Monitoring of vegetation ecosystems in Greece using vegetation indices time series

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Abstract

Monitoring vegetation function on large temporal scales is very important in climate change studies. In this direction, satellite remote sensing plays a key role in the systematic monitoring of terrestrial ecosystems function by providing the required spatiotemporal thematic information either in global or in regional scale. In particular, vegetation phenology studying the timing of seasonal events such as lead budburst and leaf senescence are considered as indicators of ecosystem adaptive responses to climate conditions. In this study, a mountainous deciduous forest ecosystem (*Fagus sylvatica)* is studied in three different locations in Greece with different topographic characteristics. For each study area, NDVI and fAPAR time-series spanning from January 2003 to December 2011 are extracted from ENVISAT MERIS satellite data. Seasonal variations are observed and correlations between these parameters are performed in terms of the seasonal leaf growth cycle of the species. First results show high correlation between NDVI and fAPAR. There is also a general North-South gradient in the average monthly values and the correlation coefficient between the two parameters. However, observed NDVI saturation and fAPAR variability in summer months indicate that the altitude also plays a significant role in canopy density and vitality explaining thus certain variations from the general pattern. Ongoing comparisons to other ecophysiological parameters such as LAI, topographic and climate measurements aim at investigating potential relations and forest responses to local climatic conditions and topographic variations.

Keywords: *Fagus sylvatica*, ecosystem, NDVI, fAPAR, MERIS, Greece

Introduction

Fagus sylvatica (beech) is the most abundant broadleaved forest tree in Central Europe and in many mountains of southern Europe. It is highly competitive in many types of zonal forest as it is shade-tolerant as juvenile and casts deep shade as canopy tree. *Fagus sylvatica* is a strictly montane species in southern Europe. However, views and hypotheses on the role of the ecological and geographical factors in observed differentiations of beech forest vegetation in the southern Balkan area are partly complementary and partly contradictory. This appears from (i) the old classifications of Balkan beech forests in geographically framed alliances, (ii) the strong North-South gradient in the southwestern Balkan (including Central Greece) and (iii) the complex-pattern classification proposed by Bergmeier and Dimopoulos (2001) which strengthens the primarily geographical differentiation and the dominance of the ecological over the geographical differentiation. Studies on the nature of the gradients underlying the differentiation of the southern Balkan beech forest vegetation are still ongoing (Tsiripidis et al. 2007). In Greece, the ecosystem is restricted to the northern and central parts of the mainland (Bergmeier and Dimopoulos 2001). At the edge of its southern range, the changing climate may even cause a retreat of beech populations (Jump and Peñuelas 2006).

The beech can be used for dendroecological studies, especially to evaluate the growth and climate relationships in different bioclimatological units, and to estimate future prospects and possible ecological risks associated with climate change (Gutierrez 1988; Biondi 1992; Rozas 2001; Eckstein 2004; Lebourgeois et al. 2005; Piovesan et al. 2005; Di Filippo et al. 2007; Cufar et al. 2008). Recently, a variety of remote sensors have been used in forest inventory studies including passive optical and active radar systems. The most commonly used broadband indicators of forest parameters issued from satellite measurements are ratio indices (vegetation indices) computed using NIR and visible reflectances. The most known vegetation index is the normalized difference vegetation index (NDVI) developed by Rouse et

al. (1974). NDVI is based on the contrast between the maximum absorption in the red due to chlorophyll pigments and the maximum reflectance in the NIR caused by scattering in the leaf mesophyll. NDVI provides information about the spatial and temporal distribution of vegetation communities, vegetation biomass, CO_2 fluxes, vegetation quality and land degradation (Nemani et al. 2003; Pettorelli et al. 2005). NDVI also correlates strongly, often linearly, with the absorbed photosynthetically active radiation (APAR), which helps lead to its common use as an estimator of the aboveground Net Primary Productivity (NPP) (Asrar et. al. 1984; Kerr and Ostrofsky 2003).
Furthermore, fAPAR is the fraction of absorbed photosynthetic active radiation (0.4–0.7μm), which can be derived from optical satellite data. It has been recognized as one of the fundamental essential climate variables (ECVs) by Global Terrestrial Observing System (GTOS) and Global Climate Observing System (GCOS). fAPAR expresses a canopy's energy absorption capacity and is thus a key variable in models assessing vegetation primary productivity and, more generally, in carbon cycle models. It often provides the link between ecosystem function and structure. Space agencies and other institutional providers currently deliver various fAPAR products at different temporal and spatial resolutions over the globe taking advantage of the various available satellite data (Barret and Weiss 2012). However, significant differences can have been observed between fAPAR products issued from different satellite systems mainly due to the computation algorithms used by each system (Martinez et al. 2013).
In Greece, few studies have been conducted on *Fagus sylvatica* ecosystems using NDVI and fAPAR issued from satellite measurements (Stagakis et al. 2007). The present study presents the preliminary results on the ecophysiological study of three *Fagus sylvatica* (beech) forests in three selected sites in Greece, namely Nymfaio, Metsovo and Vardousia, using NDVI and fAPAR time series issued from MERIS satellite data over a 9-year period spanning 01-01-2003 to 31-12-2011.

Materials and Methods

Study sites

This study includes three homogenous beech forests in different geographic latitudes, named from north to south, Nymfaio, Metsovo and Vardousia (Fig. 1). In every study site, the dominant tree species covers more than 90% of the area.
Nymfaio (lat. 40°38'31.20"N, lon. 21°25'8.40"E, altitude: 1720 meters): Due to its ecological interest, the wider region of this area is included in the European Natura 2000 ecological network of protected areas. The protected area has been catalogued with the location name "Oros Vernon – Koryfi Vitsi" (Mount. Vernon – Vitsi Summit) and under the code GR1340006. Geomorphologically, the area belongs to the wider mountain range of Pindus. The beech forest is important as a pollution absorbant in relation to the highly polluted and degraded natural environment of the Amyndeo plain, according to Natura 2000.
Metsovo (lat.39°48'43.20"N, lon. 21° 3'10.80"E, altitude 1460 meters): It is located between two areas which belong to Natura 2000. The first one is catalogued with the location name "Ethnikos Drymos Vikou – Aoou (Vikos – Aoos National Park) and under the code GR2130001 and it is located on the northwest of Metsovo site. The second one is catalogued with the location name "Periochi Metsovou (Anilio – Katara)" (Metsovo territory, Anilio – Katara) and under the code GR2130006 and it is located on the southeast of Metsovo. Geomorphologically, the area belongs to the Pindus mountains, a region with very important ecosystems due to their flora and fauna. The geographical isolation of the area, the relatively small human influence and the great variation of biotopes and microclimatic conditions favor the growth of different plant species, among them rare plants that are considered threatened taxa according to Natura 2000.
Vardousia (lat. 38°47'6.00"N, lon. 21°57'50.40"E, altitude 1490 meters): The study area is located in the massif of Vardousia, which constitutes the southernmost part of Pindus mountain range. It is one of the few mountains in Greece having Alpine characteristics. More than ten peaks exceed 2000 meters altitude and its expanse is 30 kilometers from north to south and 15 kilometers from west to east. The lowest slopes of the mountain range are

covered mainly by beech and oak forests. The site is also set close to a Natura 2000 region which is catalogued with the location name “Ori Varodousia” (Vardousia Mounts.) and under the code GR2450001, located on the southeast of the site. The occurrence of a great number of endemic and rare plants, especially in the extraforestial plant associations, renders the area as an important one from an ecological point of view, according to Natura 2000.

Figure 1. Geographic location of the three study sites.

Data acquisition and processing

For this study, we use ten-day maximum value composite NDVI and fAPAR images issued from MERIS data (Barret and Weiss 2012). The ENVISAT MERIS S10 products are near-global, 10-daily, maximum value composite images of the Normalized Difference Vegetation Index (NDVI) and the Fraction of Absorbed Photosynthetically Active Radiation (fAPAR), taken from ENVISAT MERIS Level 2 Reduced Resolution data. The projection of the data is EPSG32662 WGS84 and the resolution 0.008928571degrees. Time series span from January 1, 2003 to December 31, 2011. The NDVI and fAPAR values are extracted from pixels that include the three study areas. Two nine-year time series are constructed for each one of the sites. Both data series are shown in figure 2 and their corresponding descriptive statistics are shown in table 1. Furthermore, average monthly values are calculated and a multiple curve analysis using linear averaging is performed to all data. The latter provides a new curve corresponding to the average NDVI and fAPAR of each area (Fig. 3). Finally, correlations for a linear and 2^{nd} order polynomial fit are performed between NDVI and fAPAR for each site (Fig. 4). The resulting coefficients of determination from both fits are presented in table 2.

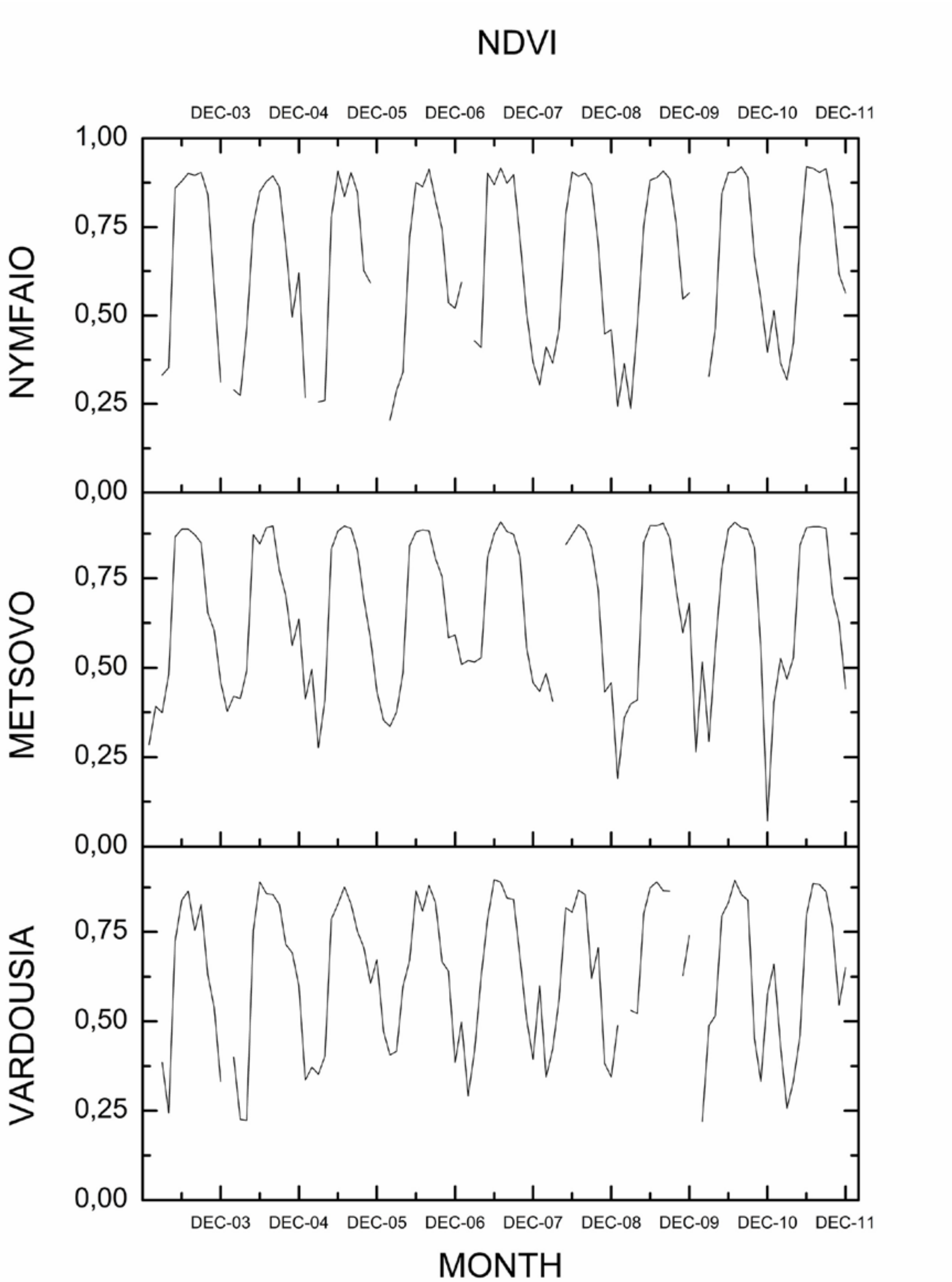

Figure 2a. Time series of NDVI.

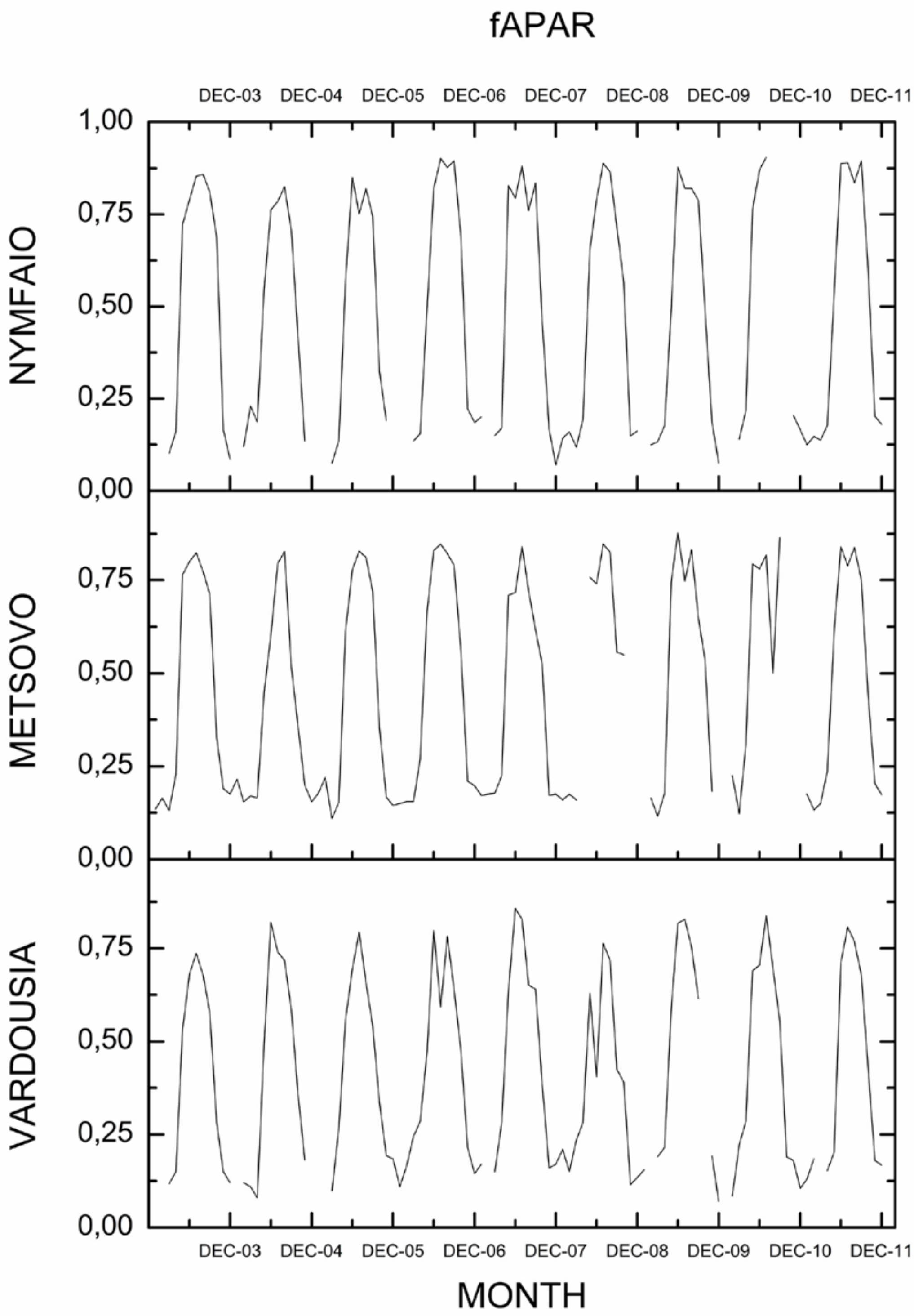

Figure 2b. Time series of fAPAR.

Table 1

Descriptive statistics of the beech forest structural parameters for the three ecosystems

NDVI	Min.	Max.	Mean	std
Nymfaio	0.204	0.920	**0.650**	0.236
Metsovo	0.072	0.908	**0.652**	0.218
Vardousia	0.212	0.896	**0.632**	0.209
fAPAR	Min.	Max.	Mean	std
Nymfaio	0.070	0.905	**0.482**	0.318
Metsovo	0.110	0.878	**0.452**	0.285
Vardousia	0.070	0.858	**0.412**	0.259

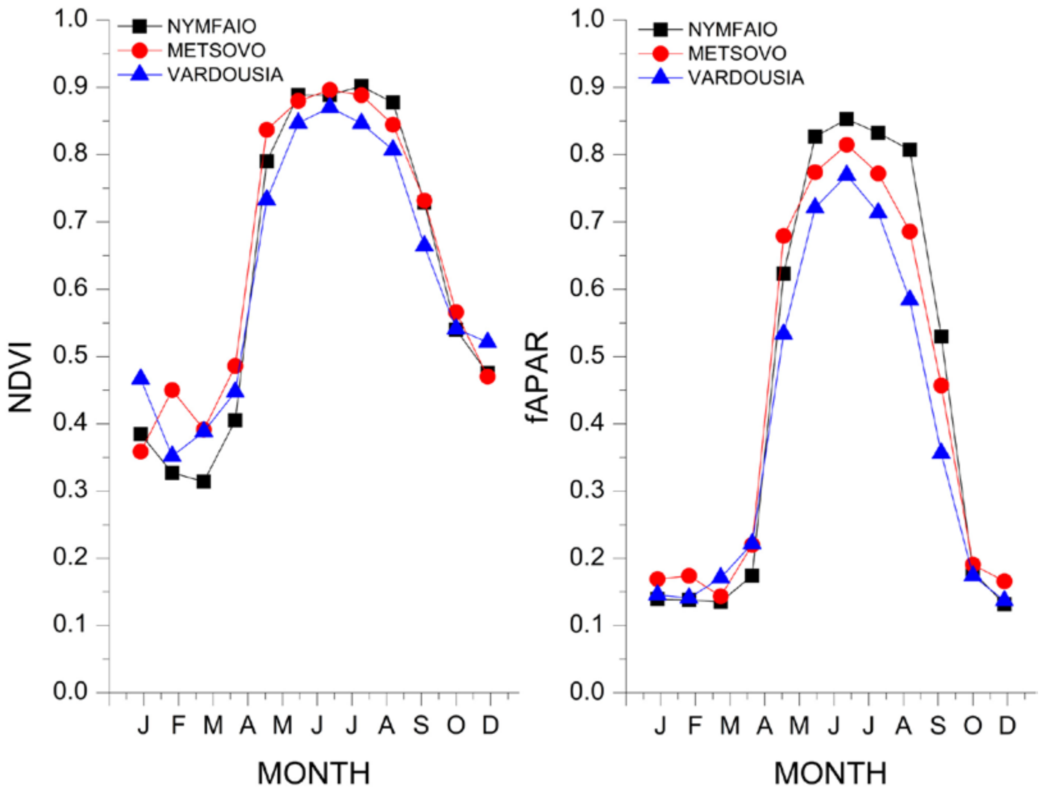

Figure 3. Average annual fluctuation of (a) NDVI and (b) fAPAR.

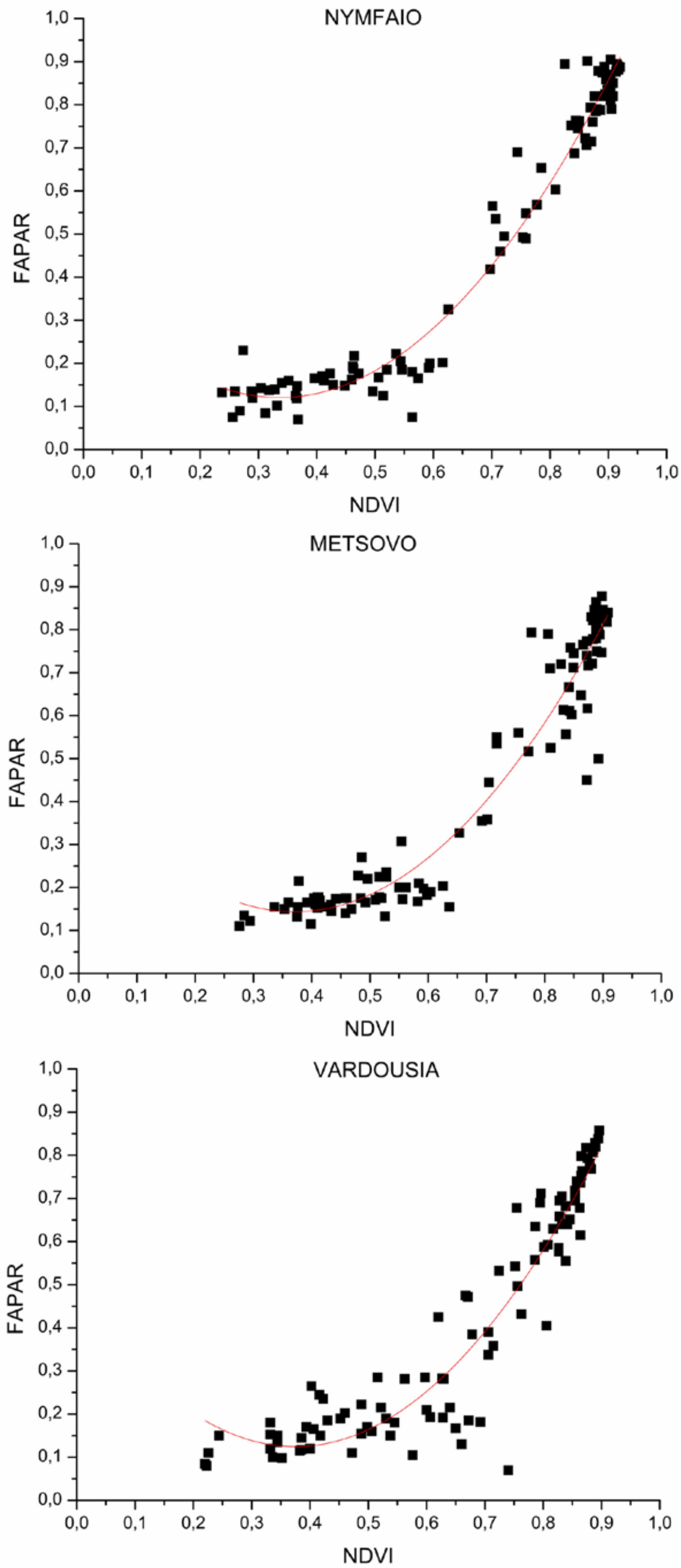

Figure 4. Relationship between NDVI and fAPAR for the three study areas: (a) Nymfaio (b) Metsovo and (c) Vardousia. In red line, the best 2nd order polyonomial fit.

Table 2

Coefficients of determination (r^2) for a linear and 2nd order polynomial best fit between NVDI and fAPAR parameters. High r^2 values are observed for both fits though slightly higher ones occur for the polynomial fit. The highest r^2 are observed for Nymfaio

r^2	Nymfaio	Metsovo	Vardousia
Linear	0.90	0.88	0.78
2nd order polynomial	**0.97**	**0.93**	**0.89**

Results and Discussion

For the three study sites, NDVI and fAPAR values show a typical rise and fall during spring and autumn, coinciding with the periods of leaf burst and senescence respectively (Stagakis et al. 2007). NDVI and fAPAR curves follow a bell shape although the pattern characteristics show differentiations between years (Fig. 2). Discontinuities observed in the curves, are due to missing data pixels, usually caused by overcast conditions.
In particular, NDVI begins with low values between December - January with variable minima, depending on the year, mainly for Metsovo and Vardousia. Measured minimum NDVI values are 0.2, 0.07 and 0.21 for Nymfaio, Metsovo and Vardousia respectively. The 0.07 value in Metsovo site is exceptionally low and it is observed in December 2010. On the other hand, the highest of the lowest values is 0.5 and it is observed in winter 2006-07. NDVI increases nearly linearly from winter to summer reaching a maximum peak during summer months (June to August). Observed highest values are 0.92 for Nymfaio, 0.91 for Metsovo and 0.90 for Vardousia. For certain years, a small depression is observed in July (e.g. in 2006, 2008 and 2011). After the summer peak, all NDVI curves decrease linearly to the end of each year. For all three sites, although maximum NDVI values show no significant variability during the period of study, the lowest values show significant variability (Fig. 2a). This is most notable in Metsovo and Vardousia sites. Finally, mean NDVI values in Nymfaio and Metsovo are similar (around 0.65) and slightly higher than the corresponding ones in Vardousia (0.63). The standard deviation values increase from Vardousia to Nymfaio (Tab. 1). Concluding, NDVI shows a North-South gradient in maximum, mean and standard deviation values as shown in figure 2a. Despite the strong seasonality, the NDVI structural pattern varies among years especially in minima peak values. Finally, a slight decreasing gradient is observed in the highest and mean values from Nymfaio to Vardousia (Tab. 1).

As observed for the NDVI, fAPAR also presents strong seasonality (Fig. 2b). The lowest observed values occur in December. Values reach 0.07 for Nymfaio 0.11 for Metsovo and 0.07 for Vardousia. A small depression is observed in December 2007 in all sites. Metsovo shows two additional depressions in December 2003 and 2004. However, there is no significant variation between lowest values during the whole period of study. From spring, fAPAR increases linearly till summer and in July it reaches its highest value, which is around 0.91 in Nymfaio, 0.88 in Metsovo and 0.86 in Vardousia. Minor depressions are also present in 2005, 2007, 2009 and 2011 in Nymfaio, in 2008, 2009 and 2010, from 2007 and onwards in Metsovo and in 2006, 2008 and 2010 for Vardousia. The highest observed values decrease from North to South as shown in figure 3. The same applies for the mean fAPAR values as shown in table 1. Concluding, fAPAR curves show a strong seasonality in all three sites with peaks in summer (July-August) and decreasing highest, mean and standard deviation values from North to South (Tab. 1).

Correlations between NDVI and fAPAR are also performed for a linear and a 2nd order polynomial best fit. As shown figure 4, NDVI and fAPAR are highly correlated. The r^2 values

are generally high (above 0.78) as shown in table 2. Although in bibliography NDVI and fAPAR are usually presented to have a strong linear relationship (Sellers et al. 1992; Kodani et al. 2002; Di Bella et al. 2004; Fensholt et al. 2004), in this study all sites present slightly higher coefficients of determination for a non-linear fit than a linear one and furthermore, with relatively lower correlations gradually going from North to South.
The observed NDVI and fAPAR values are not only strongly correlated but they also seem to be affected by the geographic location presenting a clear gradient from North to South (Fig. 3). Indeed, vitality and growth of common beech have already been strongly related to altitude-dependent weather conditions (Dittmar and Elling 2005). In this case, this can also explain the value divergence between Metsovo and Vardousia, considering their negligible altitude difference. Especially in May, NDVI and fAPAR are strongly linked but increase more rapidly in Metsovo than in Nymfaio (Fig. 3). This does not agree with the general pattern of the observed North-South gradient. However, it could be explained by the higher altitude of Nymfaio which induces a delay in leaf budburst. On the other hand, leaf senescence in September follows the North-South gradient pattern. Leaf senescence in Nymfaio starts in October and in Metsovo and Vardousia in September. Furthermore, NDVI high values in summer for Metsovo and Nymfaio are similar indicating saturation. On the other hand, fAPAR maximum values vary from site to site suggesting higher density and vitality of the Nymfaio forest canopy (Fig. 3). The aforementioned explanation may also be supported by the strong non-linear relation between the two parameters (Fig. 4).

Conclusions

In this study we present the first results of a comparative analysis for three beech forests located in different locations and altitudes in Greece. NDVI and fAPAR time series issued from ENVISAT MERIS data are extracted spanning a nine year period from January 2003 to December 2011. Both time series show a typical rise and fall during spring and autumn, coinciding with the periods of leaf burst and senescence correspondingly.
High correlations between NDVI and fAPAR show a clear North-South gradient of *Fagus sylvatica* canopy density or vitality. However, altitude differences may explain observed inversions from this pattern such as earlier leaf budburst in Metsovo.
This is an ongoing study. NDVI and fAPAR time series are currently examined in comparison to other ecophysiological parameters (e.g. LAI), topographic and climate measurements (e.g. temperature, precipitation) in order to investigate potential relations and forest response to local climatic conditions and topographic variations.

Acknowledgments

The input MERIS L2 data are provided by the European Space Agency. The algorithm to derive the global vegetation parameters (MGVI) for MERIS L2 products was developed by the Joint Research Centre (http://fAPAR.jrc.ec.europa.eu). The ENVISAT MERIS S10 products are Copyright by VITO - Flemish Institute for Technological Research.

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