Environmental Earth Sciences (2019) 78:172
https://doi.org/10.1007/s12665-019-8180-9

ORIGINAL ARTICLE

Vegetation greening trends in different land use types: natural variability versus human-induced impacts in Greece

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Received: 12 July 2018 / Accepted: 19 February 2019 / Published online: 27 February 2019

Abstract

Vegetation greening and browning patterns in two diverse land use environments, i.e., urban areas and sites protected by environmental legislation over Greece, are evaluated and presented in this work. Urban sites correspond to areas of high man intervention, whereas the protected sites are considered as areas with least human impact and are therefore representative of the natural variability of vegetation attributed mainly to climate. Analysis of time series data in the form of least square line fitting was conducted using remotely sensed Normalized Difference Vegetation Index (NDVI) of the Moderate Resolution Imaging Spectroradiometer (MODIS) and the spatio-temporal vegetation trends were examined in the two diverse land use categories. Results showed that 99% of protected sites and 95% of urban sites exhibited significant browning or greening trends ($p<0.01$) with greening patterns dominating in most parts of the country during all seasons. Regarding the magnitude of detected trends, protected areas demonstrated a higher greening trend both annually and seasonally. Average magnitudes of NDVI on an annual basis were computed to 2.04×10^{-3} year^{-1} for urban areas and 4.50×10^{-3} year^{-1}, respectively. Higher rates of NDVI increase were detected in autumn and winter. Spatially, NDVI changes in protected sites demonstrated higher increasing trends by increasing latitude, whereas no major trend in the rate of NDVI change is evident on the east–west direction. Possible causal factors of those increasing NDVI trends, both climatic and human induced are discussed. Furthermore, the role of economic crisis during the last decade has been highlighted, which caused a dramatic drop in urban expansion all over the country, seems to have positively impacted vegetation productivity in those areas as well.

Keywords NDVI · Vegetation trends · Greening · Browning · Land uses · Climate change · GREECE

Introduction

Climate change has already brought important impacts to natural and human systems globally. Sea level rise, global warming, and ice-sheet cover changes are perhaps the most widely known changes of the environment. Anthropogenic greenhouse gas (GHG) emissions are the highest in history, indicating the dominant role of human activities on climate change (IPCC 2014). Land vegetation, is recognized as a CO_2 sink even greater than oceans (Quéré et al. 2009). Therefore, it has a remarkable contribution to the mitigation of climate change effects. Quéré et al. (2009), recognized emissions from land use changes (LUC) (mainly in the form of deforestation, urbanization, intensive cultivation) as the second largest CO_2 source. However, LUC emissions are partially compensated by the secondary vegetation regrown, e.g., afforestation, growing of urban green areas, shift to soil carbon conservative agricultural practices. Particularly in urban areas, vegetation offers an additional valuable service controlling microclimate, generating cooling effects and improving thermal comfort especially during daytime and hot summer days (Sodoudi et al. 2018). Analogous results were found in Li et al. (2018a, b), where the highly dependence of land surface temperature (LST) on land cover type in the urban area of Berlin was highlighted. Accurate representation of landscape phenology has also been found to

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play a crucial role in climate models while simulating water, energy and carbon exchange between land and the atmosphere (Ma et al. 2013) but also for urban climate modeling (Li et al. 2019). Monitoring and assessing the quality of terrestrial vegetation is thus of particular interest for environmental scientists and of major importance in forming adaptation and mitigation policies regarding climate change.

Vegetation changes take place as a response to global-scale drivers that interact with regional and local scale drivers (Mishra and Mainali 2017). Vegetation and especially terrestrial ecosystems are vulnerable to temperature rise and CO_2 concentration, with range shifts (upward migration) but also changing growing period, phenology and productivity among the observed impacts (Parmesan and Yohe 2003; Cong et al. 2013).

Previous studies have shown vegetation greening trends in many parts of the world such as Central Asia (Yin et al. 2016) and China (Xu et al. 2014), as well as in Himalayas (Mishra and Chaudhuri 2015; Li et al. 2016; Mishra and Mainali 2017). Mishra et al. (2015), detected vegetation greening in African savanna associated with woody plant encroachment due to increased moisture availability. They also highlighted negative greenness trends in protected African savanna sites, attributed to unmanaged high intensity mega fire events. In boreal Eurasia, Piao et al. (2011) report increase in NDVI during 1982–1997 and a decrease up to 2006, especially in summer, attributed to decrease in summer precipitation. A mixed spatial and seasonal pattern of increasing and decreasing NDVI trend was revealed in Tianshan Mountains, China, attributed to variability of temperature, precipitation, and soil moisture (Liu et al. 2016).

Although it is difficult to attribute the causal effect of vegetation trends to climate change, a potential climate change impact can be highlighted examining vegetation trends to different/diverse environments. Previous works have investigated the possible connection of vegetation and climate changes (Li et al. 2016) and although there are evidences of possible climate change implications, it is recognized that inferring the cause of vegetation changes needs detailed knowledge of land use changes and reliable data at larger temporal scales (Mishra and Chaudhuri 2015). In various geographical areas, however, a unique vegetation response is produced which is not only related to global scale drivers but also to land use changes at local or regional scales which are introduced mostly by socioeconomic factors such as population growth and urban expansion.

Previous research has shown that current remote sensing techniques provide global coverage, short revisit cycles and spatial resolution adequate for environmental monitoring and determination of spatio-temporal changes of various environmental parameters, such as LST, vegetation indices, snow-ice cover, and land cover. Ma et al. (2013), indicates that remote sensing constitutes the only feasible technique of monitoring vegetation over regional, continental and global scales. Remote sensing of environment started in the middle of the previous century, but only after 2000 did scientists manage to provide purely scientific satellite missions which could acquire information at a reasonable high spatial and temporal resolution. Nowadays, there are numerous freely available remotely sensed products that constitute a unique source of information concerning environmental changes, such as Landsat, Sentinel, MODIS (on board Aqua and Terra satellites), Gravity Recovery and Climate Experiment (GRACE), Soil Moisture Active Passive (SMAP), and Soil Moisture Ocean Salinity (SMOS) products.

Mediterranean has been designated as one of the "Hot Spots" regarding its vulnerability to climate changes (Giorgi 2006; Giorgi and Lionello 2008) and various works have studied vegetation greening and browning trends in specified ecosystems of Mediterranean. Those works are mostly focused on limited geographical areas related to forests (Maselli 2004; Durante et al. 2009), whereas some of those target towards forest fire risk management (Chuvieco et al. 2004). Our work is not concentrated on a specific land use type, but it estimates vegetation trends in two contrasting land uses, in terms of human impact, over the whole extent of a typical Mediterranean country, i.e., Greece. The examined land use areas are either protected by environmental legislation where vegetation changes are mostly connected to climate factors, or urban areas where changes induced by human activities prevail. Spatial and temporal vegetation greening/browning trends on seasonal and annual basis were evaluated during an 18-year period, from 2000 to 2017. The aims of our work are: (a) to evaluate the unique response of vegetation to climate and human impacts and (b) to quantify vegetation trends so as climate models can provide more accurate results in their simulations and predictions.

Methods and materials

Study area description

Our methodology is demonstrated in the land areas (both continental and island parts) of Greece. According to climate projections under the A1 and B2 scenarios of the Intergovernmental Panel on Climate Change (IPCC 2000), substantial changes in vegetation are expected globally with a general increase of deciduous at the expense of evergreen vegetation (European Environmental Agency 2010). Vegetation changes are also predicted in Mediterranean countries affecting the spatial distribution, the productivity and other important aspects of terrestrial ecosystems, threatening their suitability as habitats for many endangered species.

From the climate point of view, Greece is a Mediterranean country with a diverse topography that impacts its climate. The main geographical feature causing a major climatic differentiation is the Pindus mountain chain and its extension to Peloponnesus and Crete (Fig. 1). East of Pindus the predominant climate type is Mediterranean, with mild, wet winters and hot and dry summers. On the west part of Greece, the climate is closer to Alpine type, with abundant precipitation. Thus, the annual precipitation in Western Greece amounts to more than 1000 mm/year, while in Eastern Greece and the Aegean islands annual precipitation ranges from 400 to 600 mm/year (Pnevmatikos and Katsoulis 2006; European Academies Science Advisory Council (EASAC) 2010; Eleftheriou et al. 2018). The Hellenic National Meteorological Service (http://www.hnms.gr), reports mean minimum air temperature in Greece to range from 5 to 10 °C in the coastal areas and from 0 to 5 °C over the continental parts, while mean maximum air temperature ranges from 29 to 35 °C.

Land uses in Greece are presented in Fig. 1. Agricultural areas are found mainly in the eastern and northern parts of the country. Cultivations in Greece comprise grains, cotton, legumes, fruit-bearing trees in the north, whereas tobacco farms are concentrated in the north-eastern mainland. Legumes, seasonal and green house vegetables are cultivated in the south and in the islands. Artificial areas are located mainly in lowland areas. Forest land cover dominates the central and western parts. Vegetation in Greece forms a complex mosaic as a result of the diverse topography of the country and the contrast between south and north. In the north and central parts, oak, chestnut and other deciduous trees prevail, while at higher altitude, conifer trees dominate in the forest areas. In southern regions, the Mediterranean scrub (evergreen oak, olive, oleander, bay) is prevalent. Coastal plains are mostly covered by pines, plane tree shrubs and herbaceous plants. (Ministry of Environment and Energy, http://www.ypeka.gr, accessed 28/9/2018). Greece demonstrates high plant biodiversity with 5800 native species, 913 of those are endemic (Georghiou and Delipetrou 2010). Figure 1 also depicts spatial distribution of Natura 2000 sites.

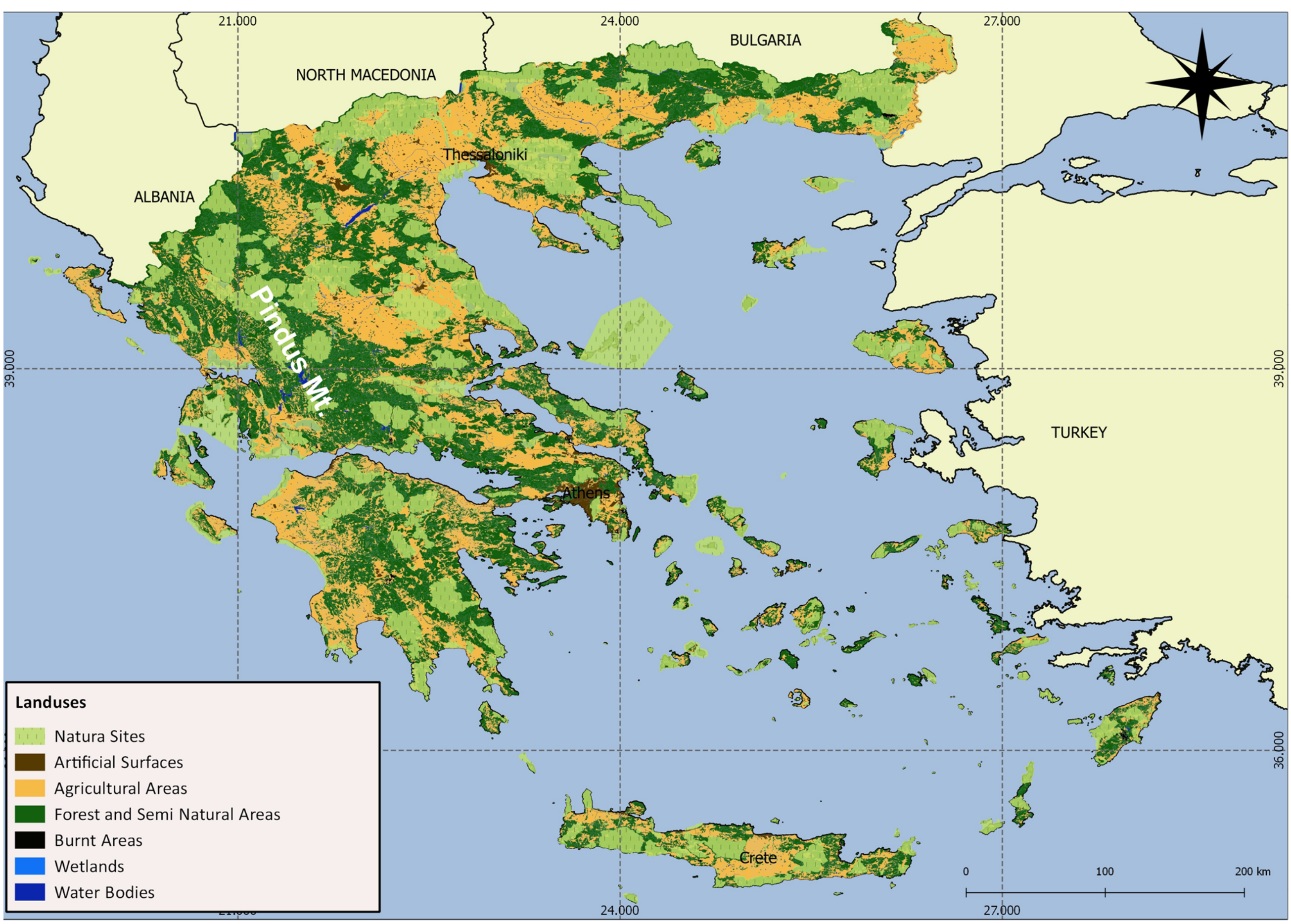

Fig. 1 Land uses in Greece based on CORINE CLC 2012 and Natura 2000 network

Aqua/Terra MODIS sensor NDVI data

Remotely sensed data which constitute an effective way of monitoring vegetation changes (Brown et al. 2012) were used. Characterization of changes in each land use type was achieved using NDVI, based on the red/infrared spectral region, which is the most commonly used and robust vegetation index (VI) that monitors vegetation amount and photosynthetic activity (Myneni et al. 1995). NDVI product from the MODerate Imaging Spectroradiometer (MODIS) on board Terra and Aqua satellites was selected for use in the present work. Performance of MODIS vegetation indices is evaluated and was found to be of high fidelity (Huete et al. 2002) in most land cover types, whereas in recent works, MODIS NDVI data have been used as a "state of the art" standard dataset to evaluate the performance of vegetation indices produced by other sensors (Kern et al. 2016). The theoretical background and the processing algorithms used to compute NDVI products are described in detail in Didan et al. (2015). The Collection 6 MOD13Q1 product (Didan 2015) was used herein which consists of gridded 16-day interval NDVI data at 250 m spatial resolution. The major improvement of Collection 6 compared to Collection 5 Aqua and Terra composite products is the use of pre-composited 8-day MODIS Level-2G surface reflectance data. Known problems related to the MODIS NDVI products are cloud or snow cover of the target area as well as aerosol contamination. MODIS vegetation indices are provided along with quality assurance metadata on a tile level (percentage of scene that passes quality control) as well as on a per pixel basis. Two types of pixel-based quality assurance layers are provided with MODIS data to help in filtering time series data based on their quality assurance flags (Ma et al. 2013; Didan et al. 2015). The first one is a simplified ranking of the data that describes the overall pixel quality (i.e., no data, good data, marginal data, snow/ice, cloudy). The second quality assurance dataset contains multiple binary encoded information sources about the pixel quality, usefulness, aerosol quantity, atmosphere correction performed, cloud presence, land/water mask, presence of snow/ice or possible shadow (Didan 2015). Both those quality assurance datasets were used to filter the entire time series of each examined pixel and only those of the highest quality were remained for further computations. Excluded pixels correspond to water-covered areas, to pixels invisible due to cloud cover, pixels covered with snow or ice or pixels not produced due to other reasons than clouds.

Supplemental land use data

Land use data were acquired from the CORINE Land Cover (CLC) 2012 inventory, coordinated and integrated by the European Environmental Agency (https://land.copernicus.eu/pan-european/corine-land-cover). CORINE categorizes land cover into 44 classes, while it depicts areal phenomena of minimum 25 hectares and linear phenomena with minimum width of 100 m. All areas designated as artificial surfaces (CLC grid codes 1–11) were introduced in the computational process, comprising areas of continuous urban fabric, discontinuous urban fabric, industrial, commercial and transport units, road and rail networks and associated land, port areas, airports, mine, dump and construction sites, artificial, non-agricultural vegetated areas, green urban areas, sport and leisure facilities. Artificial sites cover a total of 37,547 km^2. Protected sites on the other hand, are not specifically designated on CORINE CLC, therefore those sites were acquired through the European ecological network of protected sites, i.e., Natura 2000. Based on the 1992 EU Habitats Directive but also incorporating the 1979 EU Birds Directive, Natura 2000, is the implementation tool of EU protection policy aiming at safeguarding the important habitats and valuable species of Europe. Natura 2000 currently comprises 27,300 sites at the EU level, covering an area of 1.1×10^6 km^2, 18% of European land area and 4% of the European sea (http://natura2000.eea.europa.eu/, accessed 10/02/2018). In Greece, Natura 2000 comprises 419 protected sites, covering a total area of 55,279 km^2. Some of those sites include marine sections, while the total sea area covered by Natura 2000 protection is approximately 6% of the country's marine area. Marine sections of protected sites are not included in computations. A small number of Natura sites have experienced extended fire disasters during the study period. Those areas designated as burnt areas in the CORINE CLC were also excluded from computations, as they cannot represent the natural vegetation variability.

Data processing

The MODIS NDVI dataset was divided into two groups, those of the protected sites and those of artificial ones. Following, a linear regression model was applied on a pixel by pixel basis in the two distinct land use categories:

$$\text{NDVI} = a \cdot t + b, \tag{1}$$

where t corresponds to the dates of NDVI observations, a is the slope of regression line indicating the greening rate when positive or the browning rate when negative and b stands for the intercept of regression line. Annual and seasonal trends from 2000 to 2017 were computed using Eq. (1) and significance of results was tested against their p values. Statistically significant trends were considered those with p values lower than 0.01 ($p < 0.01$). The same process was repeated dividing the whole time series into four subsets for the seasonal analysis: winter (December–February), spring (March–May), summer (June–August) and autumn (September–November).

The methodology was implemented within the R software for statistical computing (https://www.r-project.org/) and results were visualized in QGIS, an Open Source Geographic Information System software (https://qgis.org/en/site/). Those two computer applications are open and free tools for scientific computations and they offer a wide spectrum of internal packages specifically developed for several scientific disciplines. In our work, we developed a custom R code for downloading and processing MODIS NDVI data, using the raster R package (Hijmans 2017) for analyzing and modeling of gridded spatial data. Additionally, the snow R package (Tierney et al. 2016) was used for applying parallel computing to handle large workloads and thus reducing execution time. After downloading the entire dataset, pixels with the highest quality, as indicated by the quality flags accompanying each pixel, were kept for further processing. Those pixels are the cloud free and error free areas.

Results and discussion

Table 1 presents basic statistics of the vegetation greening/browning trends as defined by the slope (a) in Eq. 1. The majority of examined sites from both categories demonstrated significant increase (positive slope of regression lines) in NDVI values both seasonally and annually (Table 1). Negative values correspond to browning trends, which are found only in sporadic pixels of the examined areas. Therefore, minimum values in Table 1 are always negative, representing those local browning trends. Results showed that 99% of protected sites and 95% of urban sites exhibited significant trends annually ($p < 0.01$), with greening pattern prevailing on annual and seasonal bases.

Natura sites, as expected had higher rates of NDVI increase during all seasons. Annually, Natura sites experienced a double rate of NDVI increase, i.e., 4.50×10^{-3} year^{-1} compared to artificial sites with a rate of 2.04×10^{-3} year^{-1}. Higher rates of increase were found in autumn and winter ranging from 9.04×10^{-3} to 9.16×10^{-3} year^{-1} for artificial areas and from 2.51×10^{-2} to 2.72×10^{-2} year^{-1} for protected sites, whereas during spring and summer NDVI increased at a lower rate, ranging from 6.05×10^{-3} to 6.36×10^{-3} year^{-1} and from 1.34×10^{-2} to 1.82×10^{-2} year^{-1} for artificial and protected sites, respectively. Comparing, however, annual and seasonal trends one should keep in mind that annual trends were computed based on larger dataset, since statistically significant trends were found to almost double pixels on annual basis compared to winter ones. The percentage of areas that demonstrated significant seasonal vegetation trends ranged from 63 to 61% for artificial and protected sites, respectively, in winter. Summer demonstrated the highest percentage of statistically significant seasonal trends that ranged from 91 to 93% for artificial and protected sites. Seasonal, especially winter and autumn trends were based on a much smaller dataset, since cloud cover during those seasons, especially in highland areas, resulted in a large number of low-quality pixels that were excluded from computations, therefore reducing the number of pixels with statistically significant trends. Moreover, data scarcity for mountainous areas during those seasons due to cloud and snow cover may have impacted results leading to higher NDVI trends, as statistical indices for winter and autumn were evaluated based merely on lowland pixels. The same problem was highlighted in previous works (Xu et al. 2014; Eleftheriou et al. 2018). Xu et al. (2014) indicated the divergence of results of various works using different lengths of NDVI data series at different scales and suggested that continuing efforts to monitor vegetation changes are greatly needed and will contribute towards a sustainable ecosystem management. Besides, however, those known problems that influence remote sensing applications, a definite result of the present work is that vegetation during all seasons demonstrates a greening pattern in both diverse land use environments examined, all over Greece. This finding is in agreement with previous research elsewhere in the world (Zhou 2003; Xu et al. 2014; Mishra and Mainali 2017).

Table 1 Annual and seasonal NDVI trends (10^{-3} year^{-1}) in artificial and Natura 2000 sites

Time period	Area type	Mean	Median	SD	Minimum	Maximum
Annual	Artificial surfaces	2.04	2.01	3.16	− 13.41	13.23
	Natura sites[a]	4.50	4.57	1.98	− 1.67	9.59
Autumn	Artificial surfaces	9.16	5.71	15.62	− 59.01	73.01
	Natura sites[a]	25.11	25.22	11.53	− 10.40	53.94
Winter	Artificial surfaces	9.04	3.71	15.21	− 58.02	78.91
	Natura sites[a]	27.22	27.24	12.52	− 4.74	58.02
Spring	Artificial surfaces	6.05	3.44	14.24	− 66.84	70.73
	Natura sites[a]	18.21	18.52	10.11	− 9.10	45.24
Summer	Artificial surfaces	6.36	5.87	12.92	− 55.62	58.62
	Natura sites[a]	13.43	13.92	10.31	− 19.63	42.31

[a]Excluding burnt areas from this category

Regarding the spatial distribution of detected NDVI greening/browning trends, protected sites demonstrated specific spatial patterns of distribution of NDVI trends annually and seasonally which are shown on Fig. 2a–e. Based on those results, NDVI changes in Natura sites seem to increase by increasing latitude which is more evident for the annual analysis (Fig. 2a) and less pronounced in the seasonal results (Fig. 2b–e). No major trend in the rate of NDVI change is evident on the east–west direction. The highest greening trends during all seasons were observed in the central mainland areas occupied by Pindus mountain chain. Sporadic spots with negative trends are located merely in island or coastal ecosystems. However, MODIS signal even at the resolution of 250 m in those fragmented land areas might have been influenced by the surrounding sea, and therefore no safe conclusion can be drawn for those specific spots. NDVI trends of artificial surfaces did not show any distinctive directional pattern.

Trying to elucidate the driving factors that resulted in the greening pattern prevailing both land use categories examined, one may conclude that as Natura sites correspond to areas of minimum man intervention, vegetation changes to those areas are attributed to drivers related to climate changes such as increased CO_2 concentration and nitrogen deposition and the associated temperature rise and change of precipitation variability, as found in other works as well (Mishra and Mainali 2017). Sobrino and Julien, (2011) indicated an annual increasing trend of vegetation over the northern hemisphere mid latitudes attributed to an increase of the length of the growing season. Mishra et al. (2015) examined protected sites in African Savanna and found a browning pattern, attributed to wildfires in those areas. In our work, nevertheless, burnt areas were excluded from computations, as most fire events in Greece are mainly associated with human activities mostly connected to arsons, negligence, accidents in electricity transmission cables but also to uncontrolled dumping sites (Economou 2011), and cannot be regarded as natural events. To highlight possible causal mechanisms of the increasing vegetation productivity found in our work, we cross correlated annual and seasonal vegetation trends with the annual and seasonal LST trends of the same period, i.e., 2000–2017 published in Eleftheriou et al. (2018), where annual and seasonal daytime and nighttime trends of remotely sensed land surface temperature in Greece were presented. Correlation coefficients of annual and seasonal NDVI trends in the two examined land use types with the annual and seasonal LST trends are presented on Table 2.

A general decreasing pattern of daytime LST both annually and seasonally (except winter) is observed, whereas an increasing nighttime LST trend is found during all seasons and annually (Table 2). Results of the cross-correlation analysis (Table 2) demonstrate a positive correlation of NDVI during all seasons with the night LST, with Natura 2000 sites demonstrating higher correlation coefficients compared to artificial sites. Only during winter, correlation of NDVI and LST is positive for daytime LST as well. Comparing correlation coefficients with the range of LST trends

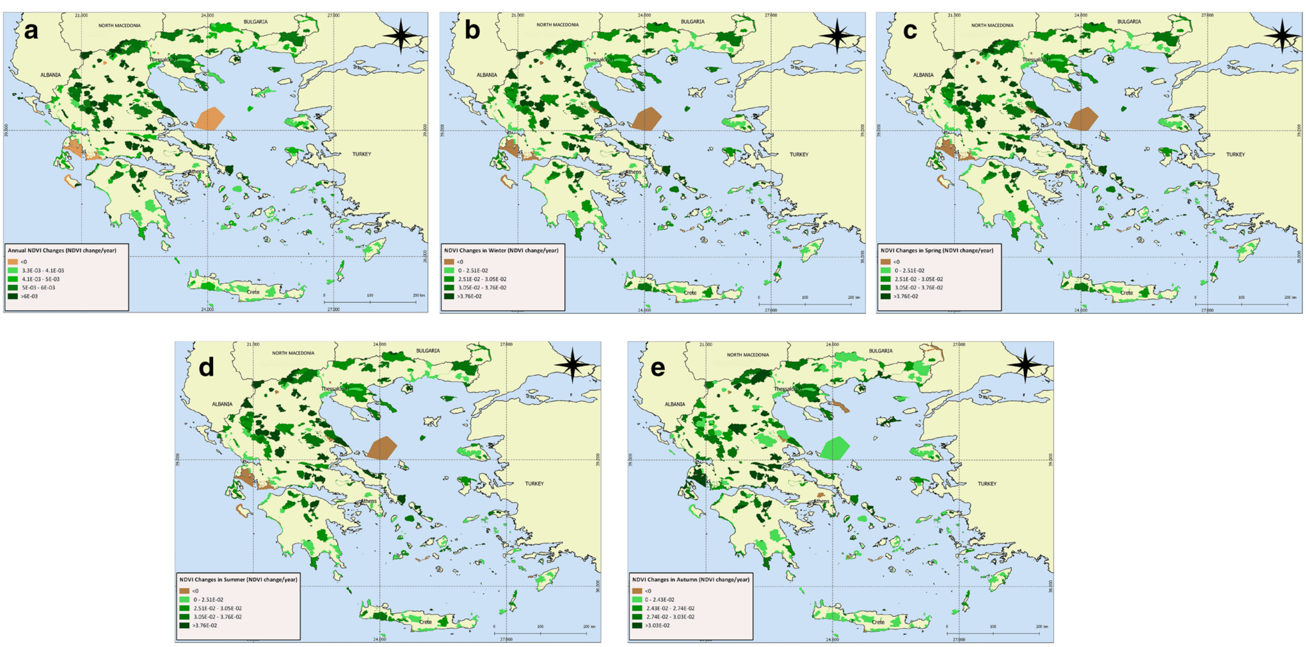

Fig. 2 Greening and browning trends of NDVI in protected sites during 2000–2017, **a** annually, **b** in winter, **c** in spring, **d** in summer, **e** in autumn

Table 2 Cross correlation of annual and seasonal NDVI trends and LST trends in artificial and protected sites across Greece

	Correlation coefficients of LST and NDVI trends over Greece*		Annual and seasonal LST trend range** over Greece (10^{-3} °C/year)***	
	Artificial surfaces	Natura 2000 sites		
	Annual NDVI change		Mean–2SDs	Mean + 2 SDs
Annual day LST change	−0.11	−0.12	−9.50	−1.90
Annual night LST change	0.29	0.38	0.50	23.00
Winter NDVI change				
Winter day LST change	0.28	0.42	3.90	13.00
Winter night LST change	0.42	0.48	2.90	8.30
Spring NDVI change				
Spring day LST change	−0.12	−0.11	−0.50	−8.30
Spring night LST change	0.25	0.36	1.20	7.30
Summer NDVI change				
Summer day LST change	−0.11	−0.17	−1.10	−10.00
Summer night LST change	0.23	0.29	2.40	7.90
Autumn NDVI change				
Autumn day LST change	−0.14	−0.20	−9.90	−1.80
Autumn night LST change	0.33	0.39	0.49	22.00

*All the correlations are significant ($p < 0.01$), **Corresponds to mean ± 2 standard deviations (SDs), ***Eleftheriou et al. (2018)

provided in Table 2 (last two columns), it is recognized that positive correlation coefficients are always found in case of increasing LST trends. This finding indicates that increasing temperature contributes to the increasing vegetation productivity. The weak negative correlation coefficients with the day LST trends in all seasons except winter, suggest that NDVI trends do not seem to have been impacted by trends in daily LST. The highest correlation coefficients of NDVI and LST trends are observed during winter, where both daytime and nighttime LST trends are positive. As winter LST corresponds to minimum annual and seasonal LST values, the greening pattern in both examined land use types may be associated with the increasing trend of both annual and seasonal minimum land surface temperature observed all over Greece. It is well known that vegetation productivity is sensitive to temperature and an increase in minimum temperature corresponds to less likelihood for frost conditions known to be constraining parameter for vegetation growth (Hatfield and Prueger 2015). The same conclusion is also supported with the documented decrease of diurnal temperature range over Greece (Eleftheriou et al. 2018), which is a strong indicator of climate change and is also connected with increased vegetation productivity (Sun et al. 2006).

Driving factors of the greening pattern observed in artificial surfaces are more complex to determine. Areas affected by man-induced land use changes, demonstrate in some cases a browning pattern as it has been observed in previous research studies (Mishra and Chaudhuri 2015). Transformation of the natural landscape to impervious surfaces such as buildings and roads results in the establishment of the Urban Heat Island (UHI) (Polydoros et al. 2017), i.e., the higher temperature observed in urban areas compared to their surroundings (Li et al. 2017). Recent research has identified strong positive correlation between percentage of impervious areas and LST (Li et al. 2018b) which may well have impacted urban vegetation as increased temperature favors vegetation growth. Levin (2016) indicates that urbanization leads to an initial sharp decrease of vegetation followed by a gradual increase of vegetated urban areas, as urban parks and recreational areas become mature. In the same work, the primary role of urban green towards reducing UHI effects is highlighted. Urban vegetation is also known to affect the Urban Pollution Island (Li et al. 2018a) and preservation and expansion of urban vegetation is proposed as a mitigation measure against urban air pollution (Fallmann et al. 2016). Taking into account that both natural and human factors influence those areas, as suggested by other researchers (Zhao et al. 2014; Zhou et al. 2016), the combined effect of background climate and UHI together with human interventions in those areas should be examined.

Figure 3 depicts the time series of MODIS NDVI trends in specific protected and urban locations scattered all over the country, covering its whole geographical extent, the different climate zones and the major urban centers of Greece. Data represent a 10 × 10-pixel average of each separate site. In general, protected sites demonstrate much higher NDVI values, whereas the distinct increasing trend is observed in all cases.

Furthermore, human-induced changes in artificial areas should be examined within the socio-political context in

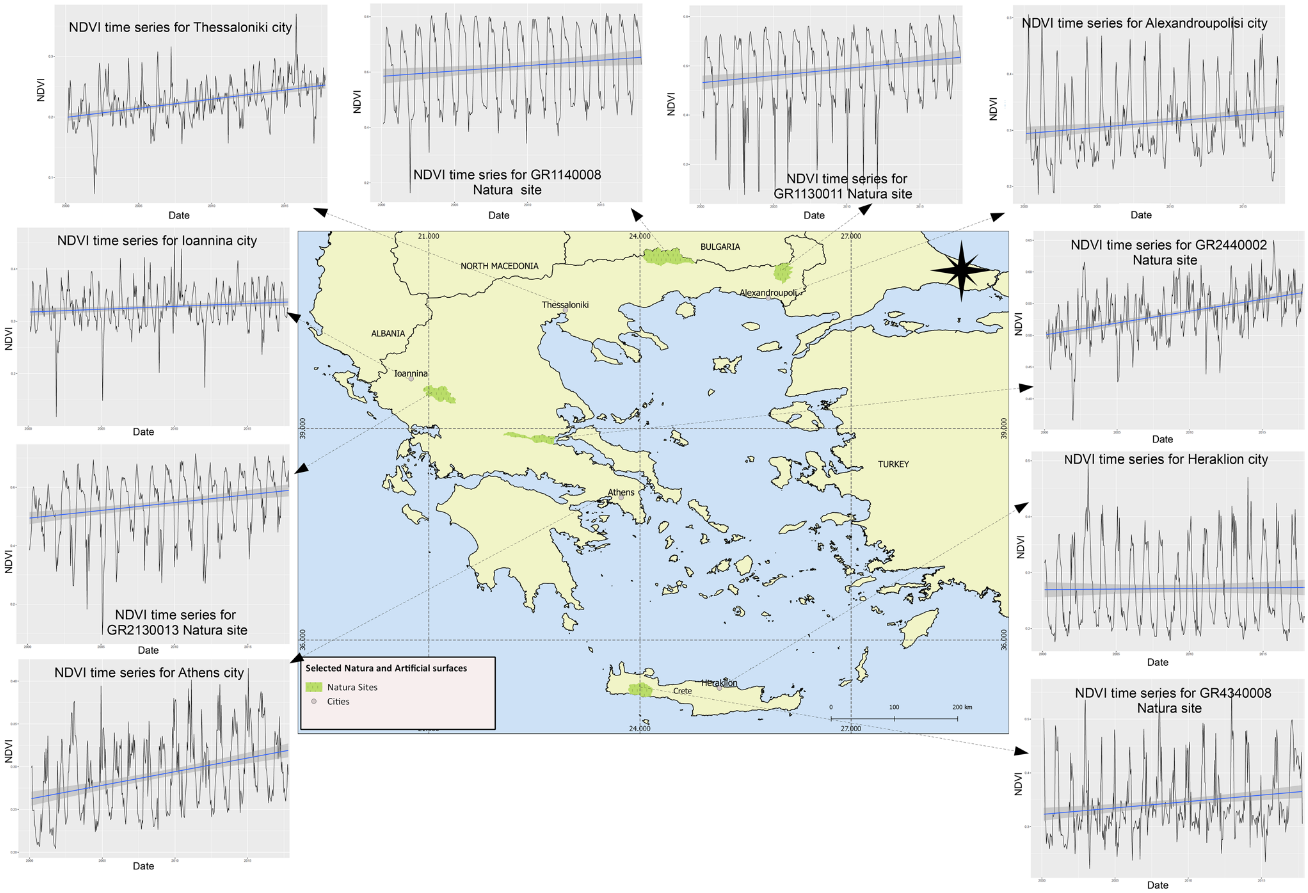

Fig. 3 MODIS NDVI trends in selected urban and Natura 2000 sites in Greece from 2000 to 2017

Greece. Recession in economy that Greece faces during the last decade has resulted in an abrupt collapse of private sector demand, deep fall in consumer's spending on goods and services (Tsampra 2018) and an associated minimization of investments on urban expansion and related activities (Cecchini et al. 2018). Economic development is usually connected to increased consumption of goods and therefore an increased demand of natural resources (European Environmental Agency 2010). Economic growth is a central driver of environmental impacts, with recession periods generally related to reduced environmental impacts, at least in the short term (European Environmental Agency 2010), which might also be an explanation of the greening pattern of artificial areas in Greece. Moreover, the changing attitude of people towards environmental sustainability, with people demanding for a higher standard of living with more green spaces and trees in urban centers might also have played an important role. Thus, vegetation is not only promoted as side effect of economic crisis, but also as conscious attitude of people towards a greener environment.

Conclusions

The present work examined annual and seasonal trends of vegetation changes in two diverse land use environments over Greece, i.e., environmentally protected areas by the EU Natura 2000 network and artificial surfaces comprising mainly areas of urban and industrial activities. Our results indicate an increased vegetation productivity in both land use types, on annual and seasonal bases. Protected sites demonstrated a higher rate of greening pattern compared to artificial areas, probably associated with climate factors such as increased temperature and CO_2 concentration. NDVI greening trends were found to correlate well with the increasing trend of both annual and seasonal minimum land surface temperatures in Greece found in the previous work. Contrary to the expected browning of areas affected by land use changes, artificial surfaces in our work demonstrated an increasing greening pattern annually and seasonally. Those vegetation trends were attributed to a combination of global climate drivers, UHI effect but also to economic recession that hindered development and land use exploitation in urban areas during the last decade. Public awareness towards a greener urban environment might have also contributed to the greening pattern in those sites. Our work documented the spatial and temporal changes of vegetation dynamics and identified possible driving factors such as annual and seasonal minimum LSTs, without, however, quantifying the cause–effect relationship due to data availability restrictions. Our results should be examined considering the inherent limitations of remotely sensed data especially in the cases of cloud presence and snow or ice cover and the lack of in situ observations concerning vegetation changes in our study area. Further research is necessary to this point integrating in the analysis additional climate factors such as precipitation, land use and socioeconomic information. Predicting future vegetation growth and the associated carbon sinks, needs further research focused on those areas experiencing greater changes, integrating the satellite and in situ observations. Incorporation of those results to global and regional climate models will contribute to the improved accuracy of predictions for future climate.

Acknowledgements The first author acknowledges the Technical Chamber of Greece for its support through the project "Climate Changes and Dependent Ecosystems in Eastern Macedonia and Thrace" (Project ID: 81472 – Democritus University of Thrace).

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