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Research Article

Investigation of aggregation effects in vegetation condition monitoring at a national scale

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Abstract
Monitoring vegetation condition is an important issue in the Mediterranean region, in terms of both securing food and preventing fires. Vegetation indices (VIs), mathematical transformations of reflectance bands, have played an important role in vegetation monitoring, as they depict the abundance and health of vegetation. Instead of storing raster VI maps, aggregated statistics can be derived and used in long-term monitoring. The aggregation schemes (zonations) used in Greece are the forest service units, the fire service units and the administrative units. The purpose of this work was to explore the effect of the Modifiable Areal Unit Problem (MAUP) in vegetation condition monitoring at the above mentioned aggregation schemes using 16day Normalized Difference Vegetation Index (NDVI) composites acquired by the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite sensor. The effects of aggregation in the context of MAUP were examined by analyzing variance, from which the among polygon variation (objects' heterogeneity) and the within polygon variation (pixels' homogeneity) was derived. Significant differences in objects' heterogeneity were observed when aggregating at the three aggregation schemes, therefore there is a MAUP effect in monitoring vegetation condition on a nationwide scale in Greece with NDVI. Monitoring using the fire service units has significantly higher pixels' homogeneity, therefore there is indication that it is the most appropriate for monitoring vegetation condition on a nationwide scale in Greece with NDVI. Results were consistent between the two major types of vegetation, natural and agricultural. According to the statistical validation, conclusions based on the examined years (2003 and 2004) are justified.

Keywords: Modifiable Areal Unit Problem, zonation, vegetation index, vegetation monitoring, MODIS

1 Introduction

Condition of vegetation is a parameter of major importance in the Mediterranean region, as it is directly linked to the risk of natural vegetation catching fire and the productivity of agricultural crops. Monitoring vegetation is useful for international and national agencies that organize fire prevention plans, compensate for agricultural yield loss, and develop national policies. In Europe, such monitoring is dictated by a number of European and Council Regulations, such as 'Forest Focus' (2003/2152/EC), support system for producers of certain arable crops (1999/1251/EC), and support for rural development from the European Agricultural Guidance and Guarantee Fund (1999/1257/EC). Monitoring schemes on a nationwide scale for these operations can be very costly if based on field surveys, or very biased if based on secondary statistics, such as agricultural census, surveys of farmers' organisations, and registers for agricultural services (Biggs et al. 2006, Droogers 2002).

Vegetation indices have been used extensively in vegetation monitoring, as they are correlated to various parameters that describe vegetation condition, such as green leaf area index (LAI), phenology, fraction of photosythetically active radiation absorbed by vegetation (fAPAR), canopy density, dryness, and the health of natural and managed vegetation (Asrar et al. 1984, Gao 1996, Gitas et al. 2004, Silleos et al. 2002, Zhang et al. 2003). Among the numerous vegetation indices available, the Normalized Difference Vegetation Index – NDVI (Tucker 1979) is widely used for monitoring vegetation condition (Baret and Guyot 1991, Huete et al. 1985), although certain drawbacks have been reported (Huete et al. 2002). The methods developed for monitoring vegetation condition using vegetation indices (Moulin et al. 1997, White et al. 1997) are difficult to apply on regional or nationwide scales due to frequent cloud cover and variable viewing angles (Zhang et al. 2003), therefore multi-temporal image composites have been proposed for large-scale operations (Chuvieco et al. 2005, Ferreira and Huete 2004, Maselli 2004). Finally, more advanced methods for vegetation condition monitoring have been developed that combine vegetation indices with land surface temperature, formulating the Vegetation Temperature Condition Index (VTCI) for drought monitoring (Wan *et al.* 2004), for monitoring desert vegetation dynamics (Dall'Olmo and Karnieli 2002), and mapping land cover at regional scales (Lambin and Ehrlich 1995).

Instead of studying and storing raster NDVI maps, aggregated statistics can be derived and used in long-term monitoring, offering advantages such as easier interpretation, increased functionality in warning systems and decision support systems. However, in these cases the Modifiable Areal Unit Problem – MAUP (Openshaw 1983) applies. The MAUP refers to the variation in results due to the use of alternative aggregation schemes on equal or similar scales, and is endemic to all spatially aggregated data and is formally defined as 'a problem arising from the imposition of artificial units of spatial reporting on continuous geographical phenomenon resulting in the generation of artificial spatial patterns' (Heywood 1998). The effects of the MAUP can be divided into two components, the 'scale effect', where results vary when the same data are aggregated at increasingly larger areal units, and the 'aggregation' or 'zoning effect', where results vary due to aggregation with alternative units of analysis at the same scale.

Except for the field of human geography - where MAUP was first introduced (Gehlke and Biehl 1934, Openshaw and Taylor 1979) - it was only recently that the MAUP was considered in the physical sciences. MAUP has been studied in the context of landscape ecology and the effects of data aggregation on the analysis of landscape structure (Jelinski and Wu 1996), in data preparation for regional ecological analyses (Wicks et al. 2002), in assessing the performance of irrigation systems (Chemin and Alexandridis 2006), in a deer habitat study

(Plante et al. 2004), and in general environmental research with an example of decision support system for admission of pesticides in the EU (Van Beurden and Douven 1999). In a specific study about forest vegetation, Marceau (1999) examined the MAUP effect on forest remote sensing, considering however the images' raster grid as a form of arbitrary aggregation scheme and focusing on the scale effect. Finally, a few studies have attempted to resolve the MAUP effect: Song (2003) suggested the use of dissimilarity and diversity indices to compare data for segregation indices attributed to different geographic levels, and Hay et al. (2001) suggested an object-specific framework to reduce the effects of MAUP when using remote sensing data for multi-scale analysis.

Despite the wide use of vegetation indices for vegetation monitoring, the aggregation effect has not been adequately explored in this sector, although it is generally acknowledged that depending on the aggregation scheme selected, results may differ. The aim of this work was to investigate the aggregation (MAUP) effects in vegetation condition monitoring using MODIS NDVI composites. The specific objectives were (i) to identify the effect of MAUP using the existing aggregation schemes in Greece, and (ii) to identify the most appropriate aggregation scheme for nationwide vegetation condition monitoring.

2 Description of the study area

The study area consists of the vegetated areas of Greece, which covers 131 000 km^2 (Figure 1). The area consists of the mainland, and numerous islands which vary in size. It is located in the Mediterranean climatic zone, with monthly average temperatures ranging from 5^{o}C in the winter to 28^{o}C in the summer. The mean annual precipitation varies throughout the country, ranging from 400 to 1800 mm/year, corresponding to the strongly undulating terrain. The wet months are March, April and November, while July and August are very dry.

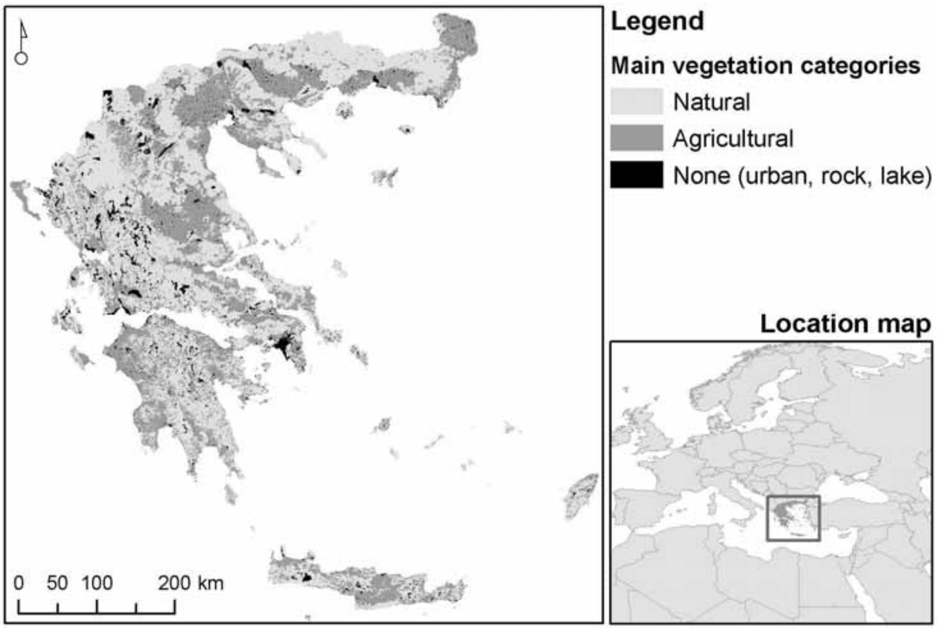

Figure 1: Location map and main categories of land cover in Greece (CLC 2000)

Vegetation cover of the area is typically Mediterranean and, can be classified into two major categories: natural (59%) and managed (41%), based on CORINE Land Cover 2000 of Greece (MINENV 2004). Since the two main vegetation categories of the study area are different in their phenological cycles, it was decided to study them separately and provide results for each main vegetation category. These two categories were defined using a generalized CORINE Land Cover map. The map's scale (1:100 000) was adequate for a nationwide study, and its production date (2000) was not expected to create any problems at this level of generalization.

The managed vegetation consists of irrigated annual crops (maize, cotton, alfalfa and others) concentrated around lowland irrigation systems, rainfed cereals located on the hillsides, and orchards scattered around villages, which correspond to Level 1 CORINE Land Cover class "2. Agricultural areas". The phenological cycle of managed agricultural vegetation is repeated on an annual basis. Development phases include seeding, growth, maturity and harvesting, which can largely be controlled by modern agriculture. Factors such as current meteorological conditions, irrigation status and availability of equipment influence the timing. Generally, there is one growing season from early spring to early autumn.

The natural vegetation consists of coniferous and deciduous forest, shrubs and pastures, which correspond to Level 1 CORINE Land Cover class "3. Forest and semi-natural areas". The phenological cycle of the natural vegetation is relatively stable throughout the year, except in the case of extreme weather conditions. Generally, the various types of vegetation leaf-out, grow to maturity and senesce at approximately the same time each year. The most notable changes occur after the dormant phase of winter, when rapid growth takes place in the spring, followed by senescence in late summer or early autumn.

2.1 Structure of the existing aggregation schemes

The study area is currently monitored by several national agencies. Natural vegetation is monitored by the Civil Protection Agency mainly for fire prevention, and agricultural vegetation is monitored by the Hellenic Agricultural Insurance Agency for yield prediction and crop damage (Silleos et al. 2002). The aggregation schemes that are currently being used by these agencies were evaluated in this study:

- The first aggregation scheme examined was the Provinces of Greece. These are NUTS3 level administrative units (EC 2003), based on early divisions of Greece, which follow physiographic and human made boundaries.

- The second aggregation scheme examined was the Fire service units of Greece. These define the jurisdiction of local fire departments, governed by the Ministry of Internal Affairs. They were designed based on administrative boundaries, catchment boundaries, vegetation fuel type, approachability from local fire departments, and estimated time of intervention in the event of fire.

- The third aggregation scheme examined was the Forest service units of Greece. These define the area managed by each local forest directorate, governed by the Ministry of Agriculture and the General Secretariat of Forests and Natural Environment. Their borders have been defined by government decrees, based on criteria such as the general vegetation zones, landscape physiography, administrative boundaries and size of the area.

Therefore, the fire and forest service units had been defined by the relevant authorities from the national NUTS3 administrative division, with appropriate modifications according to their purpose. A sample of the study area with the three aggregation schemes is displayed in Figure 2, where several similarities and differences are visible.

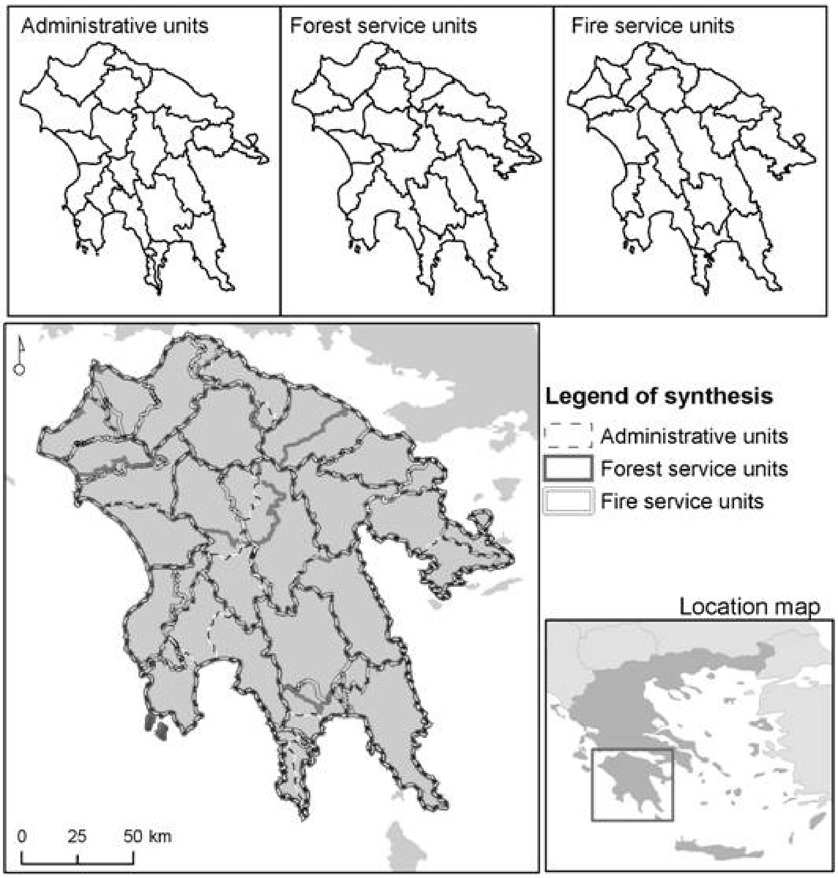

Figure 2: Differences of the three aggregation schemes, focusing in southern Greece.

3 Materials and methods

3.1 Variables used and dataset preparation

A series of Terra/MODIS (Moderate Resolution Imaging Spectroradiometer) vegetation products from years 2003 and 2004 was acquired from the Distributed Active Archive Center of NASA's Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/). The time series included a total of twelve 16-day composite NDVI images (six for each year) from end of April to end of July (DOY 113-208). This time period best represents a part of the growing season and phenological development of vegetation. Furthermore, previous studies have shown that NDVI time-series of different vegetation during the non-growing season do not provide clear phenological separation (Ramsey et al. 1995, Senay and Elliott 2000).

The MODIS instrument acquires data at 250 m spatial resolution (red and near-infrared), 500 m (5 bands at visible and shortwave-infrared), and 1 km (29 bands at visible, near- shortwave- and thermal-infrared). We used MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V004 (MOD13Q1) product. The VI output file contains 16-day NDVI values and this product relies on surface reflectance series (MOD09), which are corrected for molecular scattering, ozone absorption, and aerosols (Vermote et al. 2002). Sixteen-day composites were selected to reduce the effects of cloud cover, because cloud affected pixels have been substituted with other unaffected pixels of the same location but of another date within the 16day period. Global MOD13Q1 data are provided every 16 days at 250-meter spatial resolution as a gridded level-3 product in the Sinusoidal projection.

In addition to the remotely sensed MODIS product, the CORINE 2000 Land Cover map of Greece was employed (MINENV 2004). Ancillary GIS data layers used were the vectorized polygons of the fire service units of Greece, the forest service units of Greece, and the administrative units of Greece at NUTS3 level. These polygons were established by the relevant authorities, as mentioned earlier. They cover an equal area (the entire country), and they are roughly at the same scale (their mean polygon area is 1140, 1300, and 1250 km^2, respectively).

The downloaded MODIS products were pre-processed (mosaiced, reprojected), and subset to the borders of the study area (Figure 3). This pre-processing was applied to all the images of the time period studied, thus producing a time series of MODIS 16-day NDVI images of Greece at 250m resolution. Areas covered by other land cover types (e.g. water, urban) were removed from further analysis. Furthermore, areas covering natural and agricultural vegetation were separated using the CORINE Land Cover map, so that results could be produced for each major vegetation type separately. This analysis provided a dataset of 1 227 000 and 867 000 MOD13Q1 pixels of natural and agricultural vegetation, respectively. Finally, the NDVI raster data were overlaid with the polygons of the three aggregation schemes and aggregated statistics (zonal statistics) were extracted for each composite period. For every 16-day time period, mean and standard deviation NDVI values were calculated for every polygon of the three aggregation schemes, separately for natural and agricultural vegetation.

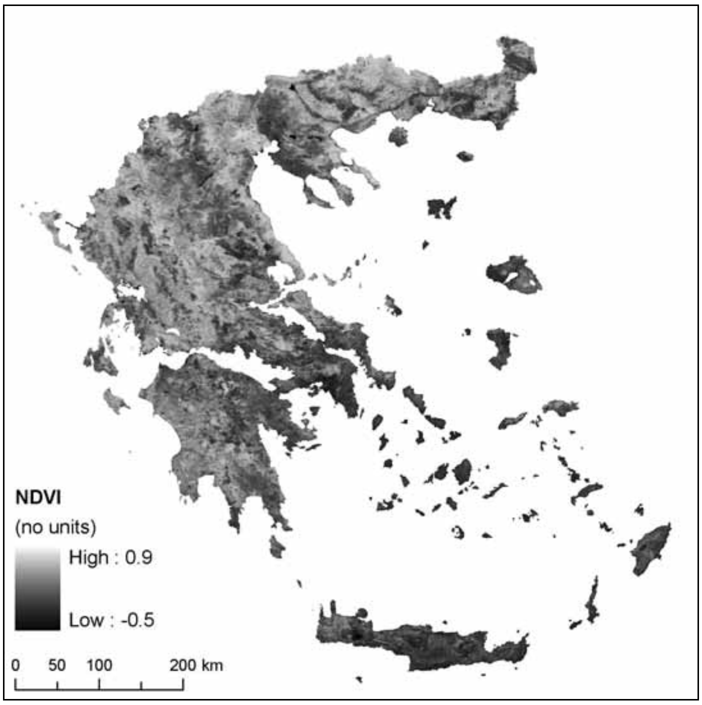

Figure 3: 16day composited NDVI of Greece (DOY 193-208 2004).

3.2 Statistical analysis (ANOVA)

In order to investigate the MAUP effect in vegetation condition monitoring with NDVI on a nationwide scale in Greece, the aggregated statistics from the three existing schemes were compared. Based on the mean and standard deviation derived in the previous section, the statistical analysis was formulated to respond to the two objectives set: (i) among polygon variation (objects' heterogeneity) was used to characterise the inconsistency when monitoring vegetation with the three aggregation schemes, thus prove the existence of the MAUP effect, and (ii) within polygon variation (pixels' homogeneity) was used to identify how representative each aggregated value is for the original NDVI values, thus select the most appropriate aggregation scheme for nationwide vegetation condition monitoring. Finally, the differences between the two years of analysis were evaluated in order to confirm the temporal consistency of the results.

Differences of among polygon variances across aggregation scheme and over time were tested using the standard F test and the F_{max} test proposed by Hahn (1969). Repeated measures analysis of variance (ANOVA) was used to test for the effects of aggregation scheme, year and time period, and their interactions on the within polygon standard deviations. The specific model used was a special split-plot in time where the aggregation scheme was the whole plot factor and year and period of observation were two split-plot factors arranged in a split-block (or criss-cross) type of structure. F-tests from this ANOVA were used to test the main effects and interactions.

The following flowchart (Figure 4) describes the overview of the methods used.

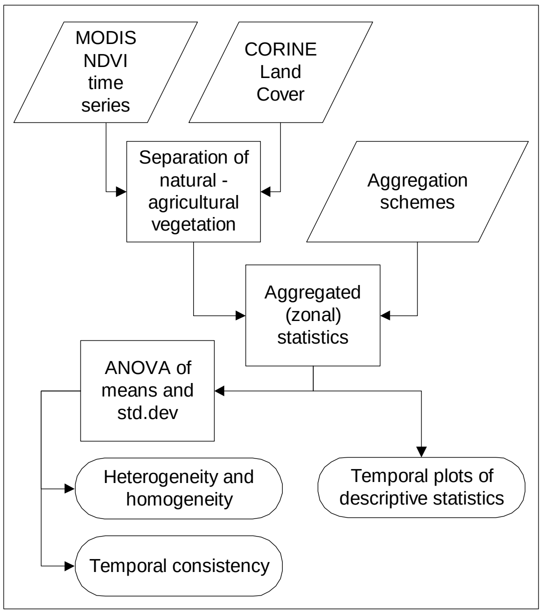

Figure 4: Overview of the methods used.

4 Results

Within polygon standard deviations were displayed in tabular form, with the means of the standard deviations of aggregation scheme-by-vegetation types (Table 1), year-by-aggregation scheme-by-vegetation types (Table 2), and the p-values (Table 3). Also, the temporal evolution of among and within polygon variation for the examined time periods were displayed as graphs (Figures 5 to 8).

Table 1: Means for within polygon standard deviations of both vegetation types for the three aggregation schemes.*

Aggregation scheme	Natural vegetation	Agricultural vegetation
administrative	0.139[a]	0.123[a]
fire service	0.127[b]	0.115[b]
forest service	0.135[a]	0.121[a]

*Means with different letters within a column differ at 0.05 significance level

Table 2: Means for within polygon standard deviations for the three aggregation schemes, two years, and both vegetation types.

Year	Aggregation scheme	Natural vegetation	Agricultural vegetation
2003	administrative	0.146	0.128
2003	fire service	0.133	0.120
2003	forest service	0.141	0.126
2004	administrative	0.132	0.118
2004	fire service	0.121	0.111
2004	forest service	0.128	0.116

Table 3: P-values for significance of effects on within polygon standard deviations

Source	DF	Natural vegetation	Agricultural vegetation
aggregation scheme	2	0.0117+	0.0525+
unit(aggregation scheme)	260	<.0001	<.0001
year	1	<.0001++	<.0001++
year x aggregation scheme	2	0.8726++	0.7375++
year x unit(aggregation scheme)	260	<.0001	<.0001
time period	5	<.0001+++	<.0001+++
time period x aggregation scheme	10	0.7941+++	0.9916+++
time period x unit(aggregation scheme)	1300	<.0001	<.0001
year x time period	5	<.0001	<.0001
year x time period x aggregation scheme	10	0.9849	0.9991
Mean square error	1300	0.2269	0.1559

+,++,+++ - F tests based on unit(aggregation scheme), year x unit(aggregation scheme) and time period x unit(aggregation scheme) error mean squares respectively.

4.1 Identification of MAUP effect in monitoring vegetation condition

The temporal response of among polygon variation (objects' heterogeneity) for the three aggregation schemes (expressed as the standard deviation of the polygon means) is displayed separately for natural (Figure 5) and agricultural vegetation (Figure 6).

For natural vegetation when comparing aggregation schemes within each time period, the fire service scheme had significantly higher among polygon variation ($p<0.07$) than the forest service scheme for all time periods except the end of April (DOY 113-128) in 2003 and the end of April – beginning of May (DOY 113-144) in 2004. There were no significant differences between the forest service and administrative schemes for any time periods ($p \geq 0.07$). For agricultural vegetation, the fire service scheme had significantly higher among polygon variation ($p<0.07$) than the administrative scheme for all time periods for both years. There were no significant differences between forest service and administrative schemes or between fire service and forest service for any time period except the beginning of April in 2003.

For both 2003 and 2004, among polygon variances differed significantly ($p<0.05$) over time for natural vegetation for the fire service and forest service aggregation schemes. There were smaller differences over time for agricultural vegetation with only the forest service aggregation scheme having significant differences over time in 2003. There was a trend for higher values (higher objects' heterogeneity) towards June and July (DOY 145-208), which was consistent with the variable phenology of the vegetation pattern in Greece. Specifically for agricultural vegetation, the higher objects' heterogeneity towards the end of July portrayed the high contrast between the rain fed (dry) and irrigated (green) vegetation of the semi-arid summer. Smaller deviations may be due to cloud influence of the 16day composites, as confirmed by local visual examination of the product’s quality flags.

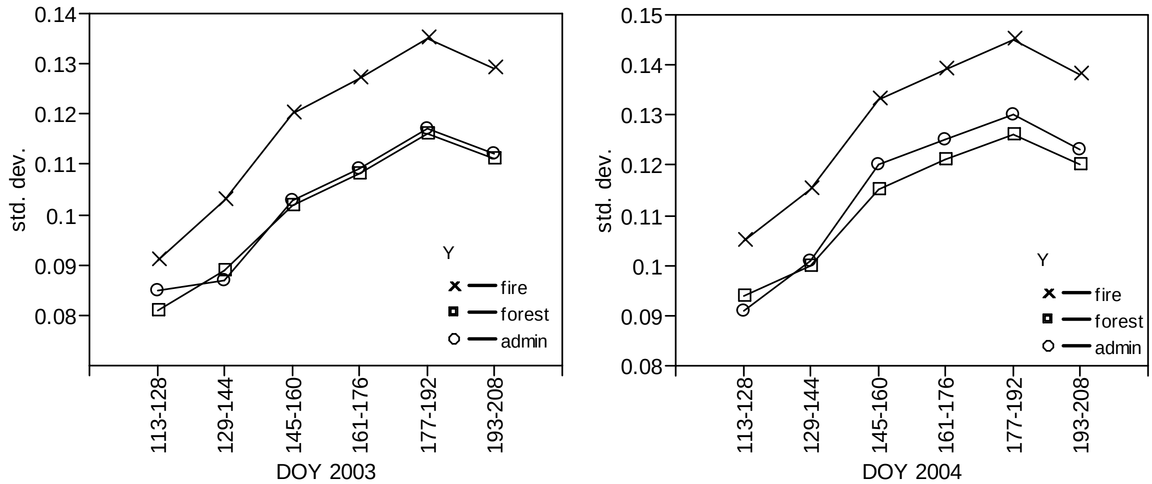

Figure 5: Among polygon variation for natural vegetation at the three aggregation schemes.

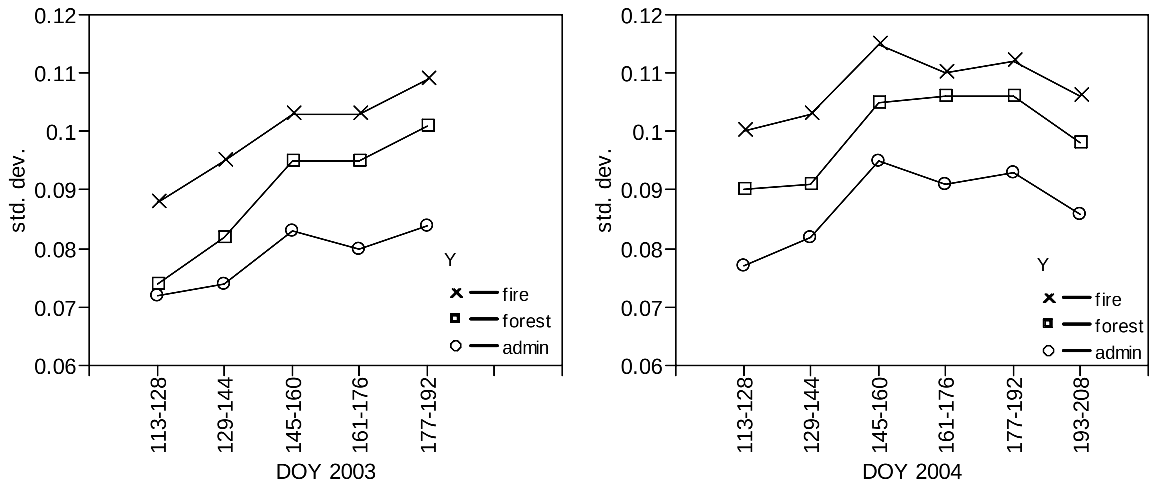

Figure 6: Among polygon variation for agricultural vegetation at the three aggregation schemes.

When considering the mean among polygon standard deviations (objects' heterogeneity) for each aggregation scheme averaged over time period and years, there were distinctive differences between the three schemes. Although differences were small (Table 1), the fire service scheme was significantly smaller ($p < 0.05$) than the forest service and administrative aggregation schemes. These results were consistent for natural and agricultural vegetation for the two years (Table 2). Therefore, there is an indication that when monitoring vegetation using the three aggregation schemes, significant differences could be observed. This implies that vegetation condition may appear different when studied using statistics of the same background information (NDVI) aggregated on different schemes, which could lead to erroneous decision making by involved agencies.

4.2 Selection of the most appropriate aggregation scheme

The temporal evolution of within polygon variation (pixels' homogeneity) for the three aggregation schemes (expressed as the standard deviation of pixels' NDVI within the polygons) is displayed separately for natural (Figure 7) and agricultural vegetation (Figure 8).

There was a significant time trend (Table 3) with lower values (higher pixels' homogeneity) towards June (DOY 152-181) for all aggregation schemes, which could be attributed to the drying up of rain fed agricultural and natural vegetation in the beginning of the semi-arid summer. The excessively low values at the end of April 2003 (DOY 113-128) for agricultural vegetation are inconsistent with the other results and could be due to random cloud influence.

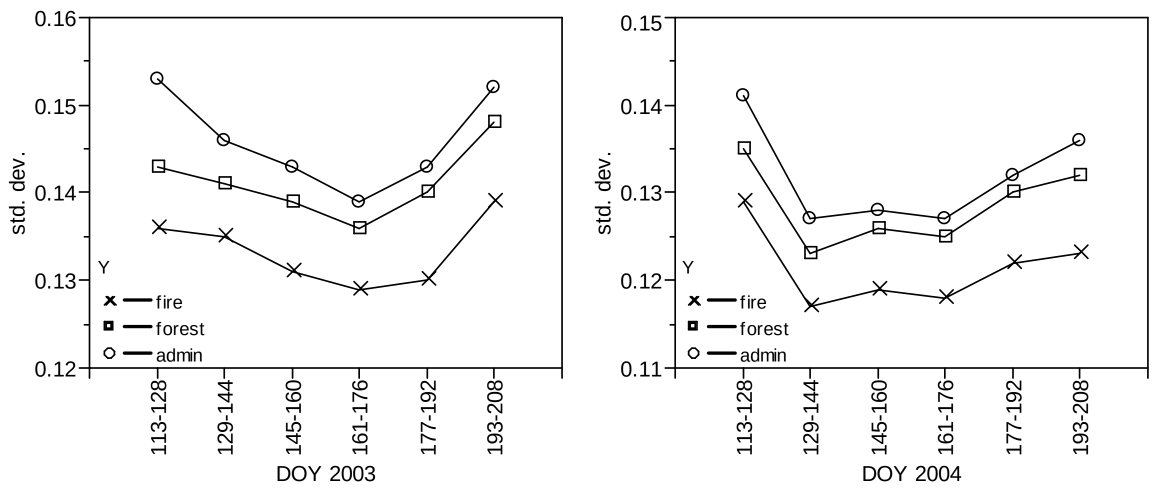

Figure 7: Within polygon variation for natural vegetation at the three aggregation schemes.

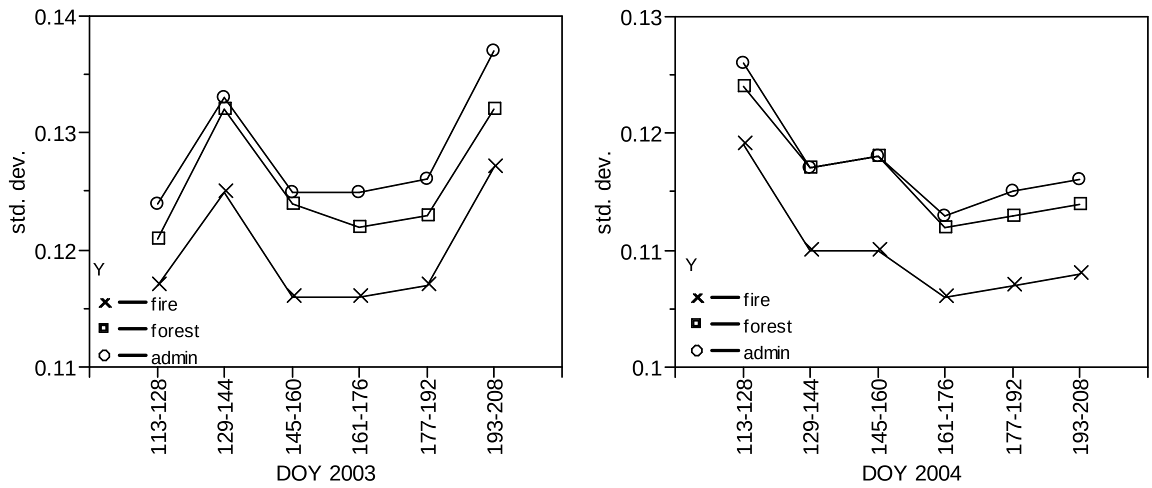

Figure 8: Within polygon variation for agricultural vegetation at the three aggregation schemes.

The means of the within polygon standard deviations was consistently lower, indicating higher pixels' homogeneity, when monitoring vegetation using the fire service units. Although differences were small (Table 1), the results using the fire service units were significantly lower than the other two aggregation schemes (p-values 0.0117 and 0.0525 for natural and agricultural vegetation, respectively). These relative differences were consistent for natural and agricultural vegetation for the two years as indicated by the year x aggregation scheme not being significant (Table 3) and by the relatively consistent differences between the schemes over both years (Table 2). Therefore, this is an indication that the previously presented results for 2003 and 2004 are consistent across years.

Combining the results that (i) the among polygon variation of the fire scheme is generally larger than the other two schemes, (ii) that the within polygon variation of the fire scheme is smaller than the other two, and (iii) these results are relatively consistent across years, it is reasonable to conclude that the aggregated results would be closer to the original values in the NDVI images when monitoring vegetation using the fire service units. Therefore, this could be the optimum aggregation scheme for monitoring vegetation using NDVI, as these aggregated statistics of vegetation condition would match better the actual conditions, as described with NDVI.

5 Discussion and implications for vegetation monitoring

It has been demonstrated that the aggregation schemes currently being used in vegetation monitoring can provide significantly different results. Moreover, when monitoring vegetation with the fire service units there is higher among polygon variation (higher objects' heterogeneity) and lower within polygon variation (higher pixels' homogeneity) than the other two aggregation schemes. These results suggest that monitoring vegetation condition using aggregated statistics from the fire service units is being more physically justified, i.e. the statistics would better represent the original values of vegetation condition parameters (NDVI), and highlight differences across units (polygons). This could be due to the design of the fire service units that were based on the characteristics that affect vegetation condition of both natural and agricultural, such as landscape physiography (elevation, slope, aspect), catchment boundaries (related to bio-climatic zones), and vegetation fuel type (related to vegetation species, structure, density).

Considering the significant differences in the phenology of natural and agricultural vegetation, which could provide an important bias at the nationwide scale, these two major types of vegetation were studied separately. Results have been consistent between the two vegetation types, with minor exceptions for agricultural vegetation (DOY 113-128 and 193-208 in 2003). This similarity could be due to the minor differences between the bio-climatic zones of Greece, which is a relatively small country (Loukas et al. 2001). Specifically, the high temperatures and lack of rainfall during the beginning of the Mediterranean summer (June) influences NDVI of both natural and agricultural vegetation, with the exception of irrigated agriculture, which however accounts for only 12% of the vegetation cover of Greece (Alexandridis et al. 2008).

Taking into account the rapidly changing phenology of Mediterranean vegetation from spring to summer, a period of three months (May, June and July) was studied to identify possible seasonal variations. Higher objects' heterogeneity and pixels' homogeneity was observed for all examined cases during the peak of the dry summer months (end of June - beginning of July, DOY 161-192). Once more, this could be attributed to the relatively homogeneous phenology of Mediterranean vegetation, which renders it safer to monitor with aggregated statistics during these months. This is beneficial as it coincides with the beginning of the fire season.

The spring – summer periods of two years have been examined (2003 and 2004) to evaluate the temporal consistency of results. Despite the high level of significance of the results and the consequent validity of the conclusions, these could change with a potential variation of vegetation pattern, either policy driven (e.g. a new Common Agricultural Policy reform), climate driven, or after extreme fire events. Another reason for potential temporal inconsistency of these results could be extreme meteorological conditions. Indeed, the years we examined displayed normal conditions, which was evaluated using the daily fire risk index issued by the Civil Protection Agency for fire prevention (Gitas et al. 2004). This index was estimated taking into account the local meteorological conditions and vegetation aridity, following the NFFDRS methodology (Deeming et al. 1972). It is evident in Figure 9 that the mean daily fire risk index of the examined years do not deviate from the inter-annual average. It remains to be verified if the findings of this work apply during years of extreme conditions, such as 2007.

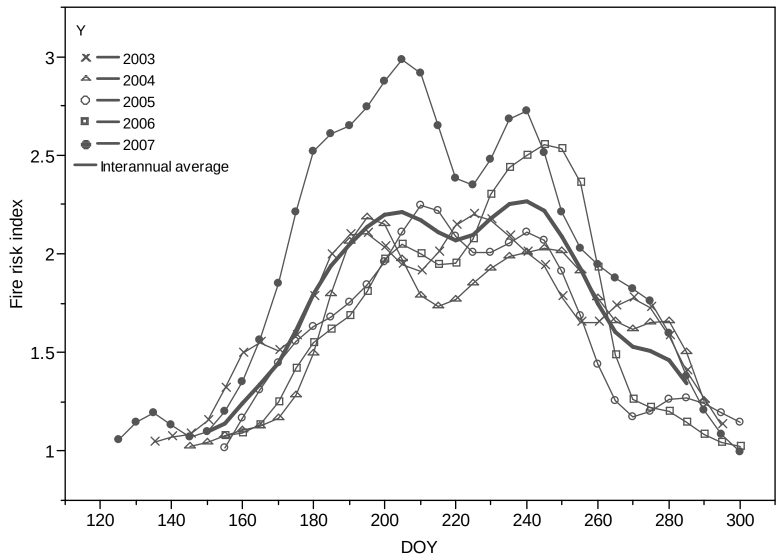

Figure 9: Daily fire risk index (country mean for Greece) during 2003-2007.

Local users and agencies involved in nationwide vegetation monitoring in the study area can benefit from this work to optimise the efficiency of their long term monitoring programmes. On the continental or global scale, other projects such as FAO's GIEWS (FAO 2000) could evaluate their aggregation strategy using the methodology presented. They have been initially using districts as the aggregation scheme of NDVI based vegetation monitoring, thus taking advantage of information available from administrative sources; however other aggregation schemes have been proposed based on raster data clustering (Griguolo and Santacroce 1996, Hay et al. 2001). Adopting these methodologies for designing optimum aggregation schemes fell outside the scope of this work, which only evaluated the existing schemes.

There are certain limitations to this work. First, we only examined the aggregation effect from what is documented as MAUP; the other is the scale effect (Openshaw 1983), which has been better documented in natural sciences (Cao and Lam 1997, Franklin and Woodcock 1997). Second, only the post-processing approach has been examined, in which the aggregation occurs after the initial datasets (reflectance values) are inserted in the model (NDVI calculation) (Van Beurden and Douven 1999). Finally, we examined the aggregation effect using the mean technique, while van Beurden and Douven (1999) suggest trying all relevant techniques, and reporting on the sensitivity of the results. Future research could address these issues, together with the effect of changing the spatial and spectral dimensions of vegetation condition monitoring: investigating the effect of changing the pixel size of the raster products, and the effect of using more advanced vegetation indices, which have been designed to reduce the background soil effect (SAVI), atmospheric effects (EVI), and variable meteorological conditions (VTCI).

6 Conclusions

The purpose of this work was to explore the aggregation (MAUP) effects in vegetation condition monitoring using MODIS NDVI composites. Three existing aggregation schemes (administrative units, forest service units, and fire service units) were examined using descriptive statistics of aggregated NDVI values.

Significant differences in objects' heterogeneity (high among polygon variation) were observed when aggregating at the three aggregation schemes, which is an indication of the MAUP effect in monitoring vegetation condition on a nationwide scale in Greece with NDVI. Monitoring using the fire service units displayed significantly higher pixels' homogeneity (low within polygon variation), which is an indication that is the most appropriate for monitoring vegetation condition on a nationwide scale in Greece with NDVI.

Results have been mostly consistent between the two major vegetation types examined (natural and agricultural vegetation), both highlighting the MAUP effect, and also indicating the fire service units as the most appropriate aggregation scheme for monitoring vegetation condition with NDVI. According to the statistical validation, conclusions based on these two years are justified.

Finally, the results of this work can help local and international agencies involved in vegetation monitoring to optimise the efficiency of their monitoring schemes.

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