Relation between Climate, Agricultural Land Cover and Bird Richness in a Mediterranean Natura 2000 Wetland

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ABSTRACT

In this study we explore for the first time the combined effect of climate variables and remote sensing land cover indicators on bird richness in a representative wetland location of the Thermaikos gulf Natura 2000 protected area in Northern Greece. In particular the association between bird diversity and climate, as well as remote sensed land cover indices was explored for seven successive seasons using correlation analysis and a Cox-Box transformed multivariate linear model. Three climate variables were tested, mean temperature, rain level and mean relative humidity and three land cover indices, the Normalized difference index (NDVI), the atmospheric resistance vegetation index (ARVI) and an agricultural band combination index (ABCI). Among the environmental drivers explored, temperature, rain levels and ABCI were significantly correlated to bird richness in contrast to NDVI and ARVI which showed a lower correlation, while relative humidity displayed the poorest correlation. Thus, temperature, rain levels and agricultural intensity significantly influenced bird composition. Additionally, the multivariable linear model indicates that temperature, rain levels and ABCI have a statistically significant effect (p<0.05) on bird species richness accounting for 73.02% of data variability. Based on the overall model results and the related 3D contour plot simulation we can conclude that in general, bird species richness increases with an increase in temperature and Rain, as well as with a decrease in agricultural intensity (ABCI). Understanding the factors that can affect bird biodiversity of species is of great importance in ecosystem management and species conservation.

Keywords: ARVI, Biodiversity, NDVI, rainfall, temperature.

I. INTRODUCTION

Agriculture is the main driving force that influences the topographic and biological diversity of Europe, shaping the natural landscape of the European countryside for thousands of years [1], [2]. Rural land covers 42% of the total area of Europe and 50.5% of the EU territory (of 15 countries). Rural ecosystems in Europe maintain 173 priority bird species, the highest number of priority species of any other ecosystem, many of which are directly dependent on agricultural activities to complete their biological cycle. 70% of these species (116 species) are under Unfavorable Conservation Status due to the dramatic reductions of their populations.

To mitigate the decline in biodiversity, Europe has established the Natura 2000 network to protect threatened species by providing a core of breeding and resting sites [3]. The network stretches across all European member states with the aim to ensure long term sustainability of species and habitats, listed under the Birds and Habitats directives. Yet, in the last 4 decades, birds – but also the biodiversity of Europe's agro-ecosystems as a whole - have undergone a dramatic decline, which is mainly due to the intensification of agriculture and climate change [3]. Furthermore, the distribution of many species in Europe is expected to be influenced due to identisification of agriculture and related human activites. It has been found, for example, that the decline in partridge populations in the UK - by 85% in the last 20 years - is due to increased mortality of chicks during the breeding season due to a decrease in invertebrate populations, which is their main food, from the extensive use of pesticides and especially insecticides in cereal crops [4].

In Greece, particularly, the intensification of agriculture in the Greek countryside, which has occurred in the last twenty years, caused significant changes in the landscape characteristics of natural habitats [5], [6]. However, apart from the intensification of agriculture, bird biodiversity may be affected due to climate change which may modify landscape characteristics, especially the availability and quality of wetlands, as well the composition of related food networks including plants and arthropodes [7].

Considering that nowadays on third of the available land to be exploited in Europe is occupied by agriculture, the study of the composition of bird populations in rural ecosystems is of great importance. Additionally, the detection of changes in farm bird populations indicate whether the various land uses are sustainable and serve as indicators of wider ecological change [8]. However, the detection of relations between climate relate landscape characteristics and species biodiversity is a difficult task considering that its virtual impossible to perform detailed field observations and detect
landscape changes over large areas. Fortunately, the last decade information obtained from earth observation (EO) platforms can be used to detect temporal changes in climate and landscape over large scales and to be further related to biodiversity data and to help inform policies that conserve and/or enhance biodiversity assessment and conservation planning over large regional and continental scales [9].

More recently the use of remote sensing technologies has been introduced to detect spatiotemporal changes in landscape characteristics and species biodiversity in relation to climate [10]. By definition, remote sensing is intended to gather information about an object or an area, without coming into contact with it, something that is done with ground sensors, satellites or aerial photographs and geographical information systems. In this context several climatic and vegetation indices are used to detect spatiotemporal alterations in a particular regions of interest. Vegetation indices are mathematical combinations of channels (spectral regions), with the best known of which being the normalized vegetation difference (NDVI) [11]. NDVI to date has become commonplace in biodiversity research in part due to its relationship to several environmental and biophysical processes such as potential evapotranspiration, photosynthetically active radiation, leaf area index, and net primary production [10].

The aim of the current research is to investigate the effects of climate factors, including temperature, relative humidity and rain, as well as agricultural landscape characteristics, on the bird richness in an important Natura 2000 wetland side in Northern Greece. Particularly, we estimate various measures of landscape spectral heterogeneity using several plant productivity and agricultural landcover indexes as predictors of field-based measures of bird biodiversity in representaive semiagricultural Natura site in northern Greece. Understanding the factors that can affect the biodiversity of species in an area is of great importance in ecosystem management and species conservation.

II. MATERIAL AND METHODS
A. Study area, Landscape and Species Characteristics
The current study is performed in the wetland complex of the Thermaikos gulf Natura 2000 protected area in Northern Greece and particularly in the Axios Delta National Park - Loudia – Aliakmonas, with an area of 338 sq.km., which includes the deltas and estuaries of the four rivers, the lagoon of Kalochori and Aliki Kitros, the wetland of Nea Agathoupoli and the riverbed of Axios to and Ellis. The wetland, which is the core of the protected area, is surrounded by irrigated and non-irrigated crops, mainly cereals, and meadows, while in the area there are also small grasslands along with mosaic of lotic and lentic water systems having complex ecosystem of seasonally flooded grassland and pastures. The protected area has high biodiversity and in there have been recorded 297 species of birds, 66% of the species observed to date in Greece, of which 106 nesting, 350 species and subspecies of plants, 40 species of mammals, 18 species of reptiles 9 species of amphibians in 25 habitats, two of which are priority habitats at European level [12].

B. Acquisition of Satellite Images
Landsat 5 satellite images were used for estimating the different land use indexes. Landsat-5 imagery was used because of its ubiquity, long-period of record and image availability, fine spatial resolution (30m pixel) in relation to the size of crop fields within the study area. In addition, the Landsat scene covered in most cases the entire study area and thus eliminating the need for radiometric and geometric calibration across multiple images.

Image acquisitions were obtained from the US Geological Survey (USGS) earth explorer and the Land Processes Distributed Active Archive Center (LP DAAC; http://lpdaac.usgs.gov) [13]. We have used different images from 2006 to 2011 and they were selected depending on their acceptable quality (i.e., clouding coverage, thermal anomalies etc.) and also so that they correspond the season of high crop production and bird population activity, especially during the summer season.

To enable to differentiate that there was no significant change in the amount of natural vegetation and irrigated lawns during the growth season, we have performed a preliminary analysis of more than one images for each month and for the particular area of interest. In the next stage we have decided to keep those pictures with had acceptable quality to be further analysed. Thus, we covered a time frame from spring till fall during the season of high bird activity and plant growth while other dates that had either partial or total cloud cover, obscuring a majority of the study area were excluded.

C. Image Processing
Three different land cover indicators were estimated from the satellite images: the normalized difference vegetation index (NDVI), the atmospheric resistance vegetation index (ARVI) and the Landsat agricultural band combination index (ABC1).

The NDVI is a standardized vegetation index [14], which is based on chlorophyll absorption in Red band and the relative high reflectance of vegetation in the near infrared band (NIR) and is calculated as follows:

\[ NDVI = \frac{[NIR-VR]}{[NIR+VR]} \]  

(1)

where NIR and VR, are the near infrared (Band 5: 0.845 to 0.885µm) and visible red (Band 4: 0.630 to 0.680 µm) wavelengths, respectively. The result of this formula generates a value between -1 and +1. For example, a low reflectance (or low values) in the red channel and high reflectance in the NIR channel, will yield a high NDVI value and vice versa.

The ARVI index is an improved NDVI index, which is used to correct the atmospheric influence and was used as a complement to NDVI to take into account possible influences pollutant aerosol contents and large dust partials of the nearby industrial area of Thessaloniki. The ARVI index is calculated as follow [15]:

\[ ARVI = \frac{[NIR-(VR-1)]+[VR-VR]}{[NIR+(VR-1)]+[VR-VR]} \]  

(2)

where VB is the visible blue wavelength (0.450 to 0.515 µm) and y is atmospheric correction index (here equal to 2). As
shown in equation 2, a lower sensitivity of ARVI to atmospheric effects is accomplished by a self-correction process, for the atmospheric effect of the red channel based on the difference in the radiances between the blue and the red channels to correct the radiance in the red channel [16].

Finally, we have applied a composite Agricultural Band Combination Index (ABCI) of a short wave infrared (SWIR1), near infrared (NIR, B5) and blue (B2) wavelengths with fixed stretch on apparent reflectance. The method is based on cutting off the upper 2% and the lower 2% values of the cumulative curve [17]. The advantage, compared to the other indexes, is that ABCI is useful for the monitoring of crops which appear as vibrant green. Thus, bright green represents healthy and vigorous vegetation, while non-crops, such as mature trees, appear in a dull green and deciduous forests appear as bright green, while sparsely vegetated and bare areas appear brown and mauve.

Image processing analysis and map development was performed using a combination of software’s including ILWIS, QGIS and Land viewer [18, 19, 20].

D. Weather Variables and Bird Sampling Data

The climate of the study area is classified as Csa Mediterranean climatic type [18] with long, hot, and dry summers (the mean maximum temperature lies often in the range of 29.0 and 35.0 degrees of Celsius), relatively mild and rainy winters, and average annual air temperatures of approximately 15 °C. In this work we have used climate data that were obtained by the national observatory of Athens. The climate data included the mean, max and min temperatures (in Celsius), daily precipitation (in mm/m²), and wind speed (km/h).

In addition, we have used bird data counts of the Natura 2000 authority. The data are intellectual property Thermaikos gulf protected areas management authority, are published and free accessible in the official website of the Thermaikos gulf protected areas management authority (Thermaikos gulf protected areas management authority 2020, http://axiosdelta.gr/en/) and have been used after official permission (license: 19/3/2019: 262).

In particular, the most complete and representative bird watching data sets from 2012 till 2017 was used recorded inside the spatial protection zone (GR1220010) of the Natura 2000 natural park. In brief, the data were collected using standardized bird survey protocols in which birds were surveyed at predefined count points twice each month from 2012 till 2017. Bird counts were carried out by experienced birders of the Natura 2000 authority, in the morning from dawn to midday at the latest, under suitable weather conditions.

E. Data Analysis

Because bird richness was recorded from one spatial protections zone and thus, representing average bird counts across the wetland site, it was prior necessary to extract the representative vegetation index average values to be further used for the statistical analyses.

To extract summary values from raster data we have used the mapping toolbox of Matlab as well as the R packages, raster, rgdal and ggplot2 (mostly for comparative reasons) [21], [22]. The values were estimated from the available satellite images of each observation year and thus represent the mean vegetation index value for the study area on the given observation season. In addition, for the same reasons we have estimated the mean values of the climate factors.

To detect any significant interactions between bird richness and climate factors as well as land cover indices we have performed a pairwise correlation analysis. The significant correlations were further used to develop and test a multivariate statistical regression model [23], [24]. Particularly, to establish if there are any significant associations between the temporal variability of the vegetation indices and the bird diversity indices, as well as between climate variability and the bird indexes, we have performed a series of pairwise correlations and linear regression analyses using a Box-Cox transformation [25], [26].

III. RESULTS

A. Land Cover Indicators

The overall area where the study was conducted is shown in Fig. 1. The land cover indicator response shape indices were different between the successive observation years (Fig. 2). The NDVI and ABCI seasonal variation showed analogous trends and reached highest values in 2014 and 2017, while the ARVI index depicted an oposite trend and experience considerable yearly change in vegetation cover and water bodies especially during 2014 and 2015.

![Fig. 1. Greece’s Natura 2000 ecological network of protected areas (left) and the Thermaikos Gulf protected areas (right) where the study was conducted. Green areas indicate spatial borer of sites, Pink areas: special protection areas of birds and blue areas zone of special protection of birds (free maps provided by the EU Natura 2000 network public viewer and epi earthstar geographics).](image)

![Fig. 2. Yearly trends of the normalized difference vegetation index (NDVI), the atmospheric resistance vegetation index (ARVI) and the Landsat agricultural band combination index (ABCI) for the Thermaikos Gulf Natura 2000 protected area.](image)
The land cover indicators (NDVI, ARVI and ABCI) for a representative observation year (2012) along the Natura 2000 wetland side of Northern Greece is shown in Fig. 3. Fig. 3a and Fig. 3b is a pair of a representative Landsat source satellite image and the related NDVI image, respectively and for the year 2012. All NDVI values are above zero which indicates strong terrestrial vegetation with increased maximum proportion close to the wetland area. Moreover, the NDVI values for study area were high and varied mostly from 0.82 to 0.94. As it can be seen clearly the vegetation cover area has maximum NDVI values in the area where bird watching was performed (Fig. 3b). Since forest area is limited in the region the above values belong to cultivations, scrub and grasslands which make a suitable habitat for indigent as well as emigrant bird species.

Fig. 3c depicts the ARVI for the particular research area and taking into account the correction of the atmospheric process on the red channels (i.e., using the difference in the radiance between the blue and red channels). In general, the dynamic range of the ARVI is quite similar to NDVI although it is, on average, four times less sensitive to atmospheric effects than the NDVI.

However, although ARVI is more robust to topographic effects (i.e., regions polluted by soot), it provides a poor information concerning the suitability of bird habitat (i.e., wet breeding sides etc.). Therefore, the ARVI provides rather confused information concerning the areas covered with water since they appear deep green as in the case of the cultivated area.

On the contrary, the ABCI provides a robust information measure of the amount of agricultural activity and related green vegetation (i.e., during the major crop phenophses), along with information of moisture and water sources and non-cultivated and urbanized area (Fig. 3d). Moreover, according to generated map, a considerably higher amount of photosynthetically active biomass is located along the Natura 2000 wetland side. Moreover, along the wetland and nearby the Delta Rivers there is a higher degree of intensified agricultural land use.

B. Correlation between Climate, Land Cover and Bird Richness

Statistical relationships among variables representing climate, vegetation structure and bird species richness were analysed through Simple Correlation Analysis (Fig. 4). The overall multivariate correlation analyses indicate that bird species richness was mainly related to temperature (r=-0.788, p<0.05), rain (r=-0.769, p<0.05) and the ABCI land cover (r=-0.788, p<0.05). Moreover, the correlation impact of each climate variable on the bird species richness as well as the significant correlations are shown in Fig. 5.
C. Multivariate Model between Influential Climate Variables and Bird Richness

The environmental drivers (i.e., climate variables and land cover indicators), that showed the most significant interactions with species richness, were further used to develop a statistical regression model having as predictors: Temperature, Rain and ABCI. The equation which describes the statistical relationship between the response variable and the predictors is:

\[ \text{Species Richness}^{(\lambda-1)}/(\lambda \times g^{(\lambda-1)}) = 89.8 - 4.07 \times \text{Temperature (Cels.)} + 0.1405 \times \text{Rain (mm)} - 27.1 \times \text{ABCI} \]

where \( \lambda = 5 \) (95% CI for \( \lambda: -2.31244; 12.3366 \)) and \( g = 31.3704 \) is the geometric mean of Species Richness. The overall model results indicate that these predictors have a statistically significant effect (\( p < 0.05 \)) on bird species richness accounting for 73.02% of data variability (Adjusted R-sq: 73.02).

Moreover, the Box-Cox transformation proved suitable in normalizing data as indicated by the residual and histogram plots as well as by the related model performance diagnostic plots shown in Fig. 6. Furthermore, the distribution of error terms appears to be bell shaped, homoscedastic and with pronounced tails.

Fig. 7 is a contour plot which depicts the interrelationship between bird species richness and the significant climatic drivers, and which were indicated by the according to the correlation analysis. The number of bird species was considerable higher as temperatures and rain increases (Fig. 7a). A large number of bird species is related both to a relatively lower NDVI index and relatively low and intermediate temperature levels (Fig. 7b). In addition, a larger number of bird species is related to considerably lower agricultural intensity, as estimated with the ABCI and relatively higher rain intensity (Fig. 7c). Bird evenness, thus, is maximal, at higher rain and temperature levels and lower values of the estimated land cover indicators.

Fig. 8 depicts a simulated interrelationship between bird species richness and the significant climatic drivers and according to the stored multivariate and normalized statistical linear model given in section II C. As in the case of the empirical-smoothed contour plots, the highest values of bird species evenness are in the lower left corner of the plot, which corresponds with high values of both temperature and rain levels (Fig. 8a). In addition, the bird evenness showed contrasting trends in relation to the NDVI and ABCI, as well as rain and temperature levels, having higher values in the upper left and lower right corner. Yet, all model simulated contour plot patterns are in accordance with the actually values shown in the empirical contour plots.

Based on the overall model results and the related 3D contour plot simulation we can conclude that in general, bird species richness increases with an increase in temperature and Rain, as well as with a decrease in agricultural intensity (ABCI) and low to moderate temperature and, finally with a decrease in agricultural intensity and increase in rain levels (Fig. 8).
Fig. 7. Contour plots of the effect of combined and significant environmental drivers on bird species richness. (a): the relation between mean temperature (°C), rain and species richness. (b): relation between mean temperature (°C), NDVI land cover index and species richness and (c): relation between Rain (mm), ABCI land cover index and species richness, in a representative Natura 2000 wetland in Northern Greece.

Fig. 8. Simulated contour plots of the effect of combined and significant environmental drivers on bird species richness according to the Box-Cox normalized linear mode. (a): the relation between mean temperature (°C), rain and species richness. (b): relation between mean temperature (°C), NDVI land cover index and species richness and (c): relation between Rain (mm), ABCI land cover index and species richness, in a representative Natura 2000 wetland in Northern Greece.
IV. DISCUSSION

Understanding the factors that can affect the biodiversity in an area is of great importance in ecosystem management and species conservation [27]. Although many organisms can be used as indicators of ecosystems biodiversity, birds are practical indicators of its effects of climate change and intensification of agriculture. However, there are few systematic studies performed in semi-rural areas that have shown strong correlations between the reduction of their populations and the application of climate and various modern agricultural practices.

In this study we have explored for the first time the combined effect of climate variables and land cover indicators on bird richness in a representative wetland location of the Thermaikos gulf Natura 2000 protected area in Northern Greece. In particular the association between bird diversity and climate as well as land cover was explored in seven successive seasons in stretch of 18×18 km line-transect rectangle using correlation analysis and a multivariate linear model.

Among the weather variables explored, temperature and rain levels were significantly correlated to bird richness. This result is in accordance with other studies having shown that temperature and participation levels may have significant direct and indirect effects on bird abundance and distribution [28], [29]. Previous studies, for instance, demonstrated relationships between bird richness and summer temperature [30], [31], winter temperature [31], [32], altitudinal temperature [34].

In this work bird richness was also significantly correlated with high rain levels and this is in accordance with other studies that have shown such a positive correlation [35]-[37]. In semi-arid ecosystems, especially, rainfall is related indirectly with bird reproduction since it affects water resource regimes and food availability acting as environmental cues to set intensity and timing of bird’s reproductive effort [38], [39]. Nevertheless, while we also detected some poor influences of relative humidity the emerging patterns were much less clear cut. Recent studies have also shown contrasting impacts of participation on Mediterranean birds [40].

Additionally, temperature has been proved as important predictor of bird abundance and directly affect population demographics through energetic constrains [41]-[43]. Particularly, the way by which temperature influences bird populations may include breeding and reproductive success [44], site selection as well as site occupancy [29], [45]. On the other hand, rainfall and water availability may have an effect on soil moisture and vegetation and additionally may have some impact on invertebrate species that constitute key prey items for many of the bird species during the breeding season.

In this context, our study adds another example but from a Mediterranean bird community to these general patterns observed in various regions. However, it should be also noted that the influence of temperature and rain levels in this study did not result from the momentary effects of these weather variables, but were based on correlations with the yearly mean values of temperature and rainfall. Therefore, it was the prevalent weather during each year which was correlated or not with bird richness. On the other hand, we have decided to use the mean land cover values, of the best quality (e.g., clounding etc.) for a time frame between early springs and late summer in order to coincide with the plant growth season and related period of high agricultural activity.

Bird diversity was negatively correlated with the agricultural land intensity that was tested. However, only the ABCI displayed a significant correlation with bird richness although there were consistent results for the two other lands cover variables, NDVI and ARVI, for the bird species analyses. This could be partially explained by the fact that ABCI has the advantage to enhance vibrant green and vigorous crop cultivations, while non-crops, such as mature trees appear in a dull green and deciduous forests appear as bright green, while sparsely vegetated and bare areas appear brown and mauve. On the other hand, the NDVI identifies and highlights areas “dense”, “moderate”, “sparse vegetation”, “open soil” or “no vegetation” and makes no detailed discrimination of plant land cover.

Concerning the selection of the ARVI, it was based on the assumption that since the Thermaikos Gulf Natura 2000 protected area is nearby the industrial zone of the city of Thessaloniki any possible atmospheric aerosols and ozone effects should be eliminated. However, although the ARVI displayed a considerable better correlation compared to NDVI with bird evenness, correlation was statistically not significant and therefore was not further included in the regression models.

On the other hand a significant correlation was observed between bird richness and agricultural intensity quantified according to the ABCI. To the best of our knowledge there are no similar studies which have estimated this ABCI band combination to be compared with. Moreover, we determined that the addition of the ABCI remote sensed vegetation parameter along with the two other climate parameters (e.g., temperature and rain) increased the amount of variation that is explained in our regression model. Therefore, based on the overall model results and the related 3D contour plot simulations, we can conclude that in general, bird species richness increase with an increase in temperature and Rain. Additionally, low agricultural intensity (ABCI) in relation to low to moderate temperature, as well as decreased agricultural intensity in combination to high rain levels favour an increase in bird richness.

In regards to other studies, avian abundance and species richness has been shown to be positively correlation with NDVI [46]-[48] Yet in this analysis we have not observed such a pattern and that was also the main reason why we have investigated the use the two additional ARVI and ABCI vegetation metrics. Actually, our findings that land cover type and agricultural intensity, particularly, exerts a significant effect upon bird richness are consistent with established evidence of the relation of vegetation structure and bird community composition. Researchers in [44], for example, demonstrated that within-season breeding occupancy of forest birds significantly correlate with gradients of vegetation composition and land cover structure after statistically accounting for the role of forest microclimate.
V. CONCLUSION

Understanding the relationships between species richness and their environmental drivers, here climate variables and the intensity of agricultural land cover, is a key component in the development of successful management practices. However, despite that the particular model projections account for the concurrent, and potentially interactive, effects of climate and land scape characteristics on the bird richness, we are looking forward to improve the model performance by exploring the effect of more variables and on larger scales. Additionally, since correlations don’t include necessary causation further research is needed to fully understand the different mechanisms through which environmental drivers and agricultural activity particularly impacts bird diversity.

Nevertheless, despite the limitations of the current study, the particular research may contribute to a better understanding of the broader bird community structure of the Thermaikos Gulf Natura 2000 protected and how it may be affected by climate and human activities exercised during the last years. Additionally, it could make monitoring and management of bird communities inside the Thermaikos Gulf Natura 2000 protected area in Northern Greece more cost effective and timely, since it provides for the first time a model toll to quantitative characterize the relationship between bird richness and environmental drivers.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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