The use of NDVI time-series for the study of ecosystem dynamics of two deciduous (*Fagus sylvatica*, *Quercus* sp.) and one conifer (*Pinus nigra*) forest

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Ecosystem function in relation to climate variability is becoming increasingly important during the last years, especially under the frame of the ongoing global climate change. Our ability to predict physiological responses at an ecosystem level is limited by the nature of field experimental data, which are usually spatially and/or temporally restricted. Remote sensing techniques, developed during the last two decades, provide an alternative approaching method, since they generate massive series of data at scales ranging from individual landscapes to the entire globe and for long time periods. In the present study the Normalized Difference Vegetation Index (NDVI), extracted from satellite images, is used (i) to investigate spatio-temporal dynamics of three different ecosystems in response to inter-annual climate variability and (ii) to examine the relation of NDVI with ground measurements, in an attempt to clarify the major physiological parameters strongly correlated with NDVI.

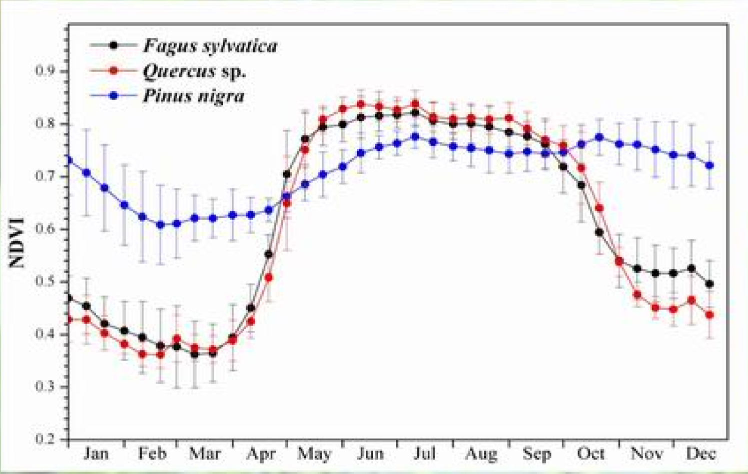
Study area

The study area is located in Northern Pindos National Park, Epirus, Greece. Three different forest ecosystems were examined, two of them dominated by deciduous species (*Fagus sylvatica* and *Quercus frainetto*/*Quercus cerris*) and one by the evergreen conifer *Pinus nigra*.

Satellite and Meteorological data

SPOT-4 satellite images (MVC) acquired by the Vegetation Program (http://www.spot-vegetation.com/), with pixel size of 1x1 Km, were used for the extraction of NDVI (1998 - 2005). The original data were corrected for clouds and poor atmospheric conditions by applying the Best Index Slope Extraction (BISE) algorithm (White et al., 1997) and time-series for the areas of interest were smoothed applying a Fast Fourier Transformation (FFT) analysis. Air temperature and precipitation amount data are estimated from: i) air temperature and precipitation amount observations recorded at two stations and ii) NCEP/NCAR Reanalysis grid point 850hPa air temperature and surface precipitation rate data (Kalnay et al., 1996), by applying step-wise regression analysis.

Fig. 1. Annual fluctuation of NDVI for *Fagus sylvatica*, *Quercus* sp. and *Pinus nigra* (values for each date are means ± SD from 8 years).



The annual growth pattern is very well depicted via the NDVI for all the studied species. NDVI values for the deciduous *Fagus* and *Quercus* species show a typical rise and fall during spring and autumn, coinciding with the periods of leaf burst and senescence correspondingly. The evergreen *Pinus* shows rather constant NDVI values throughout the year, with the exception of a small decline during winter, possibly due to the low temperature and/or the snow cover prevailing during that period.

Fig. 2. Inter-annual fluctuation of NDVI as a response to interannual climate variability for *Fagus sylvatica*, *Quercus* sp. and *Pinus nigra* for the 8-year study period. Total monthly precipitation (bars) and average monthly temperature (thick violet line) are also shown. Vertical lines on April 21 and November 1 indicate the average start/end dates of the growing period for the deciduous species.

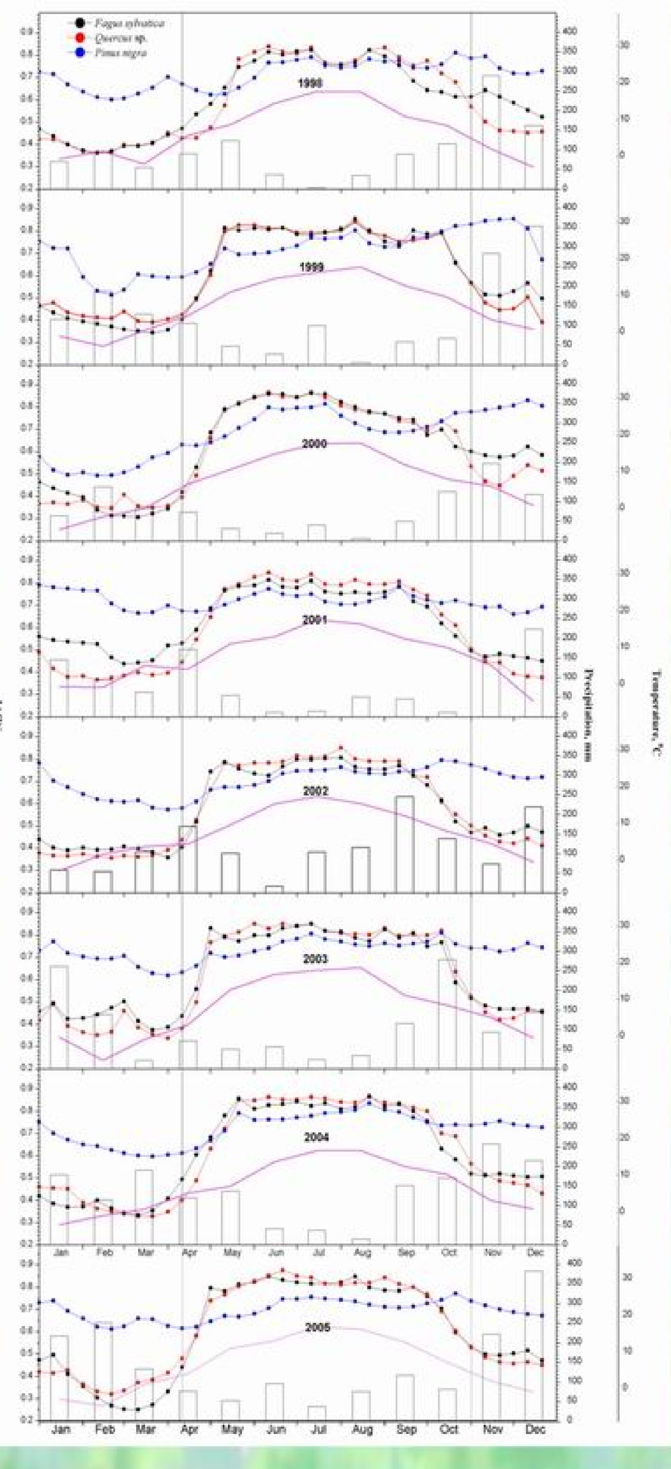


Fig. 3. Correlation between annual productivity (calculated as the integral of the NDVI curves of Fig. 2) and cumulative monthly precipitation for all studied species. Precipitation data (number of months) correspond to the last month of the growth period (October for the deciduous species, December for the evergreen) up to four years in the past (46).

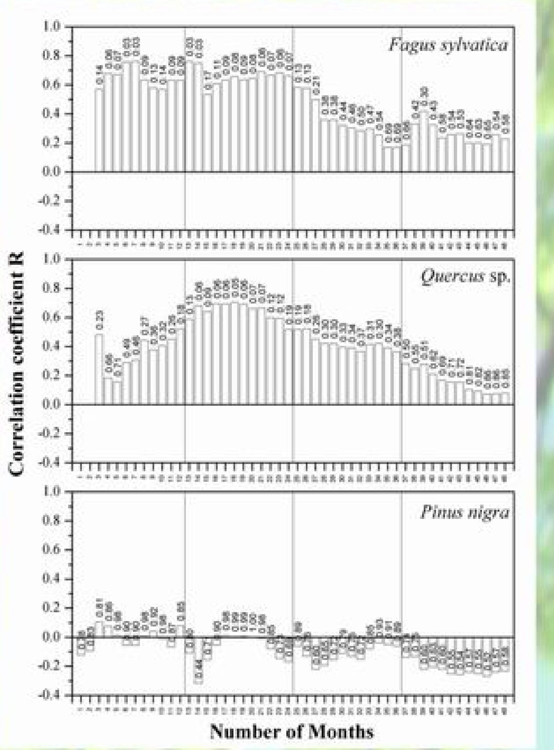
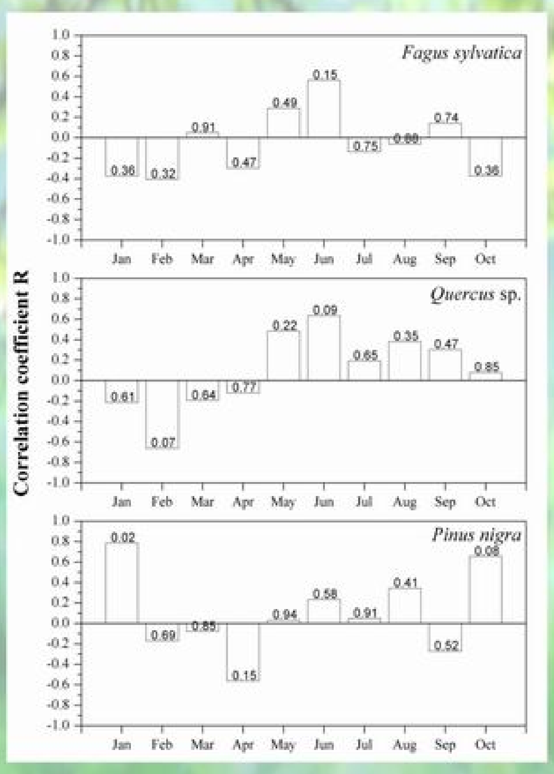


Fig. 4. Correlation between annual productivity (calculated as the integral of the NDVI curves of Fig. 2) and mean monthly temperature for all studied species.



Annual productivity of both deciduous species seems to be related mainly to the temperature of the current June. The unusual negative correlation with the temperature of February for *Quercus* may imply that snow cover, that is typical for these altitudes, is beneficial for growth, through enhanced aquifer enrichment. Evergreen *Pinus* depends strongly on winter and autumn temperature (January, October), since low temperatures of these months have direct negative effect on productivity.

The variability of vegetation state and function over space and time is well depicted in interannual NDVI fluctuations. Thus, it is essential to detect consistent relationship between NDVI and canopy attributes, which are measures or important determinants of the ecosystem productivity, such as Plant Area Index (PAI) and Chlorophyll content (Myneni et al., 1995).

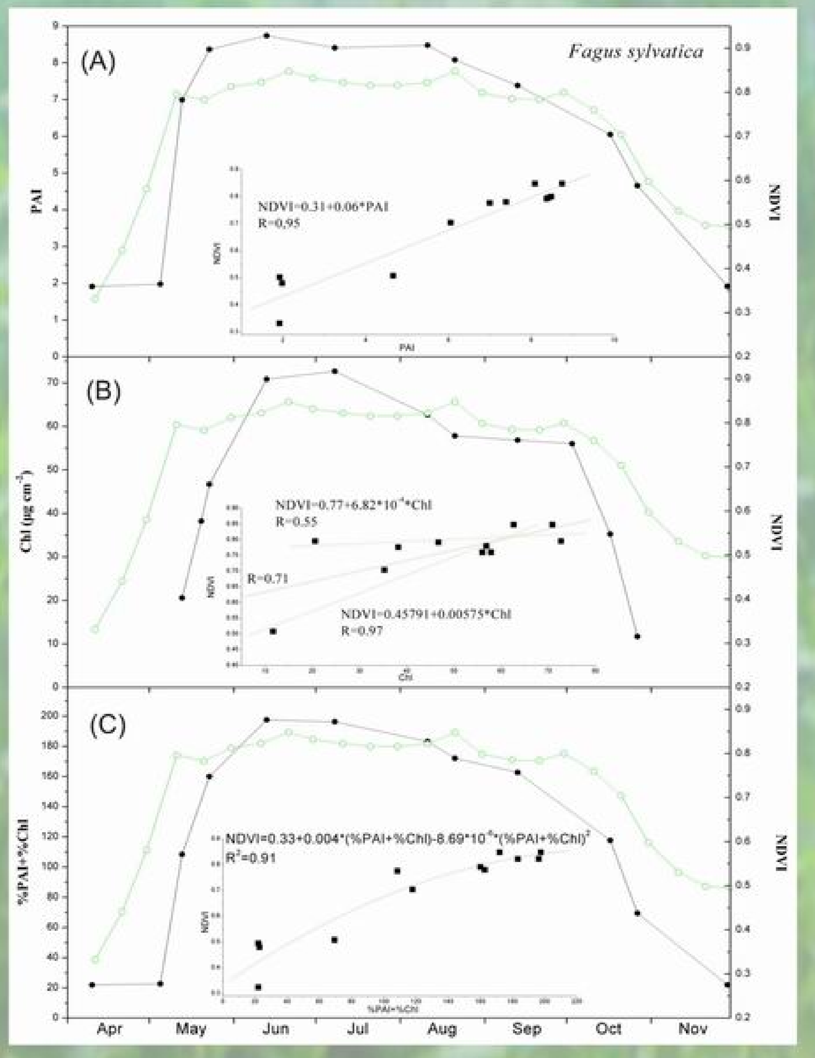


Fig. 5. Seasonal fluctuation of NDVI (green lines), Plant Area Index (PAI) (A, D), Chlorophyll content of sun leaves (B, E) and a combination of PAI and chlorophyll content (the percentage of the one summed with the other's at any given time) (C, F) for the two deciduous species during the 2005 growing period. The correlations between the ground measurements and NDVI are shown at the corresponding insets. In the case of chlorophyll content, the growing period was divided in two and three different correlations were extracted for each forest. The red line stands for the total correlation, the green line for the first half of the growing period and the dark yellow line for the second half of the growing period.

- PAI of both forests seems to co-variate with NDVI during the whole growing period (Fig. 5A, D).
- Chlorophyll content of both forests does not show a uniform correlation with NDVI throughout the growing period (Fig. 5B, E).
- The combination of PAI and Chlorophyll content shows very good correlations with NDVI, implying that is more suitable to describe the NDVI fluctuations (Fig. 5C, F).

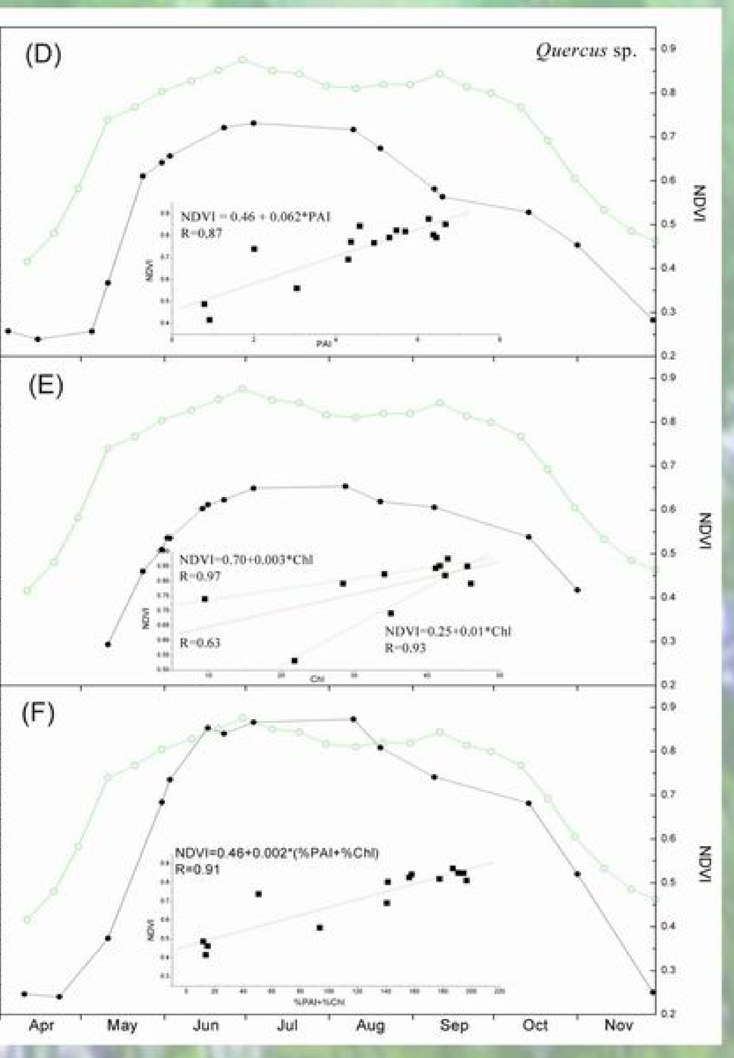
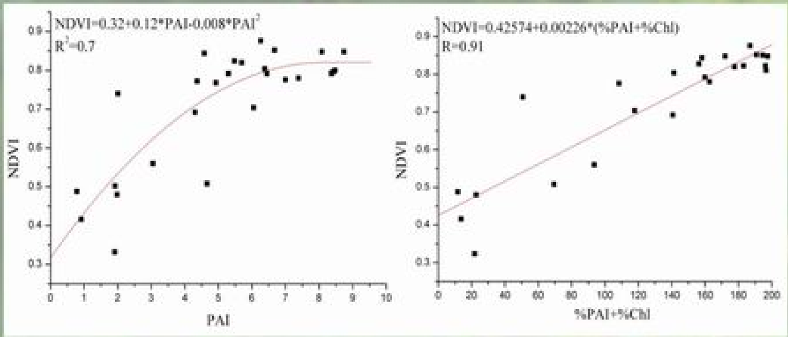


Fig. 6. Correlation of NDVI with PAI for both deciduous forests and the transformation of this correlation when the combination of PAI and chlorophyll content is used.



In relative literature is often shown that NDVI saturates over a given PAI value. Such effect is also shown in this study when trying to extract a general relationship between PAI and NDVI. Nevertheless, the combination of PAI and chlorophyll content for both forests is linearly correlated with NDVI.

Conclusions

- NDVI depicts growth patterns of both deciduous and evergreen species, as well as the interannual variability of phenological events.
- Much of the inter- annual variation in productivity of the deciduous species is explained by corresponding variation in cumulative precipitation of preceding months or years, whereas the productivity of the evergreen *Pinus nigra* seem to be unaffected by these variations.
- Temperature of the growing season and especially of June is critical for the annual productivity of the deciduous species, whereas winter and autumn temperatures are more critical for the evergreen *Pinus nigra*.
- A combination of PAI and Chlorophyll content is more suitable to describe the NDVI fluctuations for each forest, since it appears better correlations than the two determinants separately.
- Even though the general relation between PAI and NDVI shows that NDVI is saturated over a medium PAI value, a linear relationship appears if NDVI is correlated with a combination of PAI and chlorophyll content.

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Acknowledgments

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