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Calculating landscape diversity with alpha diversity indices

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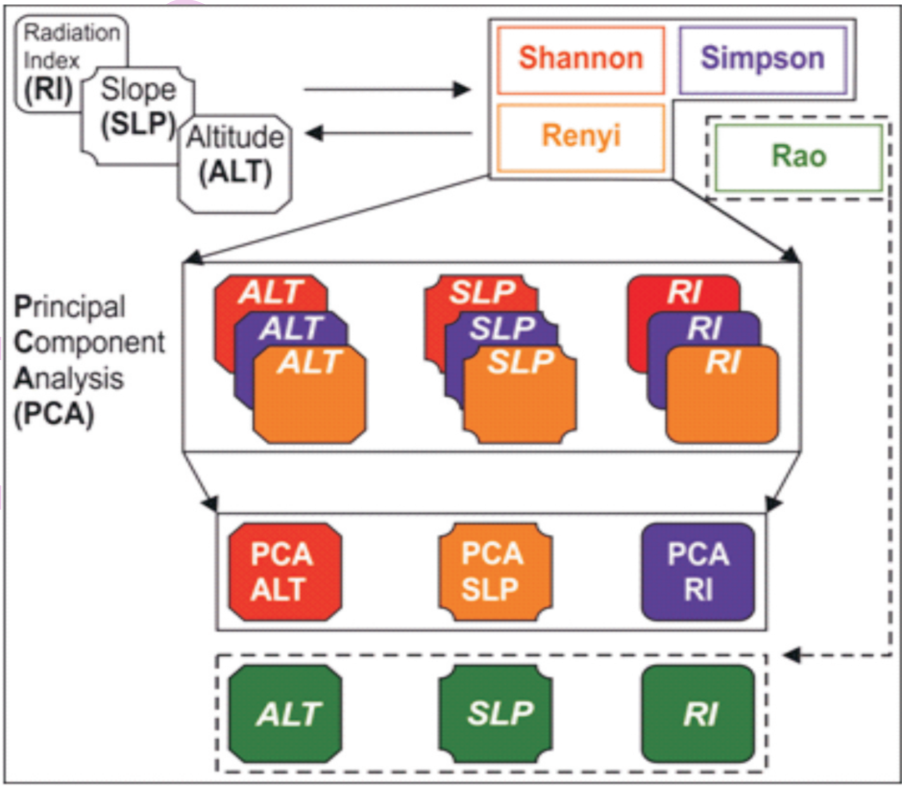
Abstract

Aim: The fundamental information layers of ecosystem –based management plans are obtained by calculating, modeling and mapping of biodiversity. This study was carried out to calculate and map of landscape diversity in the Kuyucak Mountain District, in the transition zone of the Mediterranean region.

Methodology: Topographical diversity values of altitude, slope degree and radiation index for each cell (752.09 × 752.09 m) of Kuyucak Mountain District were calculated using Shannon Wiener, Simpson diversity, Renyi H_2 and Rao indices. The index for each variable topographic map, which was prepared using cellular values after the calculations was obtained by Geographic Information Systems.

Results: The maps illustrating diversities of topographical variables were prepared in order to obtain more accurate model – based distribution map of biodiversity.

Interpretation: Climate, topography and soil properties play important roles on biodiversity. There are also significant relationships between landscape diversity and biodiversity. That is why it is important to prepare not only climatic, topographic and soil maps but also diversity maps as explanatory variables for modeling and mapping of biodiversity.



Introduction

Predictive distribution models (PDMs) have been increasingly used to visualize potential distribution areas of living entities such as birds (Manel *et al.,* 1999; Brotons *et al.,* 2004; Seoane *et al.,*2004; Ortega-Huerta and Peterson, 2008), plants (Ray *et al.,* 2011; Rameshprabu and Swamy, 2015), wild animals (Munguía *et al.,* 2008; Ahmadi *et al.,* 2013; Kramer Schadt *et al.,* 2013), insects (Tognelli *et al.,*2009; Habel *et al.,* 2010; Dáttilo *et al.,* 2012; Sobek-Swant*et al.,*2012; Filz and Schmitt, 2015; Sánchez-García *et al.,* 2015), reptiles and amphibians (Guisan and Hofer, 2003; Arntzen, 2006; Franklin *et al.,* 2009) in conservation biology, biogeography and forest ecology. Those models have been also used in mapping vegetation communities (Lees and Ritman, 1991; Dymond and Johnson, 2002; Boyden *et al.,* 2013), ecological land classification (Blasi *et al.,*2000; Özkan *et al.,* 2013; Grondin *et al.,* 2014) and biodiversity (Özkan*et al.,* 2016).

Creating a distribution model requires response data (inventory data, such as, vegetation types, biodiversity values and occurrence or productivity data of the species) and explanatory data (environmental variables composed of edaphic, topographic and climatic parameters). As for visualization of a distribution model, the main materials and tools are geo-referenced data of the inventory points, digitalized environmental layers and geographical information systems.

Among the response variables for ecological modeling, biodiversity is of great importance because it is strongly related to balance, resilience, health and sustainability of the ecosystems (Özkan and Berger, 2014). Distribution maps of biodiversity are, therefore, vital for determining priority conservation areas or hotspots in a given ecosystem.

Biodiversity is measured at alpha, beta and gamma scales. Alpha diversity is measured at a single site although beta diversity is the amount of change among the sites. Gamma diversity is similar to alpha diversity, only measured on a large scale (Whittaker, 1972).

Environmental factors and environmental heterogeneity both are potentially decisive factors in the variation of biodiversity components, in particular variation of the beta diversity (Dufour *et al.,*2006; Veech and Crist, 2007). Therefore, preparation of the layers not only of environmental factors but also of representative parameters of environmental heterogeneity is important to design stronger and more accurate predictive distribution models of biodiversity. In this regard, various indices such as Shannon entropy and Simpson diversity index can be used (Shannon, 1948; Simpson, 1949).

In Turkey, Mediterranean forests generally occur in the mountainous and karstic areas. Hence, environmental heterogeneity is high in many of the forest areas and influences the geographical distribution of biodiversity (Özkan, 2006; Özkan, 2008; Özkan *et al*., 2010). Representative parameters of environmental heterogeneity should, therefore, be considered as explanatory variables together with the other environmental variables for modeling and mapping processes of biodiversity.

In the present study, conducted in the Kuyucak Mountain district located in the Mediterranean region, Turkey, an attempt was made to create diversity maps of altitude, radiation index and slope degree by using various diversity indices so that all potential explanatory variables influencing species diversity could be ready for a further study regarding modeling and mapping diversity of species that would be undertaken in the ongoing project in the district.

Materials and Methods

The study area, Kuyucak mountain district is located in the transition zone of the Mediterranean region (37° 21' 06" N – 37° 43' 39" N and 30° 51' 15" E – 31° 18' 13" E). Of its total land area of 930.5 sq km, it is characterized by high mountainous areas (37%), deep or shallow canyons (42%), hills or upland (10%), ridges (7%) and plains (4%).

An ongoing TUBITAK project (PN: 113O495) entitled "Spatial Modelling of Woody Plant Diversity in the Kuyucak Mountain District" was been carried out since the beginning of 2013 in the Kuyucak mountain district. The main purpose of the project was based on modeling and mapping of biodiversity components (alpha, beta and gamma diversities). In this context, 200 areas approximately in size of ~ 752.09 × 752.09 m corresponding to the cell size of BIOCLIM data (30 arc - second) (Hijmans *et al.,* 2005) were selected and the plants species were recorded in four sample plots at each pixel of the BIOCLIM data (BIOPIXEL) in order to compute beta and gamma plant diversity so that those diversity components could be statistically correlated with the climatic data.

The district has four major mountain ranges: Sarp mountain (peak height: 2545 m), Duran mountain (peak height: 2214), Erenler mountain (peak height: 2023) and Tota mountain (peak height: 1852 m). The district, having a total of 478 species (Fabaceae, Asteraceae, Caryophyllaceae, Lamiaceae, Brassicaceae, Boraginaceae, Rosaceae, Apiaceae, Scrophulariaceae and Ranunculaceae) is rich in plant diversity (Özcelik and Korkmaz, 2002).

The most widespread bedrock is limestone. The others are sandstone, conglomerate, marn, dolomite, basalt and ophioliticmelange. The fact that beta diversity and gamma diversity may not be related not only to environmental factors, in particular climatic factors, but to environmental heterogeneity (Rocchini *et al.,* 2010) madeus calculate the representative variables of environmental heterogeneity at each BIOPIXEL of the district. In this regard, the relevant maps were prepared by the following processes:

1. The values of altitude, radiation index and slope degree for each of 36 equally divided sub-pixels were determined at each BIOPIXEL by using Create Fishnet toolbox in ArcMap 10.1.

2. Shannon wiener (H), Simpson diversity (1-λ), Renyi (H_2) and Rao (Q) indices were used to calculate diversity values of each of BIOPIXEL for each variable[1]. All the diversity measures were then visualized for each of the topographical variables.

3. Correlation analysis was performed among diversity indices for each variable. PCA was then applied to produce a component diversity map for each of the variables (Özdamar, 1999).

Altitude and slope degree were directly calculated from digital elevation model by using ArcMap 10.1. Radiation index (RD) was calculated by the following equation (Moisen and Frescino, 2002; Aertsen *et al*., 2010; Wei *et al.,*2010).

$$RD = \frac{[1 - \cos((\frac{\pi}{180})\ (\theta - 30))]}{2} \quad (1)$$

where, θ is a value which is measured from the north aspect. This equation's result changes between 0 and 1.

Shannon wiener (H) (Shannon, 1948), Simpson diversity (1-λ) (Simpson, 1949), Renyi (H_2) (Renyi, 1961) and Rao (Q) (Rao, 1982; Botta-Dukat, 2005; Ricotta, 2005) indices were calculated by the following equations:

$$H = -\sum_{i=1}^{n} p_i \ln p_i \quad (2)$$

where, *pi* is the proportion value of sub-pixels and *n* is sub-pixels diversity.

$$1 - \lambda = -\sum_{i=1}^{n} p_i^2 \quad (3)$$

where, λ is the Simpson dominance index, *pi* is the proportion value of sub-pixels.

$$H_2 = \frac{1}{1 - \alpha} \ln \Sigma p^{\alpha} \quad (4)$$

In the equation, $H_\alpha = H_2$ (α=2), therefore, $H_2 = \ln(1/\lambda)$ where, λ is the Simpson Dominance index (Rocchini *et al*., 2013).

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} p_i p_j \quad (5)$$

where, *n* is the number of sub-pixels, *pi* is the proportion value of sub-pixels, *dij* is dissimilarity of sub-pixels between *i* and *j.*

Results and Discussion

Maps of diversity measures of topographical variables, *i.e.*, altitude (ALT), slope degree (SLP) and radiation index (RI), are given in Fig. 1. Fig. 1 shows some maps resemble each other because there are high correlations among some indices. According to the results of the applied Pearson correlation analyses between H and 1-λ maps for each of the topographic variables, all the correlation coefficients were positive and had "r" values more than 0.90. In addition to this, H_2 maps were negatively and strongly associated with H and 1-λ maps (r<0.90) for each of all topographical variables (Table 1). However, Q maps were weakly related to H, H_2 and 1- λ maps (Table 1).

Correlation analysis shows that combining of H, 1 – λ and H_2 maps for each of the topographical variables is required due to their strong interrelations (Table 1). For this purpose, PCA was applied to create a component parameter from those diversity measures for each topographic variable. PCA results are given in Table 2.

As expected, the first axes of the applied PCA_{ALT}, PCA_{SLP}, and PCA_{RI} explained high percentage of total variance. It means that first axes represent H, 1– λ and H_2 measures for each of ALT, SLP and RI. The constants and the coefficients belonging to the

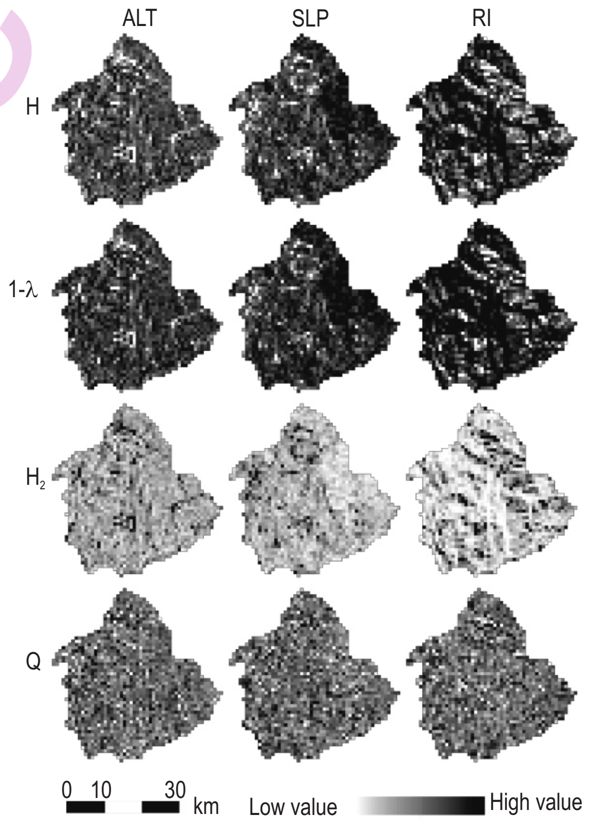


Fig. 1 : H, H_2, 1- λ and Q maps of ALT, SLP and RI in the Kuyucak Mountain District

Table 1 : The results of correlation analysis among diversity maps of ALT, SLP and RI (n=2107, p<0.001 if r>0.072)

	H_{ALT}; H_{SLP}; H_{RI}	$1-\lambda_{ALT}$; $1-\lambda_{SLP}$; $1-\lambda_{RI}$	H_{2ALT}; H_{2SLP}; H_{2RI}	Q_{ALT}; Q_{SLP}; Q_{RI}
H_{ALT}; H_{SLP}; H_{RI}	1;1;1	0.925;0.965;0.935	-0.910;-0.958;-0.921	-0.247;-0.216;-0.178
$1-\lambda_{ALT}$; $1-\lambda_{SLP}$; $1-\lambda_{RI}$	0.925;0.965;0.935	1;1;1	-0.999;-0.999;-0.999	-0.044;-0.101;0.021
H_{2ALT}; H_{2SLP}; H_{2RI}	-0.910;-0.958;-0.921	-0.999;-0.999;-0.999	1;1;1	0.034;0.094;-0.032
Q_{ALT}; Q_{SLP}; Q_{RI}	-0.247;-0.216;-0.178	-0.044;-0.101;0.021	0.034;0.094;-0.032	1;1;1

Table 2 : The results of PCA analyses for each of ALT, SLP and RI using H, $1-\lambda$ and H_2 data

	Eigenvalue	% of Variance	Cum.% of Var.
PCA_{ALT} (Axis: 1;2;3)	(2.889; 0.110; 0.000)	(96.311; 3.681; 0.008)	(96.311; 99.992; 100.00)
PCA_{SLP} (Axis: 1;2;3)	(2.949; 0.0.051; 0.000)	(98.292; 1.700; 0.008)	(98.292; 99.992; 100.00)
PCA_{RI} (Axis: 1;2;3)	(2.904; 0.096; 0.000)	(96.785; 3.207; 0.008)	(96.785; 99.992; 100.00)

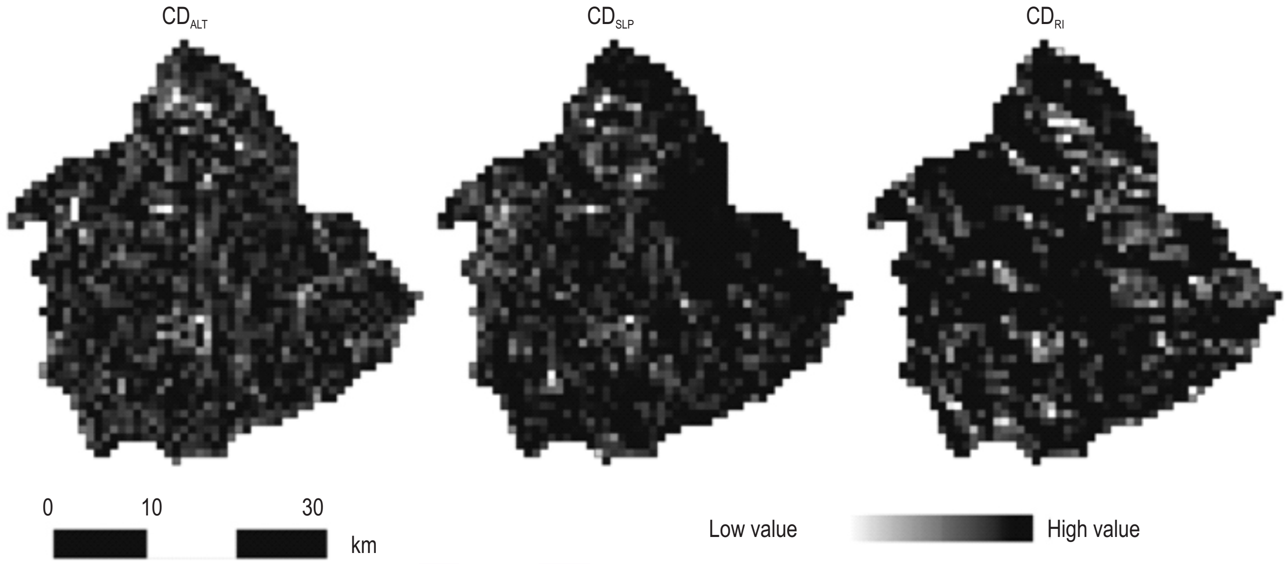


Fig. 2 : The component diversity maps of topographical variables.

first axes of PCA_{ALT}, PCA_{SLP}, and PCA_{RI} are given in the following equations.

$$CD_{ALT} = 6.0298H_{ALT} + 82.009(1-\lambda_{ALT}) - 75.555H_{2ALT} - 96.402 \quad (6)$$

$$CD_{SLP} = 6.7568H_{SLP} + 98.256(1-\lambda_{SLP}) - 91.221H_{2SLP} - 115.41 \quad (7)$$

$$CD_{RI} = 2.5638H_{RI} + 35.578(1-\lambda_{RI}) - 32.625H_{2RI} - 41.375 \quad (8)$$

In which CD_{ALT}, CD_{SLP} and CD_{RI} are the component diversity indices of ALT, SLP and RI, respectively. Using equation 6 – 8, the maps obtained from those component diversity measures are illustrated in Fig. 2.

The results of the studies carried out by Vivian-Smith (1997), Dufour *et al.* (2006), Touré and Ge (2014) and Morzaria-Luna *et al.* (2004) revealed that environmental heterogeneity effects biodiversity, in particular beta diversity and gamma diversity. Therefore, employing the surrogate variables of environmental heterogeneity as explanatory variables is of great importance in creating accurate distribution models of biodiversity.

In other words, the distribution maps of biodiversity are essential information layers to make ecosystem based management plans. Therefore, the more accurate biodiversity maps are obtained, the more successful implementations intended for sustainability of the ecosystems can be generated. The fact that environmental heterogeneity plays a crucial role in the variation of biodiversity and strong distribution models of biodiversity are vital for preparing the accurate ecosystem based management plans means that explanatory variables for modeling of biodiversity should be prepared by considering surrogate variables reflecting environmental heterogeneity as well as other environmental variables.

In the present study, first of all, the diversity indices (H, 1-λ, H_2 and Q) were calculated at each topographical variables for each BIOPIXEL to obtain the maps of the surrogate variables of environmental heterogeneity (topographical diversity maps) (Fig. 1). Next, the correlation analyses were performed to examine interrelationships of those maps. After correlation analyses, it was found very strong relationships among H, 1-λ and H_2 maps of all topographical variables. The component diversity equations were, therefore, developed from those diversity measures using the Principle Component Analyses, and those equations were applied to the districts for each of topographical variables.

As a result of the present study, three maps of Q index (Fig. 2) and three component diversity maps derived from H, 1-λ and H_2 indices were created for altitude, slope degree and radiation degree at the size of BIOPIXEL. Thus, six surrogate explanatory layers derived from altitude, slope degree and radiation index maps were stored in order to use explanatory variables for further studies dealing with modeling and mapping of biodiversity in the Kuyucak mountain district, Turkey.

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