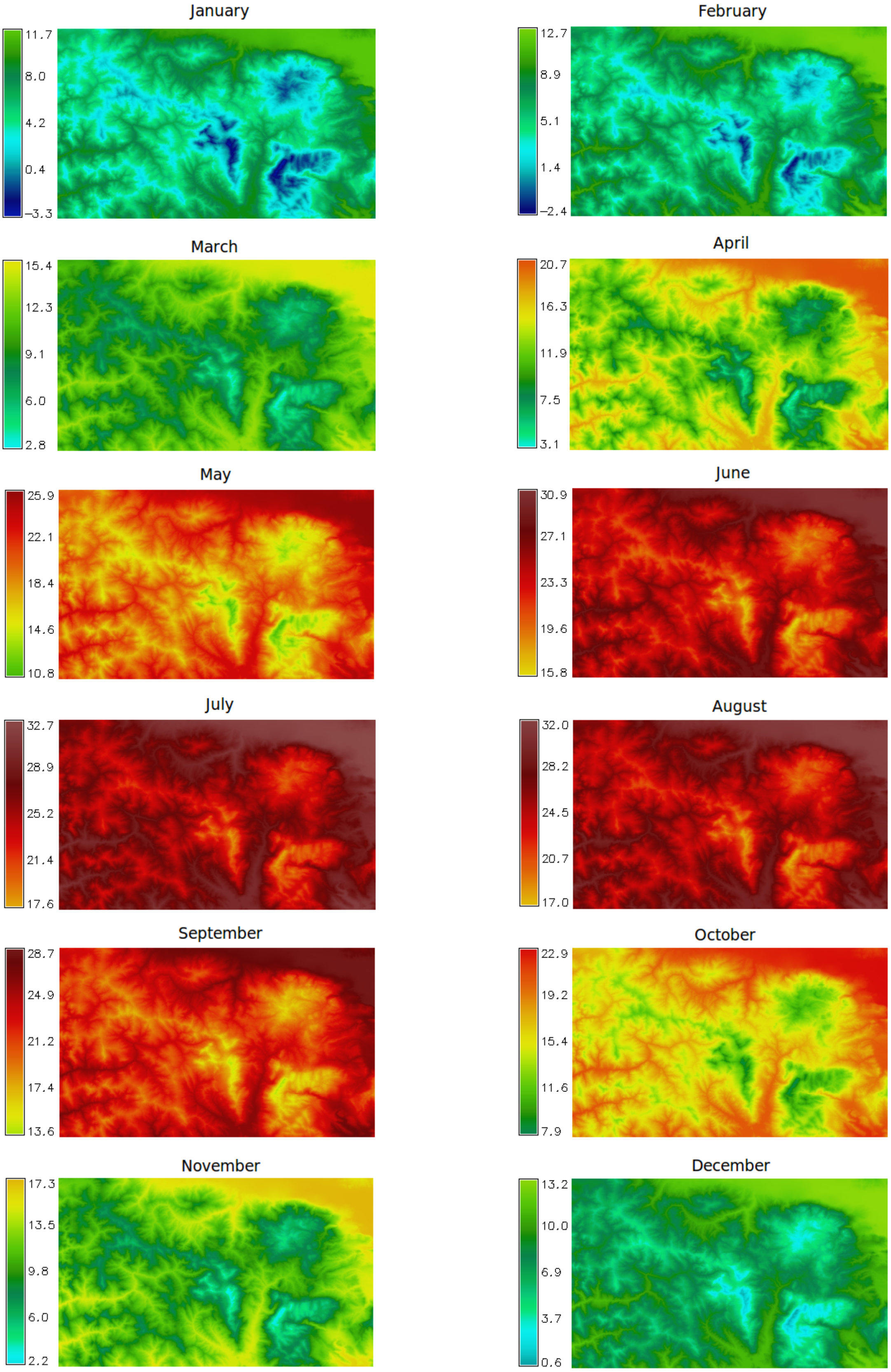


Figure A.2.1.: Maps of monthly average maximum air temperature (°C).

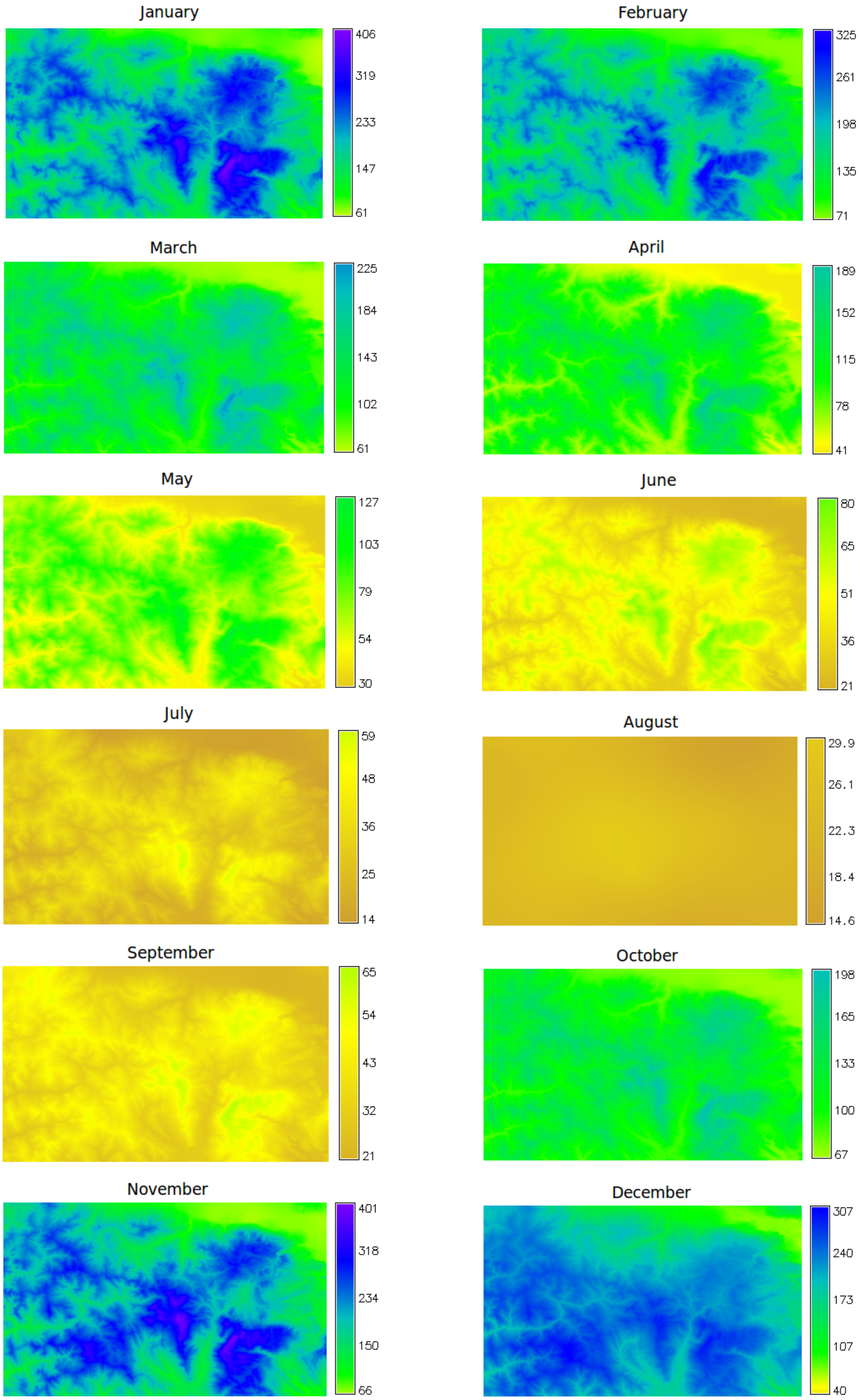


Figure A.2.3.: Maps of monthly precipitation (mm).

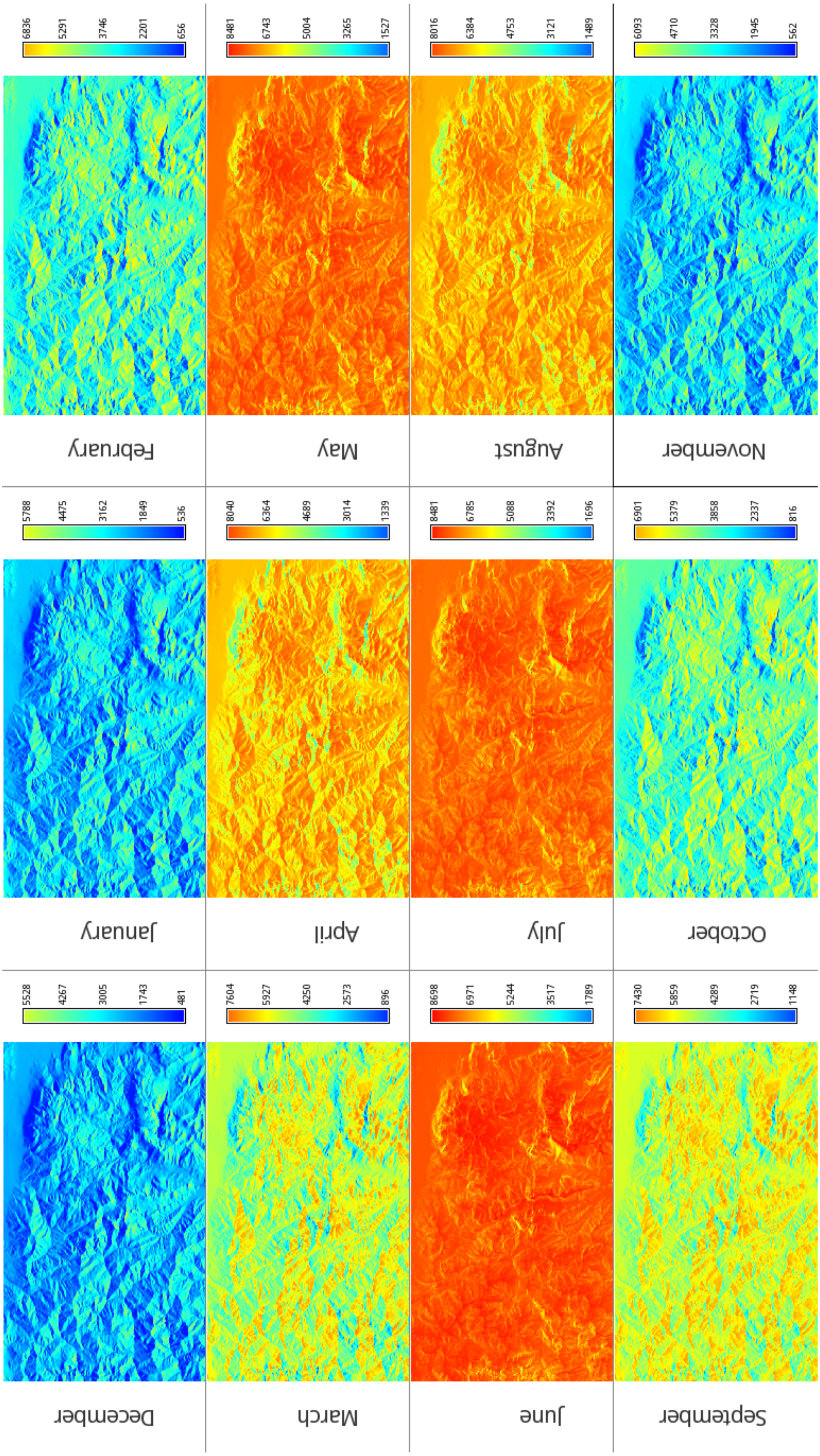


Figure A.2.2.: Monthly means of daily sums of clear-sky global solar irradiation calculated for the study area with the *r.sun*. The units are in $^{\mathrm{Wh}}/_{\mathrm{m^2 \cdot day}}$.

A.3. Statistics

A.3.1. MRPP

A.3.1.1. Between groups A and B

Dissimilarity index: bray

Weights for groups: n

Class means and counts:

	A	B
delta	0.566	0.5378
n	22	23

Chance corrected within-group agreement A: **0.1133**

Based on observed delta **0.5516** and expected delta **0.6221**

Significance of delta: **0.000999 *****

Based on 1000 permutations

A.3.1.2. Between sub-groups A1 and A2

Dissimilarity index: bray

Weights for groups: n

Class means and counts:

	A1	A2
delta	0.5798	0.47
n	9	13

Chance corrected within-group agreement A: **0.09025**

Based on observed delta **0.5149** and expected delta **0.566**

Significance of delta: **0.000999 *****

Based on 1000 permutations

A.3.1.3. Between sub-groups B1 and B2

Dissimilarity index: bray

Weights for groups: n

Class means and counts:

	B1	B2
delta	0.5064	0.4604
n	17	6

Chance corrected within-group agreement A: **0.08079**

Based on observed delta **0.4944** and expected delta **0.5378**

Significance of delta: **0.000999 *****

Based on 1000 permutations

A.3.2. PERMANOVA

A.3.2.1. Between groups A and B

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
AB	1	2.0890	2.08904	13.314	0.23642	0.000999	***
Residuals	43	6.7471	0.15691			0.76358	
Total	44	8.8361				1.00000	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

A.3.2.2. Between sub-groups A1 and A2

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
A1A2	1	0.7520	0.75200	5.5322	0.21667	0.000999	***
Residuals	20	2.7186	0.13593		0.78333		
Total	21	3.4706			1.00000		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

A.3.2.3. Between sub-groups B1 and B2

	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
B1B2	1	0.6287	0.62872	4.9866	0.19189	0.000999	***
Residuals	21	2.6477	0.12608		0.80811		
Total	22	3.2764			1.00000		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

A.4. Boxplots

Comparison of different environmental variables among the vegetation units with the use of boxplots. The vegetation units are indicated by different symbols (A1: *Crepis fraasii* - *Abies cephalonica* community subtype with *Castanea sativa*, A2: *Crepis fraasii* - *Abies cephalonica* community subtype with *Trifolium grandiflorum*, B1: *Sanicula europaea* - *Abies cephalonica* community subtype with *Silene multicaulis* ssp. *multicaulis*, B2: *Sanicula europaea* - *Abies cephalonica* community subtype with *Rubus hirtus*).

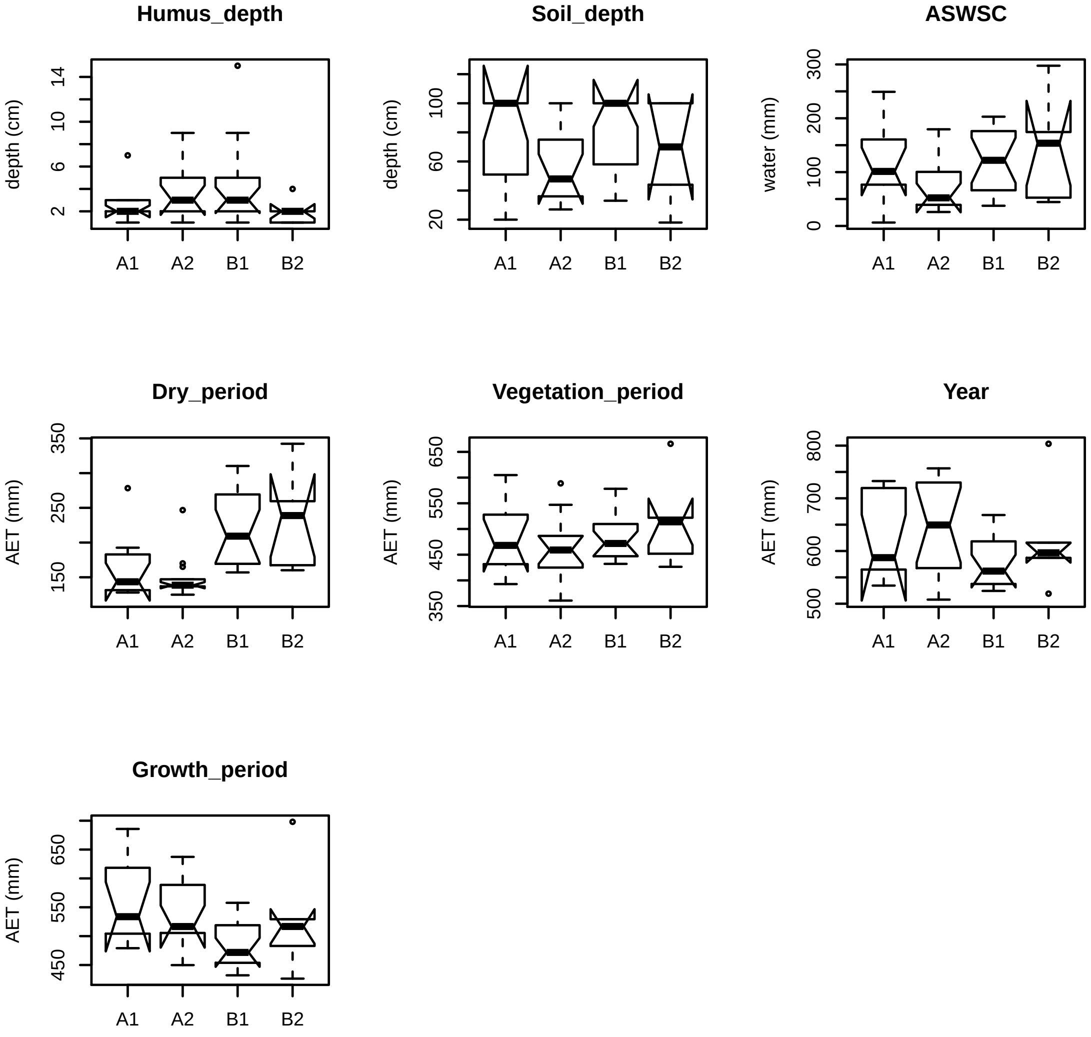


Figure A.4.1.: Comparison of humus and soil depth, available soil water storage capacity (ASWSC) and actual evapotranspiration (AET), among the four vegetation subtypes (A1, A2, B1, B2).

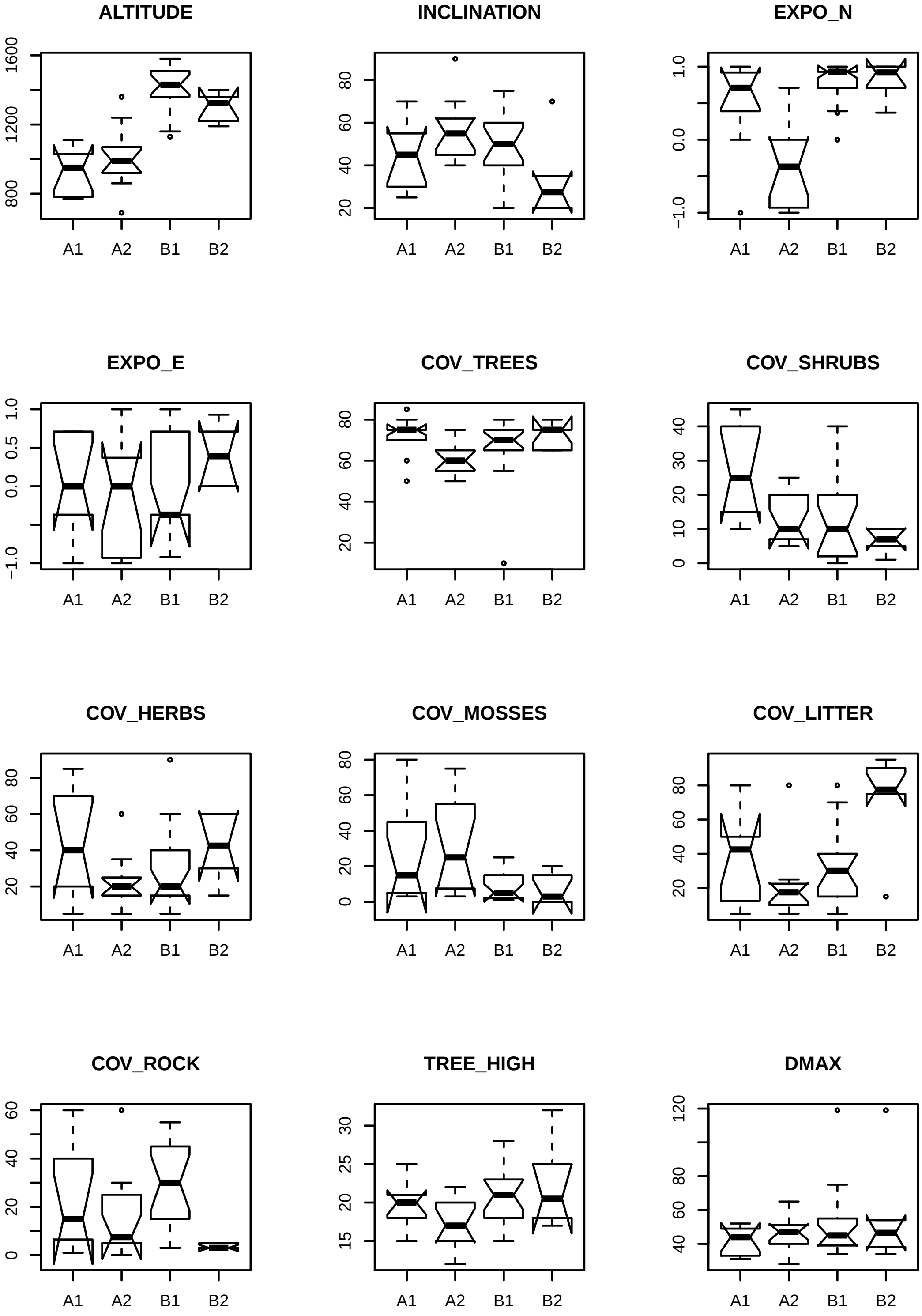


Figure A.4.2.: Comparison of topographic and structure variables among the four vegetation subtypes (A1, A2, B1, B2).

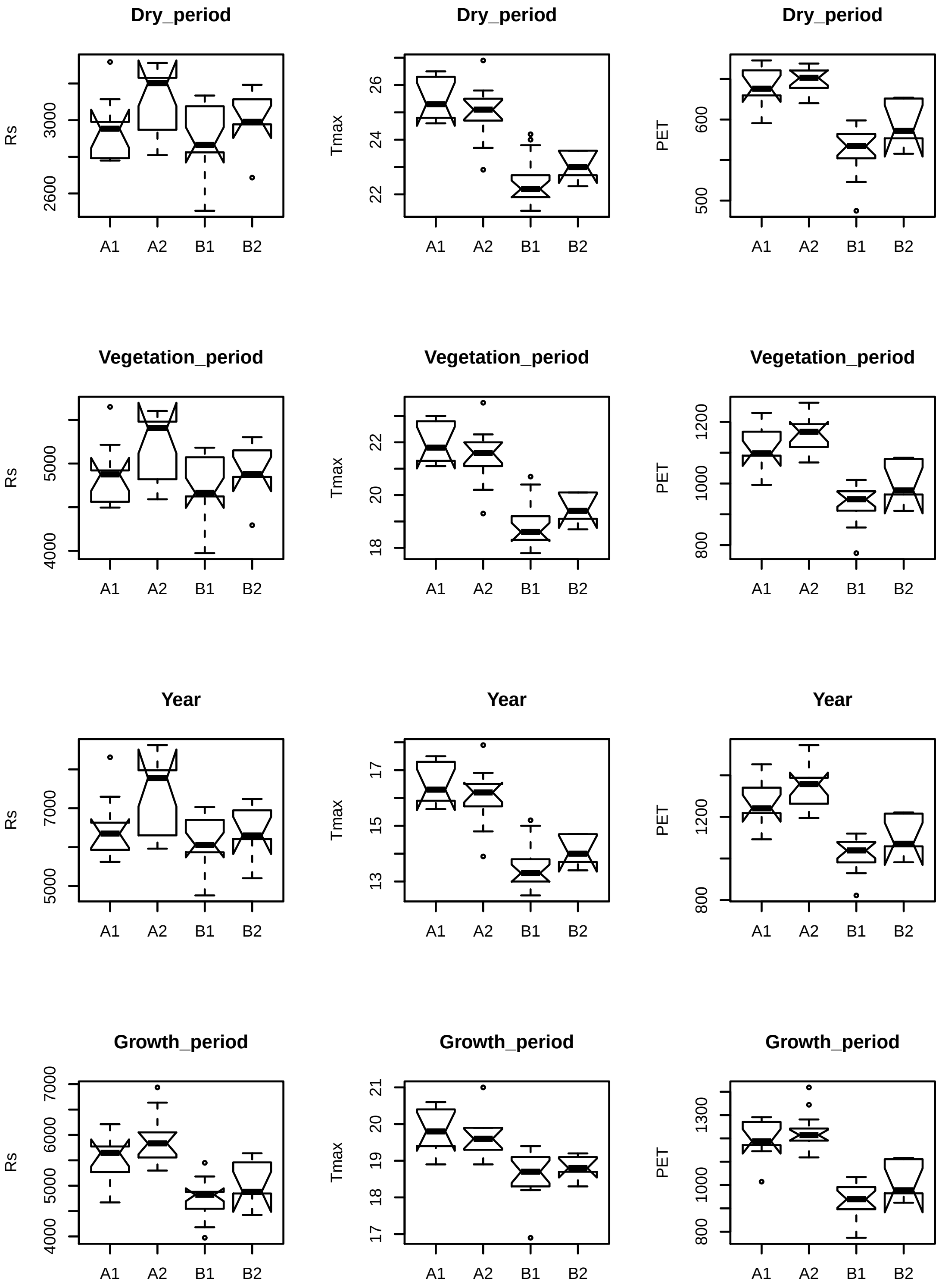


Figure A.4.3.: Comparison of climatic variables among the four vegetation subtypes (A1, A2, B1, B2). The values of solar radiation (Rs) are in $\mathrm{Mj}/\mathrm{m}^2\cdot\mathrm{day}$, of maximum air temperature (Tmax) in °C and of potential evapotranspiration (PET) in mm.

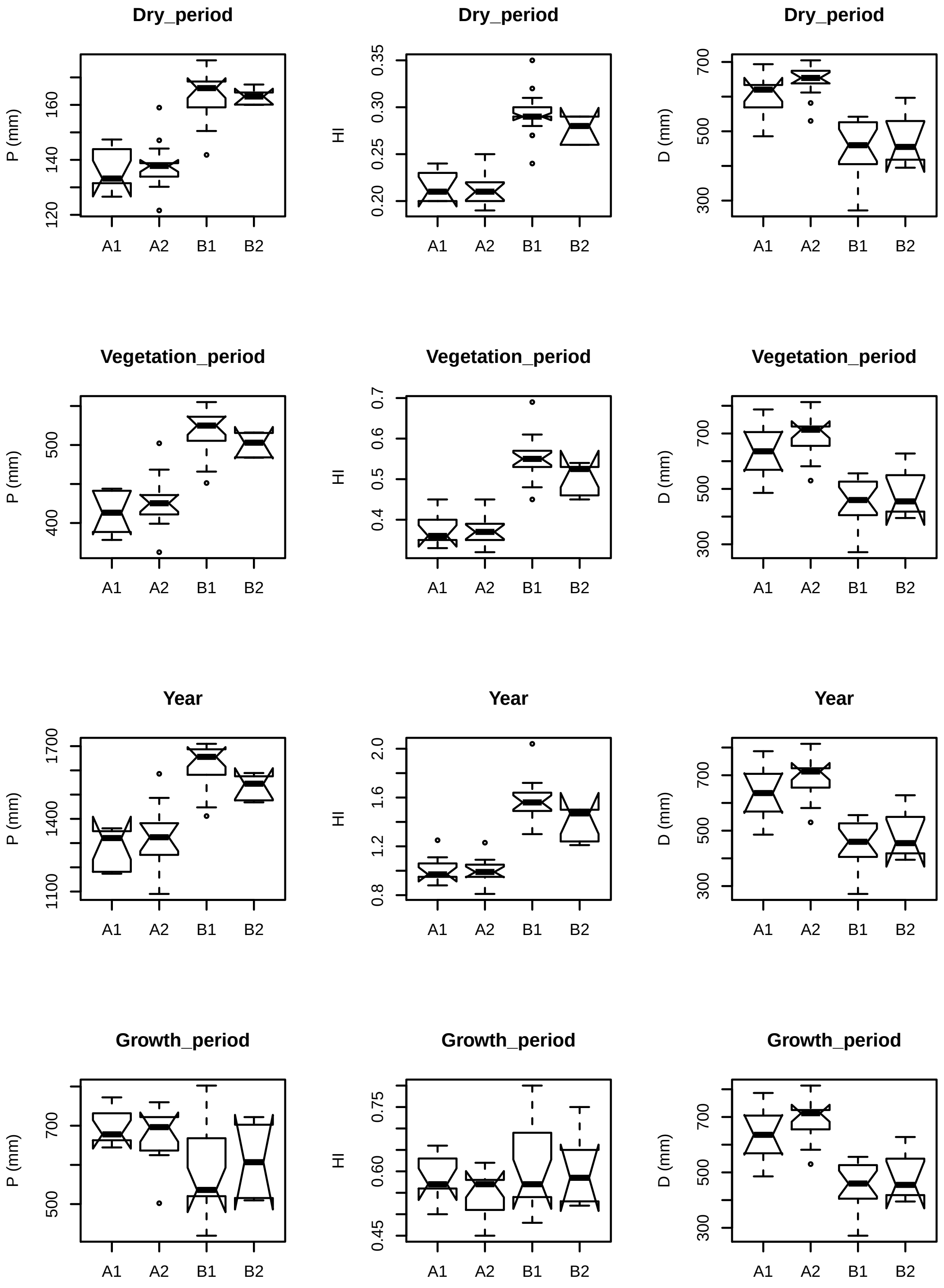
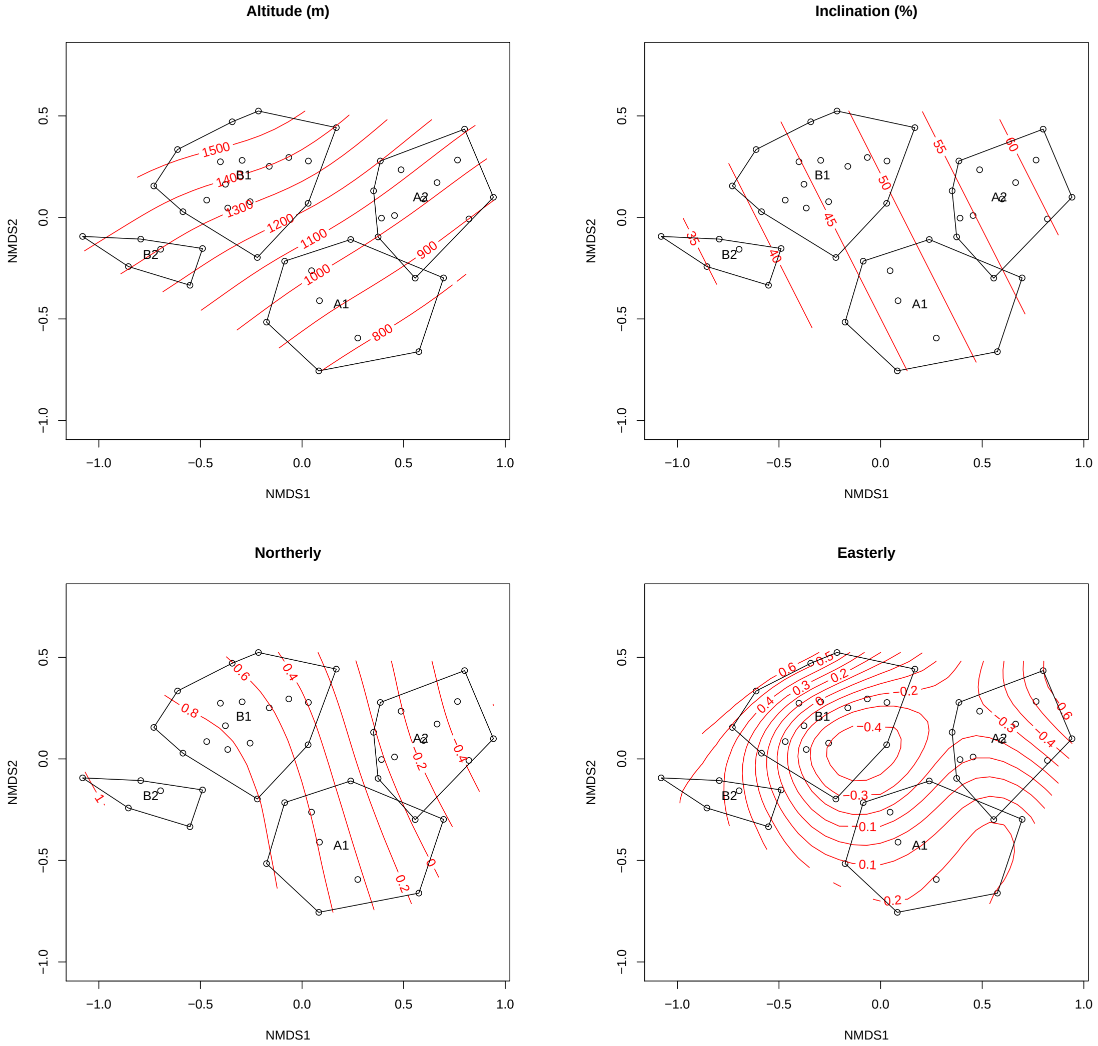


Figure A.4.4.: Comparison of Precipitation (P), Humidity index (HI) and water deficit (D) among the four vegetation subtypes (A1, A2, B1, B2). The comparison was performed for different time periods (dry period, vegetation period, growth period and annual).

A.5. NMDS

A.5.1. NMDS graphs with isolines

Ordination diagrams for Non-Metric Multidimensional Scaling (NMDS) and projection of various environmental variables on the ordination as isolines (contours). The isolines were created using thinplate splines. The vegetation units are indicated by different symbols (A1: *Crepis fraasii - Abies cephalonica* community subtype with *Castanea sativa*, A2: *Crepis fraasii - Abies cephalonica* community subtype with *Trifolium grandiflorum*, B1: *Sanicula europaea - Abies cephalonica* community subtype with *Silene multicaulis* ssp. *multicaulis*, B2: *Sanicula europaea - Abies cephalonica* community subtype with *Rubus hirtus*).


Altitude (m)

Inclination (%)

Northerly

Easterly

Figure A.5.1.: Ordination diagrams for NMDS and projection of different topographic variables (altitude, inclination, exposition to the North and exposition to the South) on the ordination as isolines (contours).

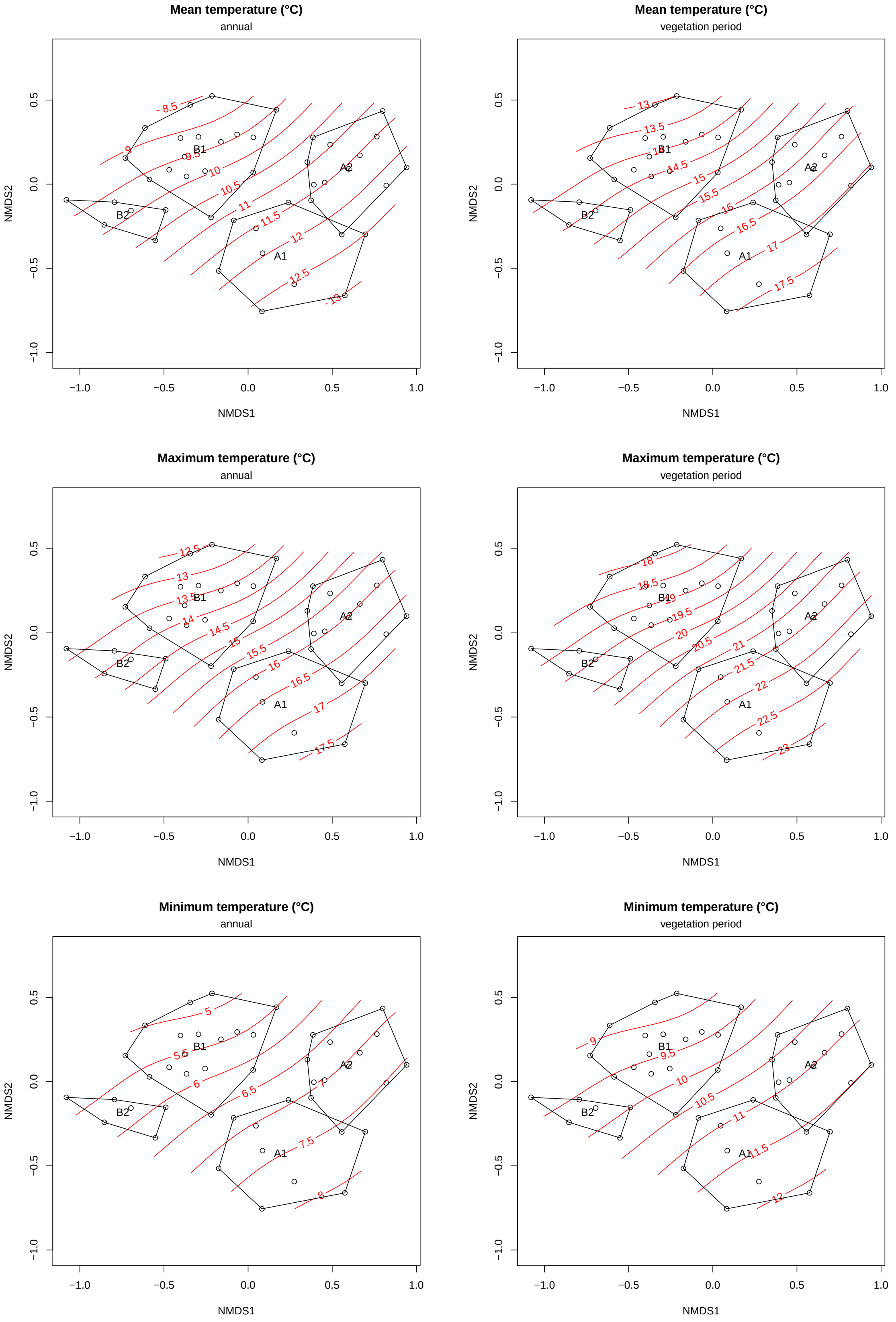
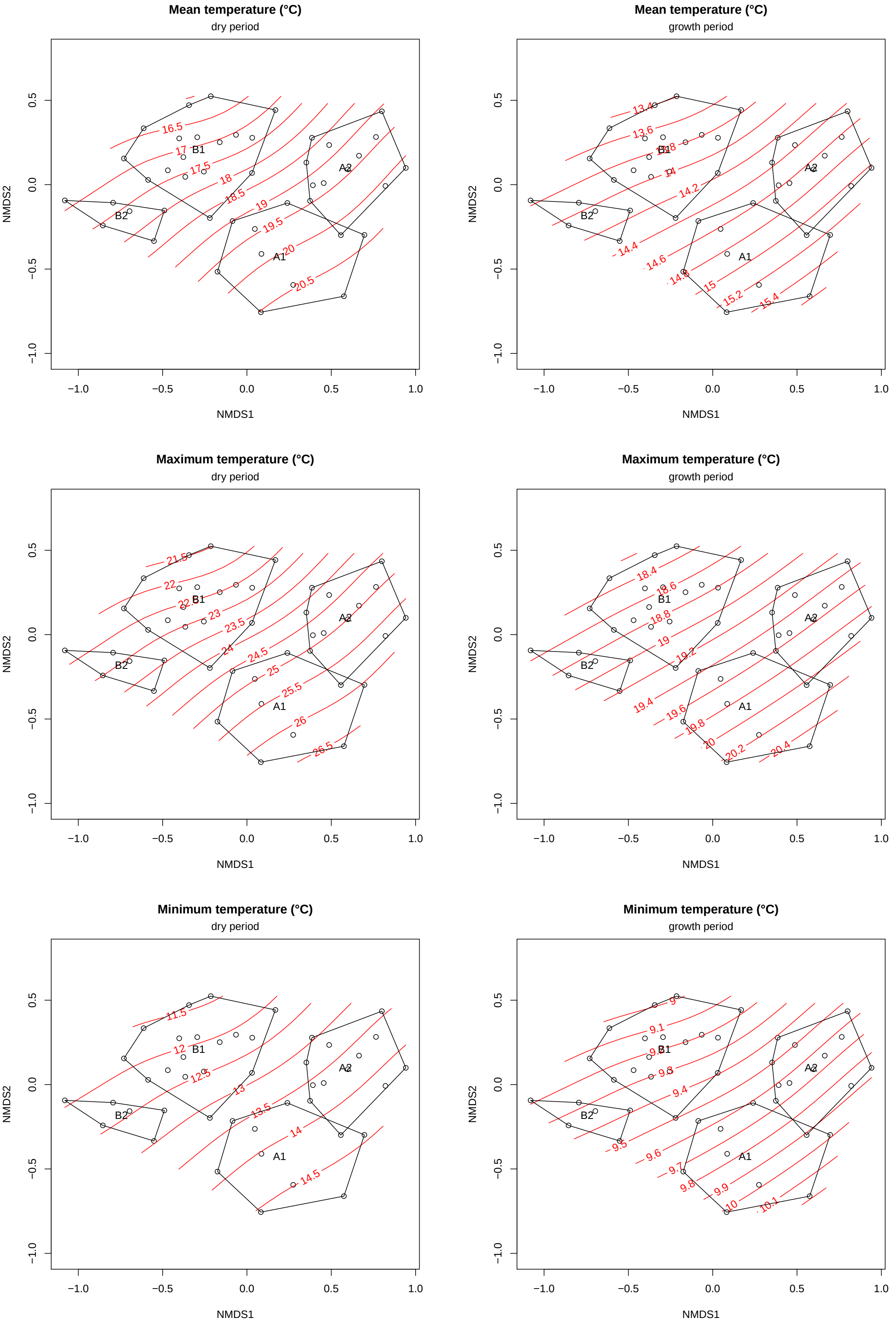


Figure A.5.2.: Ordination diagrams for NMDS and projection of mean, maximum and minimum temperature variables on the ordination as isolines (contours). The temperature was calculated for two time periods (vegetation period and annual).



Mean temperature (°C)
dry period

Mean temperature (°C)
growth period

Maximum temperature (°C)
dry period

Maximum temperature (°C)
growth period

Minimum temperature (°C)
dry period

Minimum temperature (°C)
growth period

Figure A.5.3.: Ordination diagrams for NMDS and projection of mean, maximum and minimum temperature variables on the ordination as isolines (contours). The temperature was calculated for the dry period (four driest months) and the growth period.

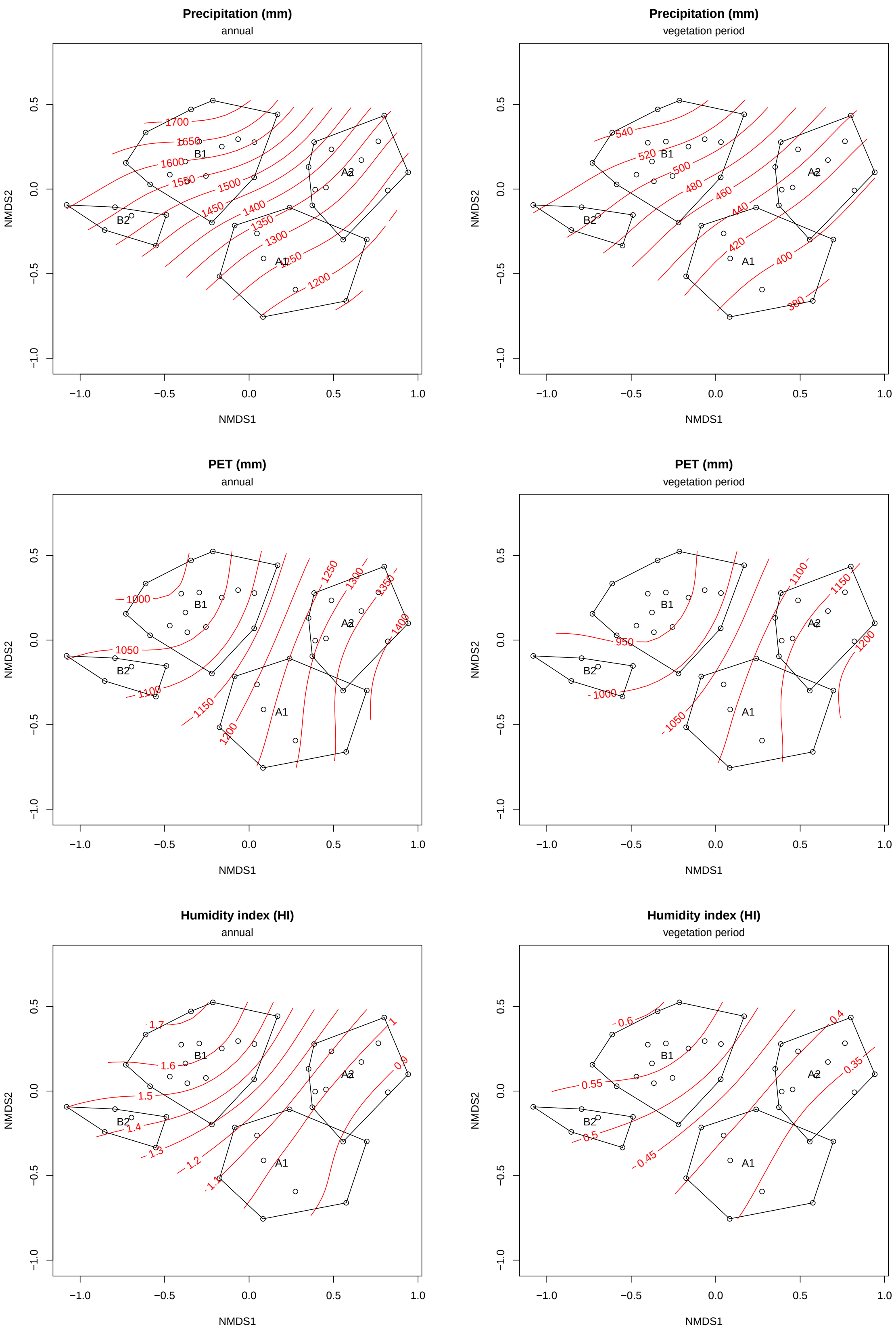


Figure A.5.4.: Ordination diagrams for NMDS and projection of precipitation, potential evapotranspiration (PET) and humidity index (HI) on the ordination as isolines (contours). The variables were calculated for the year (annual) and for the vegetation period.

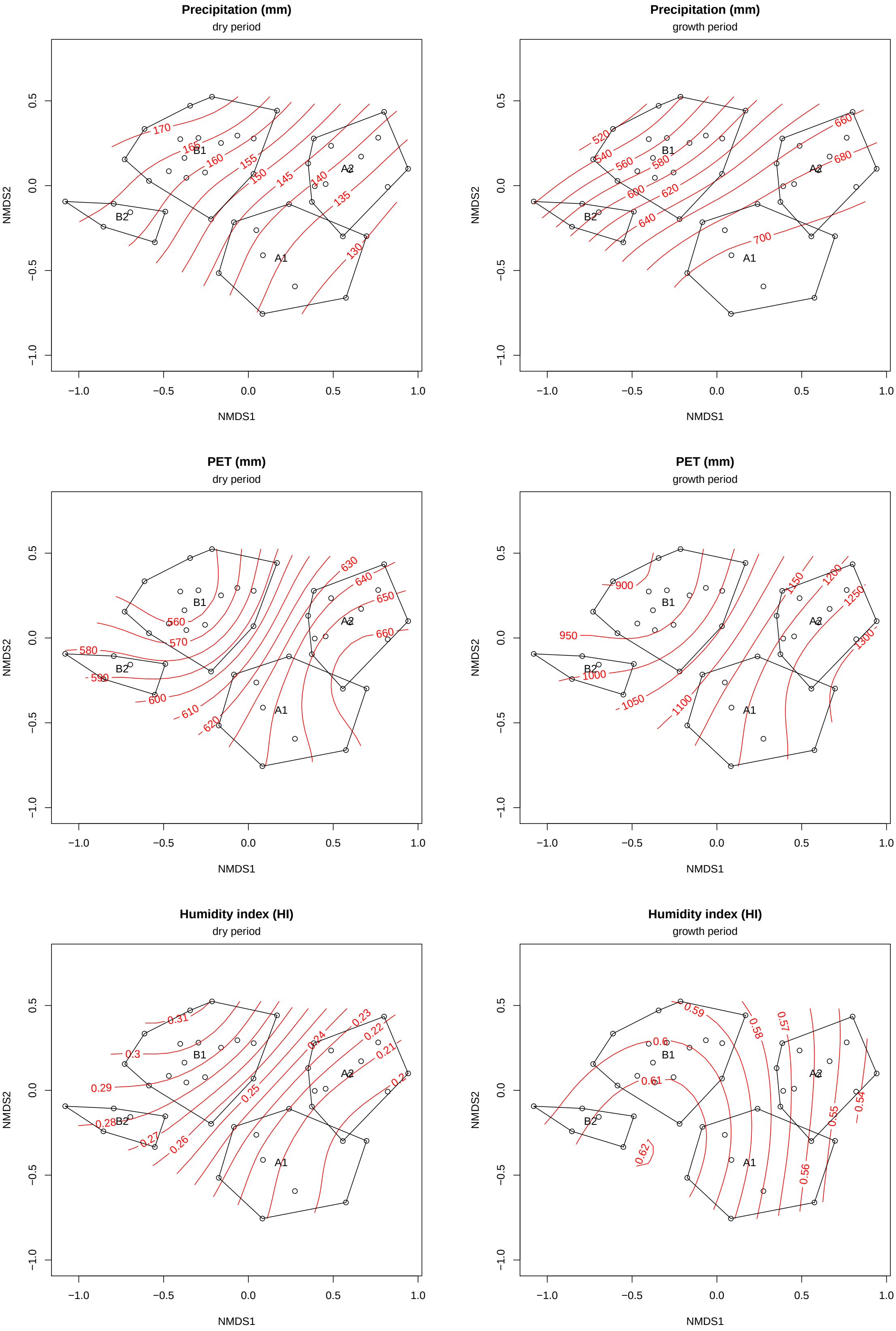


Figure A.5.5.: Ordination diagrams for NMDS and projection of precipitation, potential evapotranspiration (PET) and humidity index (HI) on the ordination as isolines (contours). The variables were calculated for the four driest months (dry period) and for the growth period.

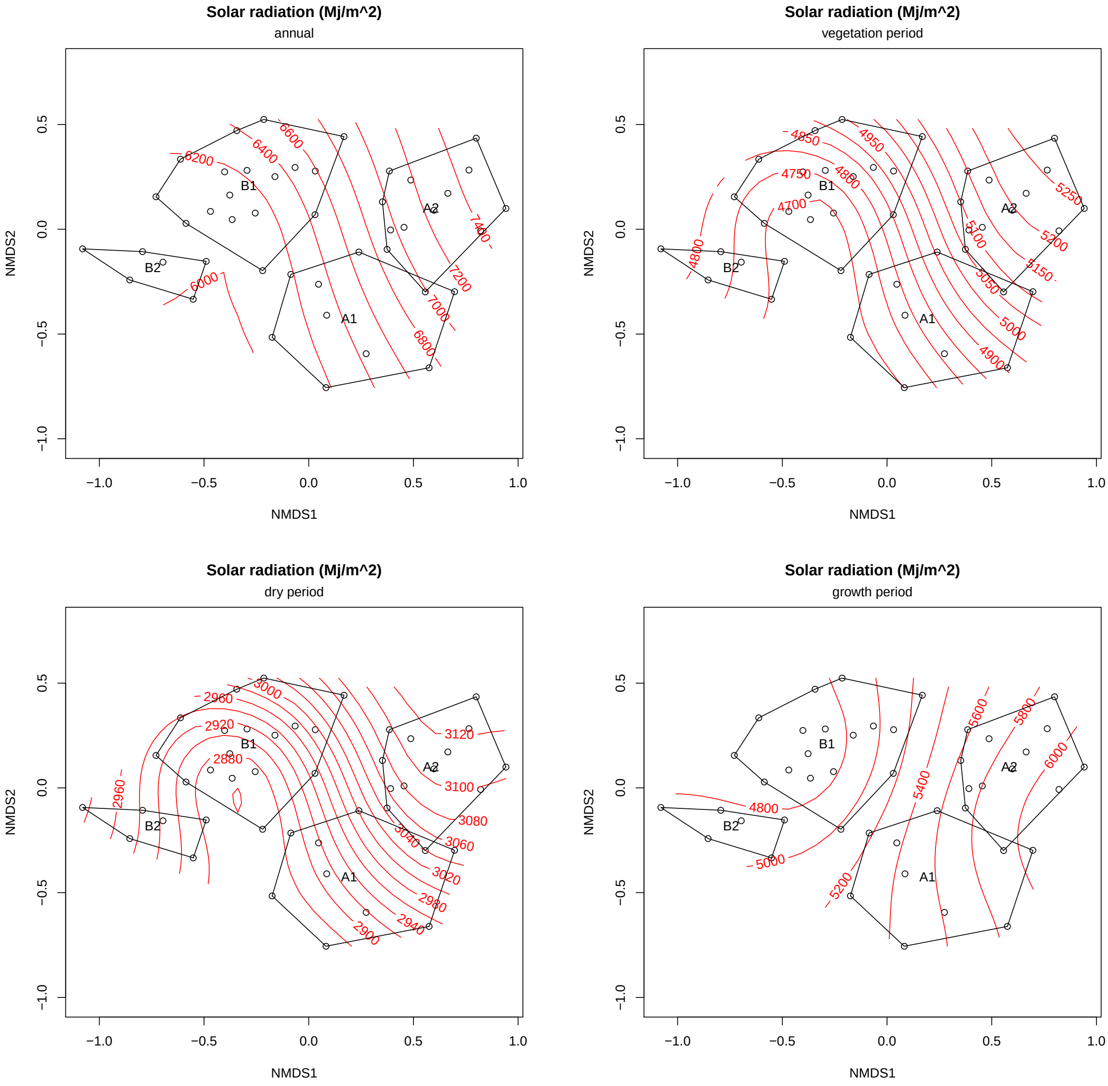


Figure A.5.6.: Ordination diagrams for NMDS and projection of solar radiation on the ordination as isolines (contours). The calculation of solar radiation was done for four different time periods (dry period, vegetation period, growth period and annual).

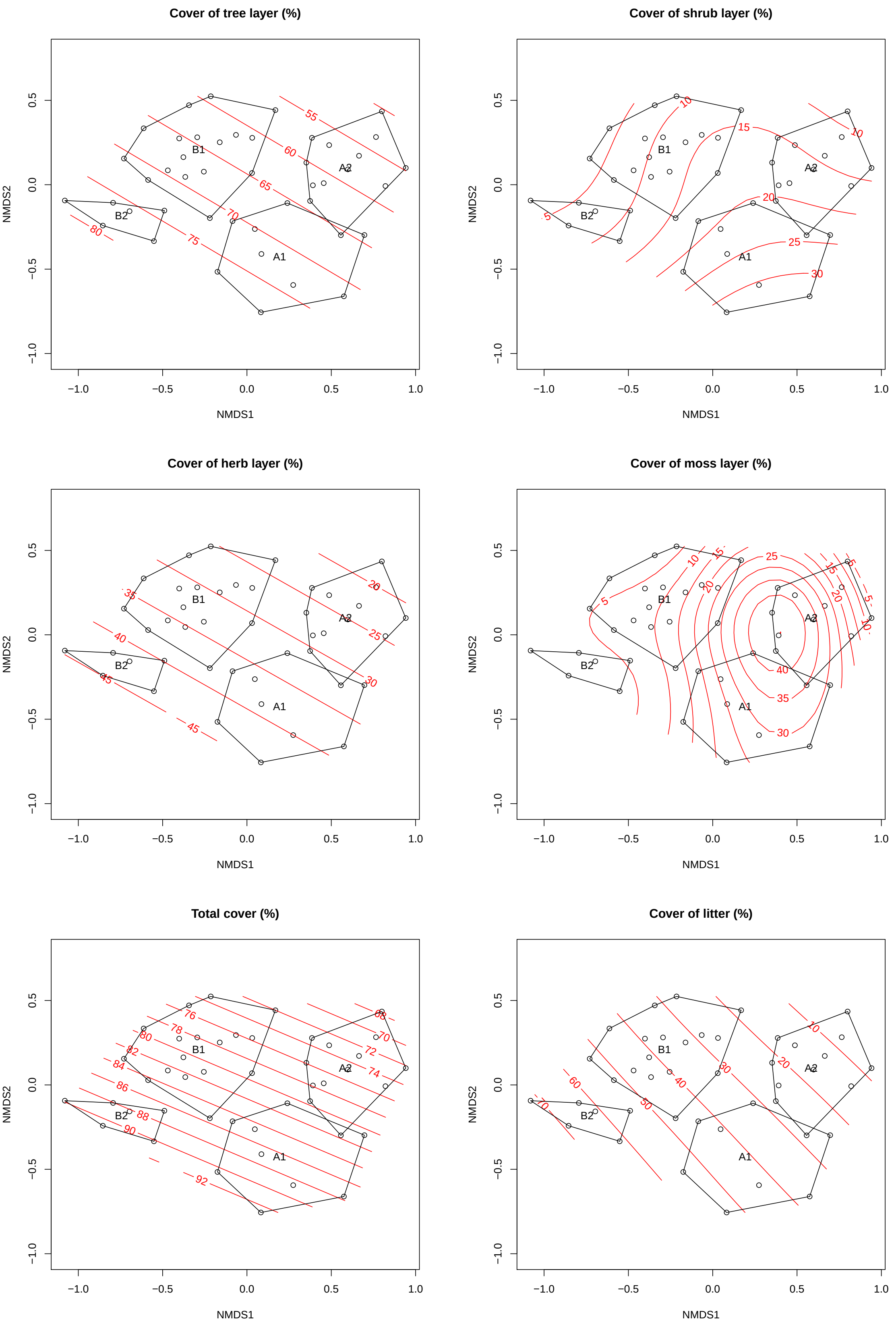


Figure A.5.7.: Ordination diagrams for NMDS and projection of various structural variables on the ordination as isolines (contours).

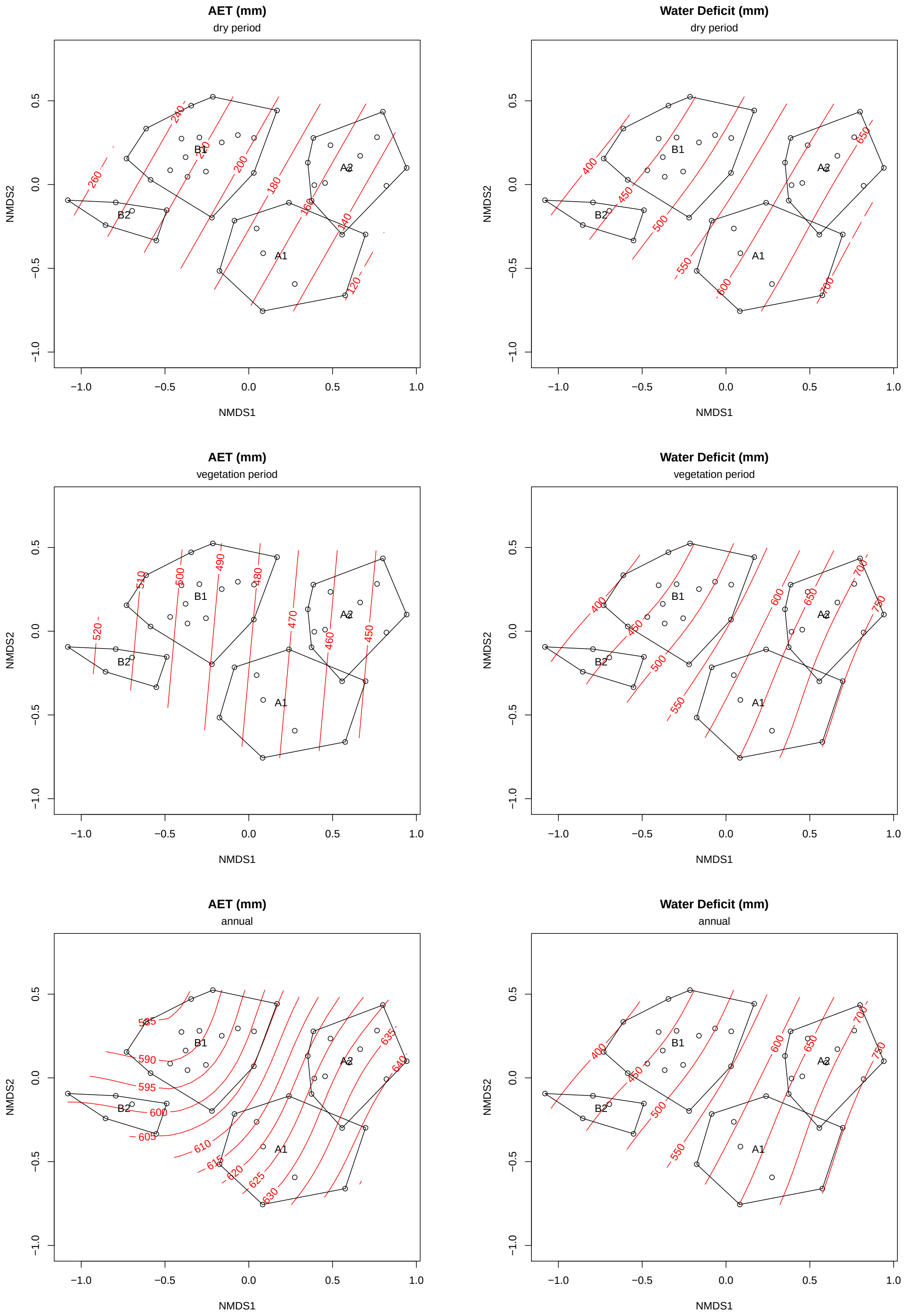


Figure A.5.8.: Ordination diagrams for NMDS and projection of the water balance outputs (actual evapotranspiration and water deficit) on the ordination as isolines (contours). The variables were calculated for the dry period (four driest months), the vegetation period and for the whole year (annual).

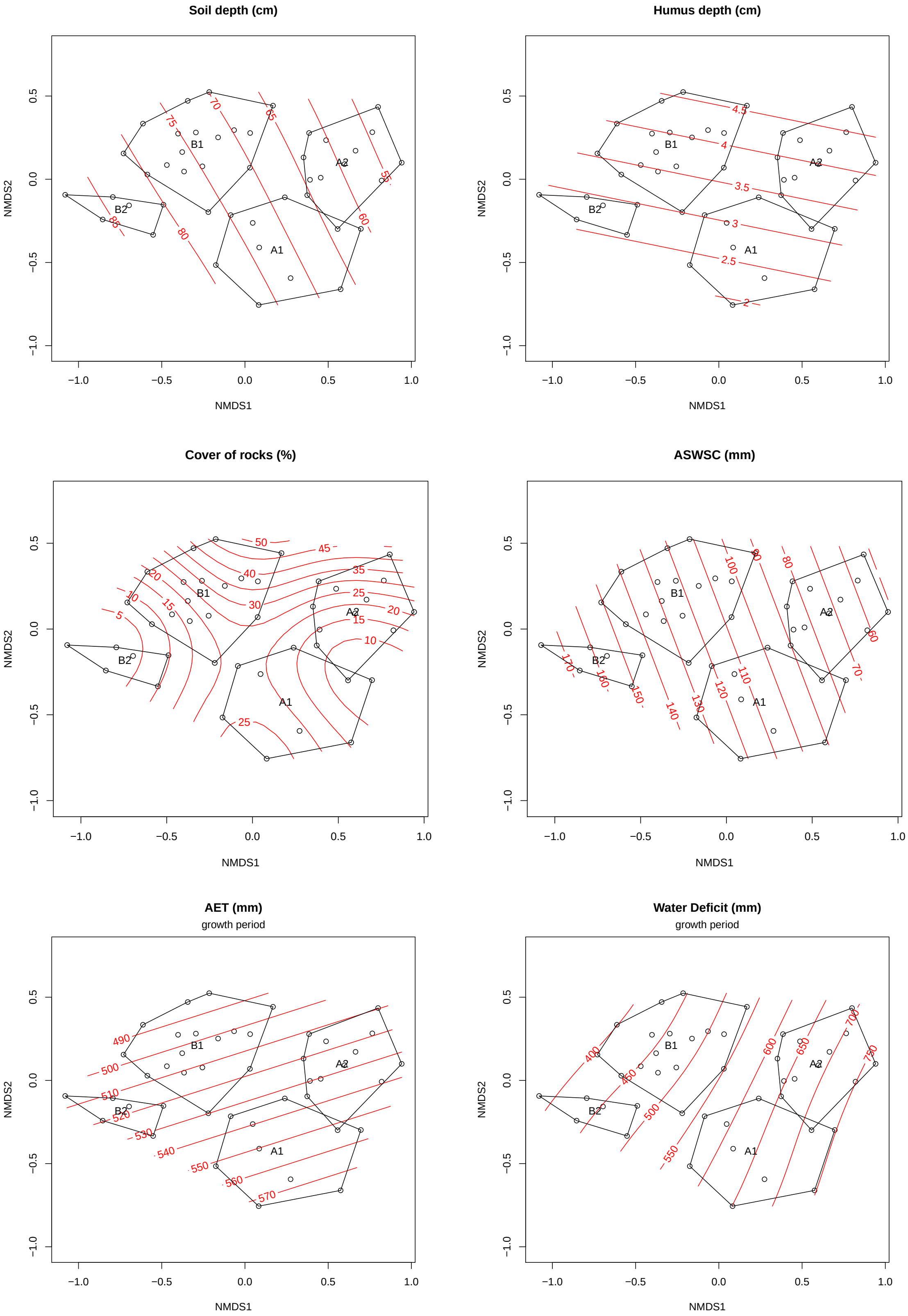


Figure A.5.9.: Ordination diagrams for NMDS and projection of various environmental variables (soil variables, actual evapotranspiration and water deficit for the growth period) on the ordination as isolines (contours).

A.5.2. Fits of environmental vectors and factors onto NMDS

Table A.5.1.: Environmental vectors fitted onto the ordination. The first two columns (NMDS1 & NMDS2) give the direction cosines of the vectors. r^2 is the squared correlation coefficient of the vectors with the ordination configuration. The significances (p-values) of the fitted vectors were assessed using 999 random permutations of the environmental variables.

Variables	NMDS1	NMDS2	r^2	p-values
ALTITUDE	-0.516602	0.856226	0.8426	0.001
INCLINE	0.917106	0.398644	0.2054	0.012
EXPO_N	-0.932891	-0.360159	0.4865	0.001
EXPO_E	-0.827054	-0.562123	0.1128	0.084
COV_TOTAL	-0.417201	-0.908814	0.4297	0.001
COV_TREES	-0.492459	-0.870336	0.3944	0.001
COV_SHRUBS	0.504192	-0.863592	0.2484	0.003
COV_HERBS	-0.605029	-0.796203	0.0739	0.208
TREE_HIGH	-0.813516	-0.581542	0.2995	0.003
DMAX	-0.992945	0.118579	0.0777	0.170
Rs_dry	0.728559	0.684983	0.1423	0.048
Rs_veg	0.817683	0.575668	0.1860	0.013
Rs_annual	0.900403	0.435057	0.2610	0.003
Rs_growth	0.908413	-0.418074	0.5220	0.001
Tmax_dry	0.548324	-0.836266	0.8572	0.001
Tmax_veg	0.548469	-0.836171	0.8574	0.001
Tmax_annual	0.546869	-0.837218	0.8587	0.001
Tmax_growth	0.526252	-0.850329	0.5880	0.001
Tmin_dry	0.543694	-0.839283	0.8587	0.001
Tmin_veg	0.543690	-0.839286	0.8585	0.001
Tmin_annual	0.550104	-0.835096	0.8527	0.001
Tmin_growth	0.506399	-0.862299	0.4391	0.001
Tav_dry	0.548955	-0.835852	0.8551	0.001
Tav_veg	0.546206	-0.837651	0.8562	0.001
Tav_annual	0.547898	-0.836545	0.8541	0.001
Tav_growth	0.511974	-0.859001	0.6235	0.001
P_dry	-0.677011	0.735973	0.8223	0.001
P_veg	-0.580268	0.814426	0.8516	0.001
P_annual	-0.527198	0.849742	0.8251	0.001
P_growth	0.570592	-0.821234	0.3847	0.001
PET_dry	0.746447	-0.665445	0.6601	0.001
PET_veg	0.822579	-0.568651	0.6606	0.001
PET_annual	0.855012	-0.518608	0.6543	0.001
PET_growth	0.773864	-0.633352	0.7527	0.001
THI_dry	-0.696699	0.717364	0.8236	0.001
THI_veg	-0.674457	0.738314	0.8389	0.001
THI_annual	-0.671523	0.740984	0.8143	0.001
THI_growth	-0.946157	-0.323707	0.0705	0.206
HUMUS_DEPTH	0.236810	0.971556	0.0498	0.350
SOIL_DEPTH	-0.910938	-0.412543	0.0914	0.134
ASWSC	-0.936493	-0.350685	0.2148	0.004
AET_dry	-0.860899	0.508775	0.4615	0.001
AET_veg	-0.99165	0.128958	0.1232	0.061
AET_annual	0.777824	-0.628482	0.0552	0.320
AET_growth	0.306643	-0.951825	0.1322	0.055
D_dry	0.834733	-0.550656	0.6902	0.001
D_veg	0.866493	-0.499189	0.6956	0.001
D_annual	0.866493	-0.499189	0.6956	0.001
D_growth	0.866493	-0.499189	0.6956	0.001

Table A.5.2.: Environmental factors fitted onto the ordination. The first two columns (NMDS1 & NMDS2) give the centroid position of each level of the factors on the ordination. The squared correlation coefficients (r^2) were calculated for the whole factors. The significances (p-values) of the fitted centroides were assessed using 999 random permutations of the factors.

Factor levels	NMDS1	NMDS2	r^2	p-values	
SLOPE_FORM.C	-0.2318	-0.1226	0.0392	0.501	
SLOPE_FORM.S	0.0307	0.0521			
SLOPE_FORM.V	-0.0763	-0.1972			
SUBSTRATE.CF	0.7483	0.0685	0.0743	0.041	*
SUBSTRATE.F	-0.0348	-0.0032			

Signif. code: 0.01 < * < 0.05

A.6. R Functions

A.6.1. Quantification of drought

Evaluation of radiation-based equations $\mathrm{PET_{ref}}$ **models** This paragraph contains two "User-defined functions" which are not available in any package of the R statistical program. The functions were developed by the author for the specific needs of this work. The `Crossvalid` function is based mainly on two other functions, the `lm` from the `stats` package and the `crossval` from the `bootstrap` package. The function was highly inspired by Robert I. Kabacoff [9]

 # Cross-validation of models

```
Crossvalid <- function(dat, form, dep, indep, ngroup) {

          require(bootstrap)

          fit       <- lm(formula = form, data = dat)

          theta.fit <- function(x,y) {lsfit(x,y)}

          theta.predict <- function(fit,x) {cbind(1,x)%*%fit$coef}

          x         <- as.matrix(dat[indep])

          y         <- as.matrix(dat[dep])

          results1  <- crossval(x, y, theta.fit, theta.predict, ngroup = ngroup)

          results2  <- fit$coef

          results   <- c(results1, results2)
```

```
          return(results)

}
```

Quantitative measures of model performance

```
Indices   <- function(x, y, z) {

lmET_model <- lm(x ~ y)
          P <- x
          P2 <- lmET_model$fitted.values
          O <- y
          D <- P-O
          Om <- mean(O)
          Pm <- mean(P)
          N <- length(O)
          PE <- sum((abs(P-Om) + abs(O-Om))^2)

#so:      standard deviation of O
          so <- sd(O)

#sp:      standard deviation of P
          sp <- sd(P)

#MBE:     Mean bias error
          MBE <- (1/N)*sum(D)

#MAE:     Mean absolute error
          MAE <- (1/N)*sum(abs(D))

#Sd^2:    Variance of the distribution of differences
          Sd <- (1/(N-1))*sum((D-MBE)^2)

#RMSE:    Root mean square error
          RMSE <- sqrt((1/N)*sum(D^2))

#RMSEu:   RMSE unsystematic
          RMSEu <- sqrt((1/N)*sum((P-P2)^2))

#RMSEs:   RMSE systematic
          RMSEs <- (RMSE^2)-(RMSEu^2)

#EF:      Model efficiency
          EF <- 1-(sum(D^2)/sum((Om-O)^2))

#d:       Index of agreement
          d <- 1-(N*(RMSE^2)/PE)

ab        <- lmET_model$coefficients
          r2 <- cor(y, x)**2
```

```
          coef <- z
          results <- c(Om=Om,Pm=Pm,so=so,sp=sp,N=N,MBE=MBE,MAE=MAE,Sd=Sd,
          RMSE=RMSE,RMSEu=RMSEu,RMSEs=RMSEs,EF=EF,d=d,ab=ab,r2=r2,coef=coef)
          return(results)
}
```

A.6.2. Vegetation analysis

The functions of this subsection are all “Built-in Functions” of different packages of the `R` statistical program.

A.6.2.1. Cluster analysis

 # Calculate the distance matrix:

```
dis.45     <- vegdist(oxia.45, method='bray', na.rm=T)
```

 # Clustering:

```
cl.45      <- agnes(dis.45, method="flexible", par.method=0.625)
```

 # Choose optimum number of clusters:

```
indval.out <- indval(oxia.cov.45, oxia.45.grp2_10, numitr=1000)
```

 # Cut the dendrogram:

```
oxia.45.grp4 <- cutree(hcl.45, k=4)
```

 # Multi-Response Permutation Procedure:

```
mrpp.45.grp4 <- mrpp(dis.45, oxia.45.grps4.factor, permutations = 1000, weight.type=1)
```

 # Permutational Multivariate Analysis of Variance:

```
perm.45.grp4 <- adonis(dis.45 ~ oxia.45.grp4.factor, permutations = 1000)
```

 # Mean distance dendrogram:

```
mdist.45.grp4 <- meandist(dis.45, oxia.45.grp4.factor)
```

Calculating the fidelity values:

```
r.pa      <- multipatt(oxia.45.pa, cluster = oxia.45.grp4, func="r.g")
```

A.6.2.2. Gradient analysis (ordination)

Non-Metric Multidimensional Scaling:

```
oxia.45.nmds2 <- metaMDS(oxia.45, k=2, distance="bray", trymax=20,
          autotransform=FALSE, noshare=1, wascores=TRUE)
```

Ordination and environmental variables

Vector fitting:

```
oxia.45.vecfit <- envfit(oxia.45.nmds2, oxia.site.45)
```

Smooth surfaces:

```
ordisurf(oxia.45.nmds2, oxia.site.45$ALTITUDE, main="Altitude (m)")
```

A.6.2.3. Classification tree

```
ctree_oxia.45 <- ctree(oxia.45.grp4.factor ~ ., data=oxia.site.45)
```

A.7. Vegetation table

Relevé number	6	9	10	15	37	50	33	39	47
Date (month/day/year)	06/12/07	06/16/07	06/16/07	06/22/07	06/22/08	06/29/08	06/19/08	06/23/08	06/26/08
Relevé area (m^2)	200	200	200	200	200	200	200	200	200
Altitude (m)	1110	780	1030	950	910	770	1040	980	780
Aspect (degrees)	360	293	338	45	23	45	180	270	45
Inclination (%)	40	45	25	50	65	30	55	25	70
Cover total (%)	95	98	97	90	89	76	81	81	90
Cover tree layer (%)	70	80	70	75	85	60	50	75	75
Cover shrub layer (%)	10	45	40	10	15	25	35	20	45
Cover herb layer (%)	80	70	85	55	15	20	40	5	25
Cover moss layer (%)	5	3	45	15	4	20	5	80	75
Cover litter layer (%)	80	40	50	50	-	45	10	5	15
Cover bare rock (%)	3	50	1	30	-	10	20	60	10
Height (highest) trees (m)	18	25	15	21	20	22	21	19	17
dmax (cm)	37	52	31	47	50	44	49	32	33
latitude (decimal degrees)	38.8050000	38.8952778	38.8861111	38.8847222	38.8700000	38.8980556	38.8136111	38.7677778	38.7083333
longitude (decimal degrees)	21.9736111	21.9083333	21.9086111	21.8988889	21.9494444	21.9213889	21.9722222	21.8536111	21.9425000
substrate (F: Flysch, CF: Flysch colluvium)	F	F	F	F	F	F	CF	F	F

Relevé number	28	29	30	31	34	35	36	38	40	41	42	46	49
Date (month/day/year)	06/10/08	06/10/08	06/12/08	06/14/08	06/19/08	06/22/08	06/22/08	06/23/08	06/24/08	06/24/08	06/24/08	06/26/08	06/27/08
Relevé area (m^2)	200	200	200	200	200	200	200	200	200	200	200	200	200
Altitude (m)	690	860	890	990	1050	1000	980	920	1070	1240	1070	940	1360
Aspect (degrees)	293	315	45	270	180	158	180	270	248	180	248	90	158
Inclination (%)	60	40	70	65	47	50	90	45	55	40	62	60	45
Cover total (%)	71	75	79	64	73	80	81	73	82	78	67	79	60
Cover tree layer (%)	60	60	65	50	65	75	50	60	75	60	55	65	50
Cover shrub layer (%)	10	15	7	5	10	10	5	20	25	20	15	25	7
Cover herb layer (%)	20	25	35	25	15	10	60	15	5	30	15	20	15
Cover moss layer (%)	10	30	-	10	3	5	4	75	60	70	20	50	30
Cover litter layer (%)	15	25	-	15	20	80	20	5	10	10	10	20	25
Cover bare rock (%)	5	0	-	60	20	5	0	10	5	5	60	10	30
Height (highest) trees (m)	13	16	20	15	22	17	18	20	19	15	12	20	13
dmax (cm)	46	36	65	38	50	51	56	42	40	59	28	50	47
latitude (decimal degrees)	38.8088889	38.8277778	38.7850000	38.7758333	38.8038889	38.8875000	38.8827778	38.7763889	38.8169444	38.8141667	38.8086111	38.7308333	38.7502778
longitude (decimal degrees)	22.0916667	22.1113889	22.0705556	22.0505556	21.9755556	21.9455556	21.9413889	21.8577778	21.8750000	21.8777778	21.8786111	21.9138889	21.8980556
substrate (F: Flysch, CF: Flysch colluvium)	F	F	F	CF	F	F	F	F	F	F	F	F	F

Relevé number	14	25	43	44	48	51	52	55	59	60	61	62	63	64	65	66	70
Date (month/day/year)	06/19/07	07/27/07	06/25/08	06/25/08	06/27/08	07/01/08	07/01/08	07/04/08	07/20/08	07/20/08	07/21/08	07/21/08	07/22/08	07/22/08	07/23/08	07/23/08	07/26/08
Relevé area (m^2)	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Altitude (m)	1580	1170	1510	1490	1130	1180	1160	1400	1540	1570	1510	1420	1440	1380	1540	1430	1360
Aspect (degrees)	90	315	315	338	338	338	360	293	68	45	68	338	338	338	45	338	360
Inclination (%)	60	50	40	25	55	60	50	55	45	55	45	40	73	75	40	60	20
Cover total (%)	68	77	87	88	82	80	80	63	83	97	64	81	88	87	73	75	84
Cover tree layer (%)	10	70	75	70	70	75	75	55	80	65	60	70	70	65	70	55	75
Cover shrub layer (%)	40	15	20	10	25	1	2	3	0	10	0	20	2	10	5	20	20
Cover herb layer (%)	40	10	35	55	20	20	20	15	15	90	10	20	60	60	5	30	20
Cover moss layer (%)	5	5	20	15	15	1	1	25	2	2	10	15	1	5	4	5	7
Cover litter layer (%)	15	50	10	70	25	40	30	40	50	5	40	25	5	10	40	30	80
Cover bare rock (%)	50	30	30	25	30	25	10	50	5	5	45	15	25	30	55	45	3
Height (highest) trees (m)	18	17	25	24	21	21	21	17	19	28	15	18	23	23	15	20	24
dmax (cm)	48	42	50	38	39	44	75	38	38	119	40	45	57	55	34	48	55
latitude (decimal degrees)	38.7683333	38.8772222	38.7222222	38.7344444	38.7716667	38.7891667	38.7911111	38.8666667	38.7547222	38.7497222	38.7272222	38.7133333	38.8030556	38.8044444	38.7402778	38.7536111	38.8666667
longitude (decimal degrees)	21.8950000	21.9008333	21.8777778	21.8611111	21.8619444	22.0369444	22.0391667	21.9030556	22.0766667	22.0786111	21.8802778	21.8952778	21.9286111	21.9144444	21.8808333	21.8886111	21.8866667
substrate (F: Flysch, CF: Flysch colluvium)	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F

Relevé number	21	26	27	57	58	69
Date (month/day/year)	07/25/07	07/27/07	07/28/07	07/12/08	07/12/08	07/26/08
Relevé area (m^2)	200	200	200	200	200	200
Altitude (m)	1140	1220	1290	1190	1360	1360
Aspect (degrees)	23	68	45	360	360	23
Inclination (%)	35	25	20	70	20	30
Cover total (%)	80	78	88	87	88	91
Cover tree layer (%)	75	65	75	65	80	75
Cover shrub layer (%)	5	10	1	7	10	7
Cover herb layer (%)	15	30	50	60	35	60
Cover moss layer (%)	0	20	15	5	1	0
Cover litter layer (%)	95	75	90	15	80	75
Cover bare rock (%)	3	3	3	5	5	3
Height (highest) trees (m)	25	17	20	21	18	32
dmax (cm)	47	46	38	34	54	119
latitude (decimal degrees)	38.7883333	38.8802778	38.8733333	38.8813889	38.8738889	38.8688889
longitude (decimal degrees)	21.9644444	21.8852778	21.8827778	21.8691667	21.8775000	21.9105556
substrate (F: Flysch, CF: Flysch colluvium)	F	F	F	F	F	F

Figure A.7.1.: Vegetation table of the fir forest communities of Mt. Oxia - North Vardousia.

	Relevé number		6	9	10	15	37	50	33	39	47	28	29	30	31	34	35	36	38	40	41	42	46	49	14	25	43	44	48	51	52	55	59	60	61	62	63	64	65	66	70	21	26	27	57	58	69	Absolute frequency	Percentage frequency			
	position (UP: Upper slope, MS: Middle slope, DS: Down slope)		UP	DS	UP	DS	MS	DS	MS	DS	MS	UP	UP	MS	DS	UP	MS	MS	DS	DS	MS	DS	DS	UP	UP	MS	UP	UP	UP	MS	MS	-	MS	DS	UP	UP	-	MS	UP	MS	-	MS	MS	MS	MS	UP	UP					
	slope form (S: Straight, V: Convex, C: Concave)		S	S	V	V	V	S	S	S	S	V	S	S	S	S	V	S	C	S	S	S	S	S	S	S	S	S	S	V	S	S	S	S	S	S	S	S	S	S	S	V	V	S	S	S	C					
	Vegetation unit		A1									A2													B1																	B2							A1	A2	B1	B2
Diagnostic taxa of *Crepis fraasii – Abies cephalonica* community																																																			
A.c.	Crepis fraasii		.	a	b	1	a	1	.	.	1	a	a	a	a	.	a	r	1	+	1	a	1	r	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	19	**67**	**92**	6	0
Q.c.	Quercus frainetto	t	.	.	a	.	.	.	1	1	1	.	.	.	.	1	a	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	**44**	**23**	0	0
Q.c.	Quercus frainetto	s	1	.	a	+	.	a	.	.	a	1	.	+	.	+	+	.	1	.	.	+	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	**56**	**54**	6	0
Q.c.	Quercus frainetto	h	a	1	a	1	1	a	1	1	a	a	a	a	r	1	1	1	1	1	1	1	1	+	.	1	.	.	1	.	.	r	.	.	.	.	.	.	.	.	+	.	+	.	.	r	.	28	**100**	**100**	24	33
	Hypnum cupressiforme var. cupressiforme	m	+	1	a	a	1	a	1	a	3	+	+	1	1	1	1	.	a	a	a	a	a	1	1	1	a	a	1	.	.	a	.	.	a	a	.	.	1	1	1	.	a	1	.	.	.	34	**100**	**92**	65	33
Q.p.	Juniperus oxycedrus ssp. oxycedrus	s	+	+	+	.	.	+	3	1	a	a	a	a	.	a	1	1	1	a	a	1	a	1	1	+	.	.	1	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	23	**78**	**92**	24	0
	Homalothecium aureum	m	.	.	1	.	1	+	1	3	1	1	+	1	a	+	1	+	a	3	.	a	a	3	1	1	+	+	a	.	.	1	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	26	**67**	**92**	41	17
D.-F.	Thymus longicaulis ssp. chaubardii		.	.	1	r	r	.	1	+	r	1	1	.	1	r	+	1	1	1	1	1	.	r	1	.	+	.	r	.	.	r	.	.	.	.	.	.	+	.	.	.	1	.	.	.	.	23	**67**	**85**	29	17
Q.c.	Trifolium patulum		.	.	+	.	r	1	a	.	.	.	.	.	.	+	.	r	1	+	.	.	1	1	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11	**44**	**46**	6	0
	Galium mollugo agg.		+	1	.	+	.	.	+	+	.	a	r	a	.	+	1	a	+	.	.	.	+	.	.	r	.	.	.	.	.	r	.	.	.	.	.	+	.	.	.	.	r	.	.	.	.	17	**56**	**62**	18	17
A.t.	Asplenium trichomanes ssp. trichomanes		.	1	.	1	.	.	.	r	.	.	.	r	.	r	.	.	r	.	.	.	+	.	+	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9	33	31	12	0
Q.c.	Chamaecytisus triflorus	h	.	.	.	.	+	.	+	.	a	+	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	33	23	0	0
	Achnatherum bromoides		.	.	.	.	.	.	.	+	+	+	.	+	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	22	31	0	0
Q.i.	Carex distachya		.	+	.	.	.	r	.	.	.	1	.	r	.	.	.	1	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	22	31	0	0
O-C	Fraxinus ornus	s	.	3	.	.	+	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	33	15	0	0
O-C	Fraxinus ornus	h	.	r	.	.	.	.	.	r	1	.	.	.	.	.	.	1	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	33	15	0	0
Q.i.	Quercus coccifera	s	.	.	.	.	.	.	.	+	a	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	22	8	6	0
Q.i.	Quercus coccifera	h	.	.	.	.	+	.	.	r	1	r	r	.	.	.	.	.	r	.	.	.	.	r	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	33	31	6	0
O-C	Carpinus orientalis ssp. orientalis	s	.	1	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	15	0	0
Diagnostic taxa of subtype with *Castanea sativa* (A1)																																																			
Q.p.	Rosa arvensis	h	+	.	+	+	.	1	r	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	**67**	0	0	0
Q.c.	Scutellaria columnae ssp. columnae		+	3	m	a	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	**56**	0	0	0
Q.p.	Rubus canescens	s	1	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	**44**	0	0	0
Q.-F.	Hedera helix	s	.	.	.	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	**33**	0	0	0
Q.-F.	Hedera helix	h	.	a	.	1	1	r	.	.	1	.	.	.	.	.	r	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	**56**	15	0	0
Q.p.	Viola alba ssp. alba		.	.	a	+	+	.	+	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	6	**56**	0	0	17
Q.p.	Cyclamen hederifolium		1	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	**33**	0	0	0
Q.i.	Asplenium onopteris		.	+	.	r	r	+	.	.	.	.	.	+	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	**44**	15	0	0
Q.p.	Platanthera montana		.	.	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	**33**	0	6	0
Q.p.	Ruscus aculeatus	s	.	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	**22**	0	0	0
Q.p.	Ruscus aculeatus	h	.	+	.	.	.	r	.	.	a	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	**33**	8	0	0
Q.c.	Castanea sativa	s	.	1	1	a	a	1	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	9	**56**	15	6	17
Q.p.	Carex flacca ssp. serrulata		.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	**22**	0	0	0
	Scabiosa sp.		r	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	**22**	0	0	0
	Trifolium heldreichianum		r	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	**22**	0	0	0
Diagnostic taxa of subtype with *Trifolium grandiflorum* (A2)																																																			
Q.p.	Trifolium grandiflorum		.	r	.	.	.	+	.	.	.	a	1	a	a	1	r	a	1	1	1	a	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	22	**100**	0	0
	Origanum vulgare ssp. hirtum		.	.	.	.	.	.	a	.	.	r	+	+	1	1	.	+	r	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	12	11	**85**	0	0
K.-C.	Myosotis ramosissima ssp. ramosissima		.	.	.	.	.	.	.	.	.	+	+	+	+	1	.	.	r	+	1	1	r	r	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	0	**85**	12	0
S.m.	Anisantha sterilis		.	.	.	.	.	.	.	.	.	.	+	1	+	+	.	.	.	1	1	1	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9	0	**69**	0	0
K.-C.	Trifolium arvense		.	.	.	.	.	.	.	.	.	.	.	.	1	r	.	+	r	+	1	+	+	+	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	0	**69**	6	0
C.-M.j.	Cistus creticus ssp. creticus	h	.	.	.	.	.	.	1	.	.	1	r	+	.	+	r	1	.	r	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	11	**69**	0	0
	Trifolium physodes		r	.	+	.	.	+	+	.	.	+	a	1	r	1	+	1	r	+	+	1	1	1	r	.	+	+	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	22	44	**100**	29	0
T.-B.	Cerastium brachypetalum ssp. roeseri		+	.	1	.	.	.	r	.	.	a	1	1	a	a	1	1	1	1	1	1	1	1	m	.	.	.	+	.	.	.	r	a	1	.	.	+	.	1	r	.	.	.	.	.	.	24	33	**100**	47	0
D.-F.	Festuca circummediterranea		.	.	.	.	.	.	.	.	.	r	r	.	a	+	.	3	+	.	.	1	.	1	+	.	.	.	r	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	11	0	**62**	18	0
T.-B.	Cynosurus echinatus		.	.	.	.	.	.	.	.	.	r	r	.	.	r	1	1	.	.	r	.	.	r	.	.	.	.	r	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	9	0	**54**	12	0
K.-C.	Vicia lathyroides		.	.	r	.	.	.	r	.	.	.	1	.	+	+	r	+	+	1	1	1	.	+	r	.	+	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	16	22	**77**	24	0
K.-C.	Trifolium scabrum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	r	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	0	**38**	0	0
Q.p.	Trifolium ochroleucon		.	.	.	.	.	.	.	.	.	r	.	.	.	r	.	r	+	.	.	.	+	+	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	8	0	**46**	12	0
	Anthyllis vulneraria ssp. bulgarica		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	r	+	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	**31**	0	0

	Releve number		6	9	10	15	37	50	33	39	47	28	29	30	31	34	35	36	38	40	41	42	46	49	14	25	43	44	48	51	52	55	59	60	61	62	63	64	65	66	70	21	26	27	57	58	69		Percentage frequency			
	Vegetation unit		A1									A2													B1																	B2							A1	A2	B1	B2
F.-B.	Chamaecytisus austriacus		.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	+	.	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	**31**	0	0
Q.p.	Lathyrus digitatus		.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	r	.	.	r	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	**31**	0	0
	Leontodon tuberosus		.	.	.	.	.	.	.	.	.	r	.	.	.	+	+	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	**31**	0	0
S.m.	Torilis arvensis		.	.	.	.	.	.	.	.	.	r	a	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	**31**	0	0
	Syntrichia ruralis	m	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	**31**	0	0
A.t.	Asplenium adiantum-nigrum		.	.	.	r	r	.	.	.	1	+	r	r	.	r	.	.	+	.	r	r	1	+	r	.	.	.	+	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	15	33	**69**	18	0
	Cota tinctoria ssp. parnassica		.	+	.	.	.	.	1	.	.	+	.	1	1	a	.	.	+	.	.	+	1	+	1	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	13	22	**62**	18	0
Q.p.	Hypericum spruneri		.	.	.	.	.	+	1	+	.	+	1	1	1	.	.	+	1	+	.	+	+	.	.	.	.	+	+	.	.	+	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	16	33	**69**	24	0
A.c.	Neotinea maculata		.	.	.	.	.	.	r	.	.	r	+	.	.	.	.	.	r	.	+	+	+	.	.	.	.	.	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	9	11	**46**	12	0
T.-G.	Inula conyzae		.	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	1	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	7	11	38	0	17
K.-C.	Trifolium campestre		.	.	+	.	.	.	.	.	.	.	1	.	.	+	.	.	r	.	1	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	11	31	6	0
S.m.	Vicia hirsuta		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	23	0	0
K.-C.	Veronica arvensis		.	.	.	.	.	.	.	.	.	.	+	.	.	r	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	23	0	0
	Petrorhagia prolifera		.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	23	0	0
	Trifolium hirtum		.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	+	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	23	0	0
	Racomitrium elongatum	m	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	23	0	0
	Ceratodon purpureus ssp. purpureus	m	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	23	0	0
Diagnostic taxa of *Sanicula europaea – Abies cephalonica* community																																																				
T.r.	Epilobium lanceolatum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	r	.	.	r	+	+	1	1	+	r	r	r	r	+	+	+	+	r	r	.	.	.	+	+	+	r	.	22	0	23	**88**	**67**
F.s.	Poa nemoralis ssp. nemoralis		.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	r	1	+	+	r	.	+	a	a	a	1	a	+	a	r	.	+	1	r	.	.	19	11	0	**88**	**50**
F.s.	Sanicula europaea		+	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	1	r	a	1	+	+	+	+	+	r	+	1	1	.	+	a	.	a	a	a	a	a	24	33	8	**88**	**83**
F.s.	Viola reichenbachiana x riviniana		.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	+	.	1	1	+	1	+	1	m	1	a	a	.	1	14	11	0	**47**	**83**
Q.p.	Fragaria vesca		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	+	1	+	1	r	+	.	.	1	.	a	m	.	.	+	12	0	0	**53**	**50**
	Lapsana communis		1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	r	.	1	1	1	+	.	r	+	+	1	.	.	+	+	.	+	+	.	1	1	r	+	.	19	11	15	**71**	**67**
Q.-F.	Lactuca muralis		b	+	1	+	.	.	.	+	.	.	.	1	.	.	.	.	1	+	+	.	1	r	+	1	1	1	1	a	a	r	.	+	+	+	+	+	+	+	+	1	1	1	1	1	1	33	56	46	**94**	**100**
Q.p.	Pteridium aquilinum ssp. aquilinum		.	.	1	a	1	+	.	.	.	.	.	+	.	r	r	.	.	+	.	.	.	+	a	1	.	a	1	+	a	+	a	3	1	1	.	.	1	+	a	1	1	b	a	a	3	29	44	38	**82**	**100**
Q.p.	Geum urbanum		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	.	.	1	.	.	+	r	.	.	r	.	r	+	.	r	.	9	0	0	**35**	**50**
Q.c.	Geocaryum capillifolium		a	.	1	.	.	.	.	.	.	r	.	+	.	.	.	.	.	.	.	.	.	.	.	r	1	1	.	1	+	+	.	1	+	1	a	1	.	+	1	.	r	m	.	.	+	20	22	15	**76**	**50**
F.s.	Epipactis helleborine		.	.	.	r	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	r	+	+	r	+	+	1	.	.	.	.	.	r	r	.	.	.	.	.	+	.	r	.	13	11	8	53	33
Diagnostic taxa of subtype with *Silene multicaulis* ssp. *multicaulis* (B1)																																																			
T.r.	Silene multicaulis ssp. multicaulis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	a	1	a	+	.	a	.	r	1	a	a	a	1	a	1	.	.	.	.	.	.	15	0	8	**82**	0
	Rumex acetosella ssp. acetoselloides		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	r	+	.	+	.	r	.	.	r	.	+	+	+	r	r	+	.	.	.	.	.	.	.	.	12	0	15	**59**	0
T.r.	Arabis alpina ssp. caucasica		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	1	+	.	a	1	.	1	.	.	.	.	.	.	.	6	0	0	**35**	0
Q.p.	Myosotis sylvatica ssp. cyanea		1	1	1	1	1	.	.	.	.	.	.	1	.	.	.	.	+	.	r	.	1	.	1	1	1	a	1	1	1	+	+	1	1	+	+	1	+	+	+	.	+	.	+	+	.	29	56	31	**100**	50
A.c.	Arrhenatherum elatius		.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	1	+	a	.	.	1	a	.	1	1	.	1	.	.	.	.	10	11	0	**47**	17
T.-G.	Vicia cassubica		.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	+	.	r	1	.	r	.	.	.	.	.	.	.	10	11	15	41	0
	Ranunculus sartorianus		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	1	.	.	.	.	.	.	3	0	0	18	0
	Genista millii		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	3	0	0	18	0
	Brachythecium salebrosum	m	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	3	0	0	18	0
	Primula veris ssp. suaveolens		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	1	.	.	.	.	.	.	3	0	0	18	0
Diagnostic taxa of subtype with *Rubus hirtus* (B2)																																																			
S.m.	Geranium robertianum ssp. purpureum		.	a	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	+	.	.	.	.	.	1	.	.	.	.	.	.	.	+	r	1	1	1	1	11	22	8	12	**100**
F.s.	Rubus hirtus	h	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	.	1	a	a	a	a	8	11	0	12	**83**
F.s.	Moehringia trinervia		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	r	.	r	r	.	.	4	0	0	6	**50**
	Bromopsis riparia		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	.	.	.	.	.	.	+	+	.	.	+	.	.	.	.	r	+	+	.	1	.	9	0	0	29	**67**
Q.-F.	Ilex aquifolium	h	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	+	2	0	0	0	**33**
T.r.	Polystichum lonchitis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	r	.	.	2	0	0	0	**33**
F.-B.	Tephroseris integrifolia ssp. integrifolia		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	r	2	0	0	0	**33**
	Epipactis greuteri ssp. preinensis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	r	r	.	.	.	.	r	r	+	6	0	0	18	**50**
F.s.	Calamintha grandiflora		.	.	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	a	.	.	+	1	.	.	a	r	a	10	22	0	24	**67**

	Releve number		6	9	10	15	37	50	33	39	47	28	29	30	31	34	35	36	38	40	41	42	46	49	14	25	43	44	48	51	52	55	59	60	61	62	63	64	65	66	70	21	26	27	57	58	69		Percentage frequency			
	Vegetation unit		A1									A2													B1																	B2							A1	A2	B1	B2
	Common diagnostic taxa of two or more vegetation subtypes																																																			
	Dactylis glomerata		+	r	1	r	r	+	1	r	+	1	+	1	1	+	1	1	.	.	1	r	1	.	.	+	+	.	+	.	.	.	.	r	.	.	r	+	+	+	+	.	.	.	.	.	.	28	**100**	**77**	**53**	0
Q.p.	Campanula spatulata ssp. spatulata		1	.	r	r	+	r	r	+	.	a	1	1	1	1	+	1	+	+	1	a	1	1	m	r	1	1	1	.	.	1	r	.	+	+	+	+	+	1	1	.	+	.	.	.	.	35	**78**	**100**	**82**	17
Q.p.	Doronicum orientale		1	.	a	r	+	.	.	.	.	r	1	+	.	1	r	+	.	+	+	.	+	1	m	r	1	a	1	1	1	1	.	r	.	a	1	+	.	1	1	.	.	.	.	.	.	28	**44**	**77**	**82**	0
	Cynosurus effusus		1	.	m	.	1	.	.	1	+	a	a	a	a	a	.	.	1	a	a	a	a	1	+	.	.	.	a	+	.	1	.	+	1	.	r	r	r	.	r	.	.	.	.	.	.	26	**56**	**85**	**59**	0
Q.p.	Juniperus oxycedrus ssp. oxycedrus	h	.	.	r	.	+	.	1	r	+	1	1	+	r	+	+	.	+	+	+	.	r	+	1	.	r	.	r	.	+	r	.	.	r	.	.	.	r	.	.	.	.	.	.	.	.	23	**56**	**85**	**41**	0
F.-B.	Pilosella piloselloides ssp. bauhinii		r	.	1	.	.	.	1	1	r	+	1	.	.	+	.	+	1	1	1	+	1	1	1	.	1	.	+	.	.	1	.	.	.	.	+	.	+	1	.	.	.	.	.	.	.	22	**56**	**77**	**41**	0
Q.p.	Geranium lucidum		a	.	r	1	.	.	.	.	.	1	+	+	1	1	.	.	.	1	.	1	1	.	.	.	.	.	.	+	1	+	.	.	.	.	.	1	a	.	.	.	.	.	.	.	.	16	33	62	29	0
Q.p.	Cardamine graeca		.	+	r	.	.	.	.	.	.	+	.	+	1	.	.	.	r	.	.	.	+	.	.	.	.	.	.	.	.	1	.	.	.	1	.	a	.	.	.	.	.	.	.	.	.	10	22	38	18	0
S.m.	Stellaria media		a	+	.	r	.	.	.	.	.	.	+	r	.	+	r	.	.	.	.	.	+	.	.	.	+	+	r	1	r	.	r	a	.	+	a	+	.	.	+	.	.	.	r	.	.	20	33	38	65	17
K.-C.	Poa bulbosa		r	.	+	.	r	.	.	.	.	+	.	1	1	1	.	+	.	.	1	1	.	+	+	.	r	.	r	.	.	+	.	+	+	.	1	.	.	.	.	.	.	.	.	.	.	18	33	62	41	0
M.-A.	Lotus corniculatus		.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	r	r	+	r	r	+	.	.	r	r	.	.	.	.	.	.	.	.	r	.	+	.	.	.	.	.	.	.	.	12	22	46	24	0
S.m.	Cardamine hirsuta		.	.	.	.	.	.	+	+	+	1	r	1	+	a	+	+	+	+	1	+	+	+	.	r	r	+	+	+	r	+	.	.	+	+	+	+	1	r	1	.	.	.	.	.	.	30	33	**100**	**82**	0
	Carlina biebersteinii et corymbosa		.	.	.	.	.	.	1	r	.	.	r	r	+	r	.	r	r	.	+	r	+	+	+	r	+	.	r	r	.	1	r	.	.	+	+	.	r	1	r	.	.	.	.	.	.	24	22	**77**	**71**	0
	Pilosella hoppeana ssp. testimonialis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	1	1	+	.	1	1	.	1	.	.	.	.	+	.	.	.	1	.	.	1	.	.	.	.	.	.	.	.	11	0	**46**	**29**	0
	Sedum amplexicaule ssp. tenuifolium		.	.	.	.	.	.	.	.	.	+	+	.	r	1	+	.	.	.	.	.	.	r	1	.	r	.	.	.	.	r	.	.	.	.	.	r	.	+	.	.	.	.	.	.	.	11	0	**46**	**29**	0
	Sanguisorba minor ssp. muricata		.	.	.	.	.	.	.	.	.	.	r	.	+	.	.	.	.	.	.	r	.	+	r	.	+	.	r	.	.	r	.	.	.	r	.	.	+	.	.	.	.	.	.	.	.	10	0	**31**	**35**	0
A.t.	Sedum hispanicum		.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	+	.	.	.	r	.	+	.	m	.	.	.	.	.	.	.	.	.	.	.	1	r	r	.	.	.	.	.	.	.	9	0	**38**	**24**	0
Q.p.	Limodorum abortivum		.	.	.	.	.	.	r	.	r	.	.	r	1	.	.	.	.	r	r	+	.	r	+	.	.	r	r	r	r	+	.	.	.	.	r	.	.	r	.	.	.	.	.	.	.	16	22	46	47	0
	Diagnostic taxa of *Quercet(-ea)alia pubescentis*																																																			
	Veronica chamaedrys ssp. chamaedryoides		1	1	1	m	+	1	+	1	1	1	1	1	r	+	1	1	1	1	1	1	1	1	+	m	1	+	1	1	+	1	+	1	1	1	1	a	+	1	1	1	m	m	1	+	+	45	100	100	100	100
	Satureja vulgaris ssp. orientalis		+	1	+	1	+	1	a	1	+	.	+	a	.	r	r	+	1	+	+	.	1	+	r	+	r	+	1	+	.	+	+	1	r	+	r	+	.	+	.	.	+	1	+	+	.	37	100	77	82	67
	Potentilla micrantha		1	+	1	+	+	1	+	r	+	.	r	1	.	r	.	.	+	r	.	.	+	1	+	r	1	+	1	+	+	1	+	+	+	.	+	+	+	+	+	r	.	.	r	.	+	35	100	54	94	50
	Luzula forsteri		1	1	b	m	a	+	+	1	1	1	.	1	.	1	a	+	.	1	+	.	+	1	m	1	+	1	a	+	r	.	.	.	.	1	.	1	.	1	+	.	m	1	a	.	.	32	100	69	65	50
	Silene italica ssp. italica		+	1	1	.	+	r	.	.	.	1	1	a	a	a	1	a	+	.	+	.	+	1	+	.	1	.	1	.	.	1	.	.	r	.	+	+	.	.	+	.	.	.	+	.	.	25	56	85	47	17
	Sedum cepaea		r	.	1	+	r	.	.	.	.	a	+	1	.	+	+	1	+	+	.	.	a	+	r	.	.	r	+	+	.	.	.	.	.	.	+	+	.	.	.	.	.	.	+	.	.	21	44	77	35	17
	Rubus canescens	h	1	1	r	+	.	+	.	.	.	.	r	r	.	r	.	.	r	.	.	.	r	.	.	1	.	.	.	.	.	+	+	.	.	.	+	.	.	.	r	.	1	r	.	.	.	17	56	38	29	33
	Helleborus odorus ssp. cyclophyllus		1	r	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	.	1	+	+	+	.	1	+	.	.	.	+	.	.	.	.	.	r	+	.	+	16	44	0	53	50
	Digitalis ferruginea ssp. ferruginea		r	.	r	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	+	.	.	.	.	.	.	+	.	1	r	.	+	.	10	22	8	24	50
	Digitalis laevigata ssp. graeca		.	.	.	.	1	.	.	.	1	.	.	.	a	.	.	.	+	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	.	.	.	.	.	.	8	22	31	12	0
	Festuca heterophylla		r	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	+	.	.	5	22	0	12	17
	Trifolium medium ssp. balcanicum		.	.	.	.	.	.	.	+	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	+	.	r	.	.	.	.	.	.	.	5	11	8	18	0
	Teucrium chamaedrys ssp. chamaedrys		.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	+	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	11	23	0	0
	Anemone apennina ssp. blanda		1	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	22	0	6	0
	Quercus pubescens	s	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	15	0	0
	Quercus pubescens	h	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	0	15	0	0
	Diagnostic taxa of *Querco-Fagetea*																																																			
	Aremonia agrimonoides		1	+	a	+	+	r	+	r	1	.	r	r	.	.	r	.	+	+	.	.	1	.	r	1	+	1	1	.	+	+	1	1	+	+	+	1	1	r	1	1	a	a	+	1	1	37	**100**	46	**94**	**100**
	Viscum album ssp. abietis	t	.	.	.	.	+	+	.	1	.	.	1	+	+	+	.	+	+	1	+	+	+	1	.	+	+	+	+	+	+	+	+	+	1	+	+	1	1	+	1	+	+	.	.	+	+	34	33	85	94	67
	Viscum album ssp. abietis	s	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	0	15	0	0
	Prunus avium	h	.	.	.	.	.	+	.	.	r	r	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	22	15	6	0
	Polystichum aculeatum		.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	3	11	0	6	17
	Diagnostic taxa of *Festuco-Brometea*																																																			
	Orchis mascula ssp. mascula		r	.	+	r	.	.	r	.	.	r	.	.	.	.	.	.	.	r	.	r	.	r	r	.	.	.	.	.	.	.	.	.	r	.	.	.	r	.	.	.	.	.	.	.	.	11	44	31	18	0
	Trifolium pannonicum ssp. pannonicum		+	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	r	.	.	.	1	.	.	.	+	.	.	+	.	.	.	.	.	+	.	+	.	.	.	.	8	11	15	24	17
	Brachypodium pinnatum		.	.	.	.	+	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	.	.	1	.	7	22	8	12	33
	Dorycnium herbaceum ssp. herbaceum		.	.	.	.	.	.	a	r	.	.	.	.	.	.	.	.	a	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	22	8	6	0
	Prunella laciniata		.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	r	.	r	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	11	15	6	0
	Phleum montanum		.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	r	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	15	6	0
	Diagnostic taxa of *Abietion cephalonicae*																																																			
	Abies cephalonica	t	4	5	4	5	5	4	3	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	a	4	4	4	4	4	4	4	5	4	4	4	4	4	4	4	4	5	4	5	4	5	4	45	100	100	100	100
	Abies cephalonica	s	a	a	3	a	1	a	1	a	1	1	a	+	a	1	a	.	a	a	a	a	a	a	3	a	a	a	a	+	1	1	.	a	.	a	1	a	1	a	a	.	a	+	a	a	a	41	100	92	88	83
	Abies cephalonica	h	m	1	1	1	a	a	1	a	1	+	1	1	1	1	1	1	1	a	1	1	1	a	1	1	a	.	1	1	1	a	1	+	a	a	1	a	a	a	a	m	a	m	a	a	1	44	100	100	94	100
	Prunus cocomilia et domestica ssp. insititia	s	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	3	11	8	0	17
	Prunus cocomilia et domestica ssp. insititia	h	+	.	r	.	.	.	.	.	.	+	.	.	.	r	.	.	r	r	r	+	.	.	.	.	.	r	.	.	.	.	r	.	.	.	.	r	.	.	r	.	+	r	.	+	.	15	22	46	24	50

	Releve number		6	9	10	15	37	50	33	39	47	28	29	30	31	34	35	36	38	40	41	42	46	49	14	25	43	44	48	51	52	55	59	60	61	62	63	64	65	66	70	21	26	27	57	58	69		Percentage frequency			
	Vegetation unit		A1									A2													B1																	B2							A1	A2	B1	B2
Diagnostic taxa of *Quercion confertae*																																																				
	Lathyrus laxiflorus ssp. laxiflorus		+	r	+	1	1	1	1	.	.	.	.	.	.	r	.	.	1	.	r	r	a	.	.	1	.	+	.	.	+	r	.	.	.	.	+	a	.	.	.	r	m	+	+	.	.	22	78	38	35	67
	Trifolium pignantii		.	+	.	1	+	1	+	.	.	.	r	1	r	.	r	.	1	1	.	.	.	1	.	r	+	.	+	.	.	+	.	.	.	.	r	a	.	+	.	.	.	r	.	.	.	20	56	54	41	17
	Castanea sativa	h	.	.	+	+	a	+	.	r	r	.	.	.	.	.	+	+	r	.	.	r	r	r	.	r	.	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	+	r	+	18	67	46	18	50
	Pilosella cymosa ssp. sabina		.	.	1	r	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1	.	.	.	1	.	.	.	1	+	+	.	.	1	.	1	.	.	r	.	12	22	8	41	33
	Quercus petraea ssp. medwediewii	s	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	22	0	0	0
	Quercus petraea ssp. medwediewii	h	.	.	r	+	+	.	.	.	.	.	.	.	r	.	.	r	.	.	.	.	.	.	.	r	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	8	33	15	12	17
	Silene viridiflora		.	.	.	r	.	.	.	.	r	.	.	.	.	.	r	.	1	+	.	.	1	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	22	31	6	0
	Symphytum bulbosum		a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	3	11	0	6	17
	Achillea ligustica		.	.	.	1	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	3	11	8	0	17
Diagnostic taxa of *Fag(-ion)etalia sylvaticae*																																																				
	Galium rotundifolium		b	r	1	m	1	.	.	a	r	.	r	+	+	r	r	.	+	1	1	1	1	+	1	1	3	3	a	a	a	a	a	1	a	a	1	1	1	1	a	m	m	m	1	a	1	41	78	85	100	100
	Melica uniflora		.	b	a	b	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	a	6	33	0	6	33
	Cardamine bulbifera		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	1	.	.	.	.	.	.	r	+	.	.	.	.	+	5	0	0	18	33
	Cephalanthera rubra		r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	11	8	12	0
	Fagus sylvatica ssp. sylvatica	s	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	.	.	.	.	.	1	0	0	0	17
	Fagus sylvatica ssp. sylvatica	h	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	+	.	.	.	.	.	3	0	8	6	17
Diagnostic taxa of Ostryo-Carpinion																																																				
	Arabis turrita		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	r	r	r	.	.	.	.	.	.	.	.	.	5	0	8	24	0
	Astragalus glycyphyllos		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	r	.	.	.	.	r	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	15	12	0
	Selinum silaifolium		.	.	.	.	r	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	8	6	0
Companion taxa																																																				
	Brachypodium sylvaticum ssp. sylvaticum		1	.	1	r	+	r	+	+	r	r	r	r	.	.	.	.	+	+	+	.	1	.	r	+	r	a	1	+	+	.	1	a	r	+	1	+	.	.	1	.	m	1	+	1	r	34	89	54	82	83
	Brachytheciastrum velutinum	m	1	1	1	.	+	+	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	1	a	1	.	+	+	a	1	.	a	1	1	1	+	1	a	.	1	a	1	1	.	25	56	15	82	67
	Hieracium bracteolatum ssp. reinholdii		1	a	b	1	a	.	1	.	.	+	.	.	.	.	r	.	1	.	+	.	a	+	.	m	.	1	1	+	r	.	1	.	.	.	1	a	.	a	1	.	.	.	1	.	.	23	67	46	59	17
	Dicranum scoparium	m	.	.	1	+	+	.	.	1	a	.	.	.	.	.	.	.	1	1	.	+	1	.	.	1	1	.	a	.	.	.	.	.	1	1	.	.	.	1	+	.	1	.	.	.	.	17	56	31	41	17
G.-U.	Galium aparine		1	+	+	.	.	.	.	.	.	.	+	.	.	+	r	.	.	.	.	.	.	r	.	.	.	+	.	.	.	.	.	1	+	.	+	+	.	.	r	.	.	.	.	.	r	14	33	31	35	17
	Bryum capillare	m	.	+	.	.	.	.	.	.	.	.	.	.	1	.	+	.	.	+	.	+	.	+	.	.	.	.	.	.	+	.	.	1	1	.	.	.	1	1	.	.	+	+	.	.	.	13	11	38	29	33
	Valerianella locusta et turgida		.	.	.	.	.	.	.	.	.	+	r	r	+	1	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.	.	.	r	.	.	.	+	.	.	.	.	.	r	.	.	.	10	0	46	18	17
	Draba muralis		.	.	.	.	.	.	.	.	.	r	.	r	.	.	.	.	r	1	.	+	.	.	.	.	.	.	r	.	.	.	.	1	.	.	r	.	.	.	.	.	.	.	.	.	.	8	0	38	18	0
	Scleropodium tourettii	m	.	.	.	.	+	.	.	.	.	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	1	.	.	1	.	.	.	.	.	.	.	+	.	.	.	+	.	.	.	7	11	15	18	17
D.-F.	Rosa pulverulenta	h	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	r	.	r	.	.	.	.	+	.	.	r	.	6	0	8	18	33
K.-C.	Arabidopsis thaliana		.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	1	+	.	.	r	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	0	31	12	0
	Verbascum chaixii ssp. chaixii		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	r	+	r	.	.	.	.	.	.	.	.	.	.	r	.	.	.	5	0	0	24	17
	Plagiomnium affine	m	1	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	a	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	5	22	0	18	0
	Pseudoscleropodium purum	m	.	.	a	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	+	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	.	.	.	.	5	11	0	18	17
	Rumex tuberosus ssp. tuberosus		r	.	.	.	.	.	.	.	.	.	r	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	4	11	15	6	0
	Verbascum epixanthinum var. pindicolum		r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	11	15	6	0
	Centaurea affinis ssp. affinis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	r	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	15	12	0
	Leontodon biscutellifolius		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	r	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	0	23	6	0
	Verbascum sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	r	.	.	.	.	.	.	.	r	.	4	0	0	18	17
	Tortula subulata	m	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	a	a	.	.	.	4	0	15	0	33
	Silene vulgaris ssp. bosniaca		1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	0	12	0
	Viola kitaibeliana		r	.	r	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	22	8	0	0
	Sonchus asper ssp. glaucescens		r	.	.	.	.	.	r	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	22	8	0	0
T.r.	Lamium garganicum ssp. garganicum		.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	3	22	0	6	0
	Taraxacum sp.1/sp.2		.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	8	6	0
E.-P.	Stachys scardica		.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	3	11	0	6	17
	Erysimum crassistylum		.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	+	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	15	0	0
	Orlaya daucoides		.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	8	6	0
	Cirsium sp.2		.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	3	11	8	0	17
	Acinos alpinus		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	r	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	8	12	0
K.-C.	Arenaria serpyllifolia		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	1	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	0	15	6	0
	Isothecium alopecuroides	m	.	.	+	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	3	22	0	6	0
	Eurhynchiastrum pulchellum	m	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	3	0	8	12	0
Q.i.	Asparagus acutifolius		.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	r	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	11	15	0	0

Taxa in two releves:

Scorzoneroides cichoriacea [h] 6: r, 10: +; Veronica hederifolia [h] 6: r, 28: 1; Viola alba ssp. dehnhardtii [h] 6: r, 26: 1; Hippocrepis emerus ssp. emeroides [s] 9: +, 46: +; Lonicera etrusca [h] 15: r, 42: r; Vicia grandiflora [h] 50: r, 30: +; Juglans regia [h] 50: r, 34: r; Crepis sp. [h] 33: r, 34: +; Arabis sagittata [h] 33: r, 34: r; Hippocrepis emerus ssp. emeroides [h] 33: r, 42: r; Acer monspessulanum ssp. monspessulanum [h] 47: +, 29: r; Aira elegantissima ssp. elegantissima [h] 28: 1, 14: r; Hieracium sp. [h] 30: 1, 31: 1; Geranium rotundifolium [h] 30: +, 34: r; Lathyrus inconspicuus [h] 30: +, 34: r; Umbilicus rupestris [h] 30: r, 36: +; Crucianella angustifolia et latifolia [h] 34: +, 42: r; Epipactis microphylla [h] 34: r, 52: r; Stachys tymphaea [h] 34: r, 57: +; Vicia villosa ssp. microphylla [h] 36: +, 51: r; Galium divaricatum [h] 36: r, 14: 1; Hieracium lazistanum ssp. leithneri [h] 38: +, 14: +; Helianthemum nummularium ssp. nummularium [h] 41: +, 42: r; Petrorhagia illyrica ssp. illyrica [h] 46: r, 49: +; Daphne oleoides [h] 14: r, 65: +; Anthoxanthum odoratum [h] 44: +, 66: r; Orobanche sp. [h] 52: r, 70: r; Sedum laconicum ssp. laconicum [h] 60: 1, 63: 1; Dryopteris filix-mas [h] 63: r, 69: r; Saxifraga rotundifolia ssp. rotundifolia [h] 64: a, 57: 1; Rhynchostegium megapolitanum [m] 6: 1, 57: 1; Plagiomnium undulatum var. undulatum [m] 37: 1, 38: 1; Homalothecium sericeum [m] 37: +, 34: +; Hypnum cupressiforme var. lacunosum [m] 28: a, 36: +; Syntrichia montana [m] 42: +, 49: +; Polytrichum juniperinum [m] 14: 1, 61: 1; Brachythecium rutabulum [m] 48: 1, 61: +; Pseudolescea incurvata [m] 59: +, 60: +

Taxa in one releve:

Ilex aquifolium [s] 69: +; Geranium asphodeloides ssp. asphodeloides [h] 6: b; Rosa canina [s] 6: 1; Poa trivialis ssp. sylvicola [h] 6: +; Campanula trachelium [h] 6: +; Lamium bifidum ssp. bifidum [h] 6: +; Valerianella carinata [h] 6: +; Chaerophyllum temulentum [h] 6: r; Acer campestre [s,h] 9: 1,r; Ptilostemon strictus [h] 9: +; Crataegus monogyna [s] 9: +; Orchis provincialis [h] 10: +; Ranunculus paludosus [h] 10: +; Tilia rubra ssp. rubra [s] 15: +; Castanea sativa [t] 37: 1; Ostrya carpinifolia [h] 37: r; Cuscuta sp. [h] 33: +; Ononis spinosa ssp. leiosperma [h] 33: r; Cornus sanguinea [h] 39: r; Eryngium creticum [h] 39: r; Phillyrea latifolia [s,h] 47: a,1; Platanus orientalis [t] 47: 1; Cercis siliquastrum ssp. siliquastrum [s,h] 47: +,r; Acer monspessulanum ssp. monspessulanum [s] 47: +; Saxifraga carpetana ssp. graeca [h] 28: +; Trifolium sp.2 [h] 28: r; Sorbus torminalis [h] 28: r; Cerastium brachypetalum ssp. tenoreanum [h] 29: a; Prunus mahaleb [h] 29: r; Thlaspi bulbosum [h] 29: r; Vicia sativa ssp. incisa [h] 30: r; Asplenium ceterach [h] 30: r; Rhagadiolus stellatus [h] 30: r; Lactuca intricata et viminea ssp. ramosissima [h] 31: r; Muscari sp. [h] 34: r; Trifolium tenuifolium [h] 34: r; Trifolium sp.1 [h] 34: r; Briza maxima [h] 34: r; Roegneria panormitana [h] 34: r; Spartium junceum [s] 36: 1; Ostrya carpinifolia [s] 38: +; Carduus nutans ssp. taygeteus [h] 40: r; Teesdalia coronopifolia [h] 41: +; Filago arvensis et germanica agg. [h] 42: +; Centaurium erythraea [h] 42: +; Dactylorhiza saccifera [h] 46: r; Alyssum minutum [h] 49: r; Koeleria lobata [h] 14: a; Erophila verna [h] 14: 1; Hypericum barbatum [h] 14: +; Cheilanthes sp. [h] 14:

r; Verbascum nigrum ssp. abietinum [h] 25: r; Crataegus orientalis ssp. orientalis [s,h] 43: +,+; Eryngium amethystinum [h] 43: +; Sonchus sp. [h] 44: +; Rosa arvensis [s] 44: +; Viola odorata [h] 52: +; Achillea grandifolia [h] 59: +; Veronica cymbalaria [h] 60: 1; Milium vernale ssp. montianum [h] 60: 1; Carduus tmoleus [h] 60: 1; Fallopia convolvulus [h] 60: +; Pilosella densiflora [h] 61: +; Festuca rubra [h] 62: +; Allium paniculatum [h] 62: r; Viola aetolica [h] 62: r; Senecio hercynicus ssp. dalmaticus [h] 63: a; Heracleum sphondylium ssp. pyrenaicum [h] 63: 1; Secale strictum ssp. strictum [h] 63: +; Senecio squalidus ssp. rupestris [h] 63: +; Solidago virgaurea ssp. virgaurea [h] 63: +; Rubus idaeus ssp. idaeus [h] 63: r; Cirsium sp.1 [h] 63: r; Digitalis grandiflora [h] 64: +; Pimpinella tragium ssp. polyclada [h] 64: r; Festuca valesiaca [h] 65: 1; Poa thessala [h] 65: +; Astragalus sempervirens ssp. cephalonicus [h] 65: r; Agrostis stolonifera [h] 65: r; Carex sp. [h] 26: +; Aristolochia elongata [h] 26: r; Ajuga reptans [h] 27: r; Poa hybrida [h] 58: +; Hordelymus europaeus [h] 69: 1; Fissidens dubius [m] 28: +; Syntrichia ruralis var. ruralis [m] 40: 1; Bryoerythrophyllum recurvirostrum [m] 14: 1; Bryum caespiticium [m] 14: 1; Bryum torquescens [m] 44: 1; Pterogonium gracile [m] 44: +; Homalothecium philippeanum [m] 55: 1; Porella platyphylla [m] 61: +; Ctenidium molluscum [m] 66: 1; Brachythecium glareosum [m] 66: 1

The abbreviations of the syntaxa which are given before taxa's names are explained in Table 3.4.1.

A.8. Species list

Species list of the vascular and lower plants that were found on the fir forests of the study area from the vegetation sampling.

PTERIDOPHYTA

ASPLENIACEAE
Asplenium adiantum-nigrum L.
Asplenium ceterach L. s.l.
Asplenium onopteris L.
Asplenium trichomanes L. subsp. ***trichomanes***

DRYOPTERIDACEAE
Dryopteris filix-mas (L.) Schott
Polystichum aculeatum (L.) Roth
Polystichum lonchitis (L.) Roth

HYPOLEPIDACEAE
Pteridium aquilinum (L.) Kuhn subsp. ***aquilinum***

POLYPODIACEAE
Cheilanthes sp.

SPERMATOPHYTA

GYMNOSPERMAE

CUPRESSACEAE
Juniperus oxycedrus L. subsp. ***oxycedrus***

PINACEAE
Abies cephalonica J. W. Loudon

ANGIOSPERMAE - DICOTYLEDONEAE

ACERACEAE
Acer campestre L.
Acer monspessulanum L. subsp. ***monspessulanum***

APIACEAE
Chaerophyllum temulentum Cham. & Schlecht. {= C. temulum L.}
Eryngium amethystinum L.
Eryngium creticum Lam.
Geocaryum capillifolium (Guss.) Cosson
{= Huetia cynapioides (Guss.) P. W. Ball ssp. cynapioides}
Heracleum sphondylium subsp. ***pyrenaicum*** (Lam.) Bonnier & Layens
Orlaya daucoides (L.) Greuter {= O. kochii Heywood}
Pimpinella tragium Vill. subsp. ***polyclada*** (Boiss. & Heldr.) Tutin
Sanicula europaea L.
Selinum silaifolium (Jacq.) Beck {= Cnidium silaifolium (Jacq.) Simonkai}
Torilis arvensis (Hudson) Link s.l.

AQUIFOLIACEAE
Ilex aquifolium L.

ARALIACEAE
Hedera helix L. s.l.

ARISTOLOCHIACEAE
Aristolochia elongata (Duchartre) Nardi

ASTERACEAE
Achillea grandifolia Friv.
Achillea ligustica All.
Carduus nutans L. subsp. ***taygeteus*** (Boiss. & Heldr.) Hayek
{= C. macrocephalus Desf. ssp. inconstrictus (O. Schwarz) Kazmi}
Carduus tmoleus Boiss. s.l.
Carlina biebersteinii Hornem. subsp. ***brevibracteata*** (Andrae) K. Werner
{= C. vulgaris L. ssp. intermedia (Schur) Hayek}
Carlina corymbosa L.
Centaurea affinis Friv. subsp. ***affinis***
Cirsium sp.1
Cirsium sp.2
Cota tinctoria (L.) J. Gay subsp. ***parnassica*** (Boiss. & Heldr.) Oberpr. & Greuter
{= Anthemis tinctoria L. ssp. parnassica (Boiss. & Heldr.) Franzén}
Crepis fraasii Sch. Bip.
Crepis sp.

Doronicum orientale Hoffm.
Filago sp.
Hieracium bracteolatum Sm. subsp. ***reinholdii*** (Heldr. & Sart. ex Boiss.) Z.
Hieracium lazistanum A.-T. subsp. ***leithneri*** (Heldr. & Sart. ex Boiss.) Greuter
Hieracium sp.
Inula conyzae (Griess.) DC.
Lactuca muralis (L.) Gaertner {= Mycelis muralis (L.) Dumort.}
Lactuca sp.
Lapsana communis L. subsp. ***adenophora*** (Boiss.) Rech. f.
Leontodon biscutellifolius DC. {= L. crispus Vill. ssp. asper (Waldst. & Kit.) Rohlena}
Leontodon tuberosus L.
Pilosella cymosa (L.) F. W. Schultz & Sch. Bip. subsp. ***sabina*** (Sebast.) H. P. Fuchs {= Hieracium cymosum L. ssp. heldreichianum Nägeli & Peter}
Pilosella densiflora (Tausch) Soják {= Hieracium densiflorum Tausch}
Pilosella hoppeana subsp. ***testimonialis*** (Peter) P. D. Sell & C. West
Pilosella piloselloides subsp. ***bauhinii*** (Schult.) S. Bräut. & Greuter {= Hieracium bauhini Schultes ex Besser}
Ptilostemon strictus (Ten.) Greuter
Rhagadiolus stellatus (L.) Gaertner
Scorzoneroides cichoriacea (Ten.) Greuter {= Leontodon cichoriaceus (Ten.) Sanguinetti}
Senecio hercynicus Herborg subsp. ***dalmaticus*** (Griseb.) Greuter {= S. hercynicus Herborg var. expansus (Boiss. & Heldr.) Herborg.}
Senecio squalidus L. subsp. ***rupestris*** (Waldst. & Kit.) Greuter
Solidago virgaurea L. subsp. ***virgaurea***
Sonchus asper (L.) Hill subsp. ***glaucescens*** (Jordan) Ball
Sonchus sp.
Taraxacum sp.1
Taraxacum sp.2
Tephroseris integrifolia (L.) Holub subsp. ***integrifolia***

BETULACEAE
Carpinus orientalis Miller subsp. ***orientalis***
Ostrya carpinifolia Scop.

BORAGINACEAE
Myosotis ramosissima Rochel subsp. ***ramosissima***
Myosotis sylvatica Ehrh. ex Hoffm. subsp. ***cyanea*** (Boiss. & Heldr. ex Hayek) Vestergren

Symphytum bulbosum C. Schimper

BRASSICACEAE
Alyssum minutum Schlecht.
Arabidopsis thaliana (L.) Heynh.
Arabis alpina L. subsp. ***caucasica*** (Willd.) Briq.
Arabis sagittata (Bertol.) DC.
Arabis turrita L.
Cardamine bulbifera (L.) Crantz
Cardamine graeca L.
Cardamine hirsuta L.
Draba muralis L.
Erophila verna (L.) Chevall.
Erysimum crassistylum C. Presl
Teesdalia coronopifolia (Bergeret) Thell.
Thlaspi bulbosum Spruner

CAMPANULACEAE
Campanula spatulata Sm. subsp. ***spatulata***
Campanula trachelium L. subsp. ***trachelium***

CAPRIFOLIACEAE
Lonicera etrusca G. Santi

CARYOPHYLLACEAE
Arenaria serpyllifolia L.
Cerastium brachypetalum Pers. subsp. ***roeseri*** (Boiss. & Heldr.) Nyman
Cerastium brachypetalum Pers. subsp. ***tenoreanum*** (Ser.) Soó
Moehringia trinervia (L.) Clairv.
Petrorhagia illyrica (Ard.) P. W. Ball & Heywood subsp. ***illyrica***
Petrorhagia prolifera (L.) P. W. Ball & Heywood
Silene italica (L.) Pers. subsp. ***italica***
Silene multicaulis Guss. subsp. ***multicaulis***
Silene viridiflora L.
Silene vulgaris (Moench) Garcke subsp. ***bosniaca*** (G. Beck) Greuter & al.
Stellaria media (L.) Vill.

CISTACEAE
Cistus creticus L. subsp. ***creticus*** {= C. incanus L. ssp. creticus (L.) Heywood}
Helianthemum nummularium (L.) Miller subsp. ***nummularium***

CONVOLVULACEAE
Cuscuta sp.

CORNACEAE
Cornus sanguinea L.

CRASSULACEAE
Sedum amplexicaule DC. subsp. ***tenuifolium*** (Sm.) Greuter & Burdet
Sedum cepaea L.
Sedum hispanicum L.
Sedum laconicum Boiss. & Heldr. subsp. ***laconicum***
Umbilicus rupestris (Salisb.) Dandy

DIPSACACEAE
Scabiosa sp.

FABACEAE
Anthyllis vulneraria L. subsp. ***bulgarica*** (Sagorski) Cullen
Astragalus glycyphyllos L. s.l.
Astragalus sempervirens Lam. subsp. ***cephalonicus*** (C. Presl) Ascherson & Graebner
Cercis siliquastrum L. subsp. ***siliquastrum***
Chamaecytisus austriacus (L.) Link
Chamaecytisus triflorus (Lam.) Skalická {“Chamaecytisus hirsutus (L.) Link”}
Dorycnium herbaceum Vill. subsp. ***herbaceum***
{= D. pentaphyllum Scop. ssp. herbaceum (Vill.) Rouy}
Genista millii Boiss.
Hippocrepis emerus (L.) Lassen subsp. ***emeroides*** (Boiss. & Spruner) Lassen
{= Coronilla emerus L. ssp. emeroides (Boiss. & Spruner) Lassen}
Lathyrus digitatus (MB.) Fiori
Lathyrus inconspicuus L.
Lathyrus laxiflorus (Desf.) O. Kuntze subsp. ***laxiflorus***
Lotus corniculatus L.
Ononis spinosa L. subsp. ***leiosperma*** (Boiss.) Širj.
Spartium junceum L.

Trifolium arvense L.
Trifolium campestre Schreber
Trifolium grandiflorum Schreber {= T. speciosum Willd.}
Trifolium heldreichianum Hausskn.
Trifolium hirtum All.
Trifolium medium L. subsp. ***balcanicum*** Velen.
Trifolium ochroleucon Hudson
Trifolium pannonicum Jacq. subsp. ***pannonicum***
Trifolium patulum Tausch
Trifolium physodes Steven ex Bieb.
Trifolium pignantii Fauché & Chaub.
Trifolium scabrum L.
Trifolium tenuifolium Ten.
Trifolium sp.
Vicia cassubica L.
Vicia grandiflora Scop.
Vicia hirsuta (L.) S. F. Gray
Vicia lathyroides L.
Vicia sativa L. subsp. ***incisa*** (MB.) Arcangeli
Vicia villosa Roth subsp. ***microphylla*** (Dum.-Urville) P. W. Ball

FAGACEAE
Castanea sativa Miller
Fagus sylvatica L. subsp. ***sylvatica***
Quercus coccifera L.
Quercus frainetto Ten.
Quercus petraea Liebl. subsp. ***medwediewii*** (A. Camus) Menitsky
{= Q. dalechampii Ten.)
Quercus pubescens Willd.

GENTIANACEAE
Centaurium erythraea Rafn s.l.

GERANIACEAE
Geranium asphodeloides Burm. fil. subsp. ***asphodeloides***
Geranium lucidum L.
Geranium robertianum L. subsp. ***purpureum*** (Vill.) Nyman
Geranium rotundifolium L.

HYPERICACEAE
Hypericum barbatum Jacq.
Hypericum spruneri Boiss.

JUGLANDACEAE
Juglans regia L.

LAMIACEAE
Acinos alpinus (L.) Moench s.l.
Ajuga reptans L.
Calamintha grandiflora (L.) Moench {= Satureja grandiflora (L.) Scheele}
Lamium bifidum Cyr. subsp. ***bifidum***
Lamium garganicum L. subsp. ***garganicum***
Origanum vulgare L. subsp. ***hirtum*** (Link) Ietswaart {“O. heracleoticum L.”}
Prunella laciniata (L.) L.
Satureja vulgaris (L.) Fritsch subsp. ***orientalis*** (Bothmer) Greuter & Burdet {= Clinopodium vulgare L. ssp. orientale Bothmer, “C. vulgare L. ssp. arundanum (Boiss.) Nyman“}
Scutellaria columnae All. subsp. ***columnae***
Stachys scardica (Griseb.) Hayek
Stachys tymphaea Hausskn.
Teucrium chamaedrys L. subsp. ***chamaedrys***
Thymus longicaulis C. Presl subsp. ***chaubardii*** (Boiss. & Heldr.) Jalas {= T. ocheus Boiss.}

LORANTHACEAE
Viscum album L. subsp. ***abietis*** (Wiesb.) Abrom.

OLEACEAE
Fraxinus ornus L.
Phillyrea latifolia L.

ONAGRACEAE
Epilobium lanceolatum Sebastiani & Mauri

OROBANCHACEAE
Orobanche sp.

PLATANACEAE
Platanus orientalis L.

POLYGONACEAE
Fallopia convolvulus (L.) Á. Löve
Rumex acetosella L. subsp. ***acetoselloides*** (Balansa) den Nijs
Rumex tuberosus L. subsp. ***tuberosus***

PRIMULACEAE
Cyclamen hederifolium Aiton
Primula veris L. subsp. ***suaveolens*** (Bertol.) Guterm. & Ehrend.
{= P. veris L. ssp. columnae (Ten.) Maire & Petitmengin}

RANUNCULACEAE
Anemone apennina L. subsp. ***blanda*** (Schott & Kotschy) Nyman
Helleborus odorus Waldst. & Kit. subsp. ***cyclophyllus*** (A. Braun) Strid
Ranunculus paludosus Poiret
Ranunculus psilostachys Griseb.
Ranunculus sartorianus Boiss & Heldr.

ROSACEAE
Aremonia agrimonoides (L.) DC. s.l.
Crataegus monogyna Jacq.
Crataegus orientalis Pallas ex M. Bieb. subsp. ***orientalis***
Fragaria vesca L.
Geum urbanum L.
Potentilla micrantha Ramond ex DC.
Prunus avium L.
Prunus cocomilia Ten.
Prunus domestica L. subsp. ***insititia*** (L.) C. K. Schneider
Prunus mahaleb L.
Rosa arvensis Hudson
Rosa canina L.
Rosa pulverulenta Bieb. {= R. glutinosa Sm.}
Rubus canescens DC.
Rubus hirtus Waldst. & Kit.
Rubus idaeus L. subsp. ***idaeus***
Sanguisorba minor Scop. subsp. ***muricata*** (Spach) Briq.

Sorbus torminalis (L.) Crantz

RUBIACEAE

Crucianella angustifolia L.

Crucianella latifolia L.

Galium aparine L.

Galium divaricatum Pourret ex Lam.

Galium mollugo agg.

Galium rotundifolium L.

SAXIFRAGACEAE

Saxifraga carpetana Boiss. & Reuter subsp. ***graeca*** (Boiss. & Heldr.) D. A. Webb

Saxifraga rotundifolia L. subsp. ***rotundifolia***

SCROPHULARIACEAE

Digitalis ferruginea L. subsp. ***ferruginea***

Digitalis grandiflora Miller

Digitalis laevigata Waldst. & Kit. subsp. ***graeca*** (Ivanina) Werner

Verbascum chaixii Vill. subsp. ***chaixii***

Verbascum epixanthinum Boiss. & Heldr. var. ***pindicolum*** (Freyn & Sint.) Murb.

Verbascum nigrum L. subsp. ***abietinum*** (Borbás) Ferguson

Verbascum sp.

Veronica arvensis L.

Veronica chamaedrys L. subsp. ***chamaedryoides*** (Bory & Chaub.) M. A. Fischer

Veronica cymbalaria Bodard

Veronica hederifolia L.

THYMELAEACEAE

Daphne oleoides Schreber

TILIACEAE

Tilia rubra DC. subsp. ***rubra***

VALERIANACEAE

Valerianella carinata Loisel.

Valerianella locusta (L.) Laterrade

Valerianella turgida (Steven) Betcke

VIOLACEAE

Viola aetolica Boiss. & Heldr.

Viola alba Besser subsp. ***alba***

Viola alba Besser subsp. ***dehnhardtii*** (Ten.) W. Becker

Viola kitaibeliana Schultes

Viola odorata L.

Viola reichenbachiana Jordan ex Boreau x ***V. riviniana*** Rchb.

ANGIOSPERMAE - MONOCOTYLEDONEAE

CYPERACEAE

Carex distachya Desf.

Carex flacca Schreber subsp. ***serrulata*** (Biv.) Greuter

Carex sp.

JUNCACEAE

Luzula forsteri (Sm.) DC.

LILIACEAE

Allium paniculatum L.

Asparagus acutifolius L.

Muscari sp.

Ruscus aculeatus L.

ORCHIDACEAE

Cephalanthera rubra (L.) Rich.

Dactylorhiza saccifera (Brongn.) Soó

Epipactis greuteri H. Baumann & Künkele subsp. ***preinensis*** K. Seiser

Epipactis helleborine (L.) Grantz

Epipactis microphylla (Ehrh.) Swartz

Limodorum abortivum (L.) Swartz

Neotinea maculata (Desf.) Stearn

Orchis mascula (L.) L. subsp. ***mascula***

Orchis provincialis Balbis ex Lam. & DC.

Platanthera montana (F. W. Schmidt) Rchb. {= P. chlorantha (Custer) Rchb.}

POACEAE

Achnatherum bromoides (L.) P. Beauv. {= Stipa bromoides (L.) Dörfler}

Agrostis stolonifera L.
Aira elegantissima Schur subsp. ***elegantissima***
Anisantha sterilis (L.) Nevski {= Bromus sterilis L.}
Anthoxanthum odoratum L.
Arrhenatherum elatius (L.) P. Beauv. ex J. & C. Presl
Brachypodium pinnatum (L.) P. Beauv.
Brachypodium sylvaticum (Hudson) P. Beauv. subsp. ***sylvaticum***
Briza maxima L.
Bromopsis riparia (Rehmann) Holub s.l. (= Bromus riparius Rehm. s.l.)
Cynosurus echinatus L.
Cynosurus effusus Link. {= C. elegans Desf.}
Dactylis glomerata L. s.l.
Festuca circummediterranea Patzke {= F. jeanpertii (St-Yves) Markgraf}
Festuca heterophylla Lam.
Festuca rubra L. s.l.
Festuca valesiaca Schleicher ex Gaudin
Hordelymus europaeus (L.) C. O. Harz
Koeleria lobata (Bieb.) Roemer & Schultes {= K. splendes C. Presl}
Melica uniflora Retz.
Milium vernale Bieb. subsp. ***montianum*** (Parl.) Jahandiez & Maire
Phleum montanum C. Koch s.l. {= P. phleoides (L.) Karsten}
Poa bulbosa L. s.l.
Poa hybrida Gaudin
Poa nemoralis L. ssp. ***nemoralis***
Poa thessala Boiss. & Orph. {= P. pumila Host var. thessala (Boiss. & Orph.) Boiss.}
Poa trivialis L. subsp. ***sylvicola*** (Guss.) H. Lindb.
Roegneria panormitana (Parl.) Nevski {= Elymus panormitanus (Parl.) Tzvelev}
Secale strictum (C. Presl) C. Presl subsp. ***strictum*** {= S. montanum Guss.}

BRYOPHYTA

BRACHYTHECIACEAE
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen
{= Brachythecium velutinum (Hedw.) Schimp.}
Brachythecium albicans (Hedw.) Schimp.
Brachythecium glareosum (Bruch ex Spruce) Schimp.
Brachythecium rutabulum (Hedw.) Schimp.
Brachythecium salebrosum (Hoffm. ex F. Weber & D. Mohr) Schimp.

Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen
{= Eurhynchium pulchellum (Hedw.) Jenn.}
Homalothecium aureum (Spruce) H. Rob.
Homalothecium philippeanum (Spruce) Schimp.
Homalothecium sericeum (Hedw.) Schimp.
Pseudoscleropodium purum (Hedw.) M. Fleisch.
{= Scleropodium purum (Hedw.) Limpr.}
Rhynchostegium megapolitanum (Blandow ex F. Weber & D. Mohr) Schimp.
Sciuro-hypnum populeum (Hedw.) Ignatov & Huttunen
{= Brachythecium populeum (Hedw.) Schimp.}
Scleropodium touretii (Brid.) L. F. Koch

BRYACEAE
Bryum caespiticium Hedw.
Bryum capillare Hedw.
Bryum torquescens Bruch & Schimp.
{= Bryum capillare Hedw. var. torquescens (Bruch & Schimp.) Husn.}

DICRANACEAE
Dicranum scoparium Hedw.

DITRICHACEAE
Ceratodon purpureus (Hedw.) Brid. subsp. ***purpureus***

FISSIDENTACEAE
Fissidens dubius P. Beauv.

GRIMMIACEAE
Racomitrium elongatum Ehrh. ex Frisvoll

HYPNACEAE
Hypnum cupressiforme Hedw. var. ***cupressiforme***
Hypnum cupressiforme Hedw. var. ***lacunosum*** Brid.
{= Hypnum lacunosum (Brid.) Hoffm. ex Brid.}

LEMBOPHYLLACEAE
Isothecium alopecuroides (Lam. ex Dubois) Isov.

LESKEACEAE
Pseudoleskea incurvata (Hedw.) Loeske
{= Lescuraea incurvata (Hedw.) E. Lawton}

LEUCOBRYACEAE
Bryoerythrophyllum recurvirostrum (Hedw.) P. C. Chen
Syntrichia montana Nees {= Tortula intermedia (Brid.) Berk.}
Syntrichia ruralis (Hedw.) F. Weber & D. Mohr var. ***ruraliformis*** (Besch.) Delogne
{= Tortula ruraliformis (Besch.) Ingham}
Syntrichia ruralis (Hedw.) F. Weber & D. Mohr var. ***ruralis***
{= Tortula ruralis (Hedw.) P. Gaertn., B. Mey. & Scherb.}
Tortula subulata Hedw.

LEUCODONTACEAE
Pterogonium gracile (Hedw.) Sm.

LOPHOZIACEAE
Barbilophozia hatcheri (A. Evans) Loeske

MYRINIACEAE
Ctenidium molluscum (Hedw.) Mitt.

PLAGIOMNIACEAE
Plagiomnium affine (Blandow ex Funck) T. J. Kop.
Plagiomnium undulatum (Hedw.) T. J. Kop. var. ***undulatum***

POLYTRICHACEAE
Polytrichum juniperinum Hedw.

PORELLACEAE
Porella platyphylla (L.) Pfeiff.

POTTIACEAE
Tortella tortuosa (Hedw.) Limpr.

Aggregated taxa: *Galium mollugo* agg. (*G. citraceum, G. absurdum*)

Abbreviations: s.l. = sensu lato, agg. = aggregation

Notes

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