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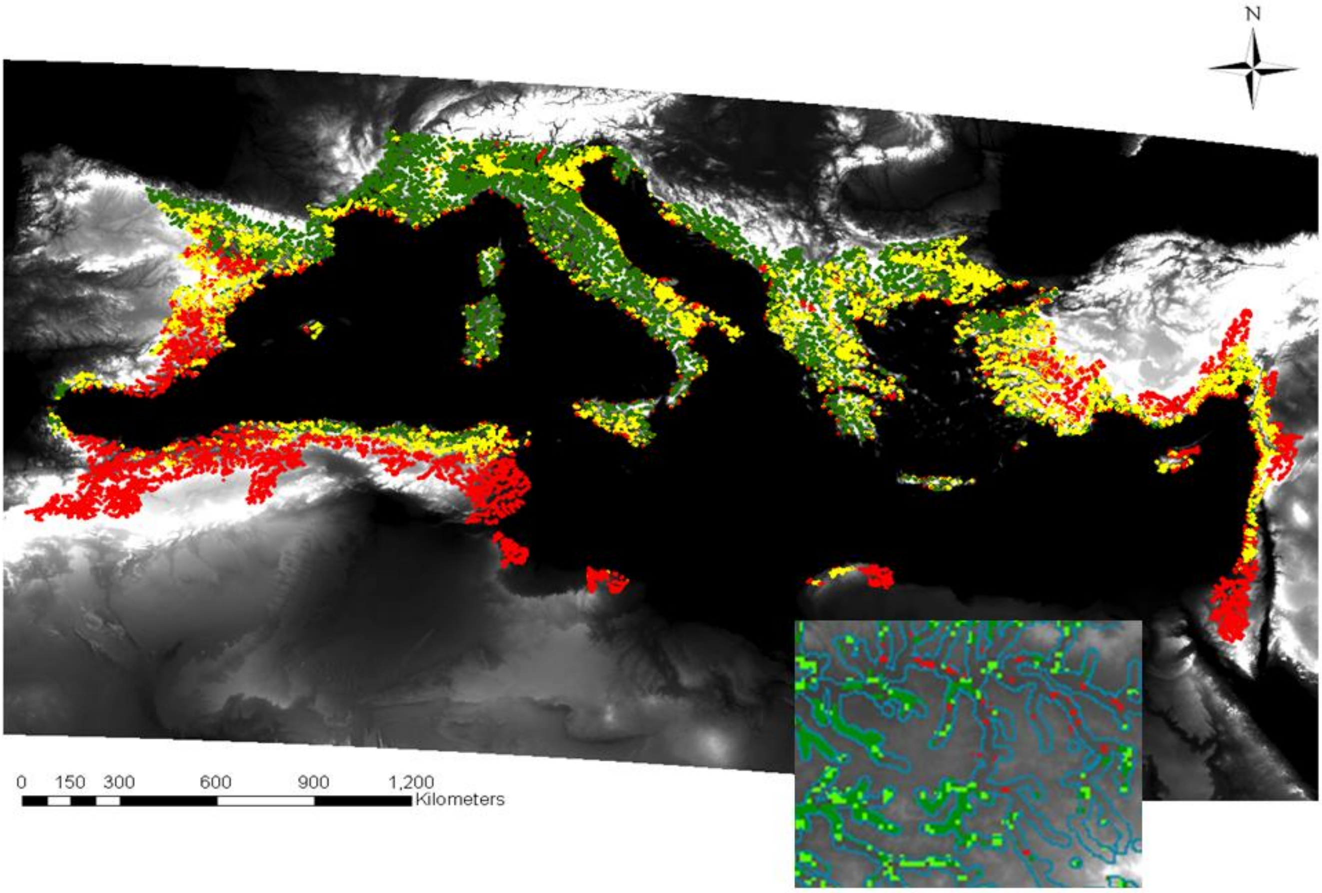

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Institute for Environment and Sustainability
DG Joint Research Centre, Ispra (Italy)

2008

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1 INTRODUCTION

The Euro-Mediterranean Governments aim to tackle the top sources of pollution by the year 2020 through the Horizon 2020 Initiative, built around 4 elements[1]:

- Projects to reduce the most significant pollution sources
- Capacity building measures for neighboring countries
- Using the Commission's research budget to develop and share knowledge on Mediterranean relevant environmental issues
- Developing Indicators to monitor the success of Horizon 2020

The EU Neighborhood Policy (ENP)[2] is looking at avoiding the emergence of new dividing lines between the enlarged EU and its neighbors. One of the aspects is to build on mutual commitments to common values, including sustainable development and environment. Indeed, the European Neighborhood Policy, through the implementation of Actions Plans, agreed between the EU and partner countries[3], aim in particular at gradual approximation of policy, legislation and practice. Sustainable development and Environment are included in each of these Action Plans.

Within the EU part of the Mediterranean, the Water Framework Directive (WFD[4]) and the Agriculture Policy (CAP) are at this moment the main policy structures to address resource management and rural planning. The EU Common Agriculture Policy (CAP[5]), being one of the first policies to be tackled by the Cardiff process, aims now at heading off the risks for soil and environmental degradation through rural development schemes. The WFD aims at integrating work on water resource management and as a second principle aims to restore every river, lake, groundwater, wetland and other water bodies to a ' good water status' by 2015.

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[1] http://ec.europa.eu/environment/enlarg/med/horizon_2020_en.htm
[2] http://ec.europa.eu/world/enp/policy_en.htm
[3] Five Action Plans were agreed with Israel, Jordan, Morocco, Tunisia and the Palestinian Authority and work is starting for Egypt and Lebanon.
[4] DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October
[5]
- COUNCIL REGULATION (EC) No 1290/2005 of 21 June 2005
- On the financing of the common agricultural policy
- COUNCIL REGULATION (EC) No 1782/2003 of 29 September 2003
- Establishing common rules for direct support schemes under the common agricultural policy and
- Establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93,
- (EC) No 1452/2001, (EC) No 1453/2001, (EC) No 1454/2001, (EC) 1868/94, (EC) No 1251/1999,
- (EC) No 1254/1999, (EC) No 1673/2000, (EEC) No 2358/71 and (EC) No 2529/2001
- COUNCIL REGULATION (EC) No 1698/2005 of 20 September 2005
- Council Regulation on support for rural development by the European Agricultural Fund for Rural Development (EAFRD)
- COUNCIL REGULATION (EC) No 144/2006 of 20 February 2006
- Council Decision on Community strategic guidelines for rural development (programming period 2007 to 2013)

This includes a good ecological and chemical status for the surface waters and a good chemical and quantitative status for groundwater.

The Euro-Mediterranean initiatives listed above offer the framework for sharing experiences on implementation of these EU environmental legislations. Specifically for optimizing strategies for water management in the whole Mediterranean, the EC set up a EUWI[6]/WFD Joint Process aiming at developing synergies between the two mechanisms to facilitate the implementation of sound water policies. The Process foresees transferring of experiences on WFD implementation between Northern and Southern Mediterranean Countries.

Agriculture practices, related soil conservation and pesticide and fertilizer use are impacting not only on the land and water quality on-site, but also on the water quality and quantity off-site within the water catchment area. Together the Directives look at taking new measures to control, amongst others, the agricultural sector in relation to diffuse pollution and water abstraction.

Due to the erratic character of the Mediterranean climate, water resources in the Mediterranean area are very diverse and not equally distributed. This is reflected in the specific seasonality of the vegetative land cover where coastal areas show a maximum in biomass activity during the winter, representing the typical Mediterranean cycle; see figure 1. Since long, land use is adapted to this situation by using adapted crops and increasingly irrigation. Greater than before population, inclusive pressure from heavy tourism, combined with regional to global market requirements – or opportunities - have lead to rather unsustainable growth in irrigated agriculture. Water demand from agriculture is the largest before drinking water and other uses. Continued agriculture intensification causes this demand to still grow. Furthermore, potential climate change might enhance this pressure due to decreasing average precipitations, increase in erratic character and more severe droughts.

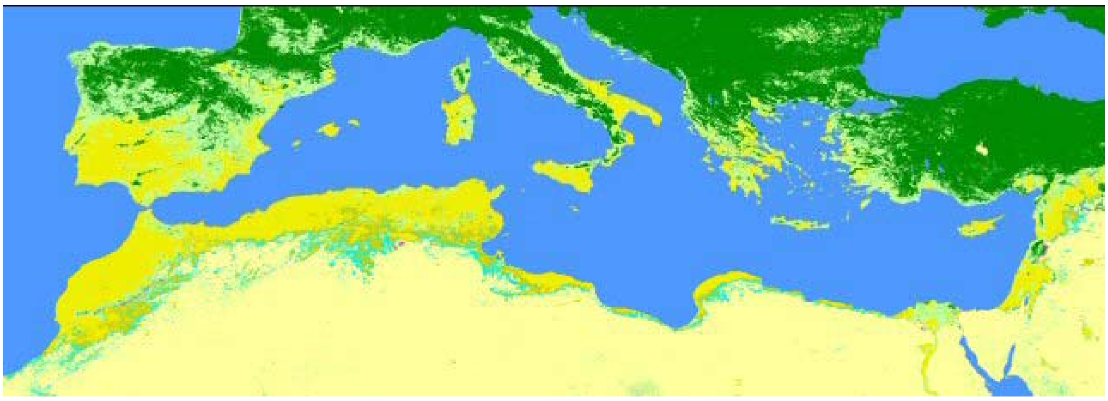


Figure 1: Seasonality in land cover in the Mediterranean area
(Based on SPOT VGT satellite data 1999-2003)
(pale yellow = desert; dark yellow = winter maximum; dark green = summer maximum; other colours = no marked seasonality)

[6] http://euwi.jrc.it/

The Mediterranean characteristics reinforce specific problems related to water quantity, but modern agriculture creates pollution stresses that are very common to more Northern European areas. The main stresses can be listed as follows:

- In many Mediterranean areas, intensification of agriculture leads to increased irrigation and when combined with non-proper practices has irrational impacts on the quantity of water resources and influences quality of groundwater.
- Pesticide and fertilizer use, the latter also for irrigated organic farming, are an increasing practice and create diffuse pollution of water resources. In certain areas together with erratic rainfall this can result in either slow residual water pollution or contribute to peak pollution concentrations creating chock impacts in e.g. coastal areas.
- Non adequate agricultural land management practices often increase vulnerability to soil erosion which can negatively disturb the soil water house holding and can increase sediment loads in water, combined with increased Phosphorus pollution.

In the Mediterranean basin, especially in the Southern Mediterranean rim, agriculture is closely linked to river systems. In the riparian-use zone 44% of the area is under agricultural use. Regarding the whole Mediterranean basin, as much as 8% of the total agricultural zone is concentrated in the 1 km Riparian-use zones. Riparian zones are widely recognized as functional buffer areas adjacent to water courses forming a transition zone with the surrounding land. They exert a number of functions ranging from physical stabilizing and buffering to acting as nutrient sinks. Ivits et al. (2008) describe the assessment of the functioning of riparian zones by using remote sensing derived parameters. In view of the intense use of the Mediterranean riparian zones for agriculture, urban dwellings, industry etc. the current competing land uses exert enormous pressures on these fragile eco-systems.

One of the specific challenges in the Mediterranean is linking agricultural land management closely to the water management and vice versa, including all stakeholders at all stages.

As contribution to this challenge and to the ongoing policy processes, this report aims at inventorying the status of Mediterranean riparian areas based on remote sensing indicators.

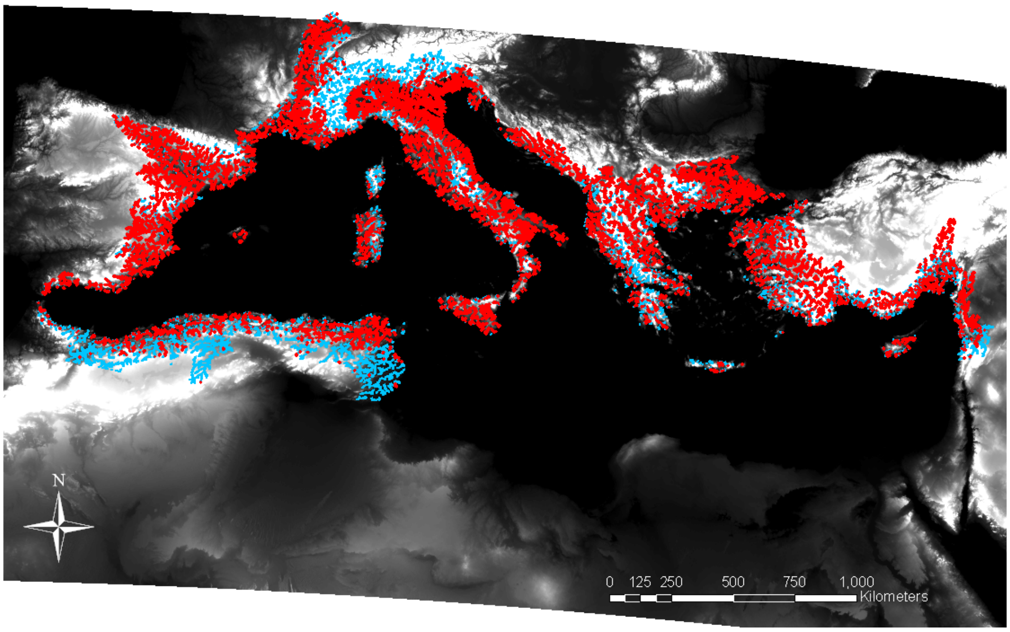


Figure 2: Agricultural use (in red) in the 1km riparian-use zone (blue) in the Mediterranean. Source: GLC2000 (16 = Cultivated and managed areas and 22 = Irrigated agriculture).

2 DATA AND METHODS

Over the last two decades, remotely sensed data has offered means of measuring vegetation properties at regional to global scales. Of particular significance has been the availability of Time Series of remote sensing images extending over many years. In interpreting multi-temporal information from time series data, it is usual to calculate "vegetation indices" defined as ratios of radiances in different bands. Currently the longest back-dating time series of biophysical variables like the NDVI are provided by the AVHRR (Advanced Very High Resolution Radiometer) sensor on board of the NOAA (National Oceanic and Atmospheric Administration) satellite. The mostly used vegetation index is the NDVI (Normalised Difference Vegetation Index), a measure of the amount of active photosynthetic biomass, correlated with biophysical parameters such as green leaf biomass, fraction of green vegetation cover, leaf area index, total dry matter accumulation and annual net primary productivity (Asrar et al., 1985, Justice et al., 1985, Myneni et al., 1995, Prince, 1991, Sellers, 1985, Tucker, 1979, Tucker et al., 1985).

2.1 Green Vegetation Fraction-GVF

The NDVI is known to be influenced by soil and rock background. Additionally, the NDVI shows sensitivity to several parameters such as atmospheric conditions, the illumination and the observation geometry. Moreover, the NDVI values are sensor dependant due to different spectral properties, observation geometry as well as sensor degradation status. This complicates a direct comparison among different sensors and hampers compiling of reliable time series. Due to these problems it was preferable to find a measure for vegetation abundance which is expected to be a better indicator for vegetation cover density.

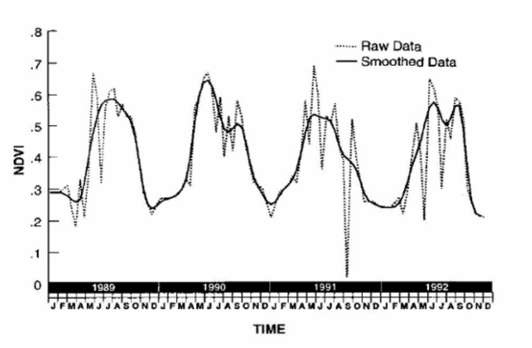
In this context Linear Unmixing has been recognized as the most promising approach for vegetation cover estimation, as shown in earlier studies (Stellmes et al., 2005; Weissteiner et al., 2008). The applied unmixing technique is based on the inverse relationship between NDVI and land surface temperature. Generally, surface temperature (Ts) is observed to be inversely proportional to the amount of vegetation canopy cover and thus to the NDVI (Sommer, 1999). This is due to a variety of factors including latent heat transfer through evapotranspiration, the lower heat capacity and thermal inertia of vegetation compared to soil (Choudhury, 1989; Goward and Hope, 1989).

Unmixing of NOAA AVHRR NDVI and Ts was done for the Mediterranean region for the years 1989 – 2005. The technical description of algorithm and results can be found in a separate report (Weissteiner et al., 2008; Stellmes et al., 2005).

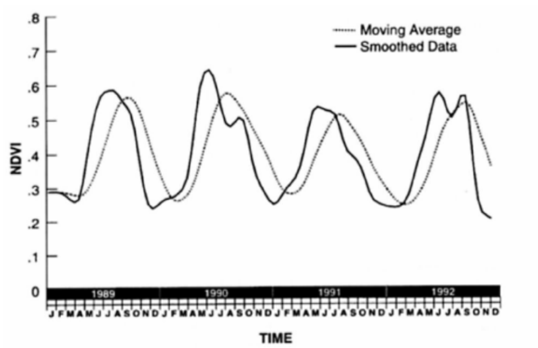
2.2 Phenological Indices

The quantification of phenological processes is very important for understanding ecosystems and ecological development. Phenological processes are determined by the length of the growing season, frost damage, timing and duration of pests and diseases, water fluxes, nutrient budgets, carbon sequestration and food availability. All these factors together determine population growth and influence species-species interactions (competition, predation, reproduction) and species distribution. Goward et al. (1987) for instance demonstrated that the time integral (area under the curve) of the Normalised Difference Vegetation Index (NDVI) over an annual period produced a measure related to net primary productivity values of different biomes. The timing and progression of plant development may also provide information to help making inferences about the condition of plants and their environment.

After the method of Reed et al. (1994) phenological indices were calculated from the time series of the Green Vegetation Fraction (GVF) image. The GVF image gives the percentage of vegetation in a 1km resolution pixel and supplies a better estimate then NDVI because the soil background interference is partly corrected for. These metrics may not necessarily correspond directly to conventional ground-based phenological events but provide indicators of ecosystem dynamics and a measurable change in ecosystem characteristics.



Running median smoothing of the time-series data (after Reed et. al, 1987)



Forward lag created by a moving average algorithm: crossing of the original and the lagged data define the start of the growing season

Figure 2.1: Running median smoothing and the mowing average lag of the time-series data

The GVF time series data was measured in dekades for 16 years (36 images a year, 576 images for the whole time series) from 1989 to 2004. The data was smoothed using a 5 interval running median filter (Figure 2.1) followed by the calculation of two forward and backward lagging curves, by means of a moving average algorithm. Moving averages are used to smooth out short-term fluctuations, thus highlighting longer-term trends or cycles. The threshold between short-term and long-term depends on the application, and the parameters of the moving average will be set accordingly. A **simple moving**

average (SMA) is the unweighted mean of the previous *n* data points. For example, a 10-day simple moving average of phenological values is the mean of the previous 10 days' phenological values. If those values are p, $p_{-1} \ldots p_{-9}$ then the formula is

$$SMA = \frac{p + p_{-1} + \ldots + p_{-9}}{10}$$

When calculating successive values, a new value comes into the sum and an old value drops out, meaning a full summation each time is unnecessary,

$$SMA_{today} = SMA_{yesterday} - \frac{p_{-n+1}}{n} + \frac{p_{+1}}{n}$$

In all cases a moving average lags behind the latest data point, simply from the nature of its smoothing. The period of the lag selected depends on the kind of movement one is concentrating on, such as short, intermediate, or long term. It should correspond approximately to the length of the non-growing season for the environment in question (Reed et al. 1994). For the present study, however this method seemed too arbitrary and subjective. Therefore another solution was searched for that defines the lag using objectively calculated information from the data itself. After several test runs, the method applying 1 standard deviation from the bary centre of the integral surface for defining the period of the lag (the lag distance) seemed the most appropriate and was used for the calculation of the moving average curve.

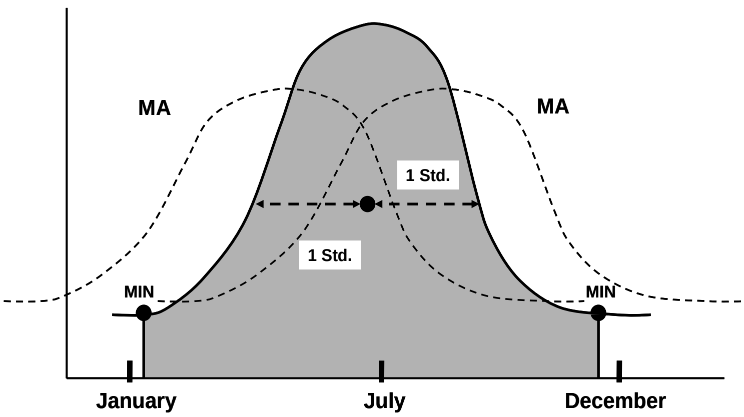


Figure 2.2: Derivation of the moving average curves

The crossing of the original smoothed curve and the forward lagged curve in the upwards direction defines the time period when the GVF curve starts being significantly and consistently higher its absolute minimum value (Figure 2.2). This potentially indicates the start of the growing season. Similarly, the crossing point of the original smoothed curve and the curve lagging behind will be significant as the end of the season.

These indices were calculated from the GVF time series curve as indicated below:

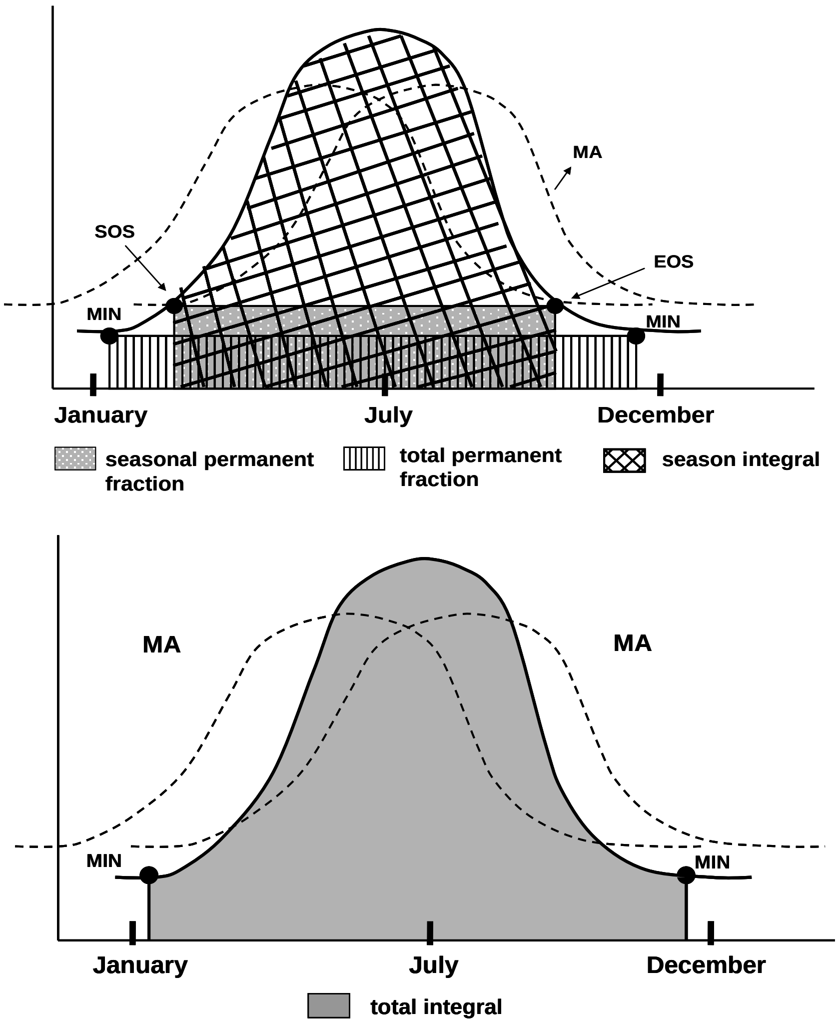


Figure 2.3: Seasonal and total permanent fractions, seasonal and total integrals.

The seasonal permanent fraction was defined as the area under the GVF time series curve where the horizontal between the start of season and end of season points is the higher limit and the X axis is the lower limit (Figure 2.3). The total permanent fraction on the other hand is the area under the time series curve that is defined by the absolute minimum GVF values and the X axis. The season integral was calculated as the area under the GVF time series curve between the start of season and end of season points where the higher limit is the absolute maximum GVF value and the lower limit is the X axis. The total integral index is the area under the whole time series curve limited by the X axis and the absolute minimum GVF values. The indices were calculated for each of the years from

1989 to 2005. For the ease of interpretation the mean value was computed for each of the index using the seventeen years values.

The length of the season was defined as the distance (in days) between the Start of season (SOS) and the end of season (EOS) points (Figure 2.4). The total lengths will be given as the distance (in days) between the absolute minimum points.

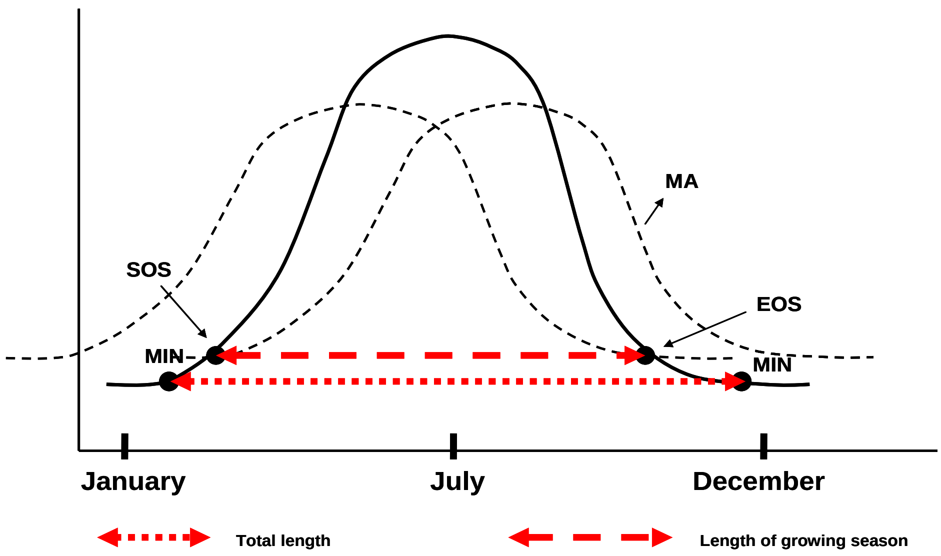


Figure 2.4: Length of the growing season and the total length.

2.3 Assessment of the status of the Riparian-use zone in the Mediterranean

The Mediterranean network of riparian-use zones was derived from the Mediterranean river network data prepared in the Agri-Env Action of the IES (Figure 2.5). A 1km buffer was created along the left and right riverside and was considered as the riparian-use zone. When managing riparian vegetation as a buffer to filter nutrients and contaminants from agriculture, a minimum of 10m width is suggested (Price et al., 2004). Many studies describe the role of the riparian zones as sinks for watershed nitrate (Gold et al., 2001). Gilliam et al., 1997) documents that buffers up to 30m wide can reduce up to 80% and 77% of N and P respectively. Considering biodiversity it was observed that 90% of the bird species of the riparian ecosystem will be found within 75 to 175 meters (Spackman and Hughes, 1995). Semlitsch (1998) observed that for salamander species the buffer zone would need to extend over 160 meters and Brinson et al. (1981) showed that buffer zones along streams need to be as wide as 400 meters to protect all components of biodiversity. Despite significant research, there is no single law of nature that defines the buffer width to consider (Meyer, 1984) and the optimal riparian buffer design or proper buffer width is still unclear (Mayer et al., 2005). For this study the most pragmatic solution was searched for and a 1km buffer was chosen to account for all the different buffer sizes in literature and for the spatial resolution given by the remotely sensed data. The concept of the wider riparian-use zone has been proven to be significantly representing the level of functioning of the riparian zone in relation to the adjacent land use (Ivits e al., EUR 23299 EN)

The assessment and characterization of the Mediterranean riparian areas were performed analysing the following four remote sensing based phenological indices (see also figure 2.3.):

- Seasonal Permanent Fraction (SPF): vegetation permanently present on the area in the growing season.
- Total Permanent Fraction (TPF): vegetation permanently present on the area throughout the whole year.
- Season Integral (SI): cyclic vegetation following the seasonal growing pattern.
- Total Integral (TI): approximation of total biomass.

The analysis was performed following the below indicated steps:

A. classification and area calculation
B. Descriptive statistics
C. Land Cover Characteristics
D. Trend analysis
E. Significance of Classes (LMM)
F. Crossing with bio-physical variables

The approach for each step is indicated here below and Chapter 3 further describes the results of each steps for each of the processed phenological indices.

A. classification and area calculation

For each of the phenological indices, the mean values were derived from their seventeen years timeseries. This value entered into the classification algorithm. The k-means unsupervised method was used to cluster the values into 3 categories such as "low", "medium" and "high" values. The k-means method calculates initial class means evenly distributed in the data space and then iteratively clusters the pixels into the nearest class using a minimum distance technique. Each iteration recalculates class means and reclassifies pixels with respect to the new means. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selected criteria. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached.

B. Descriptive statistics

For all phenological indices, for each of the obtained classes the overall descriptive statistics were calculated.

C. Land Cover Characteristics

The GEM unit of the JRC has produced a new global landcover classification for the year 2000 (GLC2000 - http://www-gem.jrc.it/glc2000/defaultglc2000.htm), in collaboration with over 30 research teams from around the world contributing to 19 regional windows. Each defined region was mapped by local experts, which guaranteed an accurate classification, based on local knowledge. Each regional partner used the VEGA2000 dataset, providing a daily global image from the Vegetation sensor onboard the SPOT4 satellite. Each partner used the Land Cover Classification System (LCCS) produced by FAO and UNEP (Di Gregorio and Jansen, 2000), which ensured that a standard legend was used over the globe. This hierarchical classification system allowed each partner to choose the most appropriate land cover classifiers which best describe their region, whilst also providing the possibility to translate regional classes to a more generalised global legend. For the present study two types of products were used:

1. The Global Land Cover (GLC) dataset (Figure 2.6) - This is the harmonisation of all the regional products, into a full resolution global product, with a generalised legend. Detailed description of the classes can be found under http://www-gvm.jrc.it/glc2000/legend.htm.

2. African Land Cover (ALC) datasets (Figure 2.7) - The classification has been produced by regional GLC2000 partners with a regionally specific legend (http://www-gvm.jrc.it/glc2000/legend.htm) to provide as much detail as possible.

The GLC dataset was used to investigate the distribution of land cover classes in the riparian network of the Mediterranean (including North African rivers) and within the classes of the phenological indices (low, medium, and high). The Regional Land Cover Datasets was used to account for the distribution of the land cover classes within the European and African riparian network, respectively, and within the phenological indices categories with as much regional details as possible.

D. Trend analysis

Linear trend model was fitted to each of the seventeen years of phenological indices for each pixel in the images to explain temporal structure in the data, in terms of decreasing, stable or increasing trends. The resulted statistical parameters were presented in a map form throughout the Mediterranean riparian area to account for spatial structure in the data. The following three statistical parameters were extracted:

- Regression coefficient *b* of the linear trend model fitted to the given phenological index:

  $$y = b * time + a$$

  The regression coefficient b gives the change in the expected value of y (the given phenological index) per a unit change of time (a year in this case). The regression coefficients were clustered into 3 classes such as weak, medium and strong to account for the strength of the regression.

- Significance (two sided P value) of the t-score of the linear regression model. The t-score is used to describe the likelihood that the regression coefficient (b) of the linear trend model equals zero. The t-score is defined as the ratio of the estimates and the standard error of b:

  $$\bar{t} = \frac{b}{std.error(b)}$$

  In case of statistical significance the null hypothesis of zero regression coefficient is rejected and the alternative hypothesis, i.e. the existence of significant trend is accepted. In the present study a confidence interval of 0.1 was set for statistical significance. Pixels outside this confidence limit represent areas where the phenological index had no trend. Pixels within the confidence limit combined with the negative/positive sign of the regression coefficient represent areas where the phenological index had a positive or negative linear trend.

- The maximum residuals analysis gives the absolute value of the maximum residual in the trend model. For each pixel in the dataset the largest positive or negative residual is saved from the linear trend analysis for each pixel. This analysis is useful to detect outliers or true extreme values. For instance, maximum residuals which are negative and have values lower then a given value (e.g. the negative peak in the distribution of the maximum residual values) depict areas where the seasonal permanent fraction data declined dramatically throughout the years from 1989-2005.

E. Significance of Classes (LMM)

To test that the three classes "low", "medium" and "high" represented significantly different phenological values a Linear Mixed-Effect Model (LMM) was applied using a repeated measures design.

The repeated measures option in a LMM models within-subject variance, i.e. variance in the same subjects over time. LMM correctly handles correlated observations of time series data and unequal variances as correlated data are very common in such situations where surveys are performed repeatedly (repeated measures).

In a LMM, responses from a subject (here the single pixels) are thought to be the sum (linear) of so-called fixed and random effects. If an effect, such as the three classes of the phenology, affects the population mean, it is fixed. Fixed factors are categorical variables where all possible category values (levels) are measured. Fixed effect parameter estimates are the regression slopes. If an effect is associated with a sampling procedure (e.g. environmental zones), it is random. In a mixed-effects model, random effects contribute only to the covariance structure of the data. The presence of random effects, however, often introduces correlations between cases as well. Though the fixed effect is the primary interest in most studies or experiments, it is necessary to adjust for the covariance structure of the data. The adjustment made in procedures like GLM-Univariate is often not appropriate because it assumes independence of the data. In the Linear Mixed Models procedure, the repeated measures variables are added to relax the assumption of independence of the error terms and they constitute the id for the repeated observations. The intercept of the LMM model is interpreted as the overall mean of the dependent variable.

The covariance structure type for the repeated measures variable was set to AR1 (a first order autoregressive structure with homogenous variances), which is often chosen when there is thought to be a common trend, such as increasing phenological scores over time. The observation years (1998-2005) were defined as the repeated measures variable while the variable "gridcode" was defined as a fixed effect factor incorporating three levels according to the three classifications "low", "medium" and "high" levels of the phenological index. To measure whether the location of the riparian zone had an effect on the classes of the phenological index the environmental zones (1^{st} hierarchical level, 13 classes) developed in Alterra (see below) were added to the analysis as another fixed effect variable. Both the effect of the individual factors and their interaction were tested. With other words, it was tested if the phenological values significantly vary within the environmental categories and if the phenological values significantly vary within the categories dependently in which environmental zones they were measured. Estimated marginal means (group means estimated from the fitted model) were calculated to reveal the predicted mean phenological index values of the three categories. In order to discover weather differences in the phenological values in the four AEM zones were significant a pair wise comparison was performed using the Sidak adjusted p-values for the multiple test (Hochberg and Tamhane, 1987).

F. Crossing with bio-physical variables

The derived phenological indices were crossed with biophysical variables through a linear regression. The biophysical data was measured within the second level hierarchy of the Environmental Classification as produced by Alterra (84 classes, Metzger et al., 2005). The measured variables were:

- Altitude
- Slope
- Mean and standard deviation of minimum monthly temperature
- Mean and standard deviation of maximum monthly temperature
- Mean and standard deviation of monthly precipitation
- Mean and standard deviation of percentage of the monthly sunshine

The phenological indices values were aggregated within the environmental classification zones (Figure 2.9) by means of the zonal statistics technique and subsequently fit to the spatial extent of the Mediterranean riparian-use area. Within the environmental zones the mean and the standard deviation of the phenological index were calculated. The adjusted R squared measures was used instead of the sample R squared for the trends to realistically estimate how well the models fit the population. The adjusted R squared attempts to correct R squared to more closely reflect the goodness of fit of the model in the population. Furthermore, the Durbin-Watson statistic was checked to screen sample autocorrelation and the model was considered significant in case $p < 0.05$. The Durbin-Watson statistic tests the null hypothesis that the residuals from an ordinary least-squares regression are not autocorrelated against the alternative that the residuals follow an AR1 process. The Durbin-Watson statistic ranges in value from 0 to 4. A value near 2 indicates non-autocorrelation, a value toward 0 indicates positive autocorrelation, and a value toward 4 indicates negative autocorrelation. For model diagnostic the normality and homoscedasticity assumptions of the linear regression were tested. For the normality assumption the histogram of the standardised regression residuals and the normal probability plot was computed. In the latter plot, the actual scores are ranked and sorted, and an expected normal value is computed and compared with an actual normal value for each case. For the normality assumption to hold the actual values should line up along the diagonal that goes from lower left to upper right. The assumption of homoscedasticity is that the residuals are approximately equal for all predicted dependent variable scores. Data are homoscedastic if the standardised regression residual vs. the standardised predicted value plot has the same width for all values of the predicted variable.

Table 2.1.: Environmental zones on the 1st hierarchy and their abbreviations

Abbreviation	Zone name (Enz_name)
ALN	Alpine North
ALS	Alpine South
ANA	Anatolian
ATC	Atlantic Central
ATN	Atlantic North
BOR	Boreal
CON	Continental
LUS	Lusitanian
MDM	Mediterranean Mountains
MDN	Mediterranean North
MDS	Mediterranean South
NEM	Nemoral
PAN	Pannonian

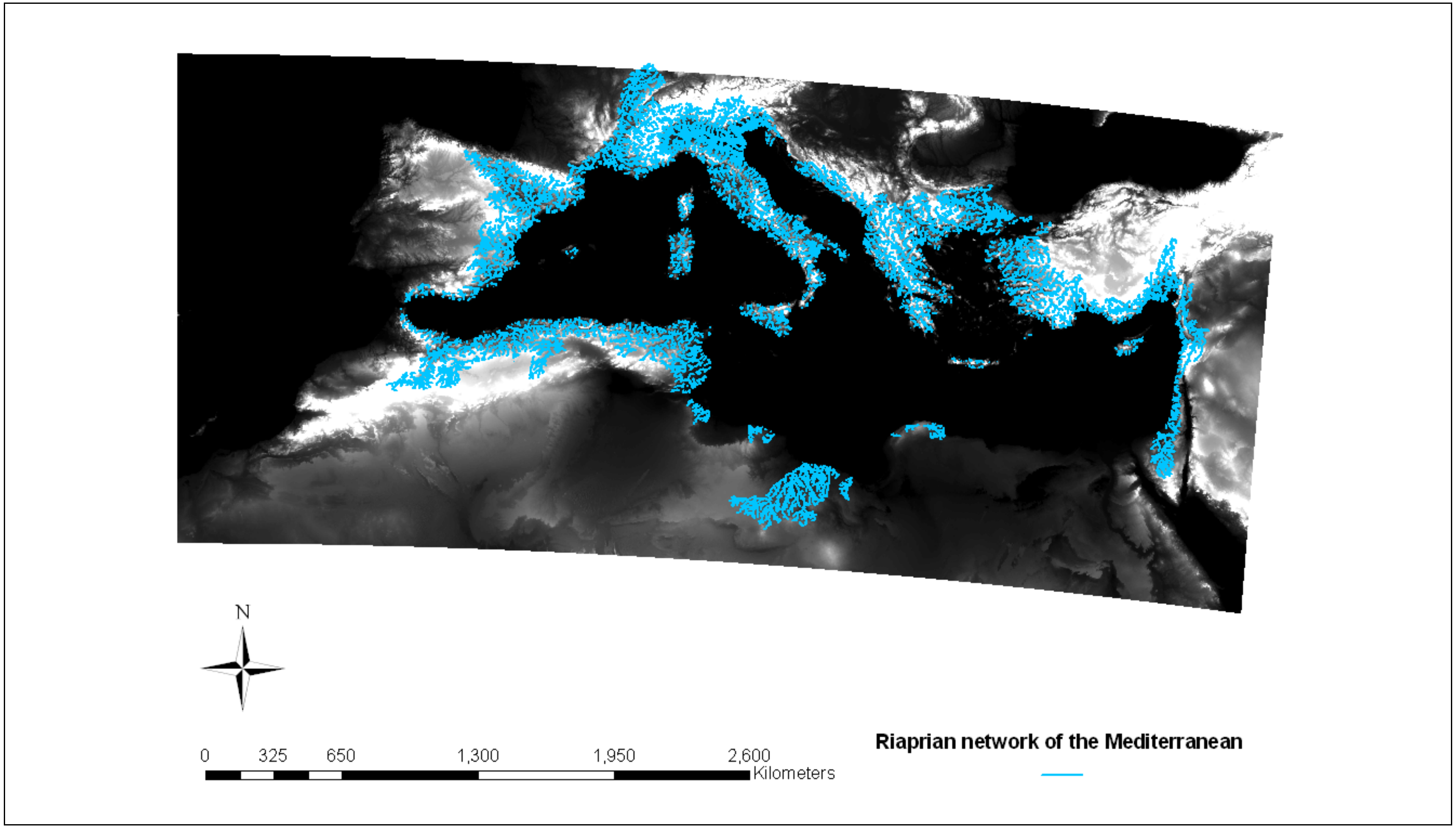


Figure 2.5: Mediterranean river network

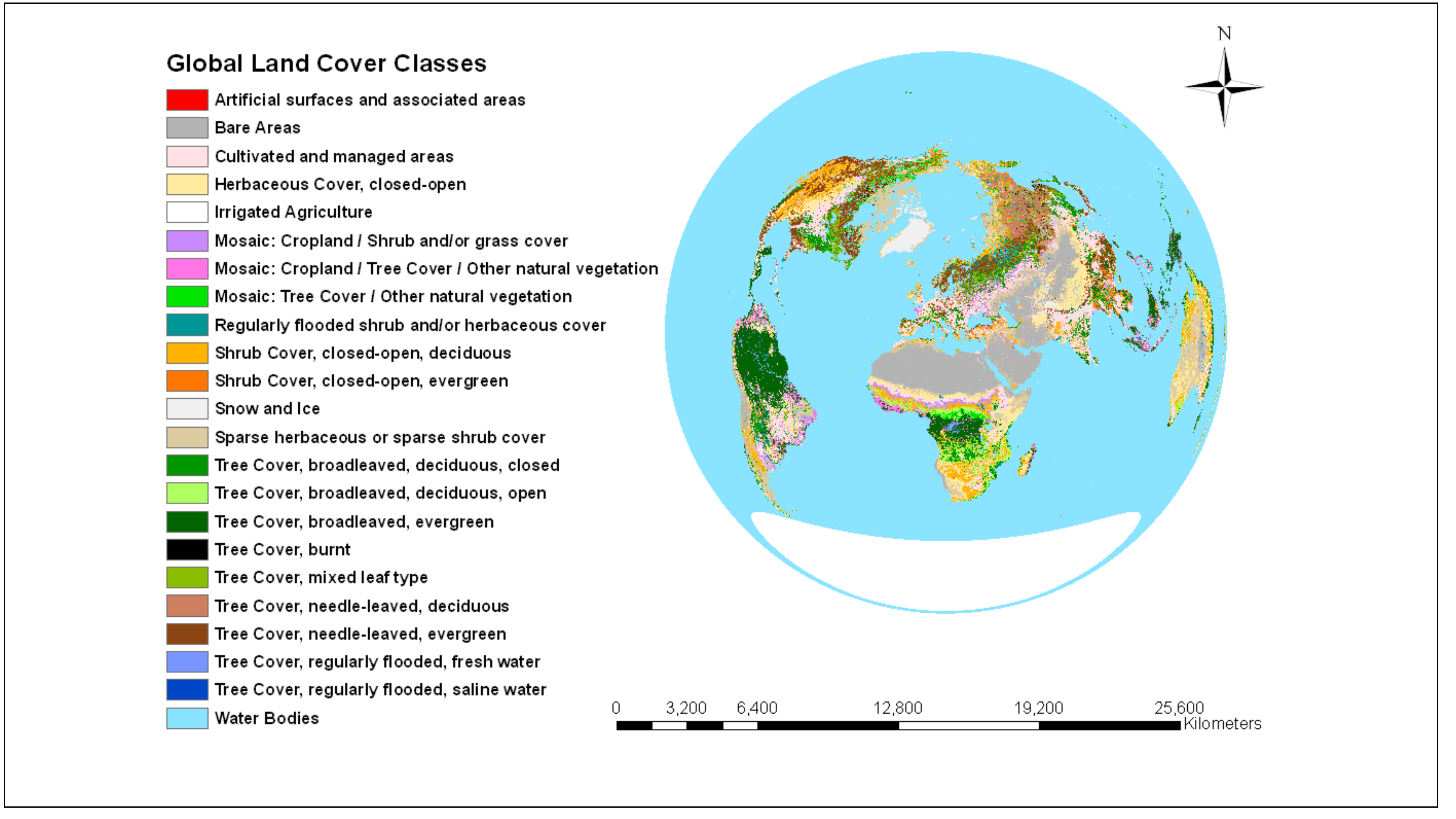


Figure 2.6: The Global Land Cover classification dataset

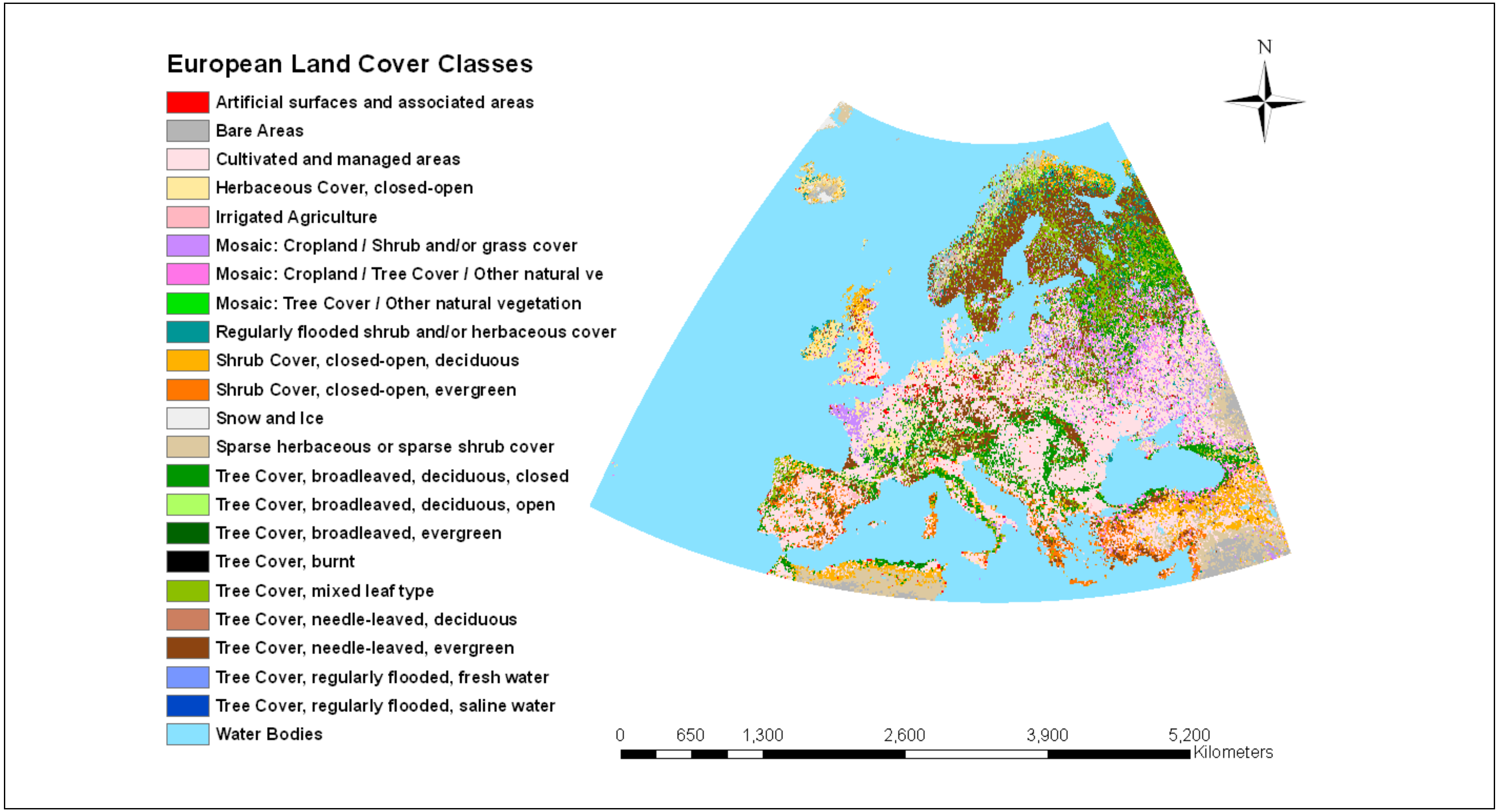


Figure 2.7: The European Land Cover dataset

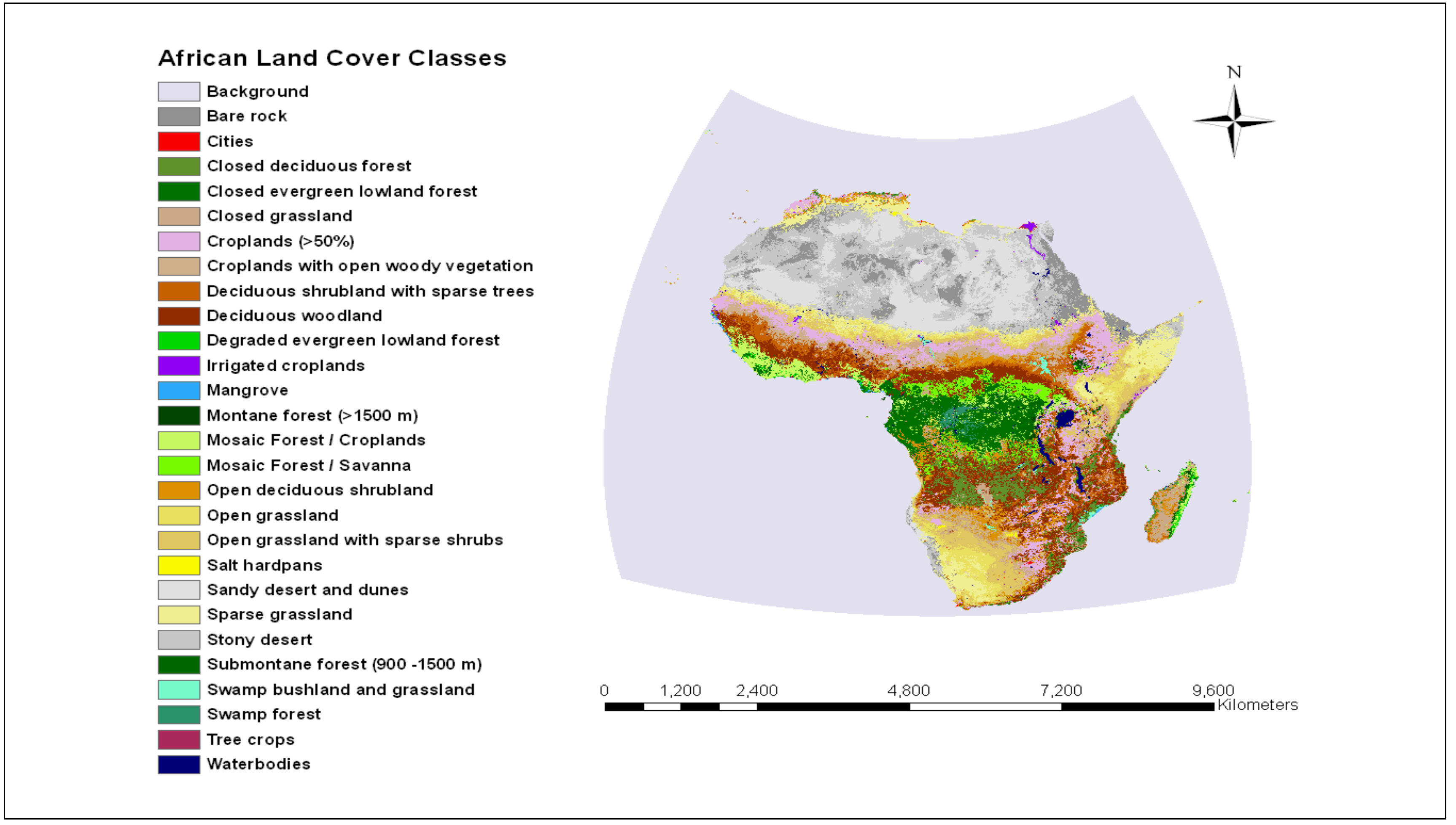


Figure 2.8: The African Land Cover dataset

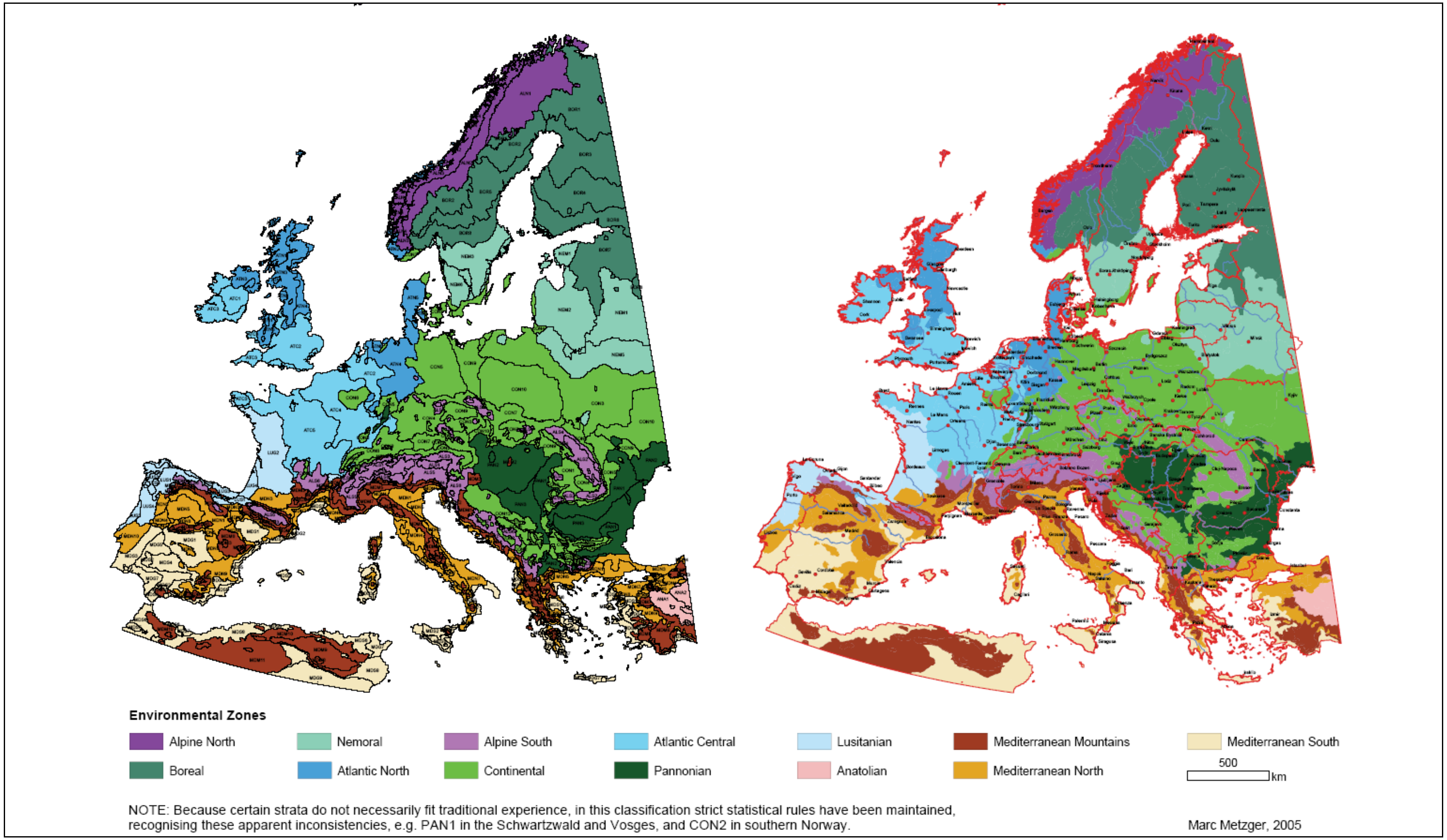


Figure 2.9: The environmental stratification of Europe (after Metzger, 2005).

3 RESULTS

3.1 Seasonal Permanent Fraction (SPF)

A. Classification and area calculation

The sixteen years mean seasonal permanent fraction is presented in a map form in Figure 3.1.3. The area distribution of the riparian zone within the three SPF classes (low, medium and high, Figure 3.1.5) was as follows. Low seasonal permanent fraction was presented in 64783 km^2 of the area (32%), 72145 km2 area (35%) has medium level of permanent vegetation fraction while 67115 km2 area (33%) has a high level of permanent vegetation fraction (Figure 3.1.1). Most of the riparian area has a medium level of seasonal permanent vegetation fraction.

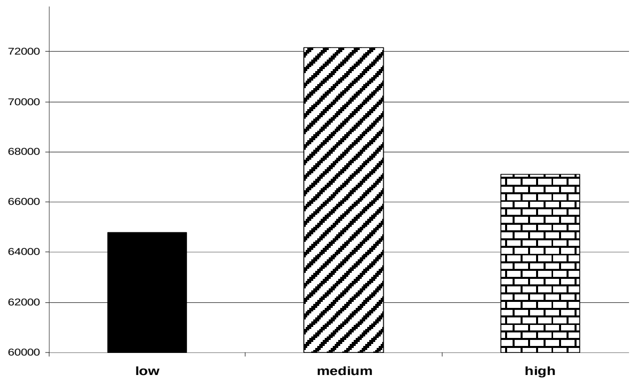
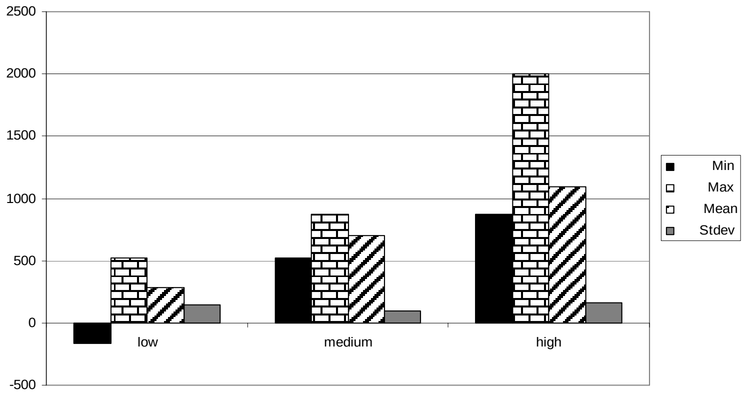


Figure 3.1.1: Area distribution of the Seasonal Permanent Fraction classes (km^2).

B. Descriptive statistics

Descriptive statistics of the Seasonal Permanent vegetation Fraction values within the classes low, medium and high in the riparian-use zones are shown in Figure 3.1.2.



Class	Min	Max	Mean	Stdev
Low	-166.06	524.82	288.32	142.12
Medium	524.88	875.06	704.43	98.48
High	875.12	1997.94	1090.82	160.92

Figure 3.1.2: Descriptive statistics of the Seasonal Permanent vegetation Fraction values *s.*

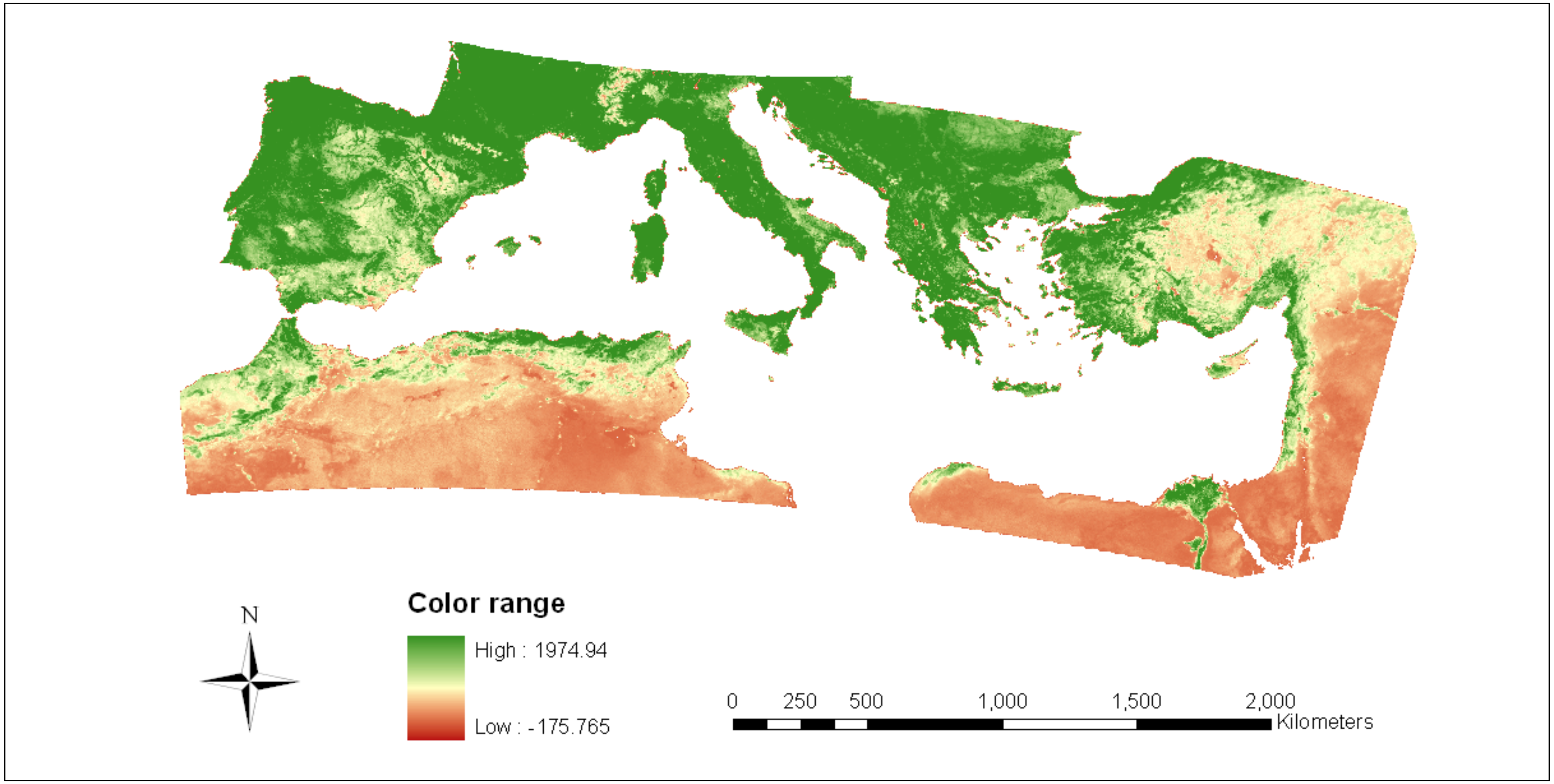


Figure 3.1.3: Mean of the sixteen years (1989-2005) Seasonal Permanent vegetation Fraction values over the Mediterranean.

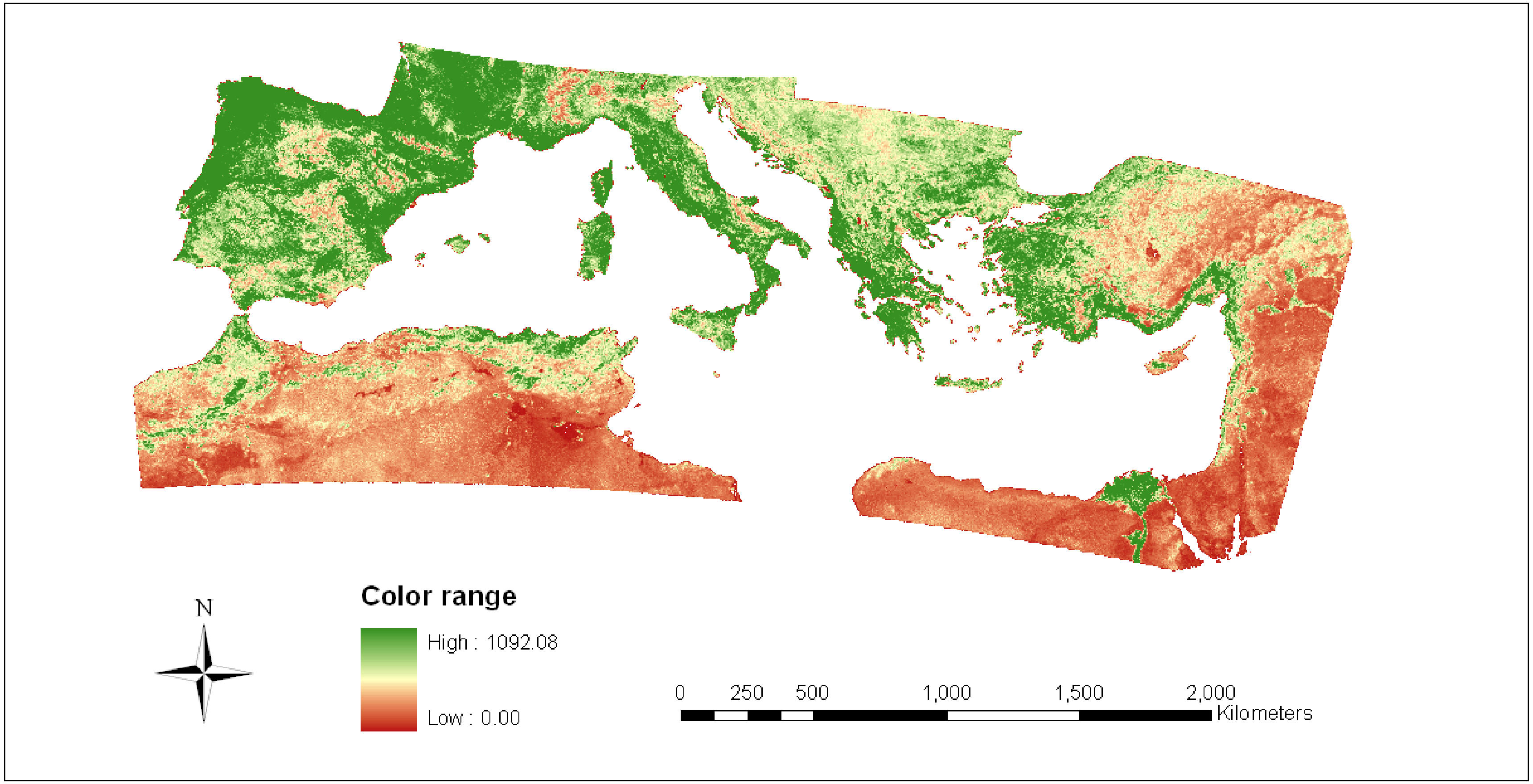


Figure 3.1.4: Standard deviation of the sixteen years (1989-2005) Seasonal Permanent vegetation Fraction values over the Mediterranean.

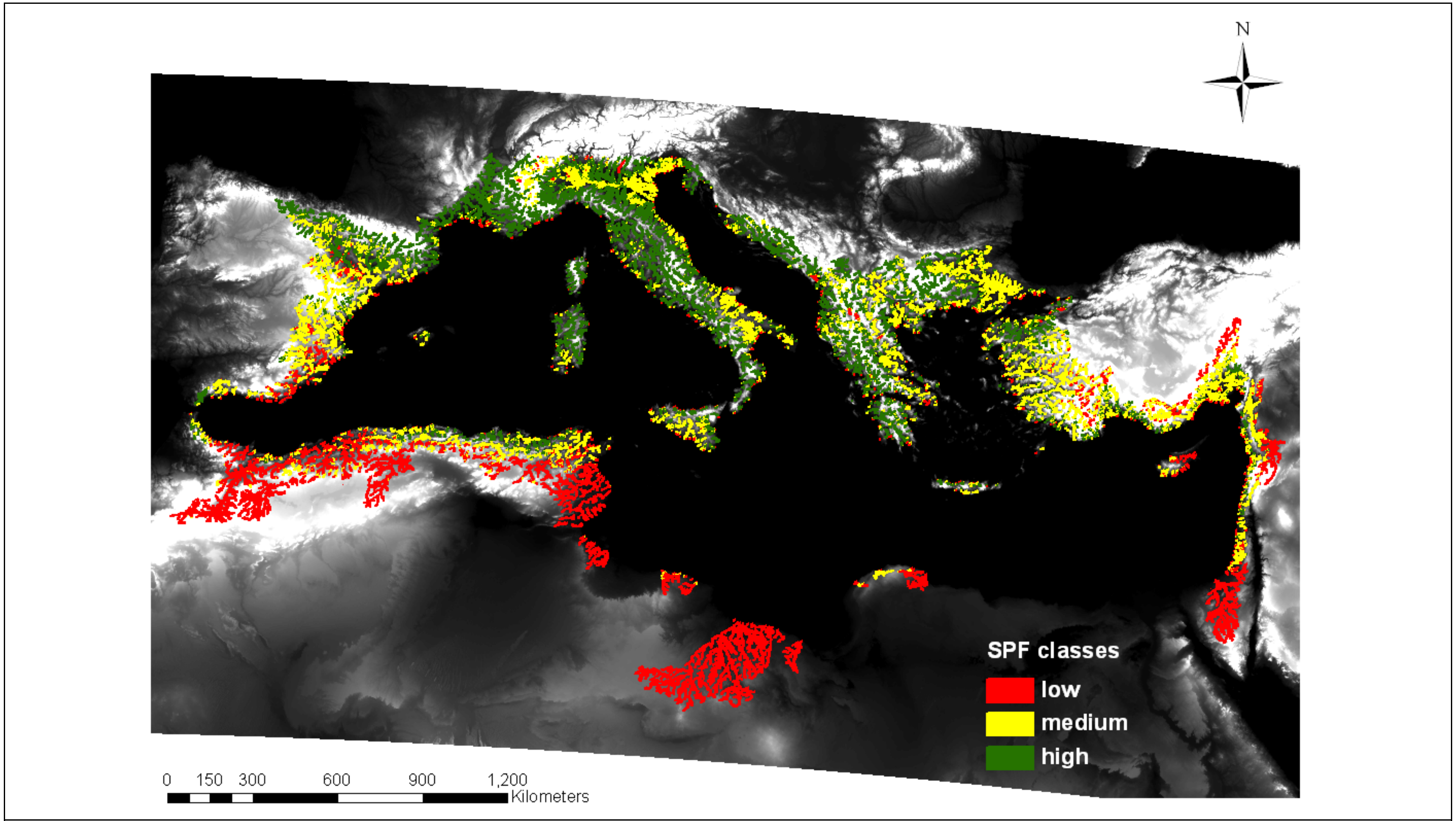


Figure 3.1.5: Classification of the riparian-use zone into low, medium and high Seasonal Permanent vegetation Fraction classes.

C. Land Cover Characteristics

In the class with high seasonal permanent vegetation fraction, broadleaved forest with closed crown coverage, coniferous forest and closed/open deciduous shrub cover reached an area coverage over 10 % (14, 12, and 12% respectively). Riparian-use zone with high and medium seasonal permanent vegetation fraction were dominated by cultivated and managed areas, as derived from the GLC dataset. (57% and 45%, respectively, Figure 3.1.6) .In the riparian-use zone with medium seasonal permanent fraction open deciduous shrubs covered 23% of the area, the coverage of the other land cover types remained very low. In the low seasonal permanent fraction class the sparse herbaceous or shrub cover dominated (30%) followed by cultivated and managed areas (23%). Furthermore, closed and open deciduous shrubs and bare areas occurred in this class with a share of 21 and 17%, respectively.

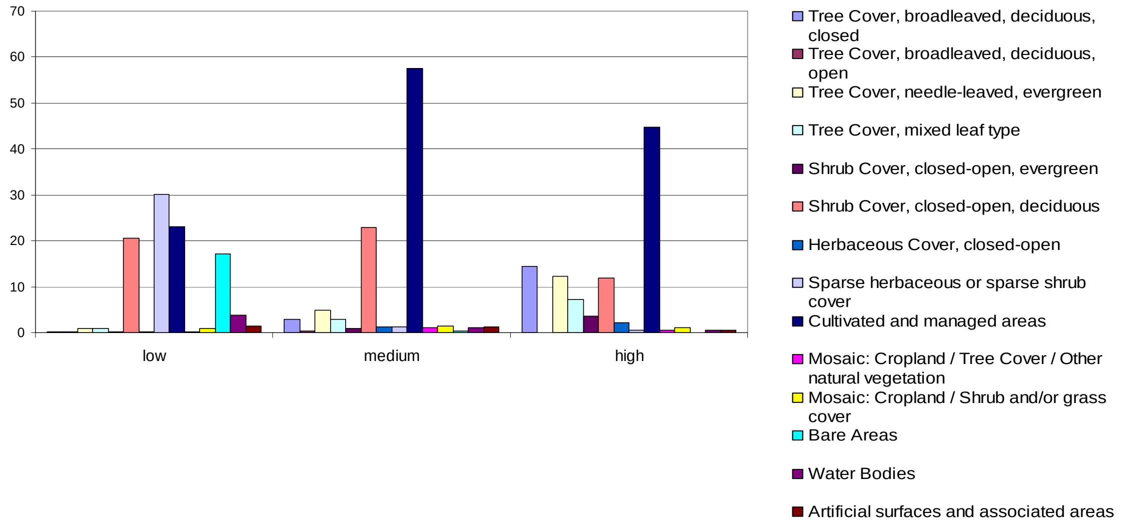


Figure 3.1.6: Distribution of the GLC2000 classes in the three categories of the Seasonal Permanent Fraction.

For the south Mediterranean in the high seasonal permanent fraction class, closed deciduous forest dominated the riparian-use zone (70%) while croplands covered another 19% of the area, as derived from the African Landcover (ALC) (Figure 3.1.7). In the medium class the share of croplands was the highest with 42% but open deciduous shrubland and deciduous forest also occupied considerable area (32 and 20% respectively). Class area distribution of the low class was less dominated by one land cover class. Sparse grassland occupied 42% of the area, open deciduous shrubland 22% and stony desert reached the area coverage of 16%. Croplands, sandy desert and bare rock covered altogether 16% of the riparian use area.

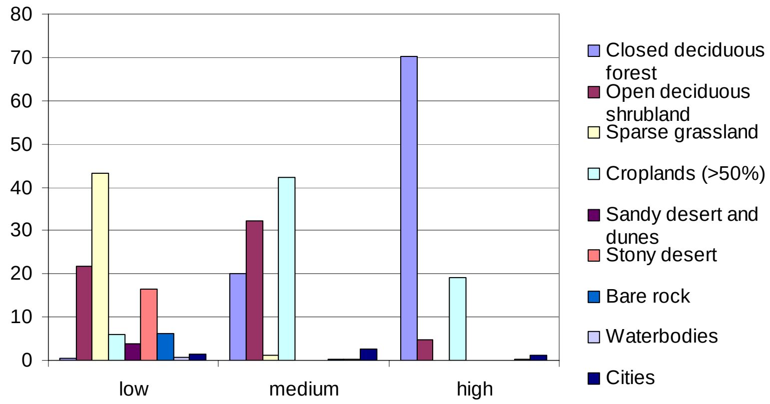


Figure 3.1.7: Distribution of the African Land Cover classes in the three categories of the Seasonal Permanent Fraction.

D. Trend analysis

Liner trend analysis results are summarized in Figures 3.1.8-3.1.12. For most of the riparian-use zone (153973 km^2, 75% of the area) no trend was observed, see Figures 3.1.8 and 3.1.9. A negative significant trend appeared in 5989 km^2, i.e. in 3% of the area, while 44914 km^2 (22% of the riparian-use zone) showed a significant positive trend of the seasonal permanent vegetation fraction values.

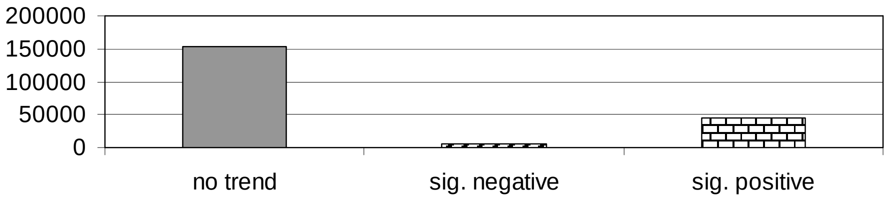


Figure 3.1.8: Area distribution of the trend significance classes of the Seasonal Permanent vegetation Fraction.

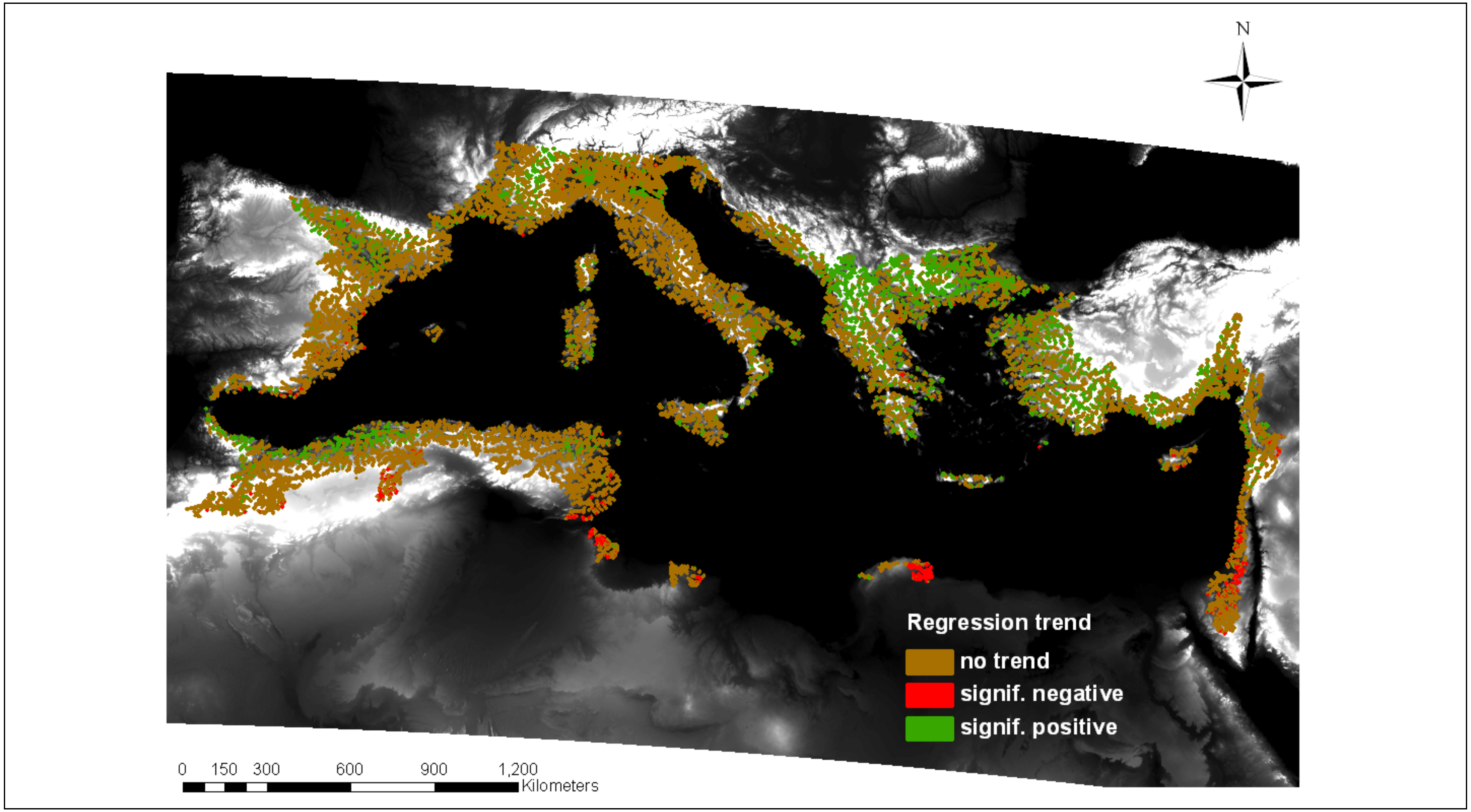


Figure 3.1.9: Significance of the linear trend model of the Seasonal Permanent Fraction data from 1989-2005. The significance values are classified into significant ($p < 0.05$) negative, significant positive, and no trend values.

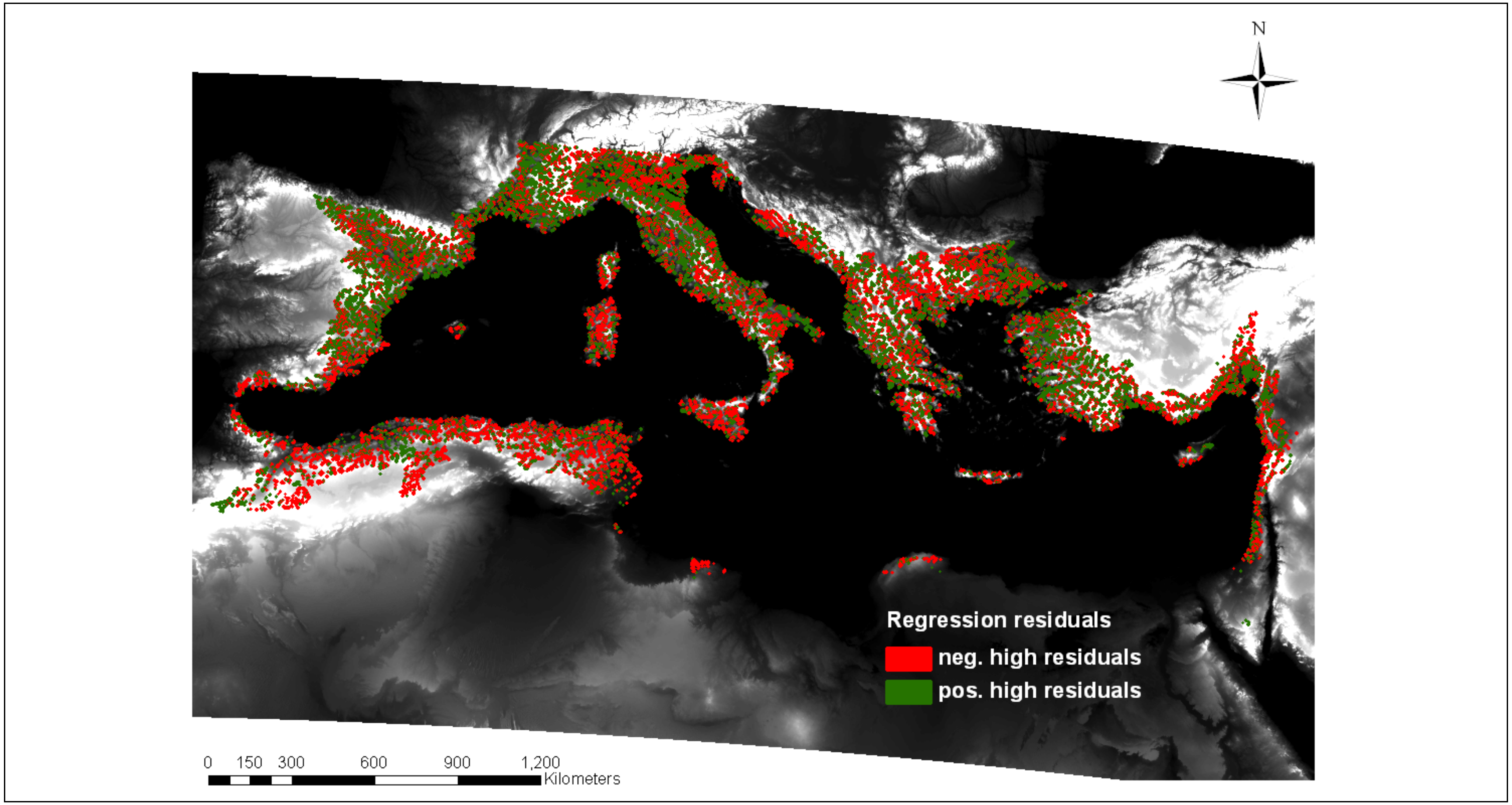


Figure 3.1.10: Residual analysis of the linear trend model of the Seasonal Permanent Fraction data from 1989-2005. High positive (> 205.14) and high negative (<-152.76) residuals are marked (see Figure 3.1.11).

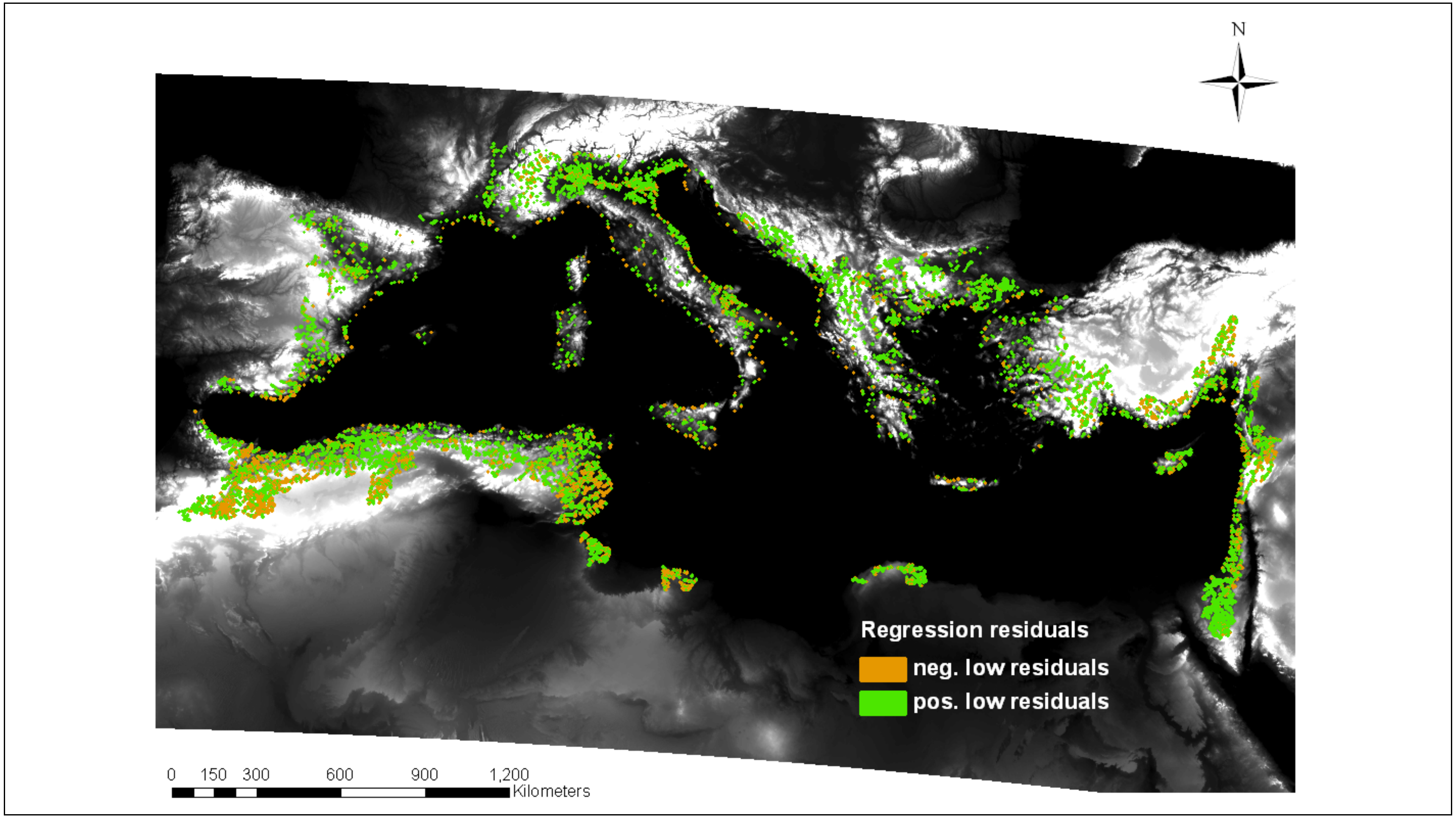


Figure 3.1.11: Residual analysis of the linear trend model of the Seasonal Permanent Fraction data from 1989-2005. Low positive (< 205.14) and low negative (> -152.76) residuals are marked (see Figure 3.1.11).

The maximum residuals analysis is useful to detect outliers or true extreme values in the data.

High negative residuals: Maximum negative residuals for instance which have values lower then -152.76 (i.e. the negative peak in Figure 3.1.12) depict areas where the seasonal permanent fraction expressed a very low value in the period from 1989-2005. This is shown in Figure 3.1.10 where the negative high residuals (due to e.g. wild fires, land degradation or drought) are presented in red.

High Positive residuals: pixels with values larger than 205.14 (i.e. positive peak in Figure 3.1.12) depict areas where the seasonal permanent fraction values were significantly larger then the average values in the time period 1989-2005.

Pixels with low residual values (either negative or positive), i.e. between the negative and positive peaks in Figure 3.1.11 depict areas where the phenological index behaved constantly throughout the years 1989-2005.

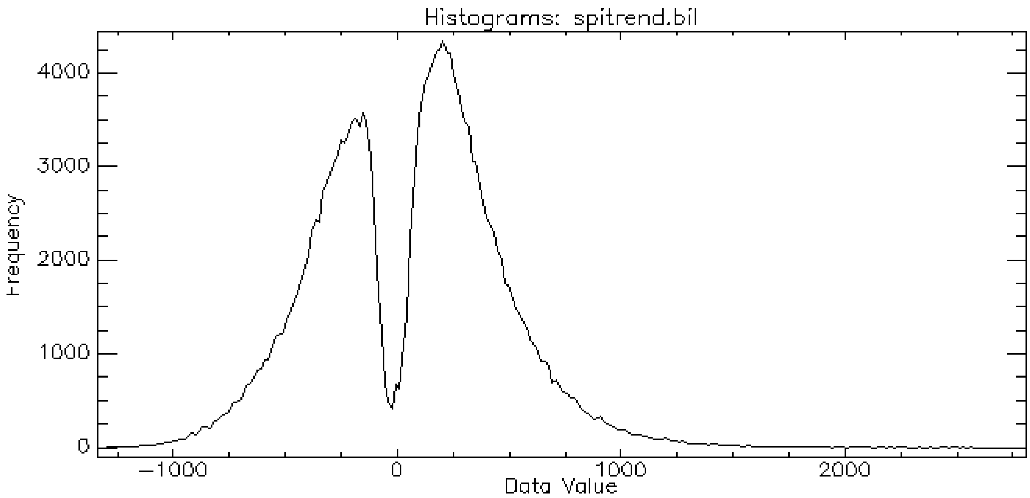


Figure 3.1.12: Distribution of the maximum residuals from the linear regression trend model fitted to the seasonal permanent vegetation fraction data (1989-2005).

Most of the riparian-use is dominated by high negative or positive residuals the linear trend analysis of the SPF. Forty percent of the area had positive high residuals (81265km2, 40%, Figure 3.1.13) while 34% (69864km2) of the riparian-use zone had negative high residuals. The linear trend analysis resulted in low residuals over 34 % of the riparian area.

Sparse herbaceous or shrub cover depicted the highest positive SPF residuals throughout the years, in as much as 23 % of the riparian-use zone (Figure 3.1.14). Another 5 % of the riparian area had low positive while an additional 2%

low negative residuals under this land cover, but none expressed high negative values.

Cultivated and managed areas were seemingly under stress as over 18 % of the riparian-use zone negative high SPF residuals were observed under this land cover. This land cover expressed low positive and negative residuals only over 7 % of the riparian area.

For the deciduous shrub cover around 8% of the riparian area shows low SPF residuals distributed in the negative and positive zones. Another 16 % of the riparian-use zone expressed high positive and negative residuals under this land cover.

Summarising the period from 1989-2005, less then average seasonal permanent fraction values were observed under *Cultivated and managed areas* and under the deciduous shrub cover, in around 25% of the riparian-use zone. Higher then average values were found under the *Sparse herbaceous or shrub cover* and under the deciduous shrubs covering around 30% of the riparian area.

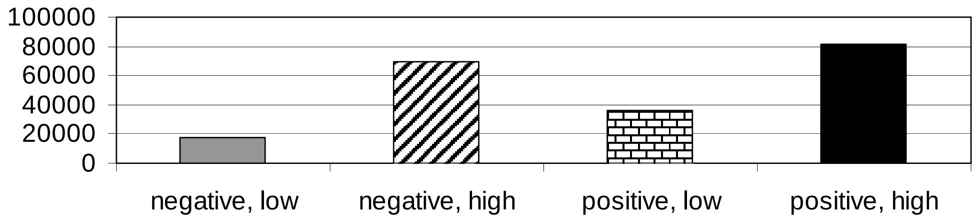


Figure 3.1.13: Area distribution (in km^2) of the negative low, negative high, positive low and positive high residuals of the linear trend model.

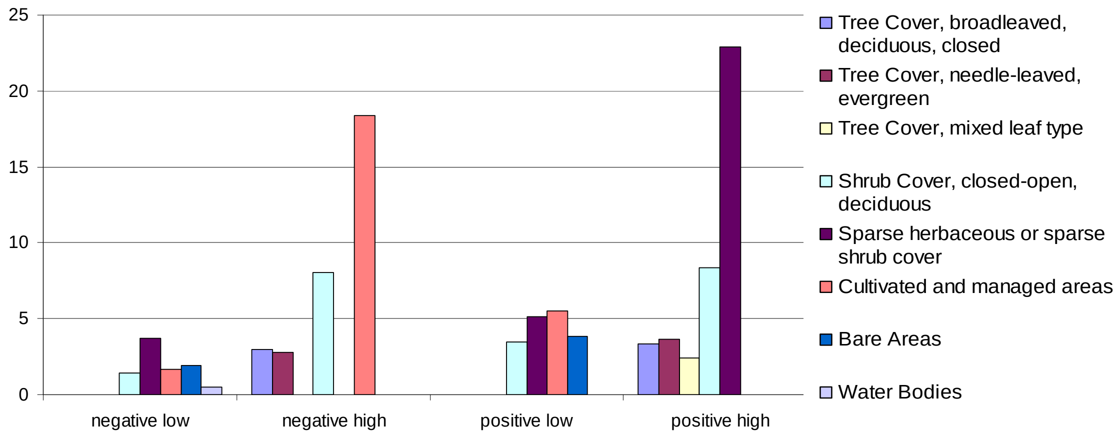


Figure 3.1.14: Area distribution (in % of riparian-use area) of the GLC classes in the negative low, negative high, positive low and positive high residuals of the linear trend model. GLC classes with an area share over 5% are plotted.

E. Significance of classes (LMM)

The main effects of the classes 'low, medium and high' and of the environmental zones were significantly related to the Seasonal Permanent Fraction values in the Mediterranean (Table 3.1.1). Furthermore, the interaction of these variables, i.e. the environmental zones in which the classes are located, also had a significant effect on the SPF values. This indicates that, as expected, the Mediterranean is not homogenous as measured by the seasonal permanent fraction parameter and that within the different environmental zones the three observed categories of this index are statistically proven to be different. Pairwise comparisons of the three categories revealed that all the three classes, low, medium and high are significantly different in their SPF values (Table 3.1.2).

Table 3.1.1: Repeated measures analysis results using a Linear Mixed Model: significance of the fixed effect variables and their estimates.

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	6794.878	9140.027	.000
GRIDCODE	2	9940.660	833.450	.000
EnZ_name	8	10832.686	28.283	.000
GRIDCODE * EnZ_name	12	11322.626	38.429	.000

a. Dependent Variable: MEAN.

Table 3.1.2: Pairwise comparisons of the categories of the fixed effect variable gridcode.

Pairwise Comparisons[d]

(I) GRIDCODE	(J) GRIDCODE	Mean Difference (I-J)	Std. Error	df	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-303.094*,b	18.119	9697.363	.000	-346.365	-259.824
	3	-675.342*,b	16.435	12098.299	.000	-714.590	-636.094
2	1	303.094*,c	18.119	9697.363	.000	259.824	346.365
	3	-372.247*	12.257	8846.795	.000	-401.520	-342.975
3	1	675.342*,c	16.435	12098.299	.000	636.094	714.590
	2	372.247*	12.257	8846.795	.000	342.975	401.520

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Sidak.

b. An estimate of the modified population marginal mean (I).

c. An estimate of the modified population marginal mean (J).

d. Dependent Variable: MEAN.

Gridcode 1 = low class; Gridcode 2 = medium class; Gridcode 3 = high class

Also marginal means, estimated for the interaction effects, revealed significant differences within the three SPF categories classified throughout the different environmental zones (Table 3.1.3 and Figure 3.1.15). Mainly the presence and absence of low marginal mean values allow differentiation of the various environmental zones based on the seasonal permanent vegetation fraction index.

In the Atlantic Central, Continental, Lusitanian and Pannonian zones, no low categories of the SPF index were measured. However, low SPF values were observed in the Southern Mediterranean (MDS) zones from Portugal through

Spain and Italy to Greece but also including the Central Albanian Coast, the Turkish coast and Valleys, and the Tunesian and Algerian coasts. For this low class of the Seasonal Permanent Fraction, the Anatolian (ANA) region of Turkey had the higher estimated mean values.

High mean SPF values were estimated in the Atlantic Central (ATC) regions including the Basin of Paris and Normandy in France. Second highest SPF values were estimated for the Lusitanian (LUS) regions including the foothills of the Cantabrian mountains and the West Pyrenees (Spain), the Atlantic plains of France, the low mountains in Galicia and the Beira Litoral region in Portugal. These regions were closely followed by the Mediterranean Mountains (MDM) in their high seasonal permanent fractions. In this high class, the mean Seasonal Permanent Fraction values were the lowest in the Pannonian (PAN) regions including the Balkans (Romania), the foothills of the Carpathians, the middle and lower Danube plains in the former Yugoslavia and Bulgaria.

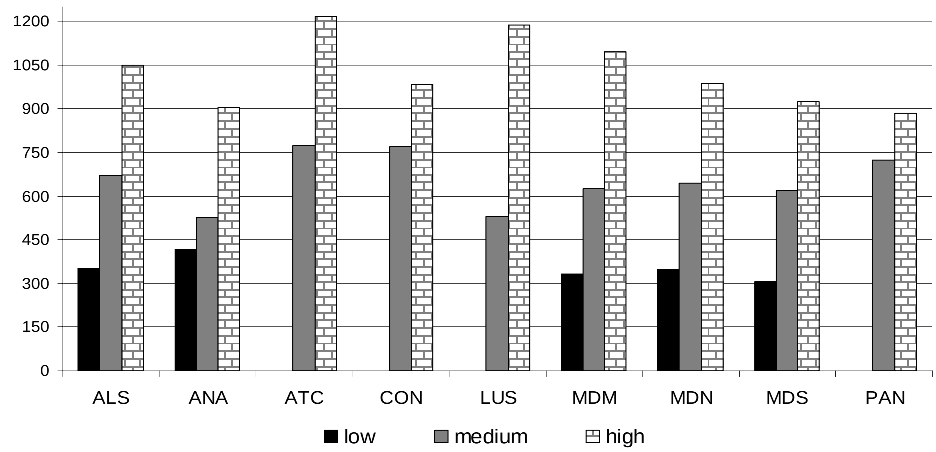


Figure 3.1.15: Distribution of the estimated marginal means of the categories low, medium and high in the environmental zones.

3. EnZ_name * GRIDCODE[b]

EnZ_name	GRIDCODE	Mean	Std. Error	df	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
ALS	1	350.690	53.113	9979.153	246.578	454.802
	2	671.576	16.056	10353.504	640.103	703.049
	3	1048.495	9.870	9971.256	1029.148	1067.843
ANA	1	416.365	50.831	12313.343	316.729	516.001
	2	525.470	26.484	12472.776	473.559	577.382
	3	904.176	43.854	12683.943	818.216	990.136
ATC	1	.[a]	.	.	.	.
	2	771.570	71.735	6232.672	630.944	912.196
	3	1216.868	34.563	10238.052	1149.118	1284.618
CON	1	.[a]	.	.	.	.
	2	769.582	21.704	11460.860	727.039	812.125
	3	983.061	14.417	11262.642	954.801	1011.321
LUS	1	.[a]	.	.	.	.
	2	530.827	32.247	10712.340	467.617	594.037
	3	1186.907	22.719	12264.540	1142.375	1231.440
MDM	1	331.636	8.467	9605.699	315.040	348.233
	2	625.171	6.617	8660.468	612.199	638.142
	3	1096.576	5.492	7134.432	1085.810	1107.342
MDN	1	347.097	14.014	10906.319	319.626	374.567
	2	645.744	5.584	6931.354	634.797	656.691
	3	987.274	4.909	6493.350	977.650	996.897
MDS	1	306.378	7.869	9540.174	290.952	321.804
	2	617.540	5.514	7152.762	606.730	628.350
	3	925.271	6.400	7974.065	912.725	937.817
PAN	1	.[a]	.	.	.	.
	2	724.268	15.238	10181.377	694.399	754.136
	3	883.345	15.848	11869.423	852.282	914.409

a. This level combination of factors is not observed, thus the corresponding population marginal mean is not estimable.

b. Dependent Variable: MEAN.

Table 3.1.3: Estimated marginal means for the interaction effect of the classes low, medium and high (gridcode 1, 2, and 3, respectively) and the environmental zones (EnZ_name).

F. Crossing with bio-physical variables

The mean and standard deviation of the sixteen years seasonal permanent vegetation index were correlated to the biophysical variables within the regions of the environmental classification (Table 3.1.4).

Adjusted R^2 of the mean values (Figure 3.1.3) reached a very high 0.840 and the model was highly significant ($P < 0.001$). The Durbin-Watson test statistic expressed a value larger than 2 therefore the null hypothesis against the alternative hypothesis of negative first-order autocorrelation was tested. The computed value was larger than the upper bound of the Durbin-Watson value with six predictors and 48 observations therefore the null hypothesis of no autocorrelation of the samples was not rejected. The plots of the standardised residuals and of the normal probability indicated no violation of the normality assumption and there was o homoscedasticity in the data (see Appendix for the plots). The sixteen years mean of the seasonal permanent vegetation fraction was significantly explained ($p < 0.05$) by March, July and October sunshine and by the May and November precipitation values.

Table 3.1.4: Regression statistics of the mean and the standard deviation of the Seasonal Permanent vegetation Faction index.

Mean			**Standard deviation**		
Adjusted R^2	***Durbin-Watson***	***p***	***Adjusted R^2***	***Durbin-Watson***	***p***
0.840	2.116	0.000	0.512	1.672	0.000
Predictors			Predictors		
Mean October sunshine (p < 0.000)			Mean December precipitation (p < 0.000)		
Std. November precipitation (p < 0.000)			Mean January precipitation (p < 0.004)		
Mean July sunshine (p < 0.000)			Mean March precipitation (0.008)		
Std. May precipitation (p < 0.001)					
Mean March sunshine (p < 0.006)					
Std. October sunshine (p < 0.012)					

The second regression model explained 51% of the standard deviation of the sixteen years seasonal permanent vegetation index (Figure 3.1.4) and was highly significant (P < 0.001). The computed Durbin-Watson value was lower then 2 therefore the null hypothesis of zero autocorrelation in the residuals against the alternative that the residuals are positively autocorrelated was tested. The computed value of 1.672 is larger the upper bound of the Durbin-Watson statistic indicating no first order autocorrelation in the residuals and therefore trustworthy model significance. The standard deviation values were positively predicted by the mean December, January and May precipitation values.

3.5 Total Permanent vegetation Fraction (TPF)

A. Classification and area calculation

The spatial distribution of the sixteen years' mean Total Permanent Fraction in the Mediterranean is presented in Figure 3.2.3. Figure 3.2.4 presents the spatial distribution of the standard deviation values of the index. The area distribution of the riparian zone within the three seasonal permanent fraction classes (low, medium and high) is mapped in Figure 3.2.5. Low total permanent fraction was observed over 70077 km^2 area (34%), 69504 km^2 area (34%) had medium level of permanent vegetation fraction while 64462 km^2 area (32%) expressed a high level of permanent vegetation fraction (Figure 3.2.1.).

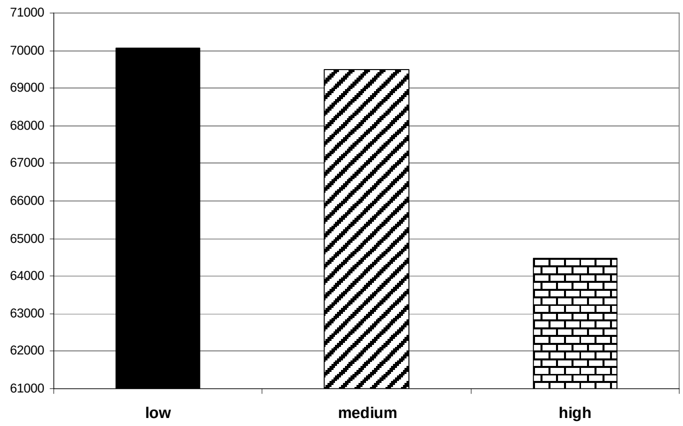
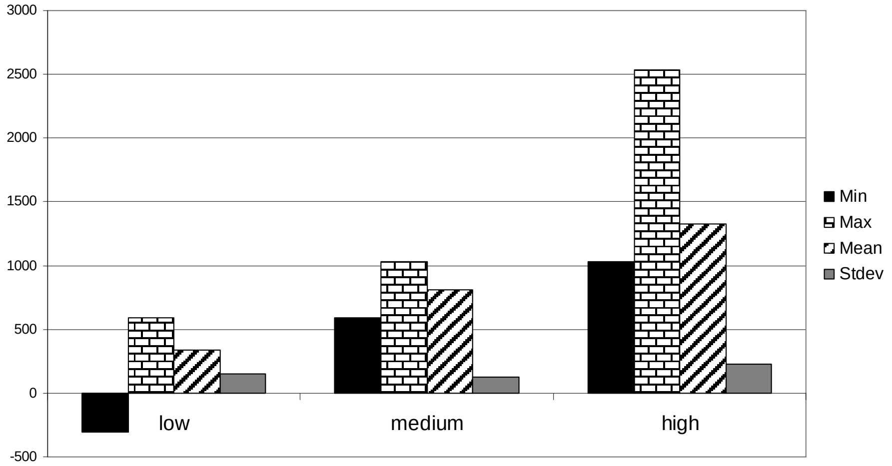


Figure 3.2.1: Area distribution of the Total Permanent vegetation Fraction classes (km^2).

B. Descriptive statistics

Descriptive statistics of the total permanent vegetation fraction values within the classes low, medium and high in the riparian-use zones are shown in Figure 3.2.2.



Class	Min	Max	Mean	Stdev
Low	-305.35	589.94	333.51	152.68
Medium	590	1028.23	806.24	123.73
High	1028.29	2532.06	1327.14	225.04

Figure 3.2.2: Descriptive statistics of the Total Permanent vegetation Fraction values.

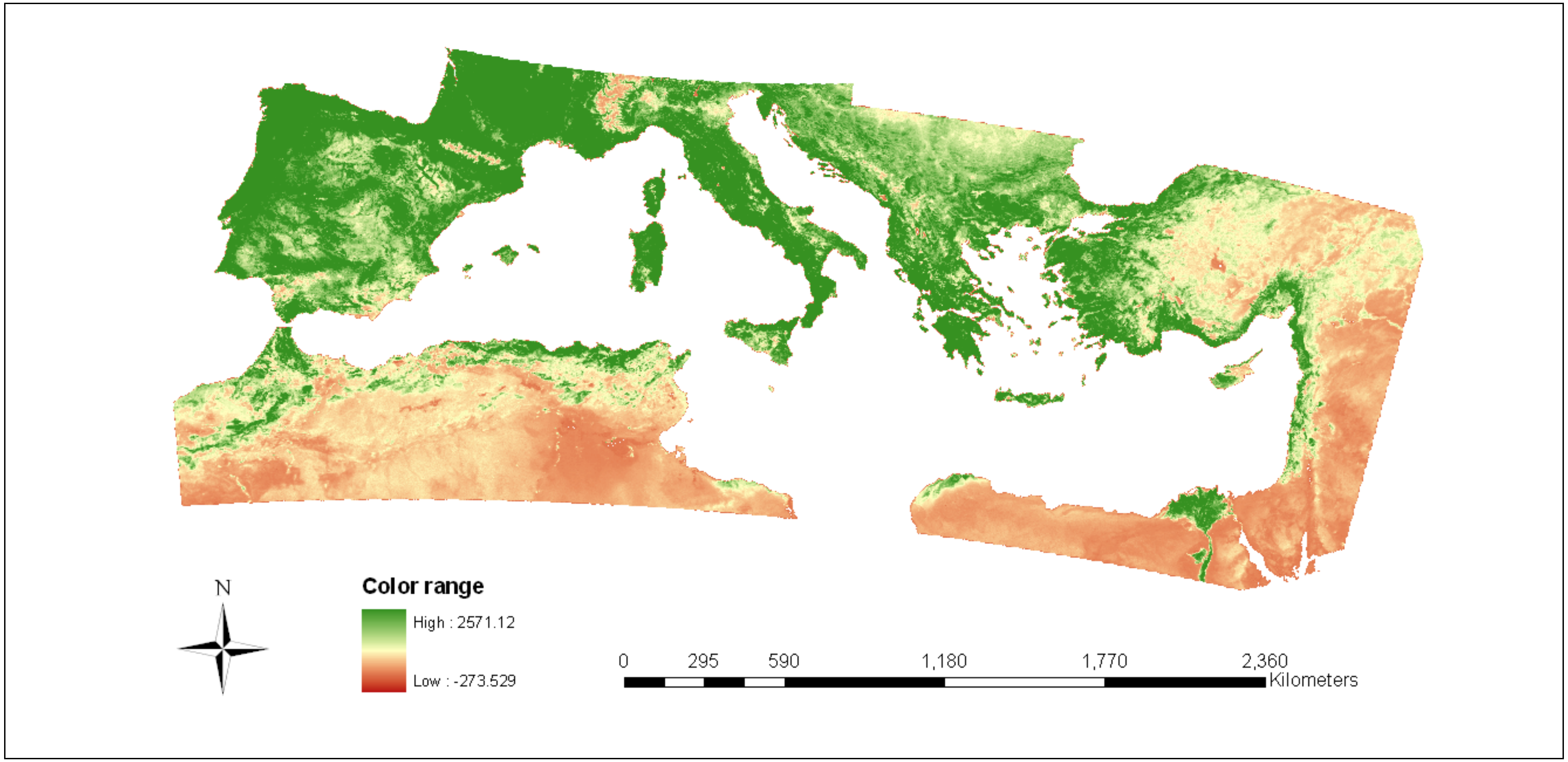


Figure 3.2.3: Mean of the sixteen years (1989-2005) Total Permanent vegetation Fraction values over the Mediterranean.

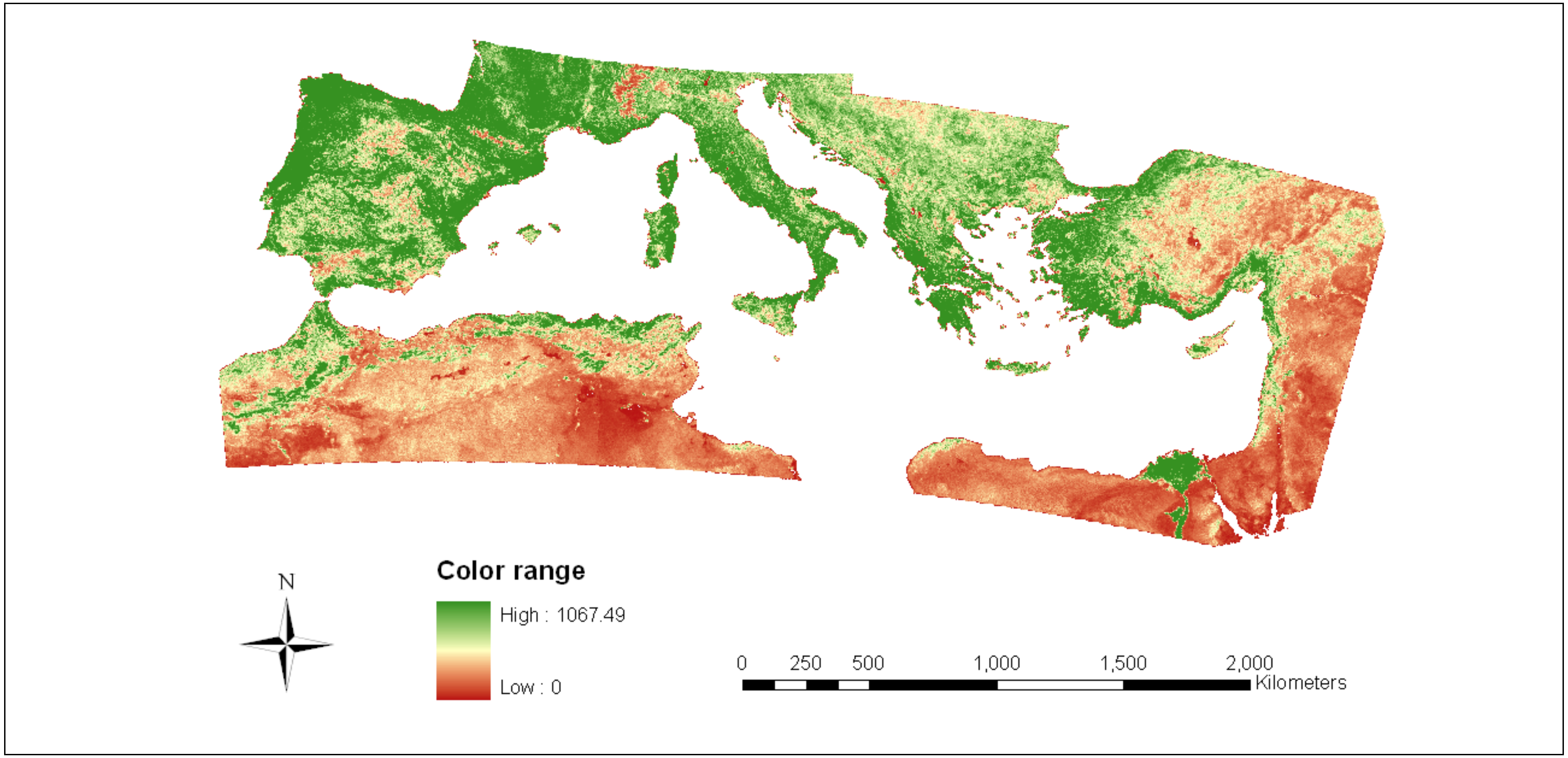


Figure 3.2.4: Standard deviation of the sixteen years (1989-2005) Total permanent Vegetation Fraction values over the Mediterranean.

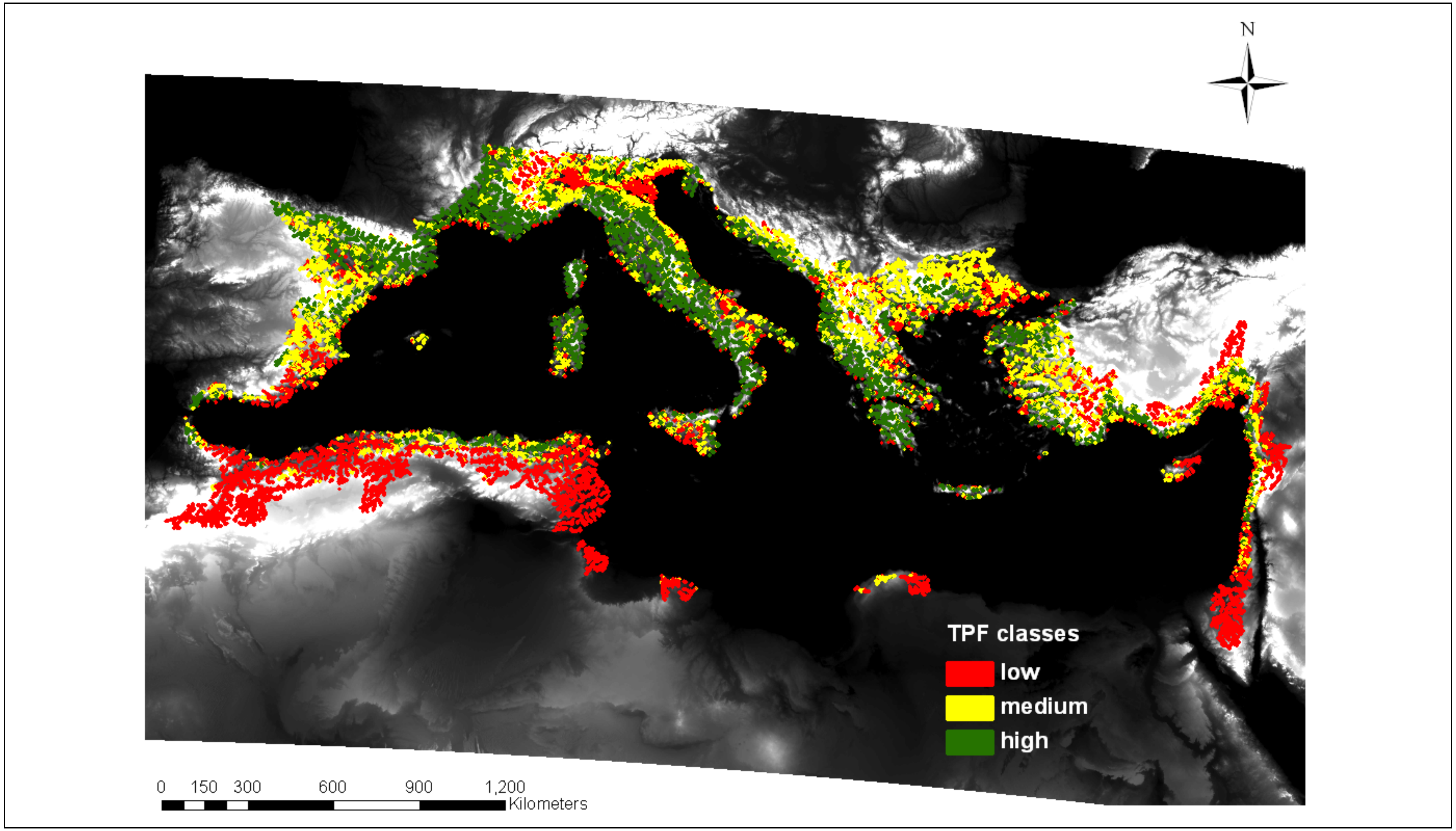


Figure 3.2.5: Classification of the riparian-use zone into low, medium and high Total Permanent vegetation Fraction classes.

C. Land Cover Characteristics

The riparian-use zone with medium and high total permanent fraction was dominated by *Cultivated and managed areas*, as derived from the GLC dataset (58 and 42%, respectively, Figure 3.2.6). In the high TPF class closed/open deciduous shrub cover, coniferous forest and broadleaved forest with closed crown coverage reached an area coverage over 10 % (16, 13, and 11%, respectively). In the riparian-use zone with medium seasonal permanent fraction deciduous shrubs covered 21% of the area, the coverage of the other land cover types remained very low. In the low seasonal permanent fraction class the sparse herbaceous or shrub cover dominated (28%) followed by cultivated and managed areas (26%). Furthermore, deciduous shrubs occurred in the class with a share of 19%.

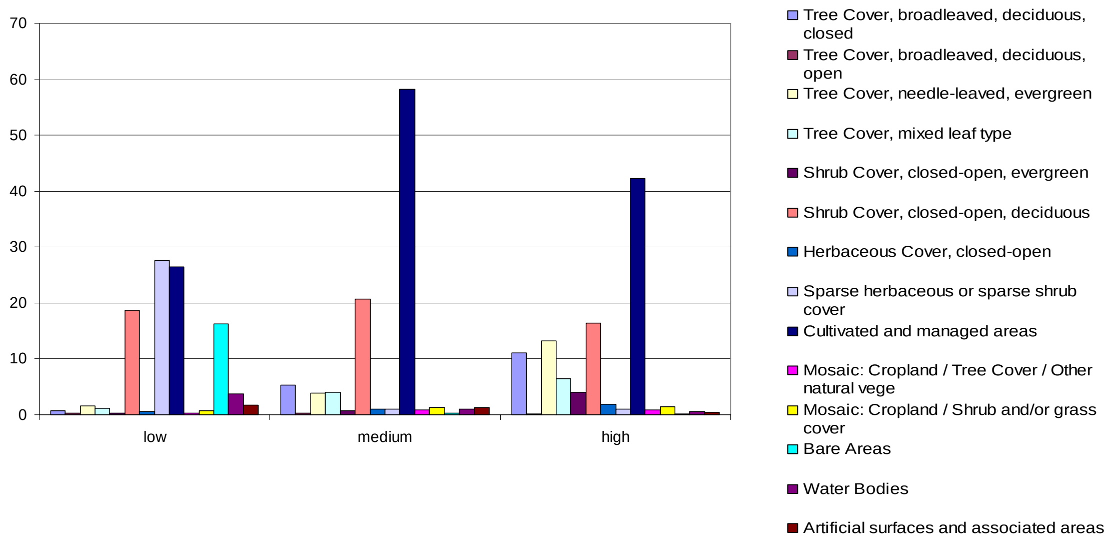


Figure 3.2.6: Distribution of the global land cover classes in the three categories of the Total Permanent Fraction.

For the South Mediterranean, closed deciduous forest dominated the class with the highest total permanent vegetation fraction and had a share of 70% of the riparian-use zone. Croplands covered another 18% of this area but the coverage of other classes remained very low. Over riparian-use areas with medium level of total permanent vegetation, deciduous shrub land dominated, covering 38 % of the zone while croplands occupied another 36 percent. Closed deciduous forest reached another 19% of the class. Sparse grassland dominated the class with the lowest amount of permanent vegetation fraction (42%). Open deciduous grassland covered 21% while stony desert area spread over 17% of the area.

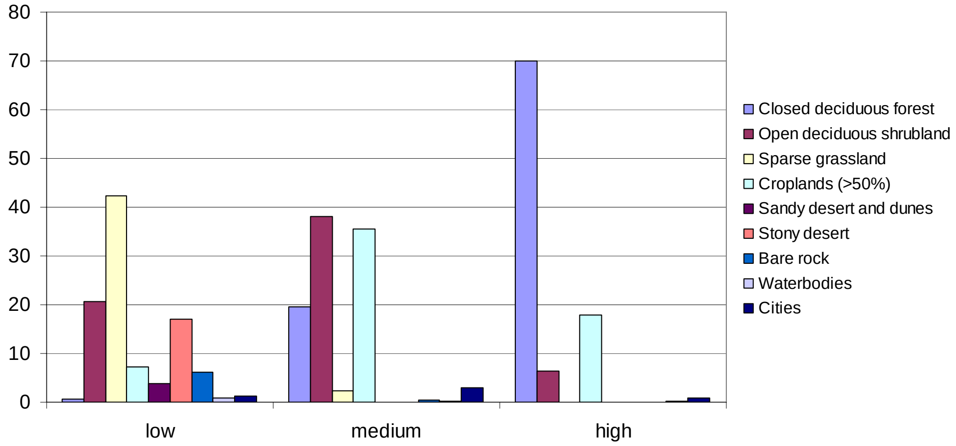


Figure 3.2.7: Distribution of the African land cover classes in the three categories of the Total Permanent vegetation Fraction.

Cultivated and managed lands produce most of the permanent biomass, as compared to other land use in the northern Mediterranean. Agricultural practices and the large extent of tree crops could explain this effect. More logically, closed deciduous forest produces more total permanent biomass than croplands in the southern Mediterranean.

D. Trend analysis

Liner trend analysis results are summarized in Figures 3.2.8-3.1.12. For most of the riparian-use zone (153498 km^2, 75% of the area) no trend was observed, see Figures 3.2.8 and 3.2.9. A negative significant trend appeared in 11058 km^2 i.e. in 5% of the area, while 40291 km^2 (20% of the riparian-use zone) showed a significant positive trend of the seasonal permanent vegetation fraction values

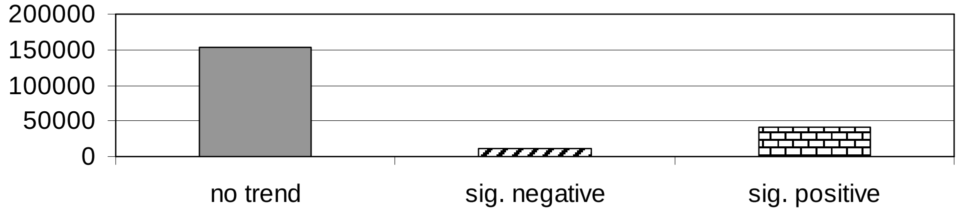


Figure 3.2.8: Area distribution of the trend significance classes of the Total Permanent vegetation Fraction.

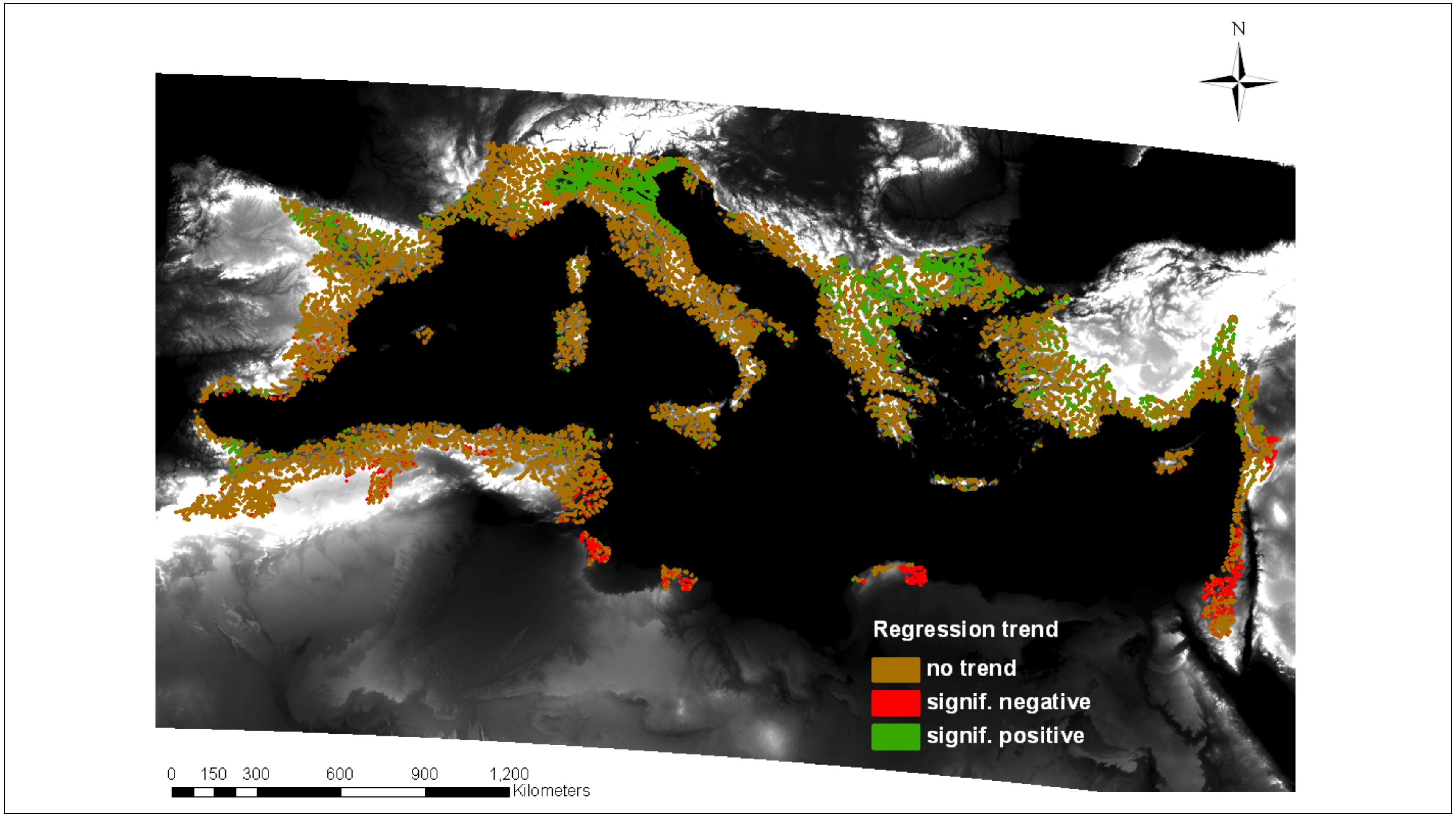


Figure 3.2.9: Significance of the linear trend model of the Total Permanent Fraction data from 1989-2005. The significance values are classified into significant ($p < 0.05$) negative, significant positive, and no trend values.

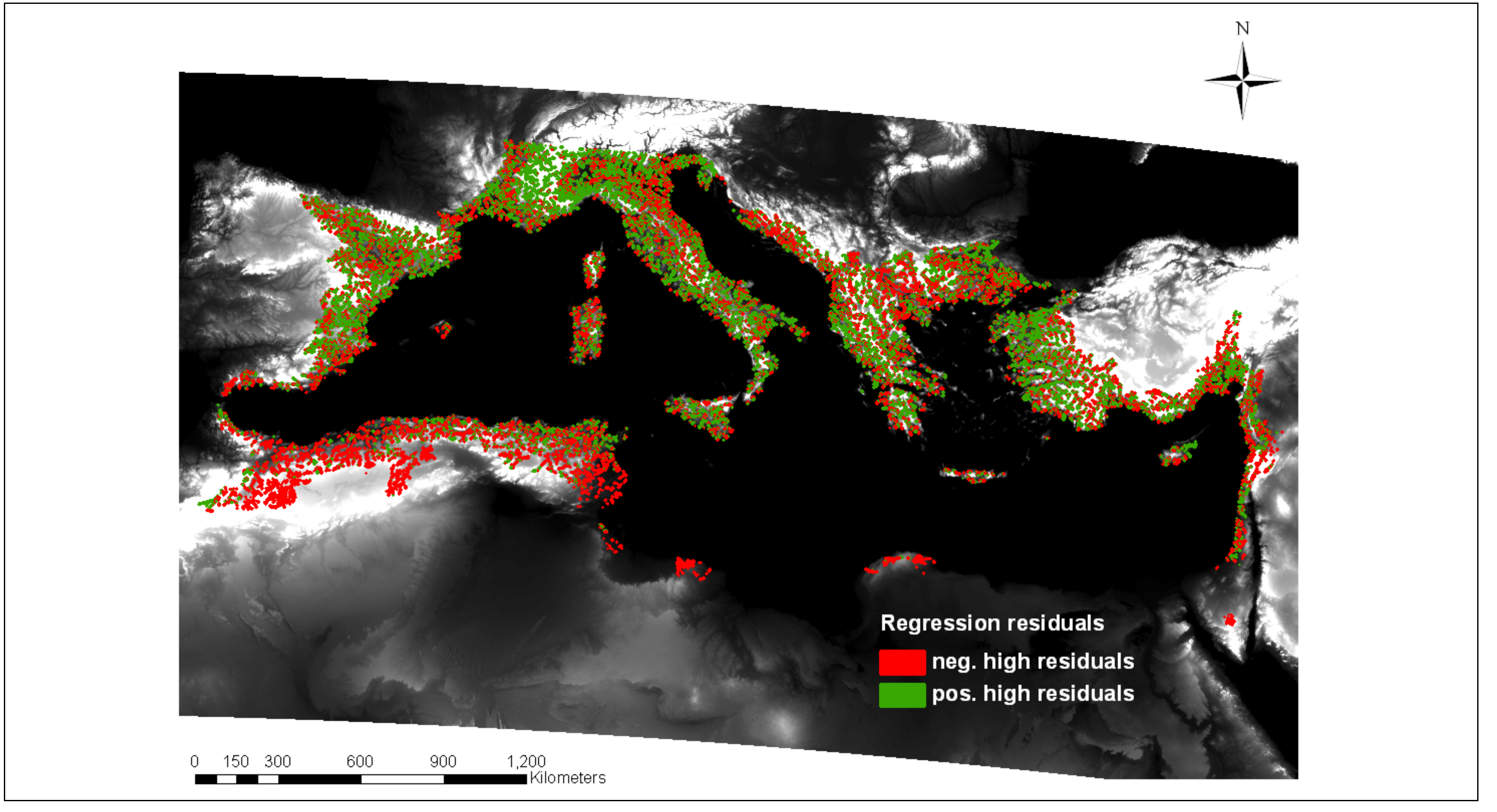


Figure 3.2.10: Residual analysis of the linear trend model of the Total Permanent Fraction data from 1989-2005. High positive (> 282.6) and high negative (<-126.8) residuals are marked (see Figure 3.2.12).

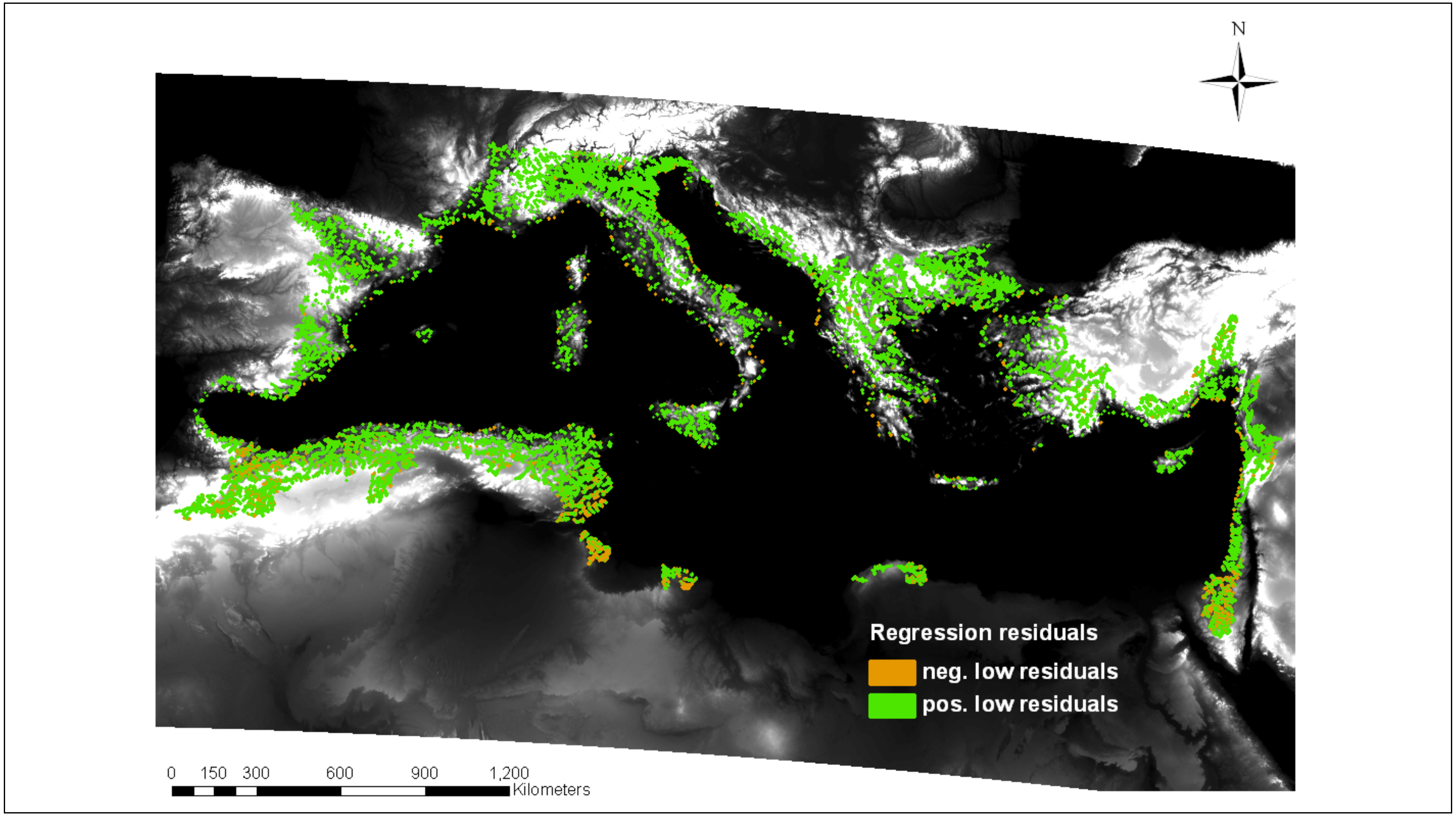


Figure 3.2.11: Residual analysis of the linear trend model of the Total Permanent Fraction data from 1989-2005. Low positive (< 282.6) and low negative (> -126.8) residuals are marked (see Figure 3.2.12).

The maximum residuals analysis is useful to detect outliers or true extreme values in the data.

High negative residuals: Maximum negative residuals for instance which have values lower then -126.8 (the negative peak in the graphic below) depict areas where the seasonal permanent fraction data declined dramatically throughout the years from 1989-2005 (negative high residuals, Figure 3.2.10).

High positive residuals: Pixels with values larger then 282.6 depict areas where the seasonal permanent fraction values were significantly larger then the average values (see Figure 3.2.10 and the positive peak in Figure 3.2.12,).

Pixels with no extreme residual values (i.e. between the negative and positive peaks in Figure 3.2.12) depict areas where the phenological TPF index behaved constantly throughout the years 1989-2005.

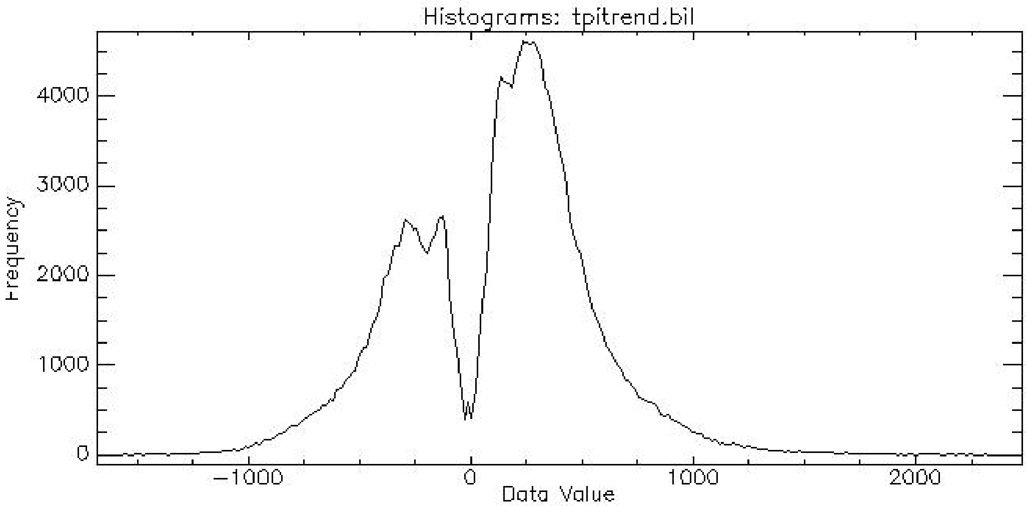


Figure 3.2.12: Distribution of the maximum residuals from the linear regression trend model fitted to the Total Permanent vegetation Fraction data (1989-2005).

Most of the riparian-use area contains high residuals from the linear trend analysis of the Total Permanent Fraction. Thirty eight percent of the area had positive high residuals (77090 km^2, Figure 3.2.13) while 30% (60957 km^2) of the riparian-use zone had negative high residuals. The linear trend analysis resulted in low residuals over 32 % of the riparian area.

Cultivated and managed areas had the highest negative residuals: over 15 % of the riparian-use zone. On the other hand high positive residuals of the same land cover came up over 20 % of the area. Low positive residuals were manifested over 11% of the riparian zone but the share of negative residuals was ignorable (0.5 %).

In areas under deciduous shrub cover the total permanent vegetation cover showed less than the average time series values over 7% of the riparian-use area. Over another 14378 km^2 (8 %) under deciduous shrubs, the total permanent biomass showed higher then average values as expressed in high positive residuals.

Sparse herbaceous or shrub cover experienced low model residuals thus stable Total Permanent Fraction trend over 9 % of the riparian-use area. Only 2% was showing dramatic TPF values in the observed time period.

Bare areas behaved likewise as over around 5% of the riparian zone their model residuals were low.

Deciduous trees manifested high positive model residuals over 4 % of the riparian-use zone while over another 2 % of the area negative residuals were observed.

Summarising the observed period 1989-2005, total permanent vegetation fraction showed more than average values for one third of the riparian area dominated by Cultivated and managed areas and by deciduous shrubs. On the other hand less than average values appeared for more then 15% of the area. Other land uses show rather low appearances of deviating biomass production.

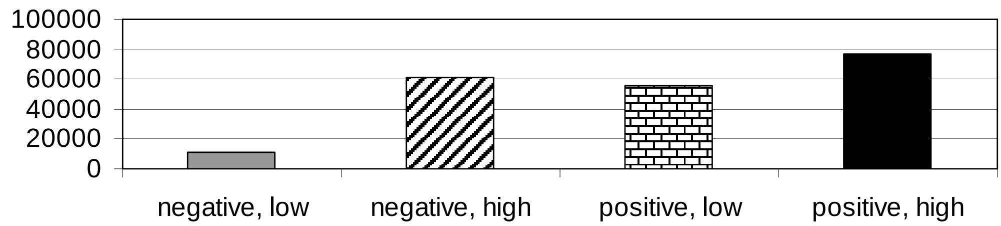


Figure 3.2.13: Area distribution of the negative low, negative high, positive low and positive high residuals of the linear trend model.

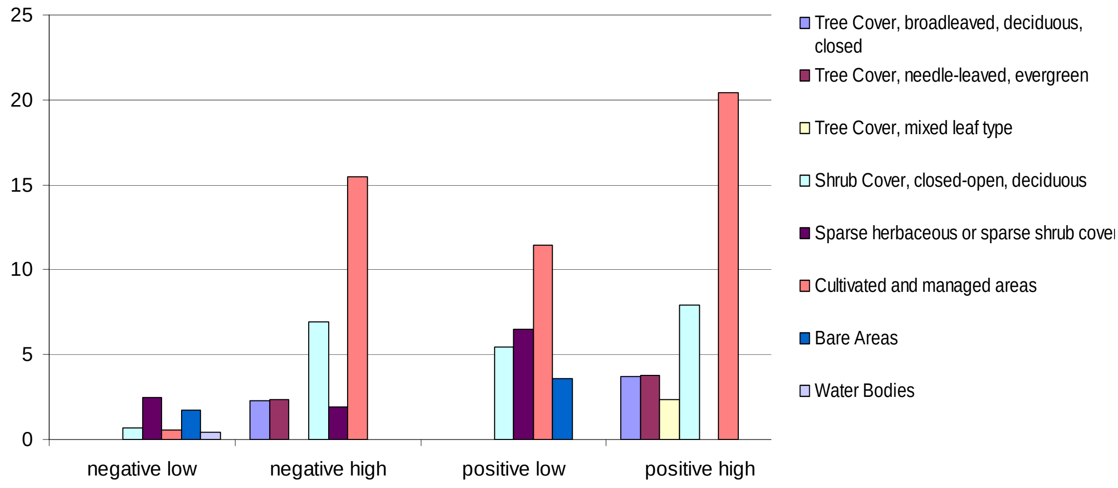


Figure 3.2.14: Area distribution (in % of riparian-use zone) of the GLC classes in the negative low, negative high, positive low and positive high residuals of the linear trend model. GLC classes with an area share over 5% are plotted.

E. Significance of classes (LMM)

The main effect of the classes *low*, *medium* and *high* and that of the environmental zones were significantly related to the Total Permanent Fraction values in the Mediterranean (Table 3.2.1). Furthermore, the interaction of these variables, i.e. the environmental zones in which the classes were located had a significant effect on the TPF values. This indicates that, the total permanent fraction parameter is not homogenous across the Mediterranean and that within the different environmental zones the three categories of this index are different. Furthermore, pairwise comparisons of the three categories revealed that the classes 'low', 'medium' and 'high' are significantly different (3.2.2) from each other. This suggests the validity of the classification of the total permanent fraction into the three categories.

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	2444.966	8214.386	.000
GRIDCODE	2	2444.966	480.401	.000
EnZ_name	8	2444.966	4.617	.000
GRIDCODE * EnZ_name	16	2444.966	4.336	.000

a. Dependent Variable: MEAN.

Table 3.2.1: Repeated measures analysis results using a Linear Mixed Model: significance of the fixed effect variables.

Pairwise Comparisons[b]

(I) GRIDCODE	(J) GRIDCODE	Mean Difference (I-J)	Std. Error	df	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
1	2	-312.115*	23.859	2444.966	.000	-358.900	-265.330
	3	-735.454*	25.299	2444.966	.000	-785.063	-685.844
2	1	312.115*	23.859	2444.966	.000	265.330	358.900
	3	-423.339*	18.752	2444.966	.000	-460.111	-386.567
3	1	735.454*	25.299	2444.966	.000	685.844	785.063
	2	423.339*	18.752	2444.966	.000	386.567	460.111

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: MEAN.

Gridcode 1 = low class; Gridcode 2 = medium class; Gridcode 3 = high class

Table 3.2.2: Pairwise comparisons of the three categories of the fixed effect variable Gridcode.

Marginal means estimated for the interaction effects revealed differences within the three categories classified throughout the different environmental zones (Table 3.2.3 and Figure 3.2.15).

Highest mean TPF values were estimated in the Lusitanian (LUS) regions including the foothills of the Cantabrian mountains and the West Pyrenees (Spain), the Atlantic plains of France, the low mountains in Galicia and the Beira Litoral region in Portugal. The mean TPF values in the class “high” were also higher in the Mediterranean mountains (MDM), and the Northern (MDN) and the Southern Mediterranean (MDS) regions. Lowest mean TPF values in the category high were estimated in the Pannonian regions including the Balkans (Romania), the foothills of the Carpathians, the middle and lower Danube plains in the former Yugoslavia and in Bulgaria. Lowest Total Permanent Faction values were measured in the Southern (MDS) and mountainous (MDM) Mediterranean regions. In the Lusitanian (LUS) regions the TPF values in the class low were the highest.

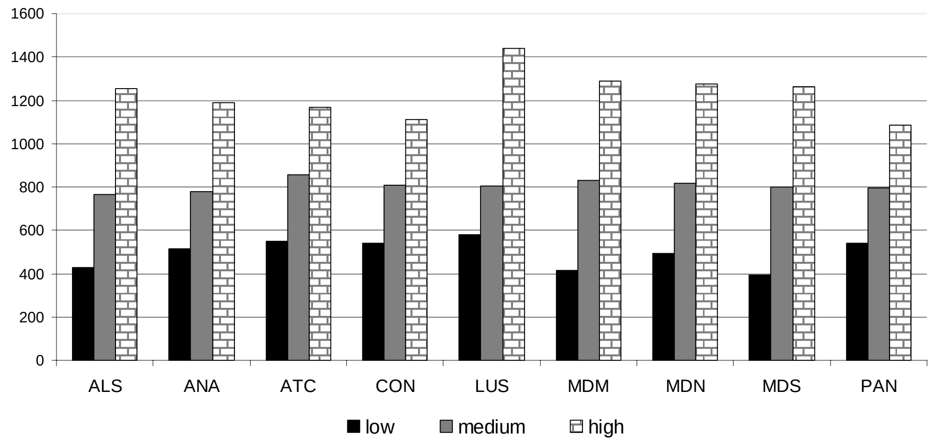


Figure 3.2.15: Distribution of the estimated marginal means of the categories low, medium and high Total Permanent Fraction in the environmental zones.

Table 3.2.3: Estimated marginal means for the interaction effect of the classes low, medium and high Total Permanent Fraction and the environmental zones.

3. EnZ_name * GRIDCODE[a]

EnZ_name	GRIDCODE	Mean	Std. Error	df	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
ALS	1	426.413	28.244	2444.966	371.029	481.797
	2	767.245	20.606	2444.966	726.839	807.651
	3	1252.074	25.035	2444.966	1202.981	1301.167
ANA	1	512.866	72.560	2444.966	370.581	655.151
	2	776.824	54.083	2444.966	670.771	882.877
	3	1187.384	81.124	2444.966	1028.305	1346.463
ATC	1	550.983	114.727	2444.966	326.011	775.955
	2	855.850	54.083	2444.966	749.797	961.902
	3	1168.464	46.837	2444.966	1076.619	1260.308
CON	1	541.107	54.083	2444.966	435.054	647.159
	2	809.592	30.129	2444.966	750.512	868.673
	3	1111.134	37.222	2444.966	1038.143	1184.124
LUS	1	579.414	93.674	2444.966	395.725	763.103
	2	806.000	57.363	2444.966	693.514	918.486
	3	1440.146	40.562	2444.966	1360.606	1519.686
MDM	1	416.774	14.285	2444.966	388.762	444.786
	2	831.654	10.241	2444.966	811.572	851.736
	3	1287.241	9.784	2444.966	1268.055	1306.427
MDN	1	492.456	13.248	2444.966	466.478	518.433
	2	816.897	8.878	2444.966	799.488	834.306
	3	1277.501	8.623	2444.966	1260.591	1294.411
MDS	1	392.025	11.802	2444.966	368.882	415.167
	2	801.972	10.241	2444.966	781.890	822.054
	3	1262.878	10.939	2444.966	1241.428	1284.328
PAN	1	541.241	57.363	2444.966	428.755	653.727
	2	796.278	24.743	2444.966	747.759	844.797
	3	1085.539	66.238	2444.966	955.651	1215.426

a. Dependent Variable: MEAN.

F. Crossing with bio-physical variables

The mean and standard deviation of the seventeen years Total Permanent Fraction index were correlated to the biophysical variables within the regions of the environmental classification (Table 3.2.4).

Adjusted R^2 of the mean values (Figure 3.2.3) reached 0.780 and the model was highly significant ($P < 0.000$). The test Durbin-Watson value was smaller than 2 therefore the null hypothesis against the alternative hypothesis of negative first-order autocorrelation was tested. The computed value was larger than the upper bound of the Durbin-Watson value with six predictors and 48 observations therefore the null hypothesis of no autocorrelation of the samples was not rejected. The plots of the standardised residuals and of the normal probability indicated no violation of the normality assumption and there was o homoscedasticity in the data (see Appendix for the plots). The sixteen years mean of the seasonal permanent vegetation fraction was significantly explained ($p < 0.000$) by the November, March, and September precipitation, by the minimum January temperature and by the maximum May temperature values.

Table 3.2.4: Regression statistics of the mean and the standard deviation of the Total Permanent Fraction.

Mean			Standard deviation		
Adjusted R^2	***Durbin-Watson***	***p***	***Adjusted R^2***	***Durbin-Watson***	***p***
0.780	1.967	0.000	0.630	1.652	0.000
Predictors			Predictors		
Mean November precipitation (p < 0.000)			Mean December precipitation (p < 0.000)		
Mean March precipitation (p < 0.000)			Mean March precipitation (p < 0.000)		
Std. of minimum January temperature (p < 0.000)			Mean January precipitation (p < 0.028)		
Mean maximum May temperature (p < 0.000)			Std. of November precipitation (p < 0.000)		
Mean September precipitation (p < 0.000)			Std. of March precipitation (p < 0.002)		
Std. of maximum May temperature (p < 0.000)					

The second regression model explained 63% of the standard deviation of the sixteen years seasonal permanent vegetation index (Figure 3.2.4) and was highly significant ($P < 0.000$). The computed Durbin-Watson value was lower then 2 but larger then the upper bound of the Durbin-Watson statistic indicating no first order autocorrelation in the residuals and therefore trustworthy model significance. The standard deviation values were significantly ($p < 0.000$) predicted by the mean December, March and November precipitation values. January and March precipitation values were significant on the $p < 0.05$ level.

3.6 Seasonal integral (SI)

A. Classification and area calculation

The area distribution of the sixteen years mean Seasonal Integral is presented in Figure 3.3.3 and Figure 3.3.4 presents the standard deviation values of the index over the Mediterranean. The area distribution of the three Seasonal Integral classes (low, medium and high, Figure 3.3.5) within the riparian zone was as follows: Low Seasonal Integral values were observed over 64515 km^2 area (31%), 72082 km^2 area (35%) had medium level of Seasonal Integral while 68279 km^2 area (33%) expressed a high level of Seasonal Integral values (Figure 3.3.1.).

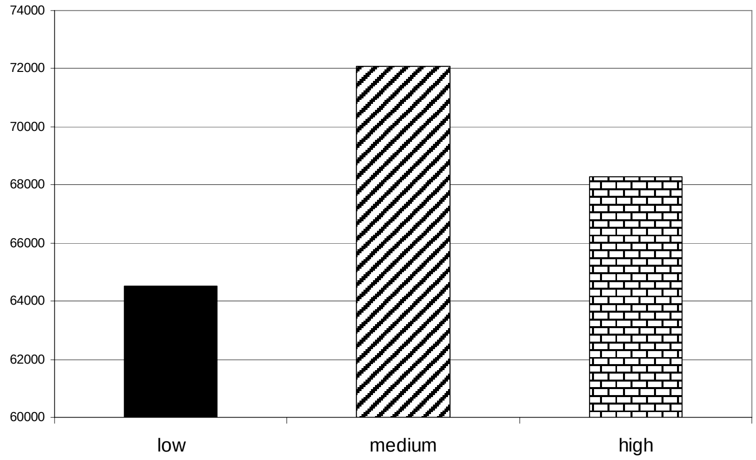
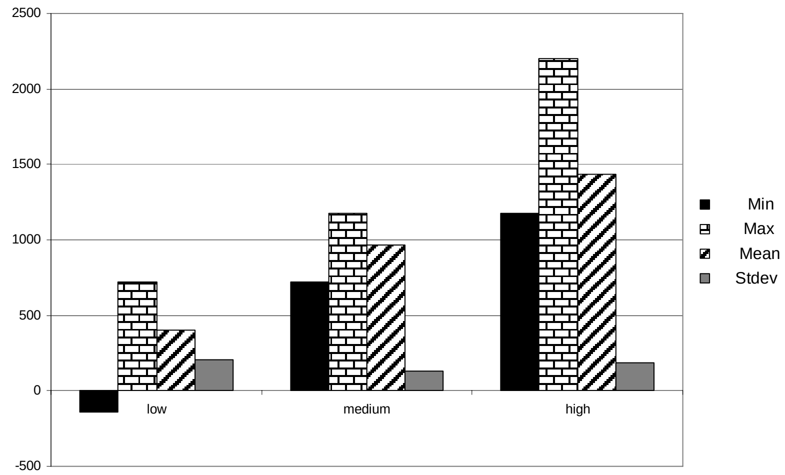


Figure 3.3.1: Area distribution of the Seasonal Integral classes (km^2).

B. Descriptive statistics

Descriptive statistics of the Seasonal Integral values within the classes low, medium and high in the riparian-use zones are shown in Figure 3.3.2.



Class	Min	Max	Mean	Stdev
Low	-142.12	721.88	403.00	203.45
Medium	721.94	1173.71	968.89	127.86
High	1173.76	2203.53	1434.37	187.40

Figure 3.3.2: Descriptive statistics of the Seasonal Integral values.

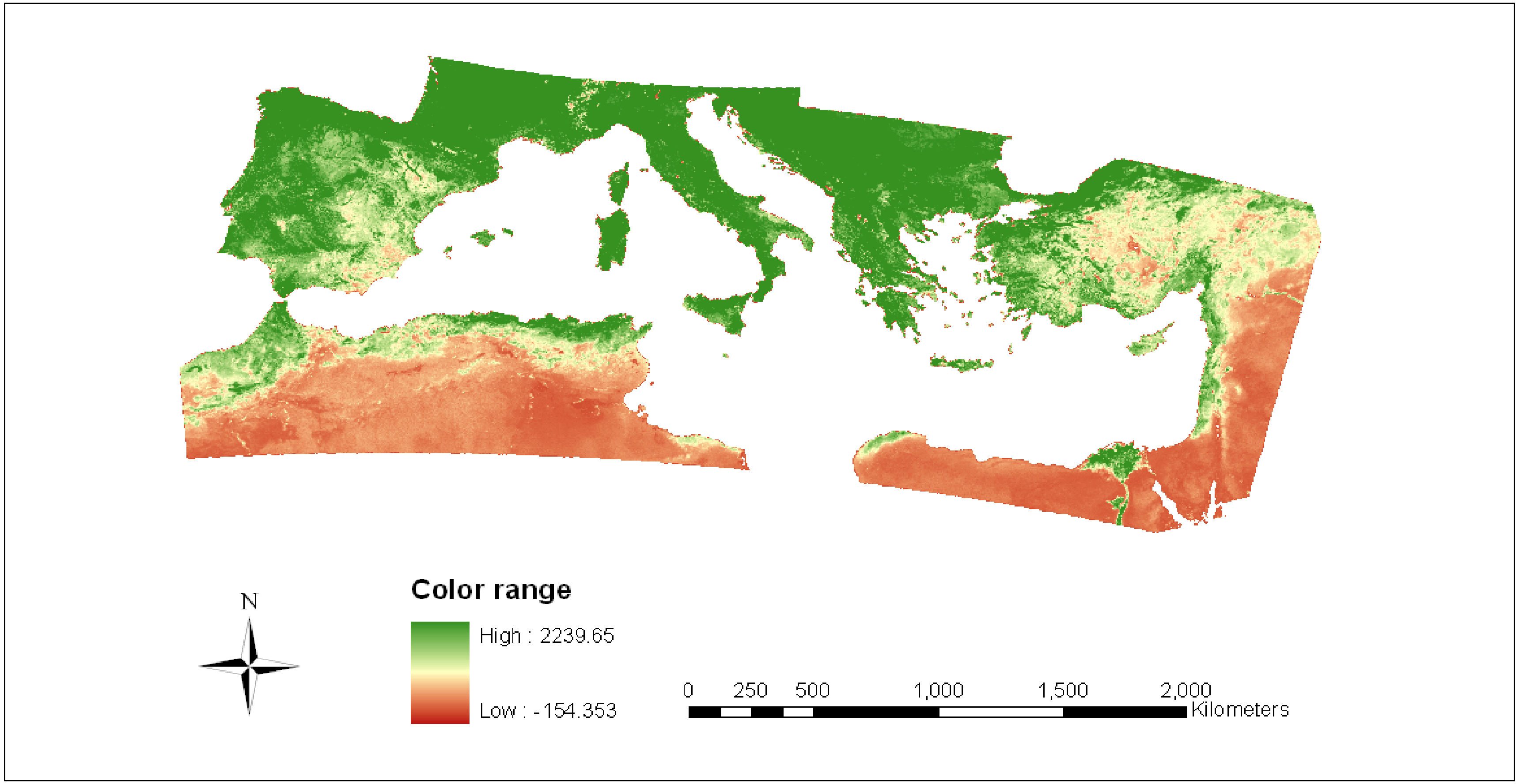


Figure 3.3.3: Mean of the sixteen years (1989-2005) Seasonal Integral values over the Mediterranean.

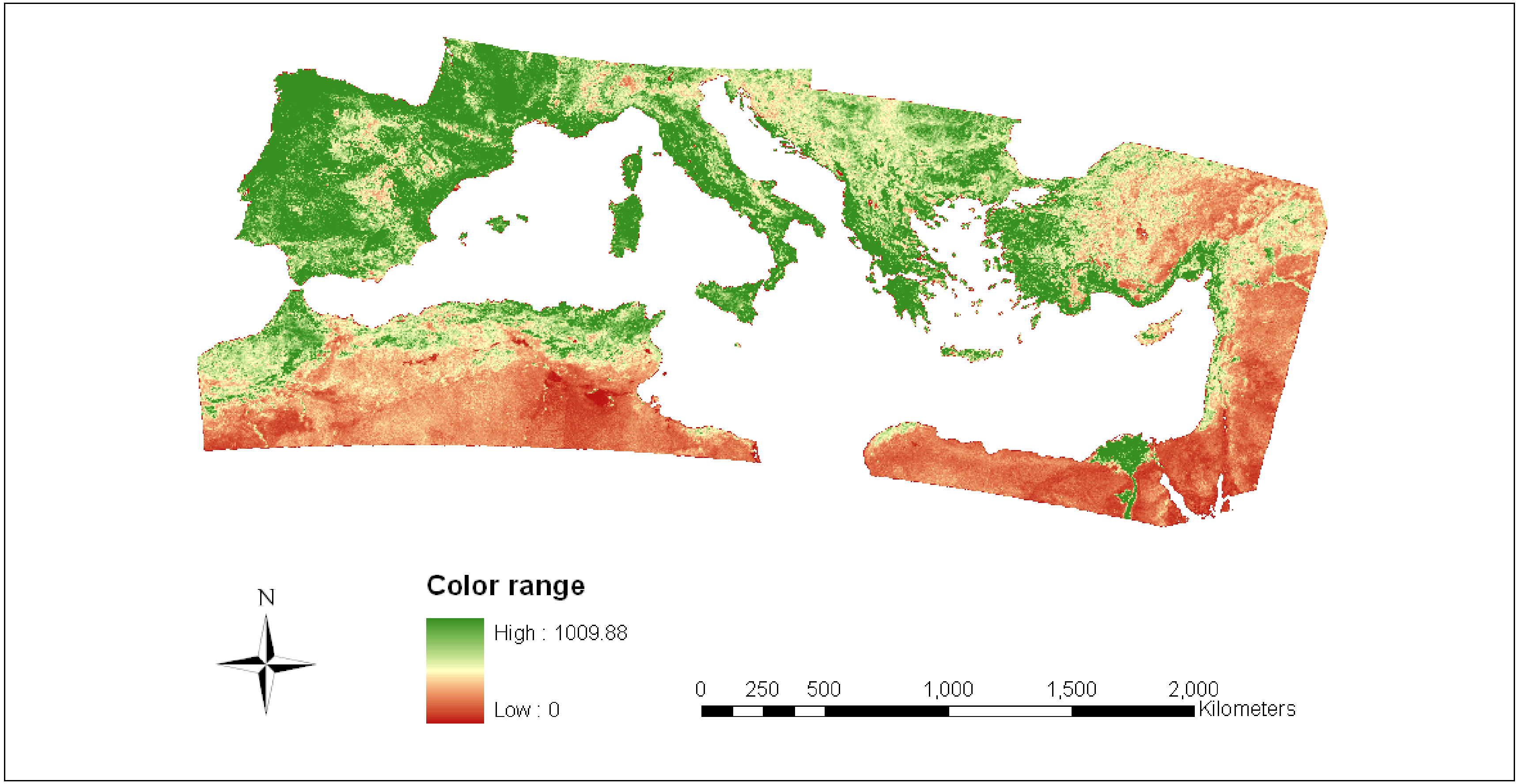


Figure 3.3.4: Standard deviation of the sixteen years (1989-2005) Seasonal Integral values over the Mediterranean.

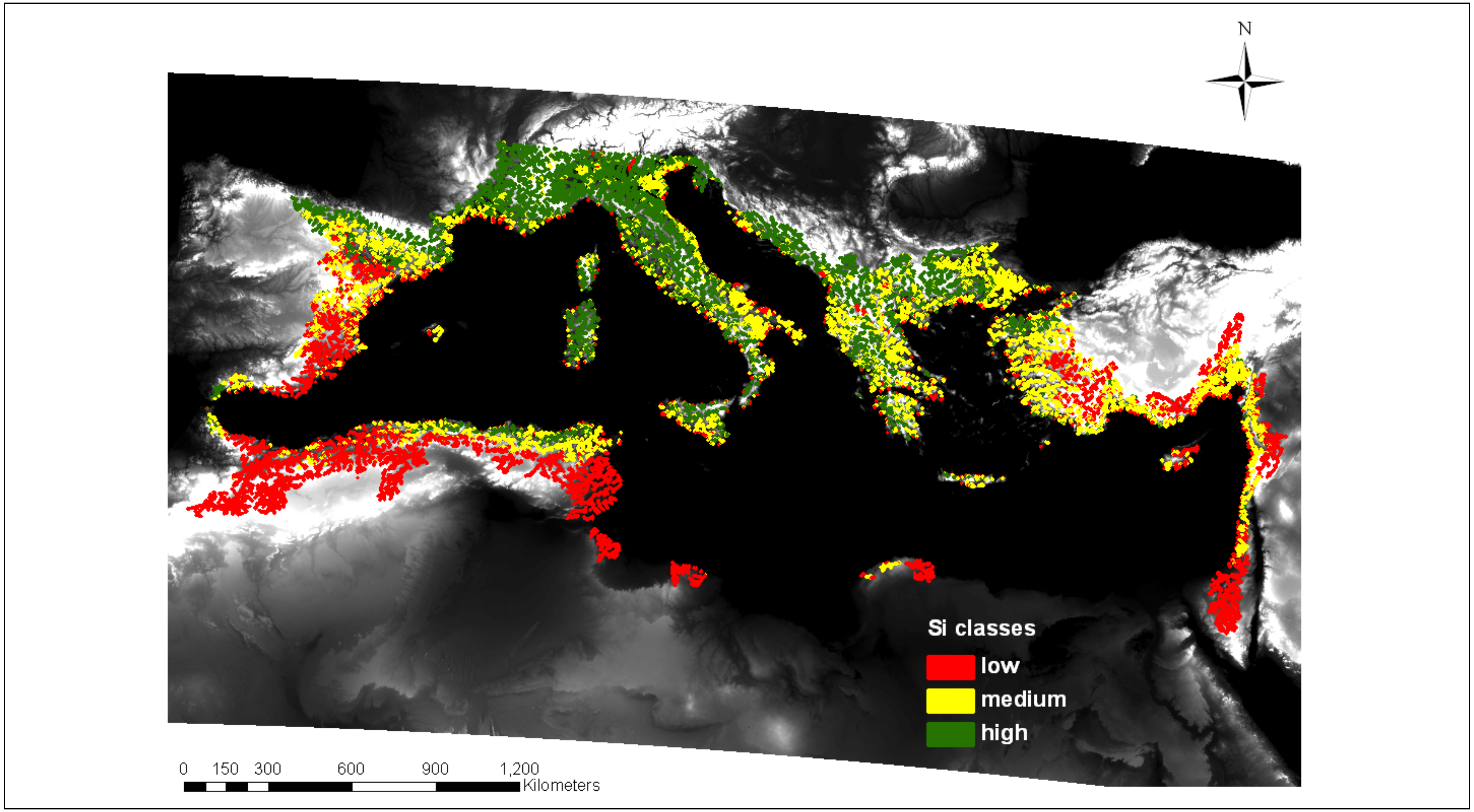


Figure 3.3.5: Classification of the riparian-use zone into low, medium and high Seasonal Integral classes.

C. Land Cover Characteristics

The riparian-use zone with medium and high seasonal integral was dominated by Cultivated and managed areas, as derived from the GLC dataset (55 and 49%, respectively, Figure 3.3.6). In the high Seasonal Integral class broadleaved forest with closed crown coverage and coniferous forest reached the second largest area coverage over 10 % (14 and 11 %, respectively). In the riparian-use zone with medium Seasonal Integral values deciduous shrubs covered 25% of the area, the coverage of the other land cover types remained very low. In the low Seasonal Integral class the sparse herbaceous or shrub cover dominated (31%), cultivated and managed areas and deciduous shrubs occurred over 21% of the riparian-use zone while bare areas covered another 19%.

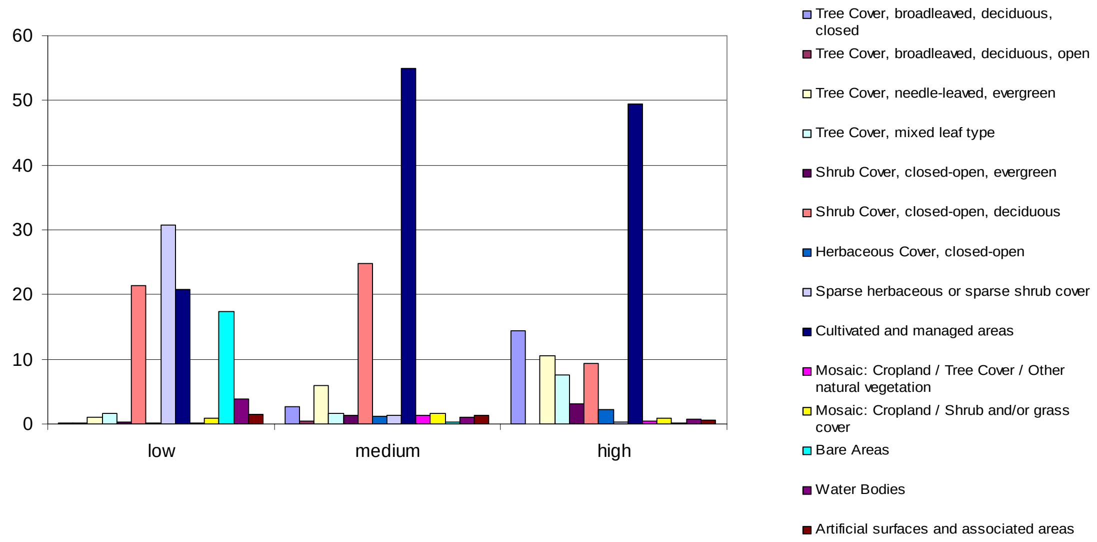


Figure 3.3.6: Distribution of the global land cover classes in the three categories of the Seasonal Integral.

For the South Mediterranean, the high Seasonal Integral class was dominated mostly by closed deciduous forest (60%), while croplands occupied another 32%. In the medium category, croplands had the highest area share (43%) while open deciduous shrubland and closed deciduous forest covered another 35% and 17% of the riparian-use zone, respectively. In the low Seasonal Integral category sparse grassland spread over 46% of the area and open deciduous shrubland over 20%. Stony desert areas occupied another 17% but the area share of the other classes remained very low.

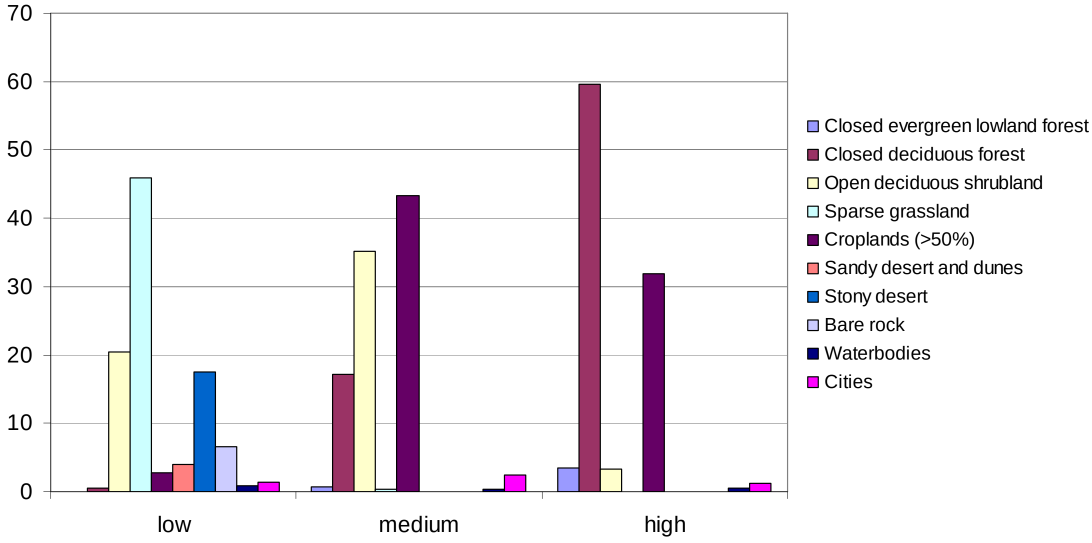


Figure 3.3.7: Distribution of the African land cover classes in the three categories of the Seasonal Integral.

D. Trend analysis

Liner trend analysis results are summarized in Figures 3.3.8-3.3.12. Most of the riparian-use zone (158880 km^2, 77% of the area) no trend was observed, see Figures 3.3.8 and 3.3.9. A negative significant trend appeared in 4144 km^2 i.e. in 2 % of the area, while 41852 km^2 (20% of the riparian-use zone) expressed a significant positive trend in the Seasonal Integral.

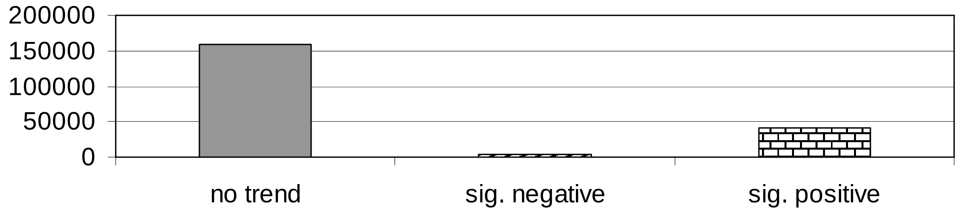


Figure 3.3.8: Area distribution of the trend significance classes of the Seasonal Integral.

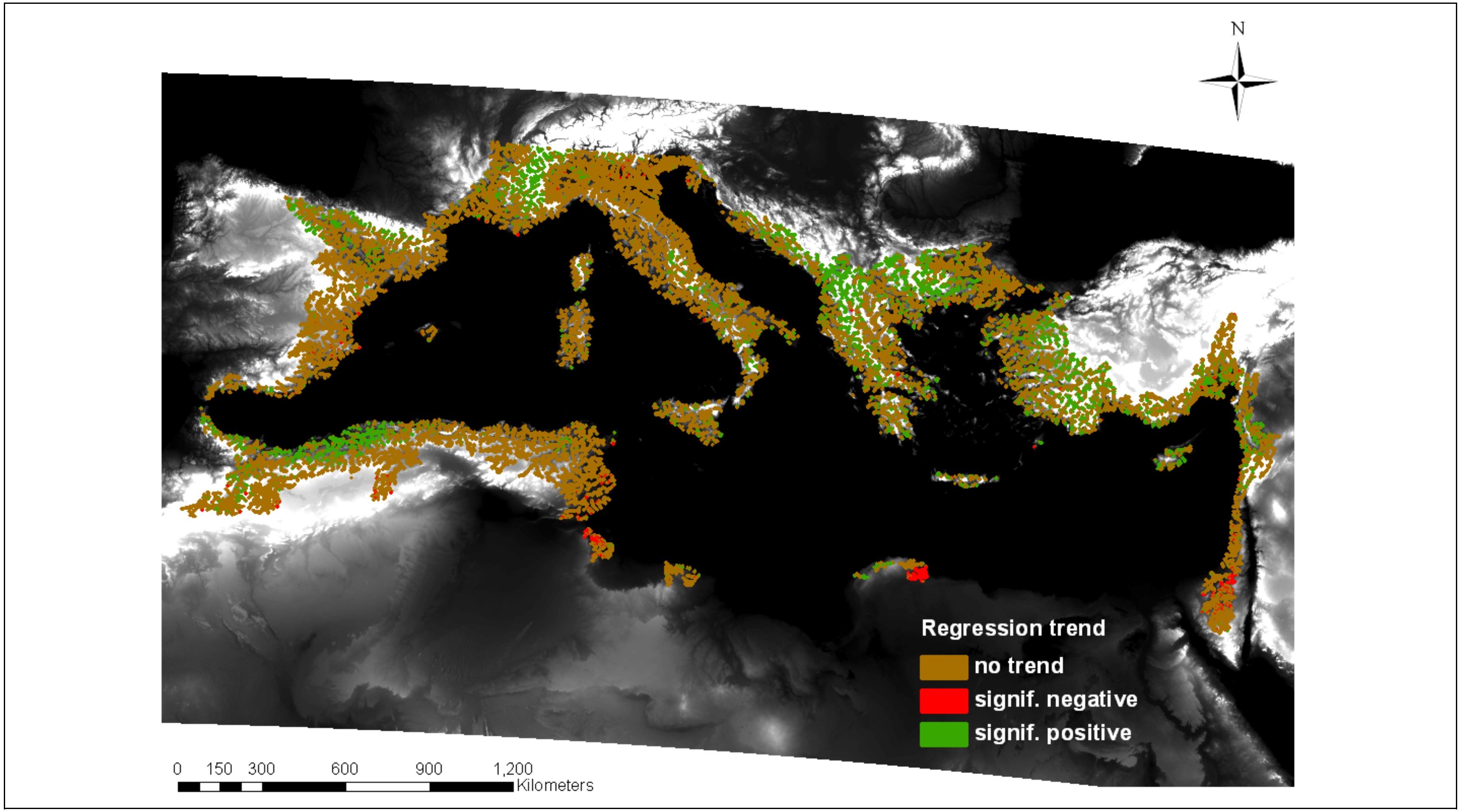


Figure 3.3.9: Significance of the linear trend model of the Seasonal Integral data from 1989-2005. The significance values are classified into significant (p < 0.05) negative, significant positive, and no trend values.

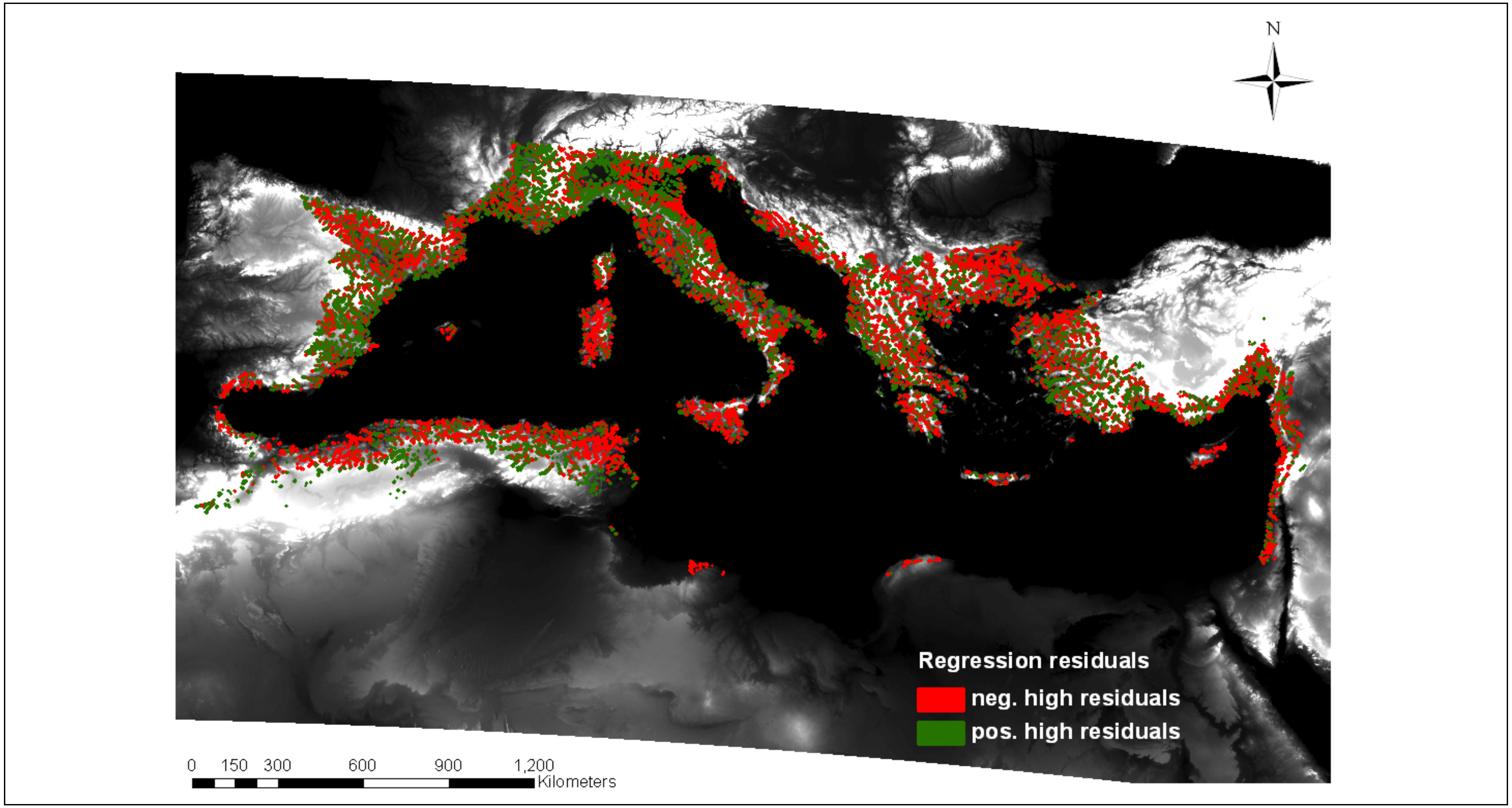


Figure 3.3.10: Residual analysis of the linear trend model of the Seasonal Integral data from 1989-2005. High positive (> 298.13) and high negative (<-312.8) residuals are marked (see Figure 3.3.12).

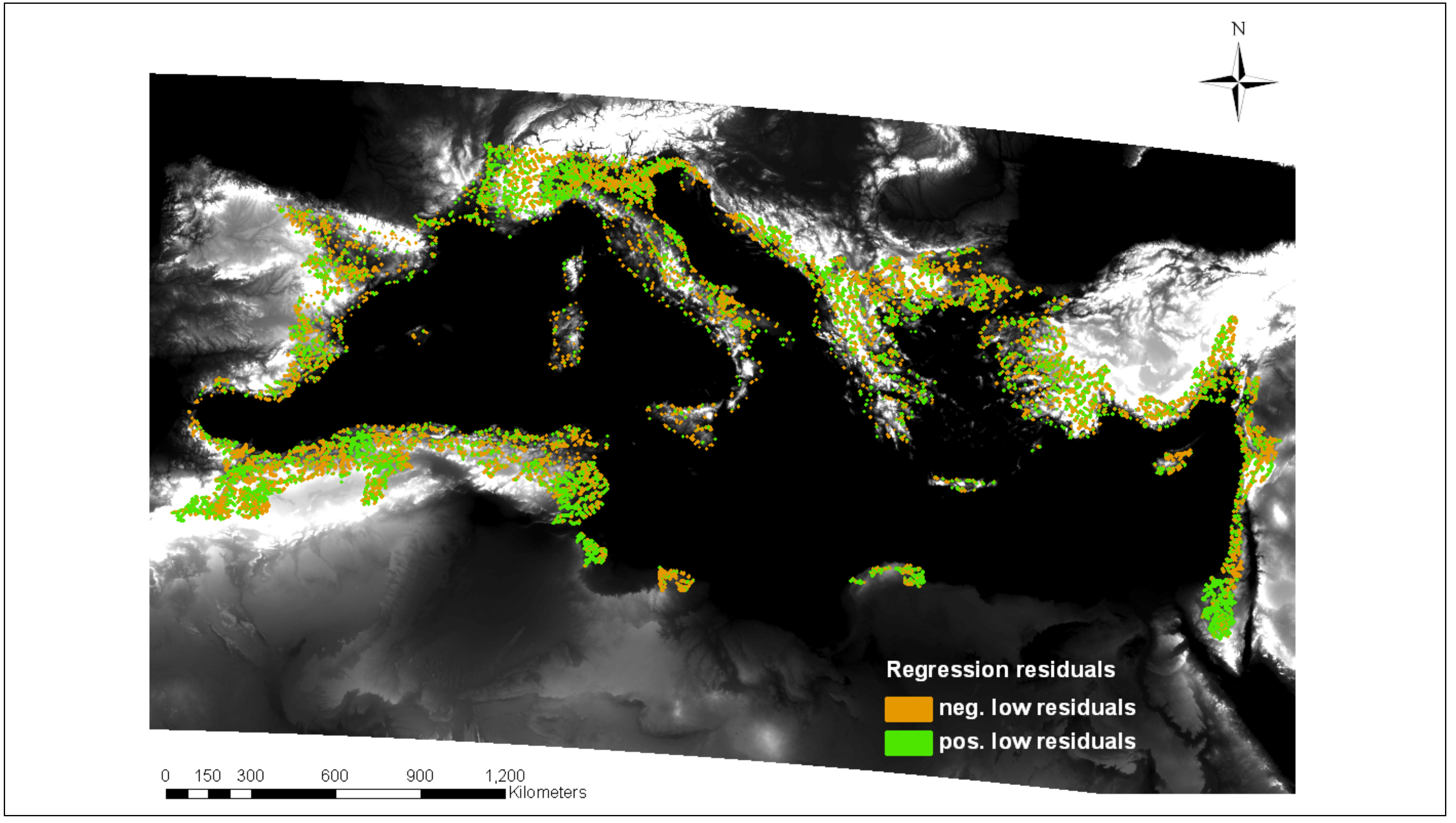


Figure 3.3.11: Residual analysis of the linear trend model of the Seasonal Integral data from 1989-2005. Low positive (< 282.6) and low negative (> -126.8) residuals are marked (see Figure 3.3.12).

The maximum residuals analysis is useful to detect outliers or true extreme values in the data.

High negative residuals: Maximum residuals which are negative and have values lower then -312.08 (the negative peak in the graphic below) depict areas where the Seasonal Integral data declined dramatically throughout the years from 1989-2005 (negative high residuals, Figure 3.3.10).

High positive residuals: Pixels with values larger then 298.13 (the positive peak in Figure 3.3.12) depict areas where the Seasonal Integral values were significantly larger then the average values (positive high residuals, Figure 3.3.10).

Pixels with no extreme residual values depict areas where the SI phenological index behaved constantly throughout the years 1989-2005.

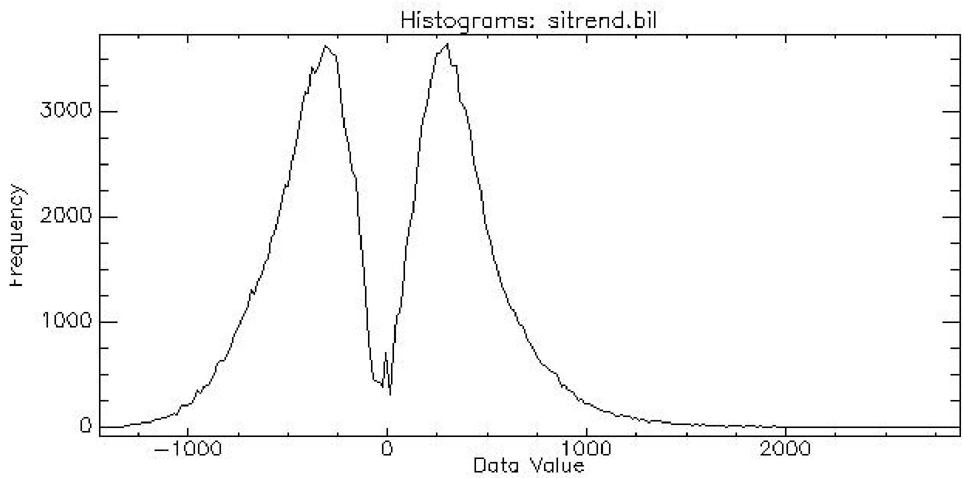


Figure 3.3.12: Distribution of the maximum residuals from the linear regression trend model fitted to the Seasonal Integral data (1989-2005).

Regarding the area distribution of the residual analysis, most of the riparian-use area contains high residuals from the linear trend analysis of the Seasonal Integral. Thirty percent of the area had positive high residuals (62490 km^2, Figure 3.3.13) while 32% (64992 km^2) of the riparian-use zone had negative high residuals. The linear trend analysis resulted in low residuals in 38 % of the riparian area.

Sparse herbaceous or shrub cover manifested the highest positive residuals over 16 % of the riparian-use zone while in another 10 % of the riparian area the residuals were low in this land cover.

Cultivated and managed areas showed negative low high residuals in the Seasonal Integral over most of the riparian-use zone (19 %). Another 14 % of this land cover expressed low negative and low positive residuals in the riparian area, respectively but none of this area manifested high positive values.

Around 8 % of the deciduous shrubs land cover had negative high and another 7 % had positive high residuals from the trend analysis. Altogether, 7 % of the riparian-use zone expressed low residual values under this land cover.

Bare areas expressed mostly low residuals thus stable trends over more then 6 % of the riparian-use zone.

Deciduous trees only manifested high positive and negative model residuals over almost 6 % of the riparian-use zone.

Summarising the period 1989-2005, the total seasonal biomass expressed more than average values under *Sparse herbaceous or sparse shrub* land cover, while during the observed period the total seasonal biomass seemed to show less than average values for the *Cultivated and managed* land use and for deciduous shrub cover.

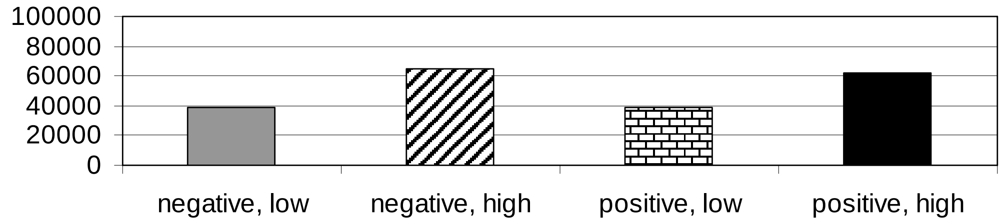


Figure 3.3.13: Area distribution of the negative low, negative high, positive low and positive high residuals of the linear trend model.

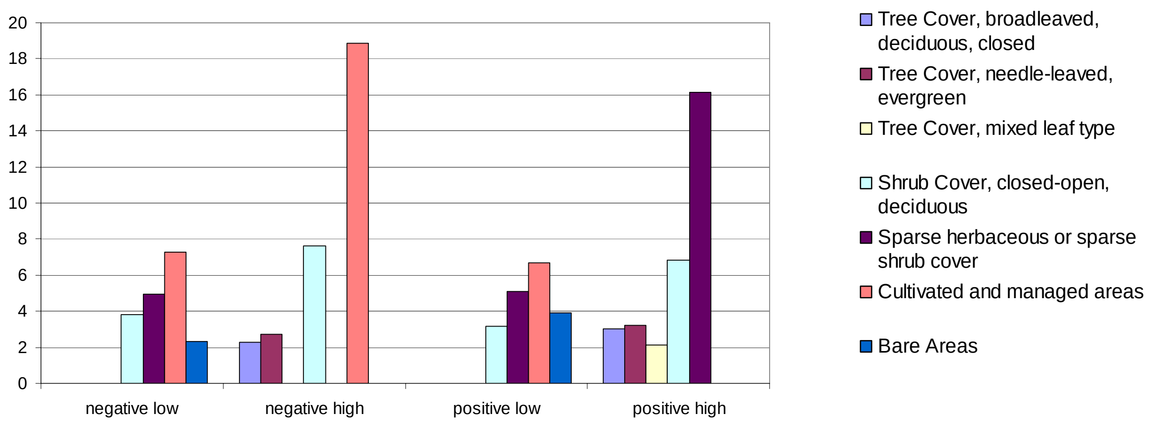


Figure 3.3.14: Area distribution (in %) of the GLC classes in the negative low, negative high, positive low and positive high residuals of the linear trend model. GLC classes with an area share over 5% are plotted.

E. Significance of classes (LMM)

Both the main effect of the classes low, medium and high and of the environmental zones were significantly related to the SI values in the Mediterranean (Table 3.2.1). Furthermore, the interaction of these variables, i.e. the environmental zones to which the classes were assigned to, had a significant effect on the Si values. This indicates that, the Seasonal Integral parameter is not homogenous across the Mediterranean and that within the different environmental zones the three categories of this index are different. This is supported by the pairwise comparisons of the three categories that revealed that the classes low, medium and high are significantly different (3.2.2). This suggests the validity of the classification of the total permanent fraction into the three categories.

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	2888.993	4173.977	.000
GRIDCODE	2	2888.993	156.291	.000
EnZ_name	8	2888.993	13.562	.000
GRIDCODE * EnZ_name	13	2888.993	12.950	.000

a. Dependent Variable: MEAN.

Table 3.3.1: Repeated measures analysis results using a Linear Mixed Model: significance of the fixed effect variables.

Pairwise Comparisons[d]

(I) GRIDCODE	(J) GRIDCODE	Mean Difference (I-J)	Std. Error	df	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-393.678*,b	40.732	2888.993	.000	-490.992	-296.364
	3	-793.220*,b	41.773	2888.993	.000	-893.022	-693.419
2	1	393.678*,c	40.732	2888.993	.000	296.364	490.992
	3	-399.542*	29.905	2888.993	.000	-470.989	-328.096
3	1	793.220*,c	41.773	2888.993	.000	693.419	893.022
	2	399.542*	29.905	2888.993	.000	328.096	470.989

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Sidak.

b. An estimate of the modified population marginal mean (I).

c. An estimate of the modified population marginal mean (J).

d. Dependent Variable: MEAN.

Gridcode 1 = low class; Gridcode 2 = medium class; Gridcode 3 = high class

Table 3.2.2: Pairwise comparisons of the three categories of the fixed effect variable Gridcode.

Also marginal means estimated for the interaction effects revealed differences within the three categories classified throughout the different environmental zones (Table 3.3.3 and Figure 3.3.15). Mainly the presence and absence of low marginal mean values allow differentiation of the various environmental zones based on the Seasonal Integral index.

Highest mean SI values were estimated in the Atlantic Central (ATC) and in the Lusitanian (LUS) regions. The former concerns the Basin of Paris and Normandy in France while the latter covers the foothills of the Cantabrian mountains and the West Pyrenees (Spain), the Atlantic plains of France, the low mountains in Galicia and the Beira Litoral region in Portugal. The mean SI values in the class "high" were also higher in the Alpine South (ALS) regions of the Pyrenees, the Soth-Western Alps of Italy and France, in the Picos de Europa, in the Sierra de la Demanda in Spain, the Massive Central in France, the outer ranges of Eastern Alps (Slovenia, Croatia) and the Dinaric Alps (Croatia, Bosnia, Albania, Macedonia). Lowest mean SI values in the category high were estimated in the Anatolian (ANA) regions of Turkey and in the Southern Mediterranean regions (MDS). Lowest seasonal Integral values were measured in the Southern (MDS) and mountainous (MDM) Mediterranean regions. In the Lusitanian (LUS) regions the TPF values in the class low were the highest.

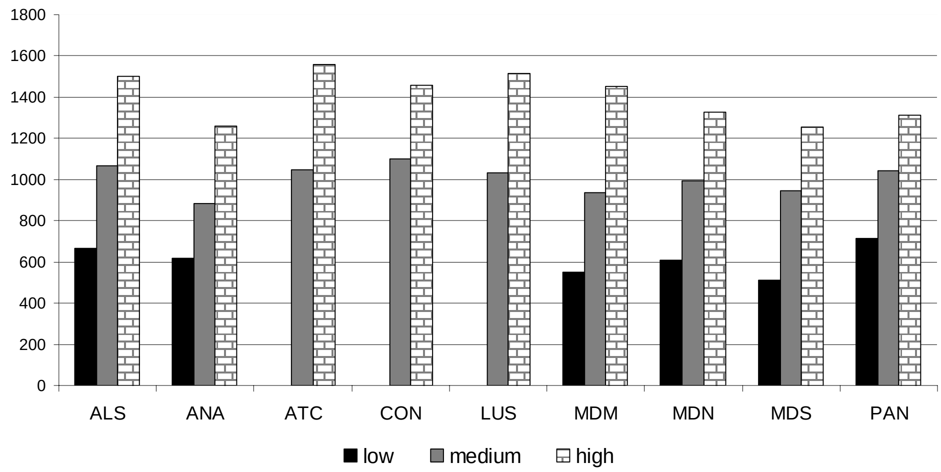


Figure 3.3.15: Distribution of the estimated marginal means of the categories low, medium and high Seasonal Integral in the environmental zones.

3. EnZ_name * GRIDCODE[b]

EnZ_name	GRIDCODE	Mean	Std. Error	df	95% Confidence Interval Lower Bound	Upper Bound
ALS	1	668.055	176.393	2888.993	322.187	1013.924
	2	1065.823	47.143	2888.993	973.385	1158.260
	3	1498.477	17.728	2888.993	1463.716	1533.238
ANA	1	618.120	55.780	2888.993	508.746	727.493
	2	880.865	48.923	2888.993	784.938	976.791
	3	1260.866	176.393	2888.993	914.997	1606.734
ATC	1	.[a]	.	.	.	.
	2	1046.884	124.729	2888.993	802.318	1291.450
	3	1560.320	66.670	2888.993	1429.594	1691.046
CON	1	.[a]	.	.	.	.
	2	1101.875	62.364	2888.993	979.592	1224.158
	3	1459.111	26.592	2888.993	1406.969	1511.253
LUS	1	.[a]	.	.	.	.
	2	1032.172	88.196	2888.993	859.237	1205.106
	3	1515.469	44.098	2888.993	1429.002	1601.936
MDM	1	549.973	13.732	2888.993	523.047	576.898
	2	934.316	10.504	2888.993	913.720	954.913
	3	1454.940	9.923	2888.993	1435.484	1474.397
MDN	1	607.754	15.714	2888.993	576.941	638.566
	2	995.040	7.904	2888.993	979.541	1010.538
	3	1324.870	8.754	2888.993	1307.705	1342.036
MDS	1	511.196	12.002	2888.993	487.663	534.730
	2	947.241	8.842	2888.993	929.904	964.577
	3	1256.460	12.504	2888.993	1231.942	1280.978
PAN	1	713.014	101.840	2888.993	513.327	912.702
	2	1041.058	25.460	2888.993	991.136	1090.980
	3	1310.640	28.999	2888.993	1253.779	1367.500

a. This level combination of factors is not observed, thus the corresponding population marginal mean is not estimable.

b. Dependent Variable: MEAN.

Table 3.3.3: Estimated marginal means for the interaction effect of the classes low, medium and high Seasonal Integral values and the environmental zones.

F. Crossing with bio-physical variables

The mean and standard deviation of the sixteen years Seasonal Integral were correlated to the biophysical variables within the regions of the environmental classification.

Adjusted R^2 of the linear regression model of the mean (Figure 3.3.3) reached 0.941 and the model was highly significant ($p < 0.000$, Table 3.3.4). The computed Durbin-Watson test value was smaller then 2 therefore the null hypothesis against the alternative hypothesis of negative first-order autocorrelation was tested. The computed value was larger then the upper bound of the Durbin-Watson value with ten predictors and 48 observations therefore the null hypothesis of no autocorrelation of the samples was not rejected. The plots of the standardised residuals and of the normal probability indicated no violation of the normality assumption and there was o homoscedasticity in the data (see Appendix for the plots). The sixteen years mean of the Seasonal Integral values was significantly explained ($p < 0.000$) by the October and May sunshine, by the slope and the maximum December temperature values. Sunny hours in April, June and September, maximum July and August temperature and July precipitation were predictors on the $p < 0.05$ level.

Table 3.3.4: Regression statistics of the mean and the standard deviation of the Seasonal Integral.

Mean			Standard deviation		
Adjusted R^2	***Durbin-Watson***	***p***	***Adjusted R^2***	***Durbin-Watson***	***p***
0.941	1.935	0.000	0.681	1.970	0.000
Predictors			Predictors		
Mean October sunshine ($p < 0.000$)			Mean December precipitation ($p < 0.000$)		
Std. of slope ($p < 0.000$)			Mean January precipitation ($p < 0.000$)		
Std. of April sunshine ($p < 0.022$)			Mean July precipitation ($p < 0.000$)		
Mean May sunshine ($p < 0.000$)			Mean maximum September temperature ($p < 0.000$)		
Std. of max December temperature ($p < 0.000$)			Mean November minimum temperature ($p < 0.020$)		
Std. of maximum July temperature ($p < 0.006$)					
Mean September sunshine ($p < 0.019$)					
Mean June sunshine ($p < 0.008$)					
Mean July precipitation ($p < 0.003$)					
Mean August maximum temperature ($p < 0.047$)					

The second regression model explained 68% of the standard deviation of the sixteen years Seasonal Integral index (Figure 3.3.4) and was highly significant ($P < 0.000$). The computed Durbin-Watson value was lower than 2 but larger than the upper bound of the Durbin-Watson statistic indicating no first order autocorrelation in the residuals and therefore trustworthy model significance. The standard deviation values were significantly predicted by the mean December, March and January precipitation values and by the standard deviations of the November and March precipitation values.

3.7 Total integral (TI)

A. Classification and area calculation

The area distribution of the sixteen years mean Total Integral is presented in Figure 3.4.3 and Figure 3.4.4 presents the standard deviation values of the index over the Mediterranean. The area distribution of the three Total Integral classes (low, medium and high, Figure 3.4.5) within the riparian zone was as follows: Low Total Integral values were observed over 62029 km^2 area (30%), 72154 km^2 area (36%) had medium level of permanent vegetation fraction while 70693 km^2 area (34%) expressed a high level of Total Integral values (Figure 3.4.1.).

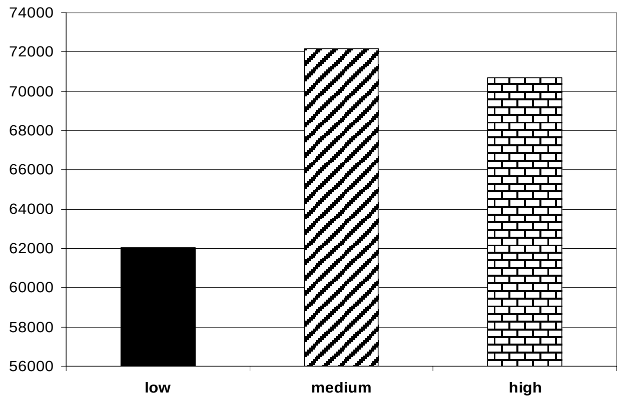
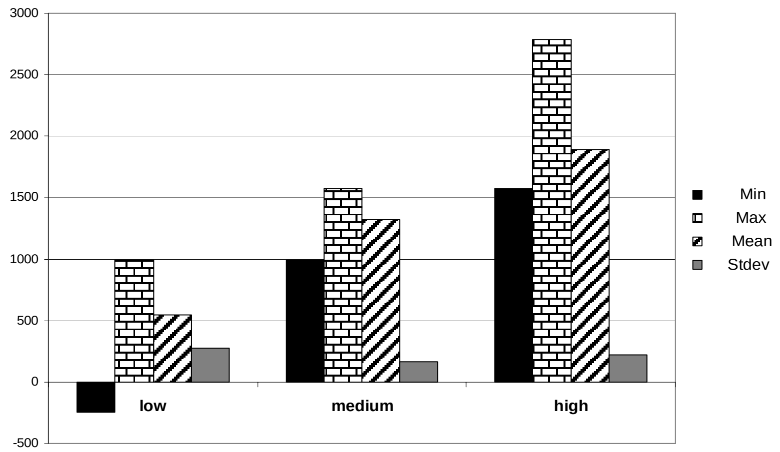


Figure 3.4.1: Area distribution of the Total Integral classes (km^2).

B. Descriptive statistics

Descriptive statistics of the Total Integral values within the classes low, medium and high in the riparian-use zones are shown in Figure 3.3.2.



Class	Min	Max	Mean	Stdev
Low	-244.59	989.53	542.20	275.01
Medium	989.56	1576.41	1318.99	161.93
High	1576.47	2787.88	1890.71	219.94

Figure 3.4.2: Descriptive statistics of the Total Integral values.

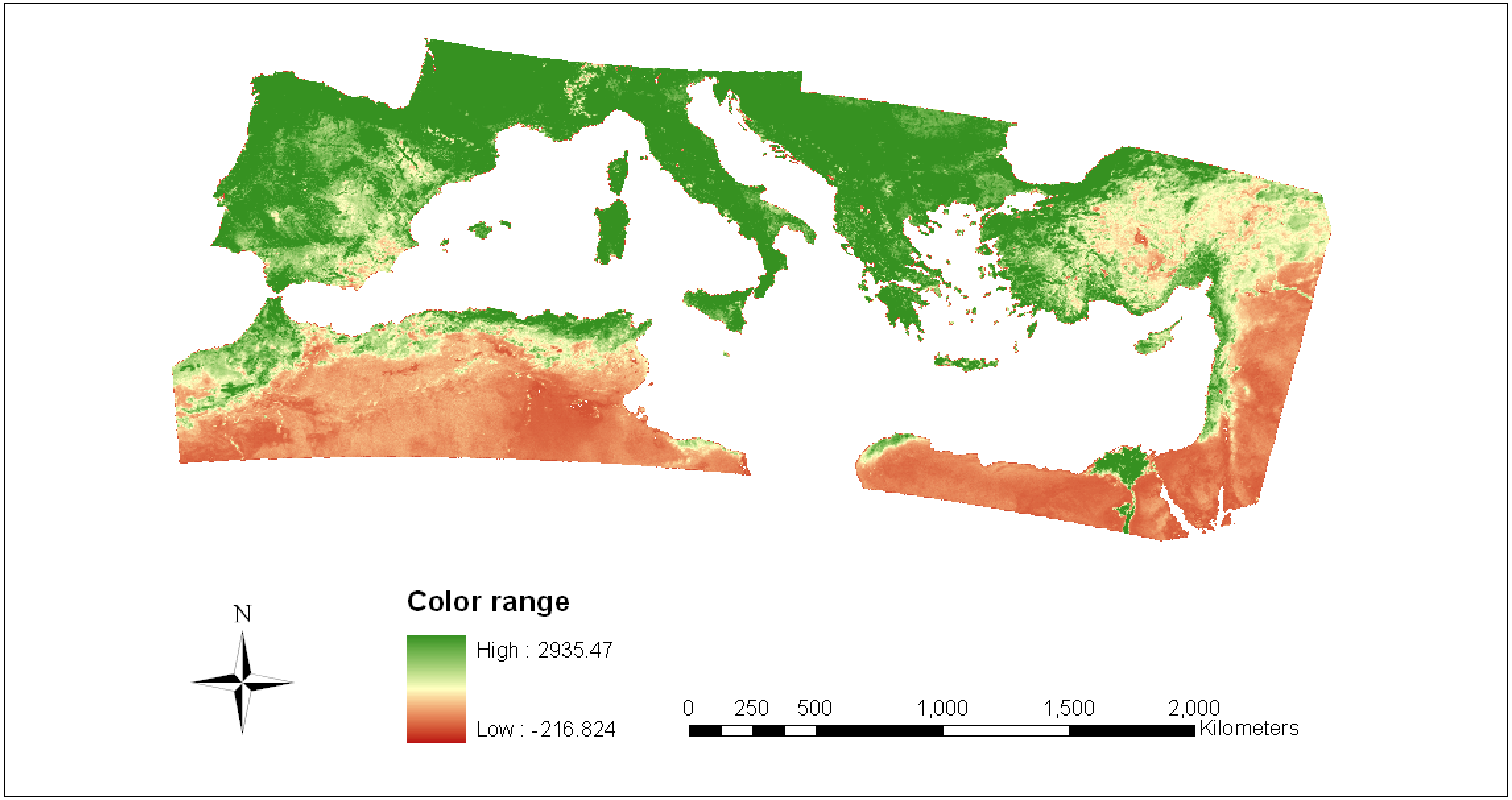


Figure 3.4.3: Mean of the sixteen years (1989-2005) Total Integral values over the Mediterranean.

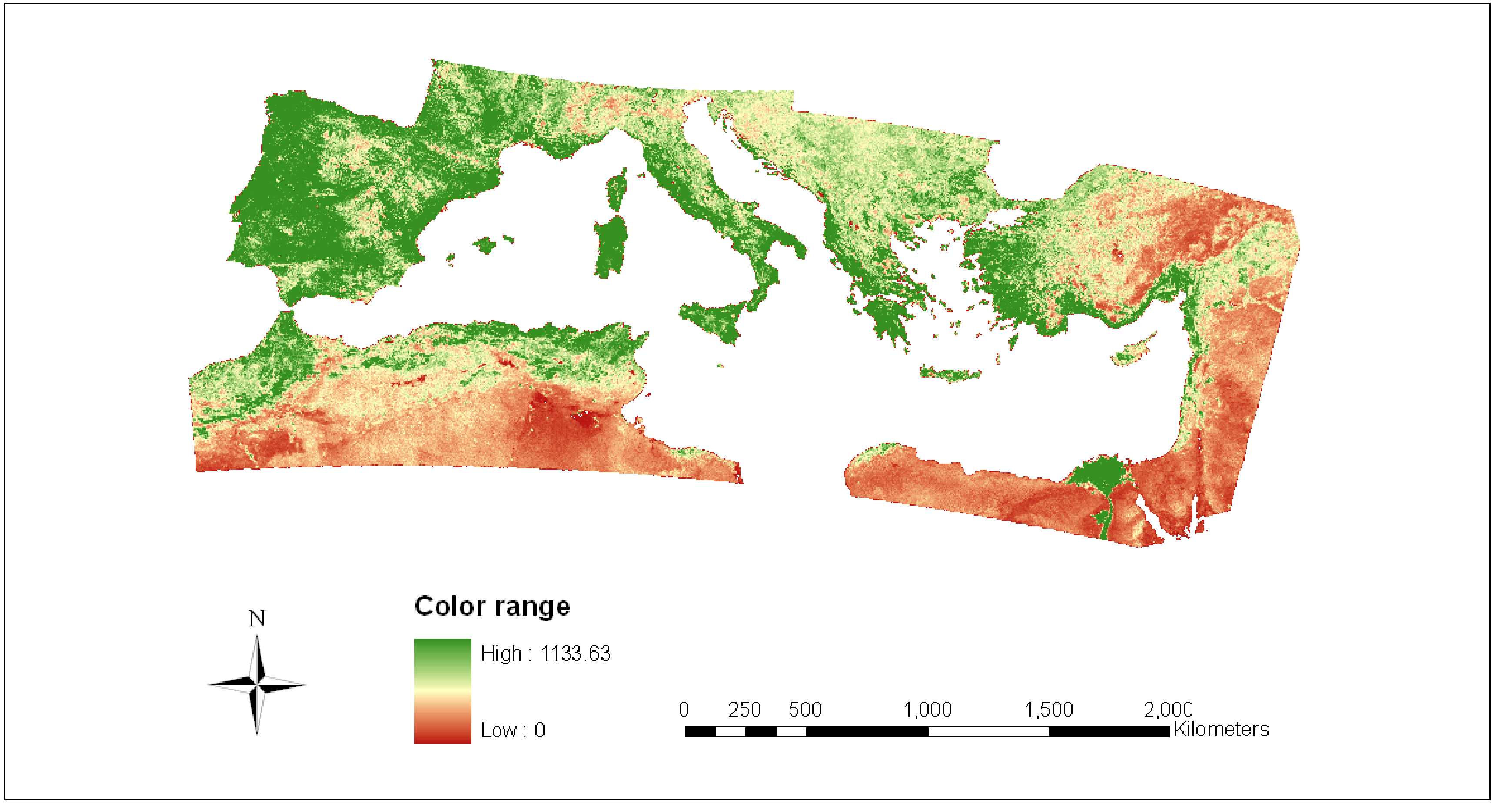


Figure 3.4.4: Standard deviation of the sixteen years (1989-2005) Total Integral values over the Mediterranean

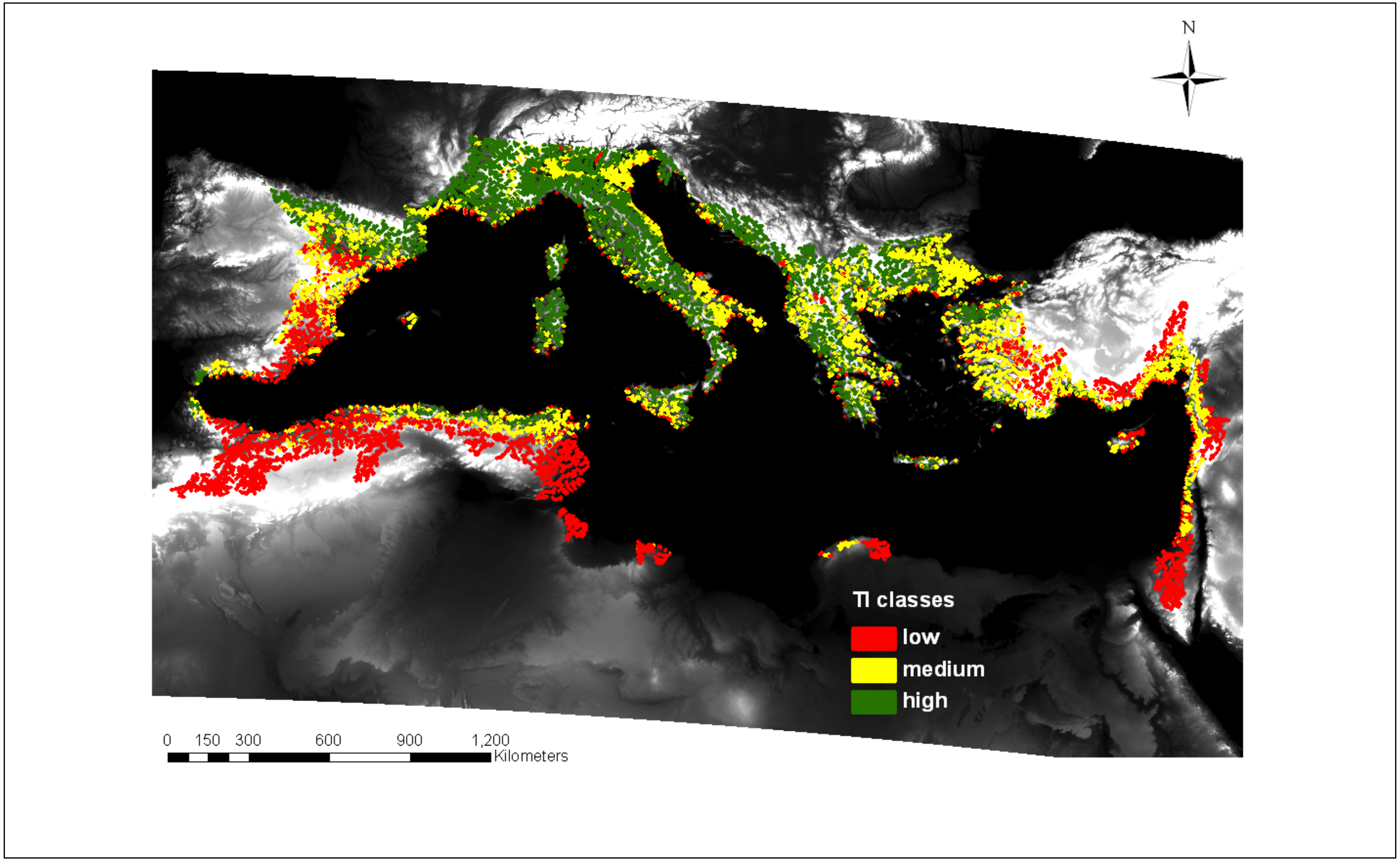


Figure 3.4.5: Classification of the riparian-use zone into low, medium and high Total Integral classes.

C. Land Cover Characteristics

Cultivated and managed areas derived from the GLC dataset dominated the riparian-use zone with medium and high Total Integral values (57 and 47%, respectively, Figure 3.4.6). In the high Total Integral class broadleaved forest with closed crown coverage, coniferous forest and deciduous shrub cover reached second largest area coverage of however just over 10 % (14 and 11 % and 11 %, respectively). In the riparian-use zone with medium Total Integral values deciduous shrubs covered 24 % of the area. The coverage of the other land cover types remained very low. In the low Total Integral class the sparse herbaceous or shrub cover dominated (32 %), cultivated and managed areas and deciduous shrubs occurred over 19 and 21 % of the riparian-use zone, respectively while bare areas covered another 18 %.

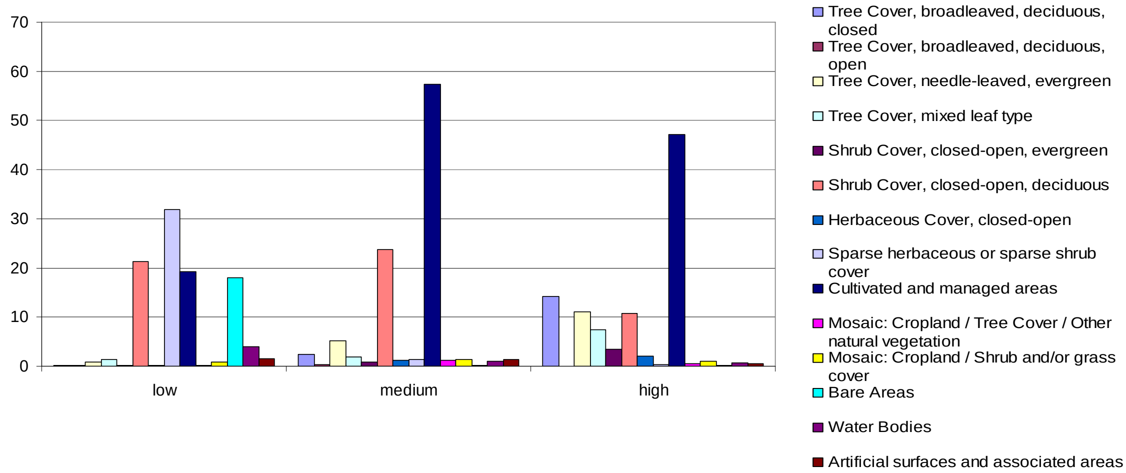


Figure 3.4.6: Distribution of the global land cover classes in the three categories of the Total Integral.

For the South Mediterranean, closed deciduous forest dominated the high Total Integral class (66 % area share) while croplands covered 24%. The coverage of the other land cover classes remained under 5 %. In the medium Total Integral class croplands had the largest area with a share of 46 %. Deciduous shrubland covered 34 % while closed deciduous forest occupied 17 % of the North African riparian-use zone. Sparse grassland covered 45 % of the area in the low Total Integral class while open deciduous shrubland had area coverage of 21 %. Stony desert covered another 17 % while the area share of the rest of the land cover classes remained around or lower then 5 %.

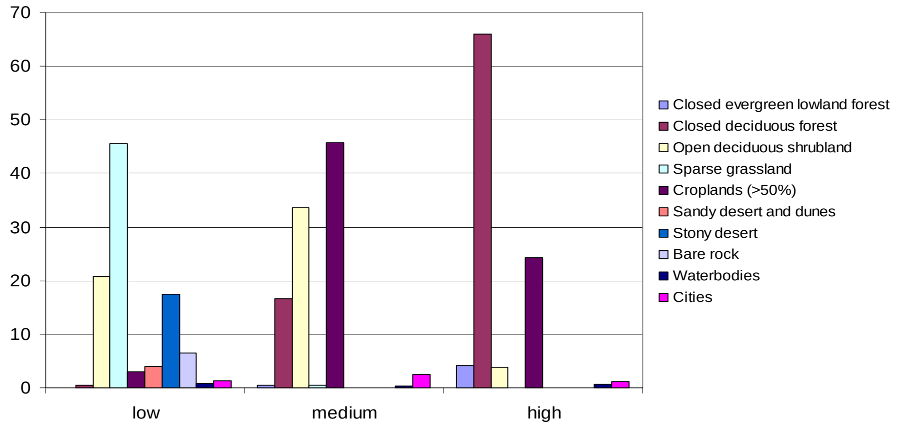


Figure 3.4.7: Distribution of the African land cover classes in the three categories of the Total Integral.

D. Trend analysis

Liner trend analysis results are summarized in Figures 3.4.8-3.4.12. Most of the riparian-use zone (152394 km^2, 74 % of the area) no trend was observed, see Figures 3.4.8 and 3.4.9. A negative significant trend appeared in 6198 km^2 i.e. in 3 % of the area, while 46284 km^2 (23 % of the riparian-use zone) showed a significant positive trend of the Total Integral values.

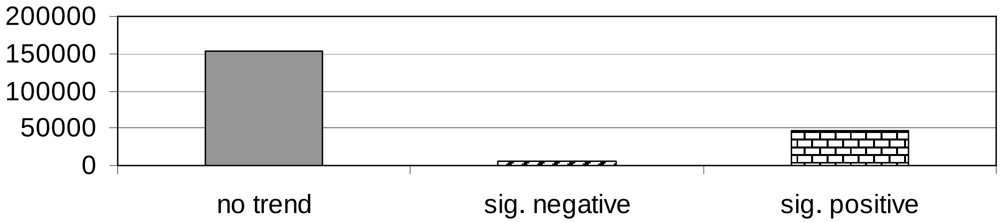


Figure 3.4.8: Area distribution of the trend significance classes of the Total Integral.

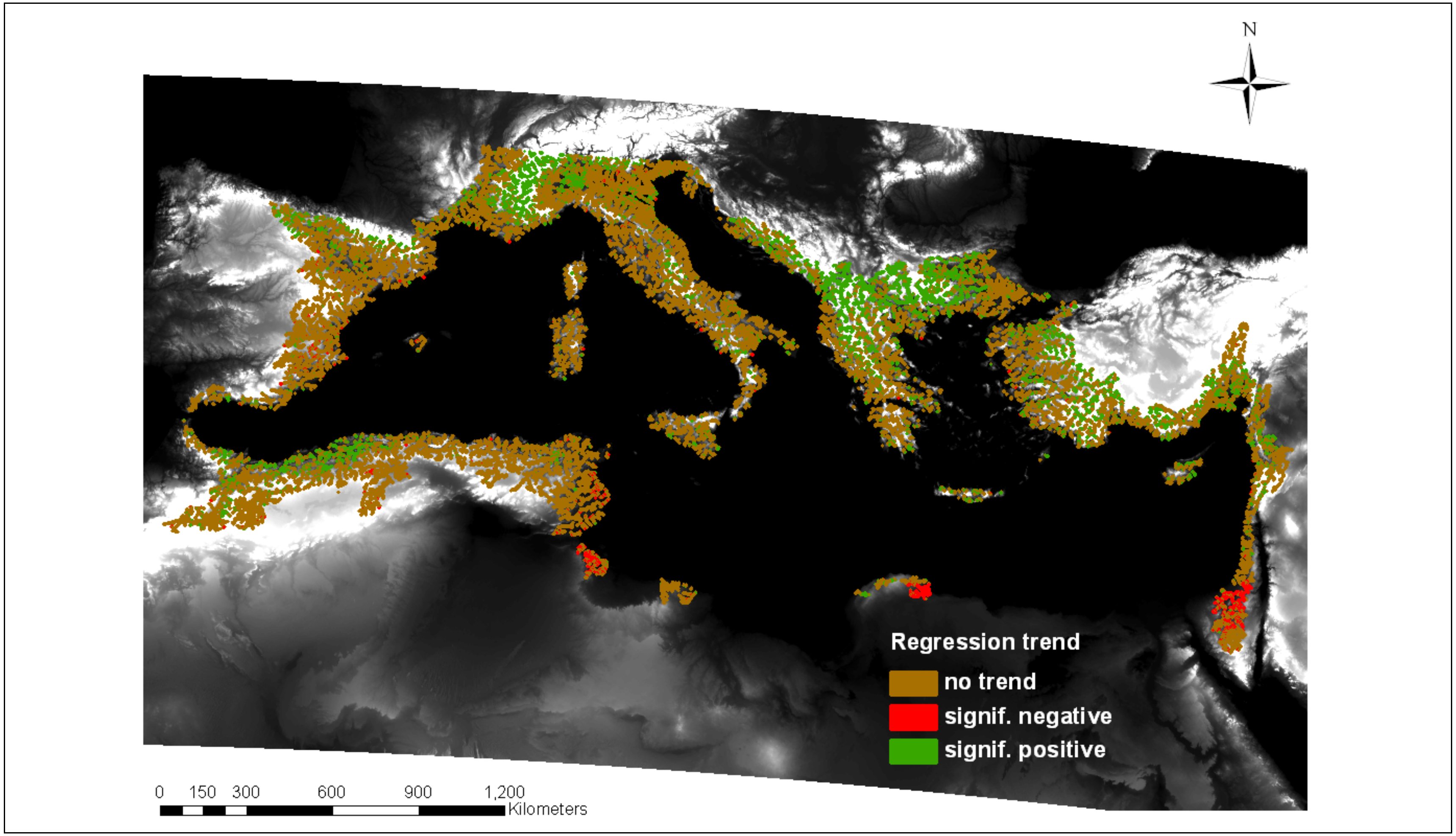


Figure 3.4.9: Significance of the linear trend model of the Total Integral data from 1989-2005. The significance values are classified into significant ($p < 0.05$) negative, significant positive, and no trend values.

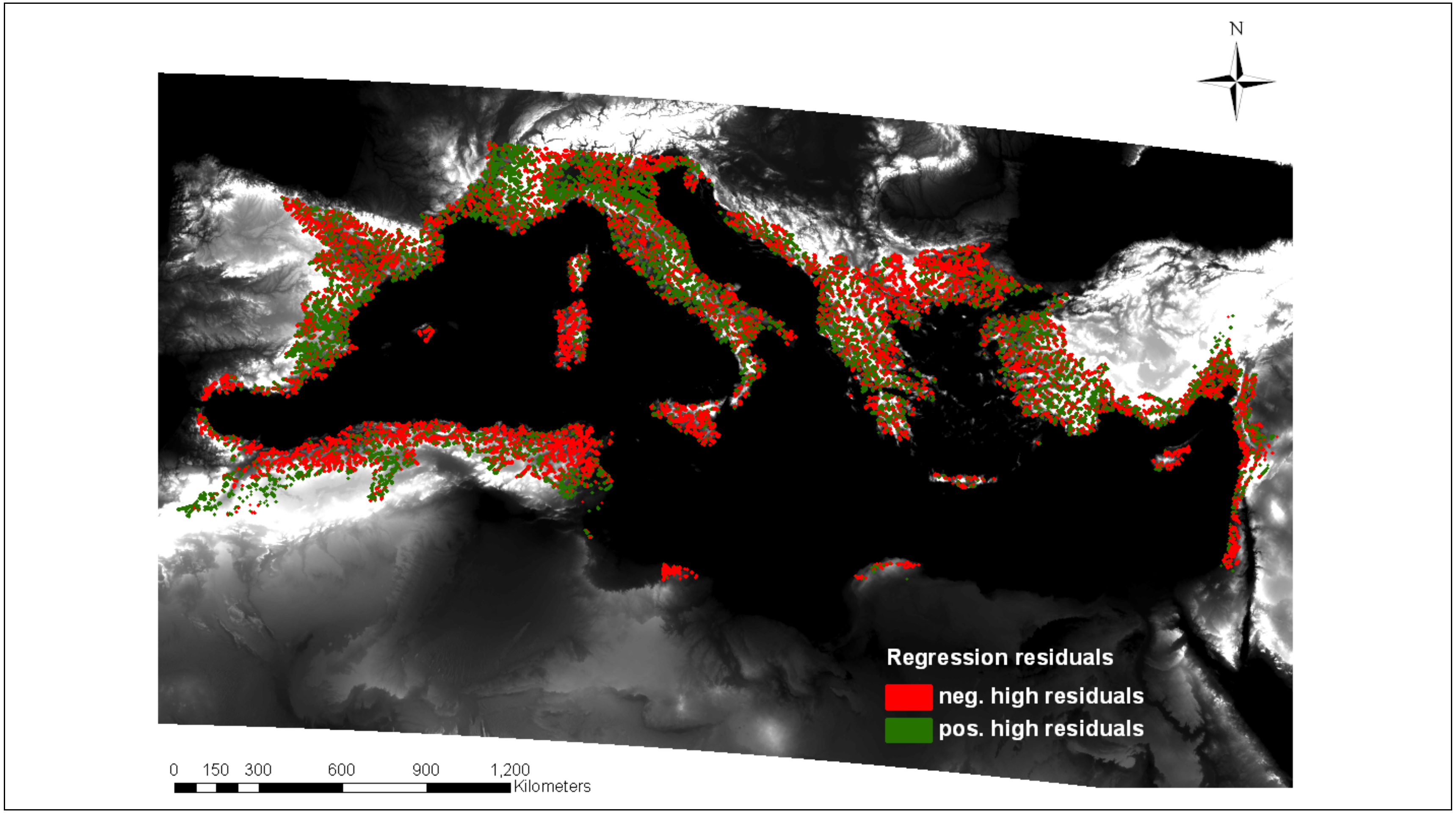


Figure 3.4.10: Residual analysis of the linear trend model of the Total Integral data from 1989-2005. High positive (> 289.15) and high negative (<-294.44) residuals are marked (see Figure 3.3.12).

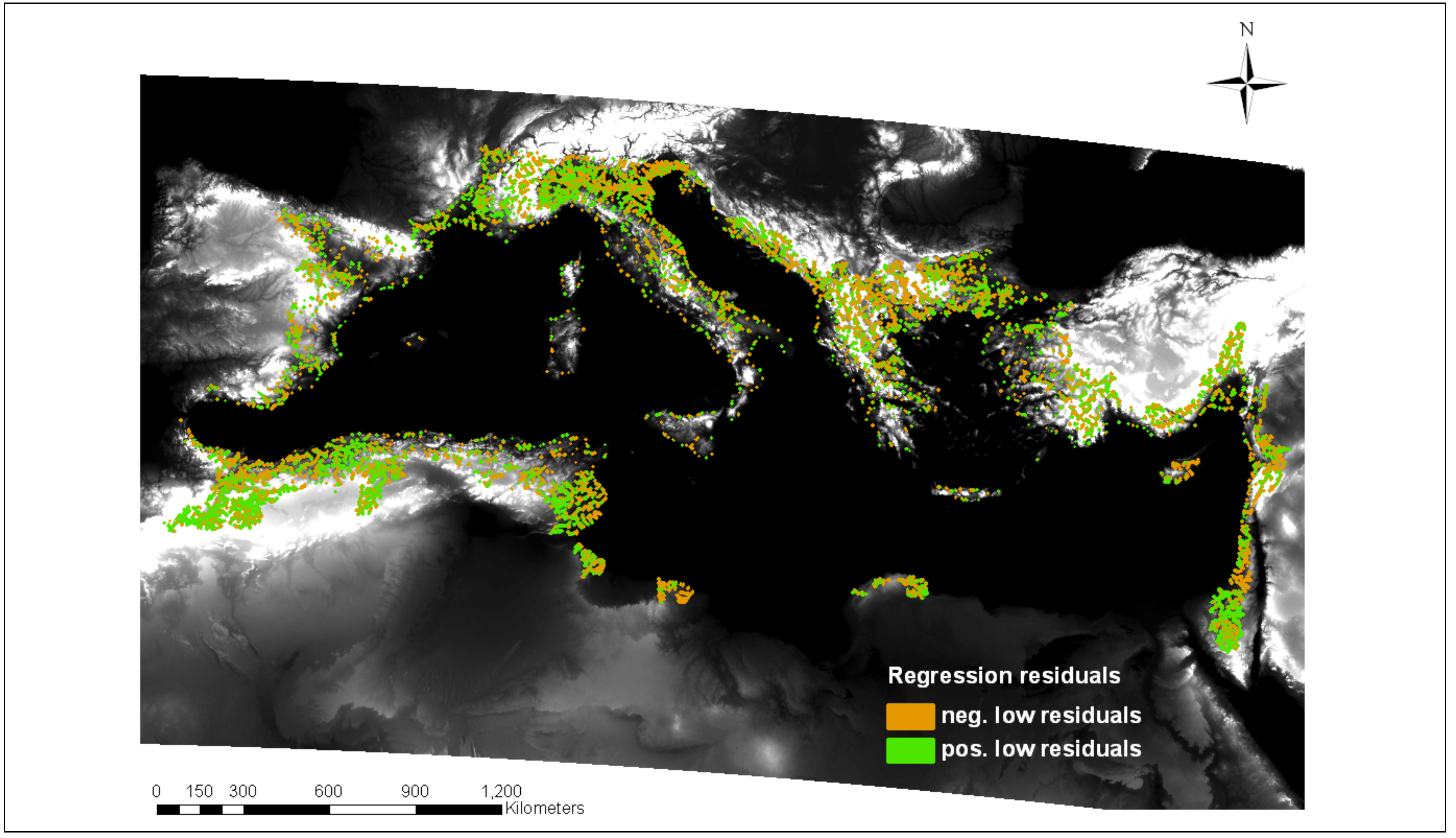


Figure 3.4.11: Residual analysis of the linear trend model of the Total Integral data from 1989-2005. Low positive (< 289.15) and low negative (> -294.44) residuals are marked (see Figure 3.4.12).

The maximum residuals analysis is useful to detect outliers or true extreme values in the data.

High negative residuals: these maximum residuals for instance which are negative and have values lower then -292.44 (the negative peak in the graphic below) depict areas where the Total Integral values were dramatically low throughout the years from 1989-2005 (negative high residuals, Figure 3.4.10).

High positive residuals: Pixels with values larger then 289.15 (the positive peak in Figure 3.4.12) depict areas where the Total Integral values were significantly larger then the average values in the observed period (positive high residuals).

Pixels with low residual values depict areas where the Total Integral phenological index behaved constantly throughout the years 1989-2005 (Figure 3.4.11).

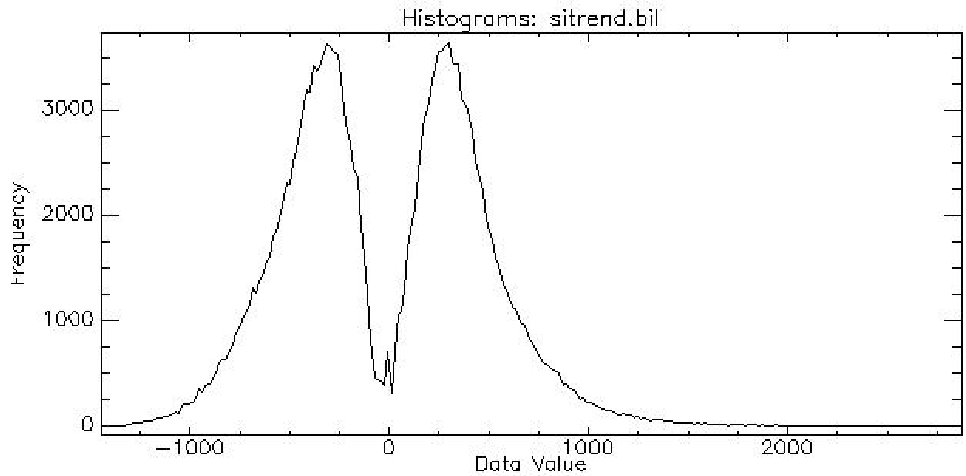


Figure 3.4.12: Distribution of the maximum residuals from the linear regression trend model fitted to the Total Integral data (1989-2005).

Most of the riparian-use area contains high residuals from the linear trend analysis of the Total Integral index. Thirty five percent of the area had positive high residuals (71718 km^2, Figure 3.4.13) while 36% (73629 km^2) of the riparian-use zone had negative high residuals. The linear trend analysis resulted in low residuals in 29 % of the riparian area.

Sparse herbaceous or shrub cover expressed the highest positive model residuals over 19 % of the riparian area while this land cover had low (positive and negative) residuals in another ca. 8 % of the riparian zone. The linear trend model over this land cover did not result in high negative residuals i.e. areas in risk of disappearing total biomass.

Cultivated and managed areas expressed negative high model residuals over 20 % of the riparian-use zone and another 6 % percent of the area manifested low negative model residuals (Figure 3.4.14). Almost five percent of the riparian zone evidenced low positive model residuals under this land cover but none of the cultivated and managed areas had high positive residual values.

Bare areas manifested only low residual values i.e. stable trend pattern over 6 % of the riparian-use zone while deciduous forest area manifested only high model residuals over 6 % of the zone.

In summary, the *Sparse herbaceous or shrub land cover* shows more than average values for this index which is considered a proxy for total biomass production. Riparian-use zones where the main land cover is cultivated and managed seem to show a decline in total biomass production over this period.

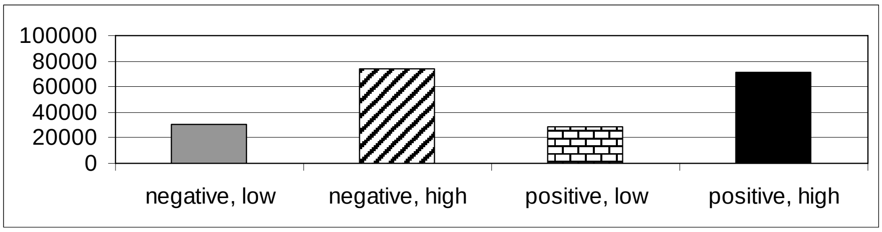


Figure 3.4.13: Area distribution of the negative low, negative high, positive low and positive high residuals of the linear trend model.

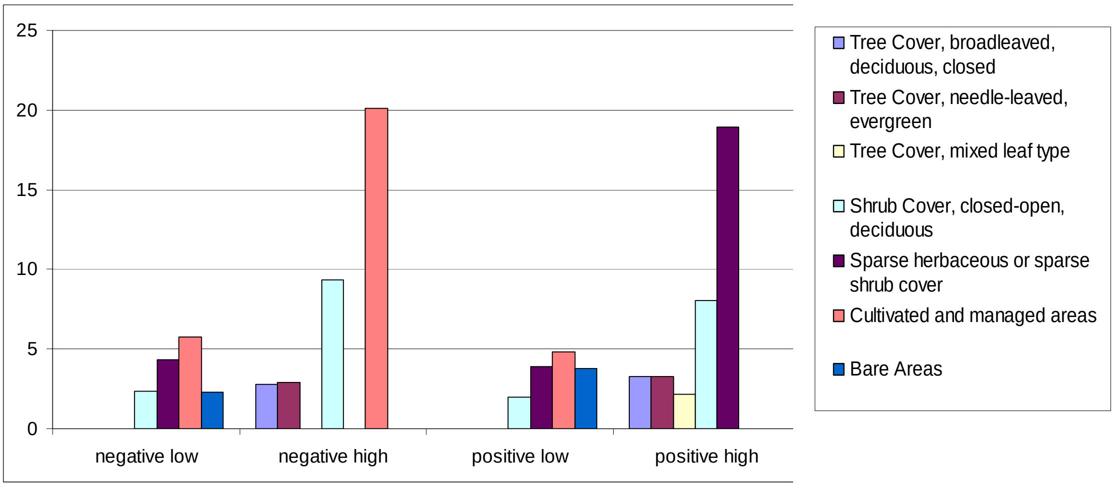


Figure 3.4.14: Area distribution (in %) of the GLC classes in the negative low, negative high, positive low and positive high residuals of the linear trend model. GLC classes with an area share over 5% are plotted.

E. Significance of classes (LMM)

The main effects of the classes low, medium and high and of the environmental zones were significantly related to the TI values in the Mediterranean (Table 3.4.1). Furthermore, the interaction of these variables, i.e. the environmental zones to which the classes were located in had a significant effect on the TI values as well. This indicates that, the Total Integral parameter is not homogenous across the Mediterranean and that within the different environmental zones the three categories of this index are different. This is also supported by the pair-wise comparisons of the three categories that revealed that the classes low, medium and high are significantly different (3.4.2). This suggests the validity of the classification of the Total Integral into the three categories.

Type III Tests of Fixed Effects[a]

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	2608.985	4498.445	.000
GRIDCODE	2	2608.985	204.506	.000
EnZ_name	8	2608.985	13.534	.000
GRIDCODE * EnZ_name	14	2608.985	7.047	.000

a. Dependent Variable: MEAN.

Table 3.4.1: Repeated measures analysis results using a Linear Mixed Model: significance of the fixed effect variables.

Pairwise Comparisons[d]

(I) GRIDCODE	(J) GRIDCODE	Mean Difference (I-J)	Std. Error	df	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
1	2	-503.937*,b	55.156	2608.985	.000	-635.719	-372.155
	3	-1015.592*,b	54.222	2608.985	.000	-1145.144	-886.041
2	1	503.937*,c	55.156	2608.985	.000	372.155	635.719
	3	-511.655*	33.262	2608.985	.000	-591.128	-432.182
3	1	1015.592*,c	54.222	2608.985	.000	886.041	1145.144
	2	511.655*	33.262	2608.985	.000	432.182	591.128

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Sidak.

b. An estimate of the modified population marginal mean (I).

c. An estimate of the modified population marginal mean (J).

d. Dependent Variable: MEAN.

Gridcode 1 = low class; Gridcode 2 = medium class; Gridcode 3 = high class

Table 3.4.2: Pairwise comparisons of the three categories of the fixed effect variable Gridcode.

Marginal means estimated for the interaction effects also revealed slight differences within the three categories classified throughout the different environmental zones (Table 3.4.3 and Figure 3.4.15).

Highest mean TI values were estimated in the Atlantic Central (ATC) and in the Lusitanian (LUS) regions. The former concerns the Bassin de Paris and the Normandy in France while the letter covers the foothills of the Cantabrian mountains and the West Pyrenees (Spain), the Atlantic plains of France, the low mountains in Galicia and the Beira Litoral region in Portugal. The mean SI values in the class “high” were also higher in the Mediterranean Mountain (MDM) regions. Lowest mean TI values in the category high were estimated in the Anatolian (ANA) regions of Turkey. Lowest Total Integral values were measured in the Southern (MDS) and mountainous (MDM) Mediterranean regions. In the Lusitanian regions the TPF values in the class low were the highest.

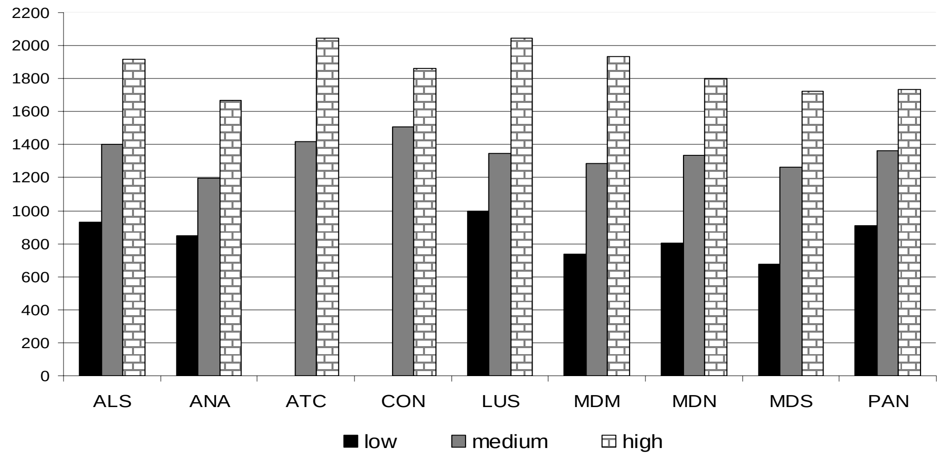


Figure 3.4.15: Distribution of the estimated marginal means of the categories low, medium and high Total Integral in the environmental zones.

3. EnZ_name * GRIDCODE[b]

EnZ_name	GRIDCODE	Mean	Std. Error	df	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
ALS	1	930.172	93.030	2608.985	747.752	1112.592
	2	1399.911	43.065	2608.985	1315.467	1484.355
	3	1916.623	24.292	2608.985	1868.990	1964.256
ANA	1	846.231	75.959	2608.985	697.285	995.176
	2	1195.232	68.707	2608.985	1060.506	1329.959
	3	1665.689	161.133	2608.985	1349.728	1981.650
ATC	1	.[a]	.	.	.	.
	2	1416.514	161.133	2608.985	1100.553	1732.475
	3	2042.086	86.129	2608.985	1873.197	2210.974
CON	1	.[a]	.	.	.	.
	2	1505.578	65.782	2608.985	1376.588	1634.569
	3	1860.490	33.970	2608.985	1793.879	1927.100
LUS	1	995.087	227.876	2608.985	548.250	1441.924
	2	1348.045	101.909	2608.985	1148.214	1547.877
	3	2043.861	58.837	2608.985	1928.488	2159.234
MDM	1	735.235	19.540	2608.985	696.919	773.551
	2	1286.283	14.529	2608.985	1257.794	1314.772
	3	1934.627	13.245	2608.985	1908.655	1960.598
MDN	1	803.098	22.453	2608.985	759.069	847.126
	2	1336.103	11.254	2608.985	1314.036	1358.171
	3	1799.618	11.451	2608.985	1777.164	1822.072
MDS	1	675.453	17.080	2608.985	641.961	708.945
	2	1262.506	12.129	2608.985	1238.723	1286.289
	3	1722.211	15.838	2608.985	1691.154	1753.268
PAN	1	907.901	227.876	2608.985	461.064	1354.737
	2	1362.202	34.751	2608.985	1294.060	1430.343
	3	1732.067	39.080	2608.985	1655.435	1808.699

a. This level combination of factors is not observed, thus the corresponding population marginal mean is not estimable.

b. Dependent Variable: MEAN.

Table 3.4.3: Estimated marginal means for the interaction effect of the classes low, medium and high Total Integral values and the environmental zones.

F. Crossing with bio-physical variables

The mean and standard deviation of the sixteen years Total Integral index were correlated to the biophysical variables within the regions of the environmental classification (Table 3.4.4).

Adjusted R^2 of the linear regression model of the mean (Figure 3.4.3) reached 0.913 and the model was highly significant ($p < 0.000$, Table 3.4.4). The computed Durbin-Watson test value was just above 2 therefore the null hypothesis against the alternative hypothesis of negative first-order autocorrelation was tested. The computed value (4-2.031 = 1.969) was larger then the upper bound of the Durbin-Watson value with ten predictors and 48 observations therefore the null hypothesis of no autocorrelation of the samples was not rejected. The plots of the standardised residuals and of the normal probability indicated no violation of the normality assumption and there was o homoscedasticity in the data (see Appendix for the plots). The sixteen years mean of the seasonal permanent vegetation fraction was significantly explained ($p < 0.000$) by the October and August sunshine and by the mean June maximum temperature. November and March precipitation, the altitude, and the May and June sunshine were significant predictors on the $p < 0.05$ level.

Table 3.4.4: Regression statistics of the mean and the standard deviation of the Total Integral index.

Mean			**Standard deviation**		
Adjusted R^2	***Durbin-Watson***	***p***	***Adjusted R^2***	***Durbin-Watson***	***p***
0.913	2.031	0.000	0.917	2.280	0.000
Predictors			Predictors		
Mean October sunshine (p < 0.000)			Mean December minimum temperature (p < 0.000)		
Std. of November precipitation (p < 0.008)			Mean March maximum temperature (p < 0.000)		
Std. of March precipitation (p < 0.001)			Mean August sunshine (p < 0.000)		
Mean August sunshine (p < 0.000)			Mean September sunshine (p < 0.000)		
Mean June maximum temperature (p < 0.000)			Mean December sunshine (p < 0.000)		
Mean of the Altitude (p < 0.003)			Std. of February minimum temperature (p < 0.004)		
Std. of the May sunshine (p < 0.026)			Mean June sunshine (p < 0.000)		
Mean January sunshine (p < 0.003)			Std. of April minimum temperature (p < 0.000)		
			Std. of January sunshine (p < 0.001)		
			Std. of November precipitation (p < 0.002)		
			Std. of maximum July temperature (p < 0.045)		

The second regression model explained 92% of the standard deviation of the sixteen years Total Integral index (Figure 3.4.4) and was highly significant ($p < 0.000$). The computed Durbin-Watson value was larger then 2 thus the value 4 –

2.280 = 1.72 was computed. The test statistic was within the tabulated Durbin-Watson lower and upper bounds indicating no first order autocorrelation in the residuals and therefore trustworthy model significance. The standard deviation values were significantly ($p < 0.000$) predicted by the December and April minimum temperature, March maximum temperature, and the August, September, December, and June sunshine. February minimum temperature, January sunshine, November precipitation and July maximum temperature were significant on the $p < 0.05$ level.

4 Summary and discussion

This report aimed at inventorying characteristics of Mediterranean riparian-use zones using statistical analysis of some phenological indices calculated and mapped across the entire Mediterranean Basin from remote sensing time series. Riparian areas are in the focus because of their prime importance in offering potential for adapted agricultural land use and important ecosystem services. The quantity of vegetation cover present in these wider riparian-use zones has been proven to be directly dependent to adjacent land use and related to the functioning of the zone as wider riparian buffer (Cherlet, 2007; Ivits et al, 2008).

Green Vegetation Fraction 17 years data series, derived from spectral unmixing of NOAA NDVI time series, were used to calculate the start and end of growing season, based on an adaptation of the method of Reeds et al. (1994) after which a number of indices can be identified. These indices are assumed to be approximations for either permanently present vegetation cover or total biomass production. For the current report the following indices were analysed (see Figure 2.3):

- Seasonal Permanent Fraction (SPF): vegetation permanently present on the area in the growing season.
- Total Permanent Fraction (TPF): vegetation permanently present on the area throughout the whole year.
- Season Integral (SI): approximation of annual cyclic biomass accumulation following the seasonal growing pattern.
- Total Integral (TI): approximation of total annual biomass.

For the analysis of the indices and statistical description and inventory of their characteristics the following steps were performed and documented:

A. classification and area calculation
B. Descriptive statistics
C. Land Cover Characteristics
D. Trend analysis
E. Significance of Classes (LMM)
F. Crossing with bio-physical variables

In addition to the statistical analysis this chapter is complemented by a discussion of the spatial distribution of mapped indices and derived classes and final conclusions regarding the further utilisation of phenological metrics to characterise and monitor environmental conditions in sensitive key areas such as the riparian zone and possibly other vulnerable environmental areas.

4.1 Statistical description and inventory of selected phenology indices

A. classification and area calculation

Area distribution of the low, medium and high classes was similar for the phenological indices Seasonal Permanent Fraction, Seasonal Integral and Total Integral. For these indices the largest portion of the Mediterranean riparian-use zone, ca. 35 %, belonged to the medium class, the second largest area, about 33% belonged to the class grouping the highest values and the least surface was covered by low values. In case of the total permanent fraction however, the class with the lowest values covered the largest area (34 % or 70077 km ^{2}) followed by the medium class while the class with the high total permanent fraction values covered, 32% or 64462 km ^{2}.

Area distribution of the high, medium and low phenological classes. The numbers 1, 2, and 3 indicate the extent of area, i.e. 1=largest area and 3=smallest area.

Area class Index	SPF	TPF	SI	TI
High	2	3	2	2
Medium	1	2	1	1
Low	3	1	3	3

The three first indices are related to each other in the way they are calculated based on the derived start and end of season points on the time series curve. They are relative parameters and influenced by the accuracy of the algorithm to derive the index points and the behaviour of the seasonal aspects that define the curve. Therefore they are all dependent on the yearly season conditions that are correlated to the geographical position. The LMM results reflect very well this effect in showing presences and absences of the lowest class for the various eco-zones.

The total permanent fraction is independent from the calculation of the season starting point as it is based on the absolute minimum values in the time series curve. These minima are however influenced by sensor and pathway characteristics and not necessarily reflect the stable minimal value over the pixel. Furthermore, this index is also not season dependent and minimum values are more homogenous for the whole areas. Their classification inherently includes this homogenous aspect and this is reflected by the LMM analysis showing a more equal distribution of all classes for all the geo/eco-zones.

B. Descriptive statistics

While the minimum, maximum and mean of the phenological indices naturally followed the same distribution pattern in the classes 'low', 'medium' and 'high' the standard deviations of the indices were different.

The standard deviation of the Total Permanent Fraction classes was higher than the standard deviation of the Seasonal Permanent Fractions. This is probably due to the fact that the TPF covers a larger area under the time series curve resulting in higher descriptive statistical values. On the other hand the lower variation of the SPF index might also be due to the calculation with Moving Average statistics where the influence of sensor characteristics and variable observation geometry/pathways (as mentioned above) are expected to be significantly reduced, hence the SPF appears more stable throughout the years with lower standard deviations.

For the permanent fractions highest variation occurred in the class 'high' while for the total biomass and for the Seasonal Integral highest variation was observed in the class 'low'. This is probably due to the fact that the area of the Total Integral and the Seasonal Integral parameters under the time series curve include the area of the permanent fractions. In the 'low' class the underlying permanent fraction dominate more hence causing high variation in the SI and TI parameters. In the 'High' class of these indices the influence of the permanent fractions is lower resulting in lower standard deviations.

C. Land Cover Characteristics

1. Northern Mediterranean based on the GLC 2000.

- ***High and Medium value classes:***

The land use class 'cultivated and managed areas' had the highest area share in the medium and high categories of all the phenological indices. This class includes not only annual crops but also managed lands, which have mostly semi natural characteristics, such as agro-silvo-pastoral systems e.g. Dehesa or Montado, or cultures that are nearly permanently vegetated, such as important tree crops (e.g. olives, citrus plantations, etc). Hence it is along the expectations that this land use class is reflected by the high and medium values of all indices, i.e. there is a considerable amount of permanent vegetation often coinciding with pronounced cyclic or seasonal growth, as in many Mediterranean agricultural systems multiple cropping is used to extend the scope in view of optimal economic production. The fact that the classification clustering corresponds to this logic for all the 4 indices, confirms the intrinsic sensitivity and validity of their behaviour.

Deciduous trees covered the largest area next to cultivated and managed areas for the high values of the seasonal permanent fraction, seasonal integral and total integral classes. For the Total Permanent Fraction however *Deciduous shrubs* covered the second largest area in the high value class. *Deciduous shrub cover* was also dominant in the middle class of all the phenology indices next to the *Cultivated and managed areas*. The area share of **other land cover** was ignorable in these two classes.

- ***Low value classes:***

Sparse herbaceous or sparse shrub cover represented the largest area in the low phenological value class. This class in GLC 2000 is defined with a remarkably low ground cover between 1 % and 20 % and therefore it is reasonable that both a low amount of seasonal or permanent vegetation is associated the most to it.

Cultivated and managed areas shared another high percentage in the low value class of the Seasonal and Total Permanent Fractions. This class is supposed to represent primarily areas dominated by annual crops or intense forms of permanent/tree crops cultivation with intensive management practices (e.g. olive cultivations) manifesting in the removal of any spontaneous vegetation/understory and hence is characterised by relatively low levels of permanent fractions and low biomass accumulation during a growing season respectively throughout a full year. The Total and Seasonal Integrals however were more indicative for the deciduous shrub cover. This is probably due to the fact that these indices reflect the total amount of accumulated biomass throughout the entire period of vegetation growth, respectively the entire year, which in environmental conditions with limited potential for vegetation growth should be typically higher for semi-natural land cover than for the above mentioned managed land cover types.

This result further indicates that a broader interpretative level in terms of bio-physical/functional differentiation of some land cover classes can be obtained by using the phenological indices.

2. ***Southern Mediterranean based on the GLC 2000 African Land Cover.***

- ***High value class:***

Deciduous forest land cover dominates the high value classes of phenological with over 60 % and reaching even a maximum of 70 % for the classified Seasonal and Total permanent Fractions.

Croplands also covered a considerable area and seem to correlate the most to the seasonal integral index since 32 % of its high value class belonged to this land cover while in the other phenological indices the area share was around 20 %.

Shares of other land cover types did not reach considerable levels, respectively not even their totals reached 5% of representation in the class.

- ***Medium value classes:***

Croplands were the dominant land cover type in pixels with medium values for the Seasonal Permanent Fraction, Seasonal Integral and Total Integral indices.

Deciduous shrubland covered the largest area of the medium values of the total permanent fraction index.

These results confirm for the southern Mediterranean that the seasonal vegetation behaviour is mostly characterised by the integrals under the curve and by the permanent fraction defined by the start of season and end of season points. In other words the permanent vegetation offset is associated with the seasonal behaviour of vegetation phenology.

On the other hand deciduous shrubland, though also showing a cyclic pattern, is more related to the total permanent vegetation fraction index. This indicates higher amounts of permanent shrubs contributing to this land cover type as in the case of croplands, which is in line with known characteristics of South Mediterranean shrublands.

- ***Low value class:***

Sparse grassland dominated the low value class of all the phenological indices. This land cover type has low cyclic performance as represents sparse or open vegetations, meaning low ground cover and low biomass production. Due to this also their permanent vegetation cover can be expected to be low as well.

In summary, the behaviour of the cluster classification of all studied phenological indices seems to be logically related to the various land cover types. Hence, in complement they could increase the further characterization, distinction and interpretation of the various land covers.

D. Trend analysis

Most of the riparian-use zone expressed no trend of the phenological indices. This holds for about 75 % of the area for all 4 indices. A negative trend occurs only in 2 to 5 % percent of the area for all indices, while equally around 20 % of the riparian-used zone expresses a positive trend. The reason for this could both be climate driven or anthropogenic as is indicated also by the linear regression analysis with the biophysical (precipitation and temperature) variables and land use/cover classes. The latter could be a function of improved farming practices together with more field residuals or land abandonment. Similarly, negative trends should be further validated as to what they could be attributed to, as for instance the processes of land degradation.

Trend	SPF % area	TPF % area	SI % area	TI % area
None	75	75	77	74
Negative	3	5	2	3
Positive	22	20	21	23

In this context maximum residual analysis of a linear trend model is a useful tool not only to detect outliers in the data (in the phenological indices in the present case) but also to assess the level of magnitude of occurring true extreme values throughout the observed time period.

Most of the riparian-use area (over 65 %) expresses high positive and negative residuals. The high negative residuals in principal should indicate areas which were affected at least once by significant disturbance of vegetation cover over the explored time period, either due to natural reasons e.g. drought events and wild fires, or due to direct human intervention e.g. crop change etc.

The statistical analysis for instance shows, that cultivated and managed areas exhibit the highest **negative** model residuals of all four phenological indices, which may indicate a higher sensitivity/reactivity of managed areas to short term disturbance compared to areas with pre-dominance of semi-natural vegetation cover, primarily reflecting the adapted response of Mediterranean land use systems to the high natural climatic inter-annual variability.

On the other hand, sparse herbaceous or shrub cover, typical of dry-land semi-natural vegetation, shows the highest **positive** residuals for the seasonal permanent fraction, seasonal and total integral indices, which corresponds well to the known adaptation of these plant communities to the high inter-annual variability of rainfall availability in the Mediterranean region.

In conclusion it can be stated that the observed multiple occurrence and statistical distribution of high value residuals appears to reflect primarily the known inter-annual variability of vegetation growth conditions in the Mediterranean region, which is expressed both in the high inter-annual dynamics of semi-natural vegetation types and in the traditionally applied highly dynamic land use systems.

E. Significance of classes (LMM)

The classes 'low, medium and 'high' and the environmental zones were significantly related to the phenological values in the Mediterranean. Furthermore, the interaction of these variables, i.e. the environmental zones in which the classes were located, also had a significant effect on the phenological indices. This indicates that, as expected, the Mediterranean is not homogenous as measured by the seasonal and total permanent fractions, and by the total biomass and seasonal integral indices. Within the different environmental zones in the

Mediterranean the three classified categories of these indices were statistically different. Pair-wise comparisons of the three categories revealed that all the three classes, low, medium and high were significantly different in their phenological values. This reveals the validity of the classification of the Mediterranean riparian zone because the assigned categories do not overlap.

F. Crossing with bio-physical variables

The mean and the standard deviation calculated from the sixteen years of phenological indices were correlated to biophysical variables within the regions of the second level environmental classification (84 classes) by means of a least squared linear regression. This analysis served, on one hand, as a first step in a validation of the methodology deriving phenological information from remotely sensed data because high adjusted R^2 values would support the assumed link between phenological events and climate. On the other hand the corresponding analysis respecting the selected explanatory variables (biophysical variables) facilitates the interpretation of phenological indices with respect of their response to precipitation, sunshine or temperature data. Considering the resolution and the nature of the indices, it is clear that validation against e.g. field observations or similar observations from high resolution satellite data is hardly relevant. Therefore in this context, 'validation' is to be understood as a convergence of evidence from various analysis procedures considering more ancillary datasets than included yet in this study.

The mean of the phenological indices were better explained by the biophysical variables than their standard deviations. Highest adjusted R^2 values were reached by the mean of seasonal integral index, the goodness of the model fit reached 0.941. The mean of the total integral and the seasonal permanent fraction was explained up to 91 and 84 % while for the total permanent fraction index 78 % of the variation was explained by the independent variables. All the models were highly significant on the $p < 0.000$ level and the Durbin-Watson statistic indicated no autocorrelation in the data. Plots of the residuals approximated the normal distribution and there was no homoscedasticity in the data.

These statistics indicate very good model fits and support the assumption that phenological indices derived from time series of remote sensing follow biophysical events that define real world vegetation phenology.

The tables below list the biophysical parameters that best explain the values if the indices.

Index	***Best correlation with***
Seasonal Permanent Fraction (SPF mean)	Sunshine (spring, summer and autumn)
	Precipitation (spring and autumn)
Total Permanent Fraction (TPF mean)	Precipitation (spring, late autumn)
	Temperature (winter min., spring max)
Seasonal Integral index (SI mean)	Sunshine (spring, summer and autumn)
	Temperature (winter and summer maxima)
	Precipitation (summer)
Total Integral index (TI mean)	Sunshine (4 seasons)
	Precipitation (winter and spring)
	Temperature (summer maxima)

Thus it seems that the amount of permanent vegetation in general depends primarily on precipitation. However, the season depending calculated permanent fraction (SPF) strongly react on the amount of sunshine while the permanent fraction (TPF) calculated as season independent, measured between the absolute minima, is more influenced by the maximum spring and minimum winter temperatures.

Interesting that while the permanent fraction (TPF) is dependent on minimum winter temperatures the seasonal integral index (SI) rather reacts on the maximum of the winter and summer temperatures. It seems that in order to explain the growing season the amount of spring, summer and autumn sunshine is indispensable as both the seasonal permanent and the seasonal integral indices are dependent on these variables. However, while the seasonal permanent fraction reacts on precipitation as well, in order to explain the amount of vegetation within the growing season the summer and winter maximum temperatures will be also needed. The total integral index was significantly explained by the sunshine of the four seasons, spring and winter precipitation and by the summer maximum temperature. This index describes the total biomass in a year and due to the more complex curve probably biophysical parameters of all the four seasons are needed. Probably this is why the seasonal integral values are explained only by the summer precipitation, but for the total biomass precipitation values in the spring and winter were needed.

4.2 Discussion on the spatial distribution of mapped indices, derived classes and trends

For each of the four phenological indices a set of six Mediterranean-wide riparian zones maps was produced, providing a 1km spatial resolution representation of:

Map produced for each of the indicators: *Document page numbers*	SPF	TPF	SI	TI
(1) 1989-2005 mean	*29*	*45*	*61*	*77*
(2) 1989-2005 Standard Deviation	*30*	*46*	*62*	*78*
(3) class (low, medium, high) distribution	*31*	*47*	*63*	*79*
(4) trend (1989-2005) significance	*34*	*50*	*66*	*82*
(5) trend high residuals for riparian zones	*35*	*51*	*67*	*83*
(6) trend low residuals for riparian zones	*36*	*52*	*68*	*84*

Overview giving the page numbers in this document where Maps produced for each of the indicators can be found.

The maps of the index means of the Seasonal and the Total Integrals (SI and TI) primarily represent the known principal climatic gradients of vegetation amount and productivity across the Mediterranean region. The Northern Mediterranean is typically characterized by a considerably uniform distribution of high amount of mean annual green biomass in its central parts (South France, Italy, the Balkans and Greece). High amounts of vegetation occur as well in its Western/North Western (NW-Spain and Portugal) and in the East in the Northern and Western parts of Turkey. Less productive regions are particularly the Central and South Eastern Iberian peninsula, representing the most arid conditions of Mediterranean Europe, and Anatolia characterised by dry continental conditions.

In the Southern Mediterranean the SI and TI maps typically reveal the narrow margin of productive land along the coastal zone of the Western part of North Africa reaching from Tunisia to Morocco, where the zone includes the Atlas mountains and thus extends further to the south. South of the margin vegetation amounts rapidly decrease reaching quickly the arid and hyper-arid conditions of the Sahara. In the Eastern part of North Africa, comprising Libya and Egypt, desert conditions reach to the Mediterranean sea, hence the coastal productive margin is much less pronounced, respectively widely lacking, while the high productivity area under the specific conditions of the Nile valley and especially the delta is clearly exhibited.

Also in the east of the Nile Delta in the Sinai and Negev region vegetation is almost missing. The eastern shore from Israel, Palestine up to Lebanon and finally to Syria and its border to Turkey is again characterised by a narrow strip of productive land parallel to the coast, showing a strong gradient of aridity towards east. In the southern parts it rapidly reaches hyper-arid conditions in the Death Sea depression and the Arabian desert, while the gradients gets wider and less pronounced towards North, where the productive areas are more extended towards east including the Jordan valley and the Lebanon mountains with a more gradual transition from Mediterranean coastal conditions to semi-arid conditions of the Syrian steppes.

The temporal mean maps of the Seasonal Permanent (SP) and Total Permanent (TP) vegetation show a considerable higher complexity of the vegetation pattern. Other than the first two maps of mean total vegetation, they give an expression of the mean permanent or minimum amount of vegetation present in a pixel. While the overall climatic gradients remain still evident much more local differentiation of vegetation is apparent. In both cases the same types of pattern appear, however more emphasized in the TP map. The general differentiation represents not only higher or lower amounts of permanent vegetation, but inherently primarily distinguishes between areas with higher or lower shares of cyclic behaviour of vegetation cover. This cyclic behaviour indirectly links with shorter or longer annual periods of vegetation growth and is a function of local climate conditions, type of vegetation cover and indirectly even land use/management practice.

Thus the areas with strong annual cyclic vegetation behaviour are much more pronounced in the SP and TP maps. This is for instance clearly demonstrated in the pronounced appearance of the alpine region, the more emphasized large cereal growing areas in Central Spain/Castilla la Mancha, the large arable areas in Bulgaria and Romania but also the smaller structures of in Southern Italy (Sicily, Sardinia or Apulia). Other specific situations such as periodically flooded cultivations (extended rice cultivations) of the Andalusian Marismas or the rice area west of Milan are clearly revealed. Also in Northern Africa and in the eastern Mediterranean structures like the intense agricultural production areas of Northern Tunisia or the climatic gradient in Israel/Palestine are displayed in a more differentiated way than in the SI and TI maps.

This higher, more complex, but nevertheless logical differentiation of vegetation patterns is further enhanced in the maps displaying the Standard Deviations of the four tested indices. In all four cases mean standard deviations are low in areas with low overall vegetation amounts and in areas which are characterised by strongly pronounced seasonal vegetation development. Areas with high amounts of permanent vegetation reveal higher levels of mean standard deviations. Not withstanding the fact that absolute values are generally higher in areas with high vegetation cover. This may be additionally explained by the algorithm used to calculate the indices that primarily determines minimum values and barycentre of the annual curve of vegetation growth cycle, and thus introduces higher variability in the metrics in areas which are characterised by high amounts of vegetation associated with apparently less pronounced seasonal variability. In addition, the used NOAA AVHRR time series features, despite of careful radiometric and geometric pre-processing, still contain a considerable level of residual noise due to differences in atmospheric and especially illumination conditions. This indeed has a stronger impact on the reflectance of densely vegetated pixels than on relatively bare ones. Hence, the standard deviation maps contain useful information on functional and structural differences of different types of vegetation cover.

Other than the previously discussed maps, the index classification has been performed exclusively for those pixels shaping the two km wide riparian zones of the drainage network convergent with the Mediterranean Sea (excluding he Nile basin). The classification distinguishes for each index three levels of abundant vegetation where SI and TI are an approximation of overall productivity, while TPF and SPF also contain information on relative proportions of permanently present vegetation in relation to those vegetation elements that follow a strong annual cycle. In all the four maps the main apparent class distribution reflects again the large climatic gradients throughout the Mediterranean basin. The northern Central Mediterranean shows the highest concentration of decreasing vegetation. Hence predominance of the low phenology index classes towards the more arid areas is shown, e.g. in the SE of the Iberian Peninsula and towards Turkey in the North East. North Africa and the Middle East coast are clearly also dominated by the low values class.

Comparing the TPF classes with the TI class distribution it becomes evident that the TPF reveals a higher level of local distinction over areas where this permanent fraction is low but that have considerably high productivity as is visible from the TI classes. E.g. in Northern Italy the TPF highlights the high intensity agricultural areas of the Po plane. Similar observations, though less pronounced, can be made in the Sicilian cereal growing areas or in Apulia and Basilicata regions of Italy. The other way round, the TPF shows to some extent relatively high class assignment combining high levels of permanent vegetation in low and moderate productivity/TI classes of SE-Spain. This may represent the increase of semi-natural shrubs in areas known to suffer from land abandonment.Generally these observations correspond to the statistical evaluation of the phenological indices versus the main land cover classes as described in section 4.1 above.

The above clearly indicates that the two types of phenology indicators TI/SI and TPF/SPF provide different aspects of vegetation information which are however logically associated, coherent and complementing each other. Hence, as next step, there is clear scope to move to a classification scheme combining different phenology metrics. This would significantly enhance the discriminative power of classification schemes for mapping more homogeneous units on the basis of vegetation structure and functioning.

For all 1 km pixels inside the classified 2 km wide riparian zone the linear trend of each of the four phenological indices was calculated over the 16 years observation period. The trend was displayed in four Mediterranean wide maps (1 per phenology index) each map showing three classes of trend significance (no trend, significantly positive trend and significantly negative trend). All 4 maps reveal a highly congruent spatial pattern of trend distributions, where the vast majority of all pixels (ca. 75%) don’t show any trend. About 20% (20-23%) show a significantly positive trend and only about 5% (2-5%) show a significantly negative trend. The spatial distribution of positive and negative trends apparently provides evidence of the explored statistical correspondence between the trends, the available bio-physical variables (precipitation, temperature, sunshine and terrain) and the land cover/land use information.

The majority of the negative trend pixels are concentrated in a few clusters in the Southern and Eastern Mediterranean Basin. The 3 major ones are located in S-Tunisia in the Gabes-Djerba-Medenine region, the small productive zone along the Libyan coast and in the Sinai-Gaza/S-Israel region. In these three areas all four indices show a negative trend. All the three regions are known to suffer from degradation/desertification due to loss of productive land owed to overexploitation in conjunction with urban expansion, expansion of tourism and agricultural intensification of marginal lands. Diverging interplay of trends of seasonal vegetation variables and permanent vegetation components even appears to explain some specific situations in the Libyan Bengasi area, with apparent extension of irrigated areas, and in the area of Damaskus in Syria, where agricultural intensification may be indicated by a reduction of permanent vegetation combined with stable or even increasing trends of total and/or seasonal biomass trends.

The more abundant positive trends appear in their majority concentrated in the Northern Mediterranean, with one significant exception in the South-west Mediterranean comprising the western parts of Algeria and their continuation into eastern Morocco. In the North, positive trends of all four indices coincide particularly in the headwaters of the western Alps, northern Greece and Bulgaria and, to a lesser extend in Turkey and the margins of the Ebro Basin in Spain. These positive trends clearly indicate the well known development of extensification, if not abandonment, of the traditional mountainous agro-silvo-pastoral land use systems. Clearly, different situations are indicated in the northern Italian Po-plane, where we observe a widespread increase of permanent vegetation component, with a widely stable situation of the seasonal components and partial increase of total biomass. In this particular case there is high probability that the change indicates the substantial modification of agricultural practice in a highly productive farming system as an impact of the changing EU common agricultural policy. The opposite combination of positive trends prevails in the south-west Mediterranean case. Here the positive trends indicate a coinciding increase of total biomass and seasonal vegetation components, which may hint at an increase of agricultural/pastoral production during the observation period.

4.3 Conclusions

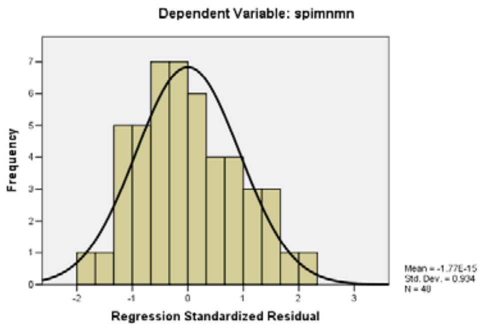
In summary we can confirm that the phenological indices derived from low resolution remote sensing time series:

- are objectively calculated and repeatable
- have values following a logical geographic distribution in correspondence to the natural gradient of environmental zones as well as to the known associated characteristics of land use/land cover systems
- are correlating well with the biophysical conditions that are crucially defining real world plant phenology
- are logically related to main land cover types and can help explaining variations depending on e.g. different land use practices
- show observable trends that can help explaining the evolution of land conditions due to climatic and anthropogenic influences
- provide a basic dataset that significantly and relevantly characterizes some aspects of the riparian-use zones
- can be used in complement with other data to assess and monitor dynamics and stresses of the riparian-use zones.
- have a high potential to allow for a more functional classification of riparian zone vegetation by using combinations of phenological indices and their respective trends.

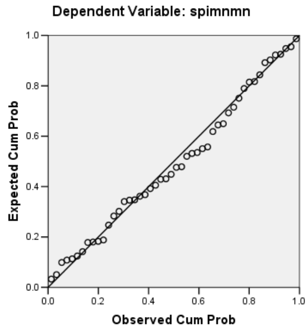
Appendix – Regression diagnostic

1 – Seasonal Permanent Fraction

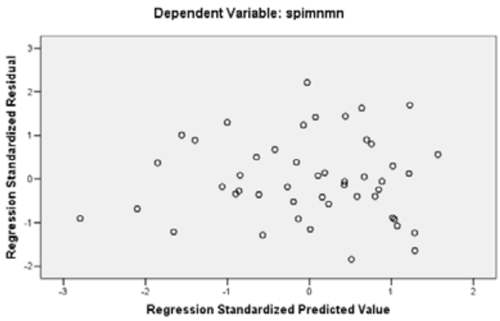
Regression with the mean of the SPF and the biophysical variables.



Histogram of standardised residuals

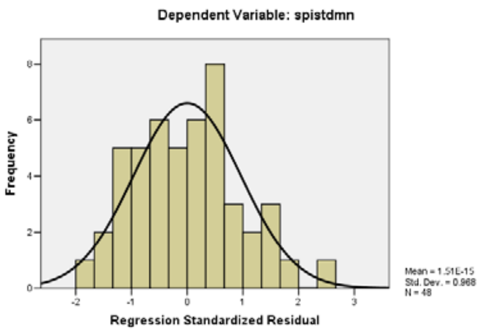


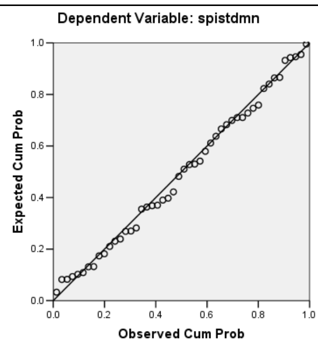
Normal probability plot

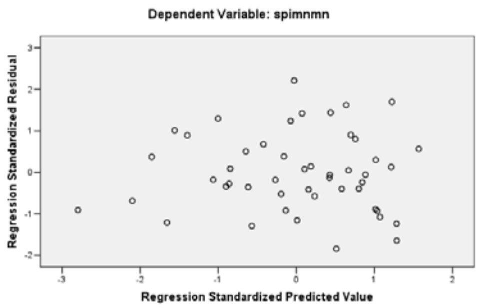


Standardised residuals vs. standardised predicted value

Regression with the standard deviation of the SPF and the biophysical variables.



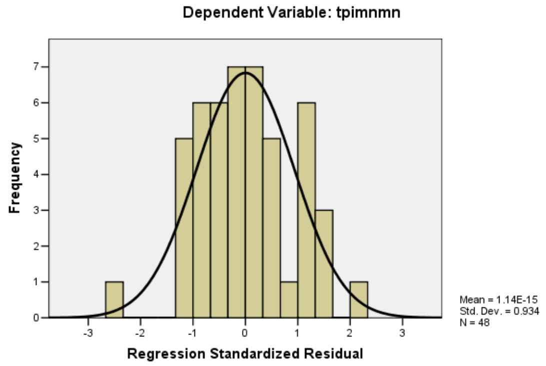




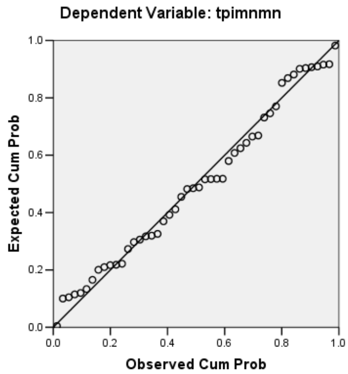
Standardised residuals vs. standardised predicted value

2 – Total Permanent Fraction

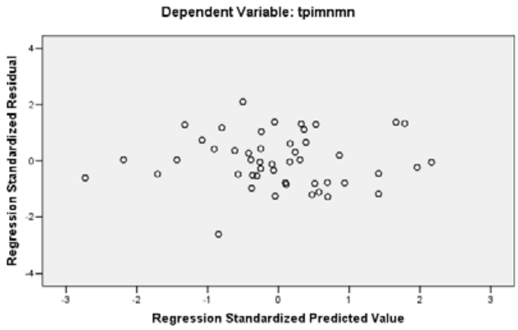
Regression with the mean of the TPF and the biophysical variables.



Histogram of standardised residuals

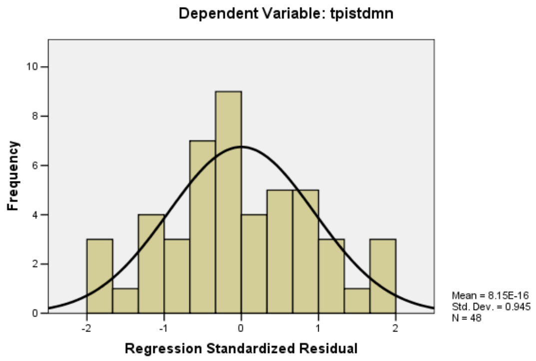


Normal probability plot

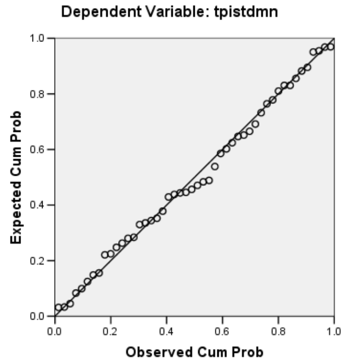


Standardised residuals vs. standardised predicted value

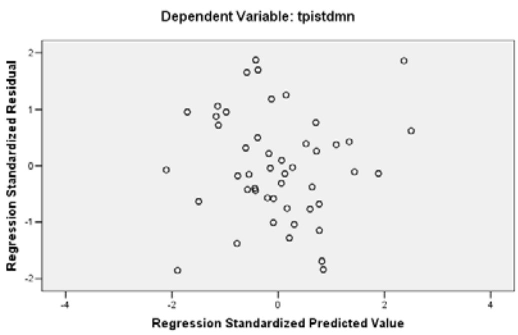
Regression with the standard deviation of the TPF and the biophysical variables.



Histogram of standardised residuals



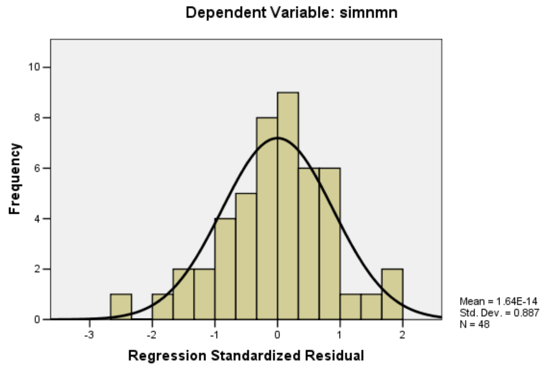
Normal probability plot



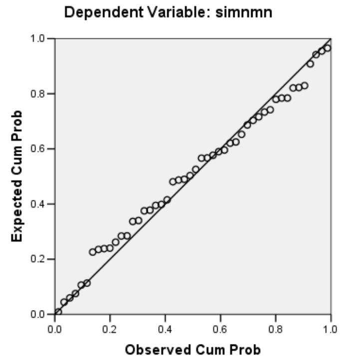
Standardised residuals vs. standardised predicted value

3 – Seasonal Integral

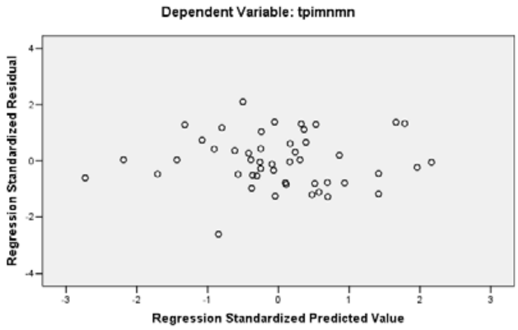
Regression with the mean of the SI and the biophysical variables.



Histogram of standardised residuals

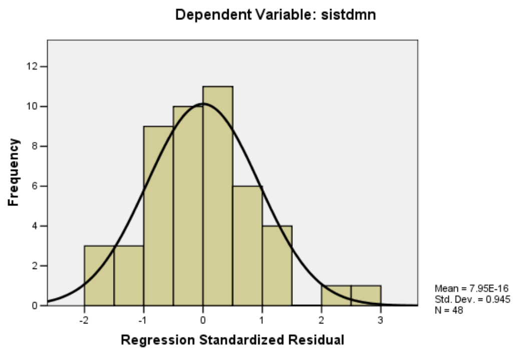


Normal probability plot

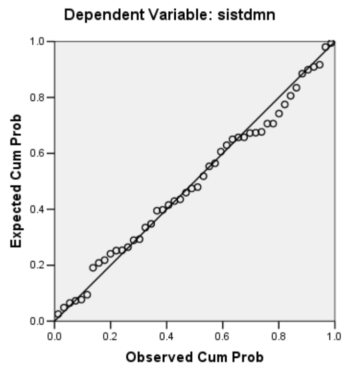


Standardised residuals vs. standardised predicted value

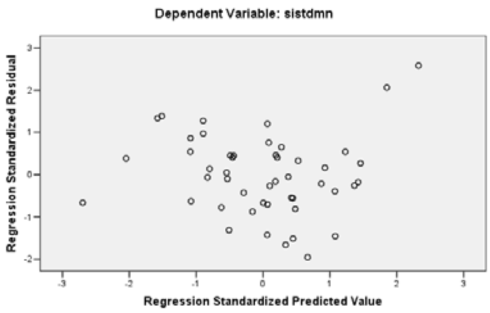
Regression with the standard deviation of the SI and the biophysical variables.



Histogram of standardised residuals



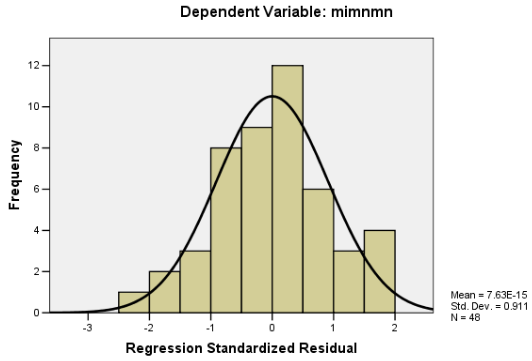
Normal probability plot



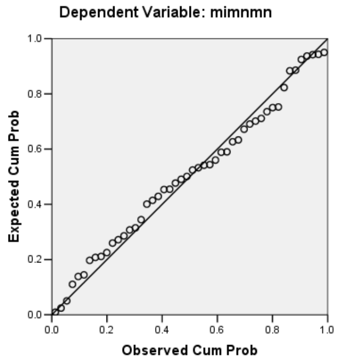
Standardised residuals vs. standardised predicted value

4 – Total Integral

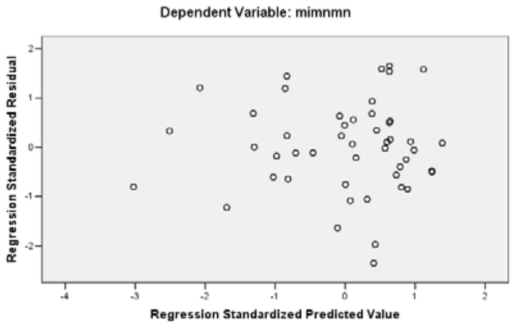
Regression with the mean of the TI and the biophysical variables.



Histogram of standardised residuals

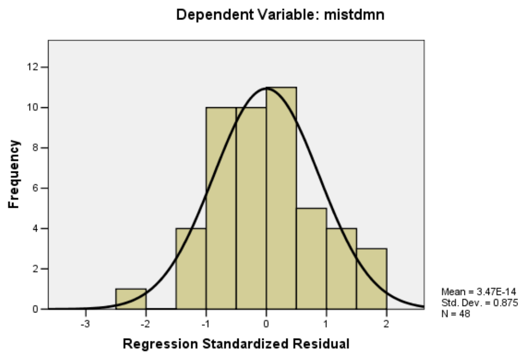


Normal probability plot

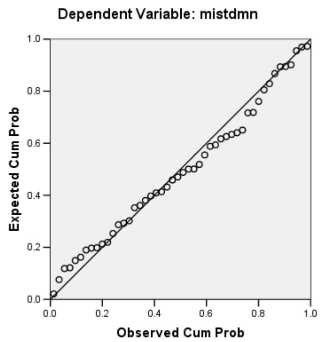


Standardised residuals vs. standardised predicted value

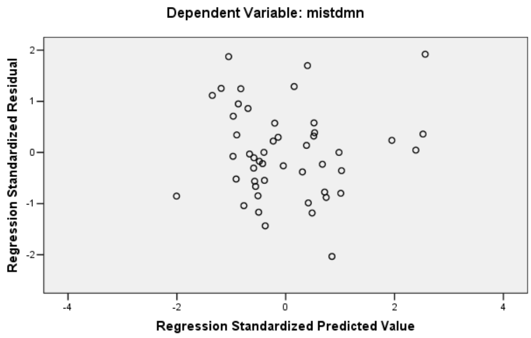
Regression with the standard deviation of the TI and the biophysical variables.



Histogram of standardised residuals



Normal probability plot



Standardised residuals vs. standardised predicted value

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Abstract
This report aimed at inventorying characteristics of Mediterranean riparian-use zones using statistical analysis of some phenological indices calculated and mapped across the entire Mediterranean Basin from remote sensing time series. Riparian areas are in the focus because of their prime importance in offering potential for adapted agricultural land use and important ecosystem services. Green Vegetation Fraction 17 years data series, derived from spectral un-mixing of NOAA NDVI time series, were used to calculate the start and end of growing season, based on an adaptation of the method of Reeds et al. (1994) after which a number of indices can be identified that can be used in complement with other data to assess and monitor dynamics and stresses of the riparian-use zones.

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