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Evaluating Carbon Use Efficiency in Forest Types and Ecoregions of Turkey

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ABSTRACT

The total amount of carbon deposited by forests is gross primary productivity (GPP), and the net amount remaining after respiration is net primary productivity (NPP). The carbon storage effectiveness of forests is determined by the NPP:GPP ratio. This ratio is carbon use efficiency (CUE), and it is important for understanding the dynamics of carbon exchange between the biosphere and atmosphere. The aim of this study is to evaluate the variation of CUE, which is commonly used as a constant value in terrestrial carbon models, in different forest types and ecoregions of Turkey. The distribution of forest types in different ecoregions of Turkey was determined and, NPP, GPP, and CUE values were calculated for the different forest types in each region in this study. Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image was obtained for NPP and GPP content of forest types. In addition that the CORINE land use classification system was used for the spatial distribution of coniferous, broad-leaved and mixed forests in Turkey. The highest mean NPP (640 gC / m^{-2} y^{-1}) and GPP (856 gC / m^{-2} y^{-1}) were found in coniferous forests. The lowest NPP (267 gC / m^{-2} y^{-1}) and GPP (493 gC / m^{-2} y^{-1}) were detected in mixed forests in the Southeastern Anatolian Transitional Region. The highest CUE value was found in the Black Sea Climatic Region (0.89). Our results showed that the CUE was not a constant value. Although the mean CUE values among forest types were close to each other, significant differences were found between ecoregions. With the findings obtained, it is recommended that the CUE value should be determined under different environmental conditions

Keywords: Net primary productivity, Gross primary productivity, CORINE, MODIS, NPP:GPP ratio

Türkiye'nin Ekolojik Bölgeleri ve Orman Tiplerinde Karbon Kullanım Etkinliğinin Değerlendirilmesi

ÖZ

Ormanların biriktirdiği toplam karbon miktarı bürüt birincil üretim (GPP), solunumdan sonra kalan net miktar ise net birincil üretimdir (NPP). Ormanların karbon depolama etkinliği, NPP:GPP oranı ile belirlenir. Bu oran karbon kullanım verimliliğidir (CUE) ve biyosfer ile atmosfer arasındaki karbon değişiminin dinamiklerini anlamak için önemlidir. Bu çalışmanın amacı, karasal karbon modellerinde yaygın şekilde sabit bir değer olarak kullanılan CUE'nin Türkiye'nin farklı orman türleri ve ekolojik bölgelerindeki değişimini değerlendirmektir. Bu çalışmada, Türkiye'nin farklı ekolojik bölgelerindeki orman türlerinin dağılımı belirlenmiş ve her bölgede farklı orman türleri için NPP, GPP ve CUE değerleri hesaplanmıştır. Orman türlerinin NPP ve GPP içeriği için Orta Çözünürlüklü Görüntüleme Spektroradyometresi (MODIS) uydu görüntüsü ile elde edilmiştir. Ayrıca Türkiye'de iğne yapraklı, geniş yapraklı ve karışık ormanların konumsal dağılımı için CORINE arazi kullanım sınıflandırma sistemi kullanılmıştır. En yüksek ortalama NPP (640 gC/m^{-2} y^{-1}) ve GPP (856 gC/m^{-2} y^{-1}) iğne yapraklı ormanlarda bulunmuştur. En düşük NPP (267 gC/m^{-2} y^{-1}) ve GPP (493 gC/m^{-2} y^{-1}) Güneydoğu Anadolu Geçiş Bölgesindeki karışık ormanlarda tespit edilmiştir. En yüksek CUE değeri Karadeniz İklim Bölgesinde bulunmuştur (0.89). Bulgularımız CUE'nin sabit bir değer olmadığını göstermektedir. Orman türleri arasındaki ortalama CUE değerleri birbirine yakın olmasına rağmen, ekolojik bölgeler arasında önemli farklılıklar tespit edilmiştir. Elde edilen bulgularla CUE değerinin farklı çevre koşullarında belirlenmesi önerilmektedir.

Anahtar kelimeler: Net birincil üretim, Toplam birincil üretim, CORINE, MODIS, NPP:GPP oranı

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1. Introduction

There are two different flows in the carbon budget of terrestrial plant communities: photosynthesis and autotrophic respiration. While carbon is accumulated by photosynthesis, loss occurs during autotrophic respiration. The carbon assimilated in the photosynthesis process is gross primary production (GPP), and the amount remaining after autotrophic respiration is net primary production (NPP). These parameters are widely researched on a global and regional scale and used in ecological-based models in the interpretation of carbon emissions and climate change (Field et al., 1995; Ruimy et al., 1996; Malhi et al., 2011). Especially the change in NPP is an effective indicator in observing the impact of climate change. The NPP is a very successful indicator in evaluating the effects of climate change on vegetation in terrestrial ecosystems, which is a complex system (Gower et al., 1999; Yu and Chen, 2016; Zhang et al., 2019).

The ratio of NPP to GPP is called the carbon use efficiency (CUE). The CUE describes efficiency of plants in carbon storage and contributes to the understanding of the dynamics of carbon biosphere-atmosphere exchange. The CUE is commonly used as a constant coefficient of 0.5 in terrestrial carbon models, but not a constant variable. In actually, the CUE varies depend on site productivity, climate type, ecosystem type, forest management and forest age in forest ecosystems. Therefore, using CUE as a constant value for all biomes, ecosystems and species may cause uncertainties in the understanding of carbon dynamics (Collalti and Prentice, 2019; Tang et al., 2019).

Turkey was divided to eight ecoregions in this study (Atalay, 2014). The spatial distribution of coniferous, broad-leaved and mixed forests in each region was determined. The CUE was calculated for Turkey's forest types and how CUE varies with ecoregions and forest types in Turkey was analyzed.

2. Material and Method

2.1. Study area

The study area covers the forest areas of Turkey (Fig 1). Turkey's forest areas consist of coniferous, broad-leaved and mixed forest types and the area amounts are 10.969.246, 7.405.972 and 4.557.782 hectares, respectively (GDF 2020). About half of Turkey's forests consist of coniferous forests (47%). Deciduous and mixed forests cover 32% and 21% of the total forest area, respectively. Turkey's land structure consists mostly of the countryside and mountainous areas. The average elevation of Turkey is 1250 m, and the forest cover spreads up to an altitude of about 2000 m. The average elevation of the forest areas is about 800 m and the slope is 25%.

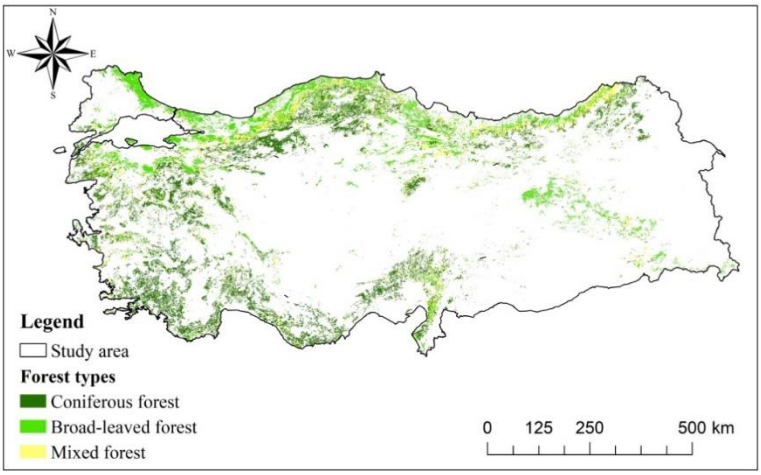
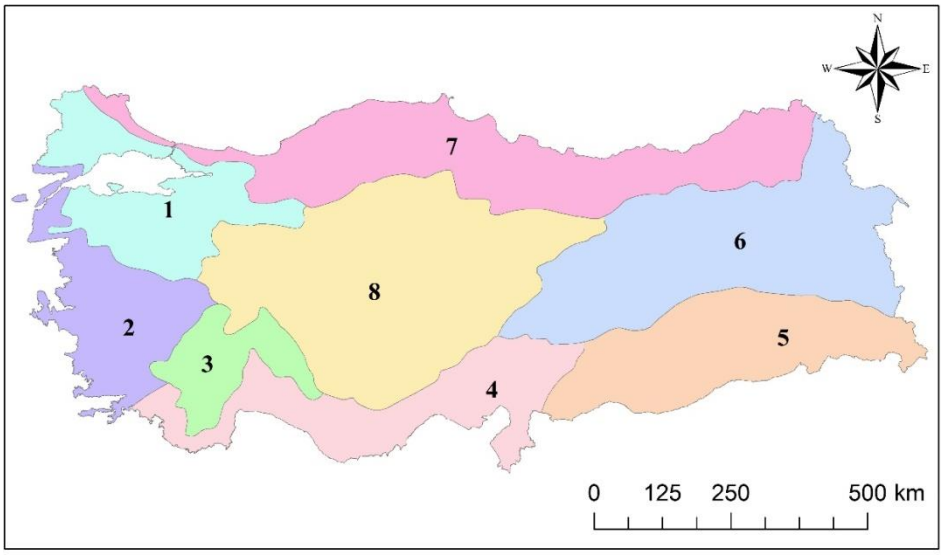


Fig 1. Study area

2.2. Ecoregions of Turkey

Turkey is located in the transition zone of Asia and Europe and covers different climate types due to the diversity in the land structure, coastlines and location in the Mediterranean region. Considering these ecological regions, many studies have been carried out on the scale of Turkey and within its borders (Erşahin, 2016; Seki and Sakıcı, 2021). Eight different ecoregions according to Atalay (2014) were used in this study. These regions are Marmara Transitional Region, Aegean Geographical Region, Mediterranean Transitional Region, Mediterranean Geographical Region, Southeastern Anatolian

Transitional Region, Eastern Anatolian Region, Black Sea Climatic Region and Inner Anatolian Region (Fig 2).



Ecoregions of Turkey: 1- Marmara Transitional Region, 2- Aegean Geographical Region, 3- Mediterranean Transitional Region, 4- Mediterranean Geographical Region, 5- Southeastern Anatolian Transitional Region, 6- Eastern Anatolian Region, 7- Black Sea Climatic Region and 8- Inner Anatolian Region

Fig 2. Ecoregions of Turkey

2.3. Data processing

Digital layers of NPP, GPP, land cover types, and ecoregions were used in this study (Table 1). Firstly, the ecoregions of Turkey organized by Atalay (2014) were coordinated and turned into a digital layer. Spatial distribution of forest cover types was determined through the CORINE land cover classification system in eight ecoregions of Turkey. Moderate Resolution Imaging Spectroradiometer (MODIS) products were used for providing NPP and GPP data for the year 2019. The 1-year composite MODIS NPP data at a 500 m spatial resolution (the MOD17A3H product) and the 8-day composite MODIS GPP data at a 500 m spatial resolution (the MOD17A2H product) were used. The NPP and GPP products have incompatible temporal resolutions. To resolve this inconsistency, annual data were produced by collecting 46 GPP layers in 2019. After that, the carbon use efficiency (CUE), which is the NPP:GPP ratio, was then calculated (Eq. 1). As a result of these processes, the mean NPP, GPP, and CUE amounts of coniferous, broad-leaved and mixed forests for eight ecoregions of Turkey were calculated.

$$CUE = \left(\frac{NPP}{GPP}\right) \quad (1)$$

Table 1. Description of the study materials

Dataset and Map	Usage purpose	Source
NPP	Determining net primary productivity	MODIS-MOD17A3H Product
GPP	Determining gross primary productivity	MODIS-MOD17A2H Product
Land cover classification	Determining forest cover types of Turkey	CORINE (Coordination of Information on the Environment)
Ecoregion	Determining ecoregions of Turkey	Atalay (2014)

3. Results and Discussion

Our findings were obtained from remotely sensed data and do not include field measurement. This study was carried out with 7844-pixel data derived from the MODIS satellite image (Table 2). Results showed that the lowest and highest NPP amounts per unit area in Turkey's forests were found to be 30 (gC / m^{-2} y^{-1}) and 1106 (gC / m^{-2} y^{-1}), respectively. Mean NPP and GPP amounts were found as 645 (gC / m^{-2} y^{-1}) and

826(gC / m^{-2} y^{-1}), respectively. The GPP variability of Turkey's forests was less than NPP. While the GPP amounts of the forest types were more similar to each other, the variability in NPP was higher due to the differences in carbon consumed by respiration (Cv=29.50%). The CUE amounts varied between 0.05-0.95. In Turkey's forests, an average of 75 percent of the total production was stored as net production. Turkey's forest areas mostly had a CUE amount above 0.5, and the average CUE value was found to be 0.75.

Table 2. Descriptive statistic values of net primary productivity, gross primary productivity and carbon use efficiency

Variable	N	Minimum	Maximum	Mean	Std.D	Cv (%)
NPP (gC / m^{-2} y^{-1})	7844	30	1106	645	190.28	29.50
GPP (gC / m^{-2} y^{-1})	7844	223	1148	826	158.52	19.19
CUE	7844	0.05	0.95	0.75	0.14	18.67

In the literature, it is stated that the average CUE values were variable in different land types in terrestrial ecosystems. Tang et al. (2019) reported that the most important factors in CUE variability were found to be annual mean temperature, maximum temperature, and management practices. In addition, CUE values varied from 0.13 to 0.93 between different land cover types and found CUE value of 0.45 for all terrestrial ecosystems. In our study, the CUE values were changed between 0.05 and 0.95. One of the reasons in CUE values that Turkey has different climatic zones, and the other reasons may be due to the species diversity and forest structure (stand age, stand height, biomass, etc.) in Turkey. Because these criteria greatly affect the NPP:GPP ratio (Collalti and Prentice, 2019).

In some studies, it has been argued that the change in the CUE value is minimal and can be considered invariant. One of these studies was carried out by McCree and Troughton, and they were revealed that the CUE can be considered constant in terms of age, CO2 and temperature (McCree and Troughton 1966). In some studies, it has been stated that the CUE varied significantly, especially with respect to stand characteristics. De Lucia et al. (2007) determined that the CUE value changes in terms of stand age. The highest CUE value was obtained in 5-year-old Populus nigra (L.) plantation forest stands, and the lowest value was obtained in 115-year-old Picea mariana (Mill.). Mäkelä and Valentine (2001) determined that the CUE value varies between 0.6 and 0.2 in stands with tree heights between 5 and 30 m. In this study, stand characteristics could not be examined and evaluations could be made in terms of forest types and ecoregions. It was determined that the CUE value showed high variability, especially in different environmental conditions.

The mean NPP, GPP and CUE amounts of forest types in Turkey were calculated (Table 3). The highest average NPP and GPP amounts were found in coniferous forests. Broad-leaved forests were found to have an annual net production of 559 (gC / m^{-2} y^{-1}) and a total production of 724 (gC / m^{-2} y^{-1}). The ability of forest types to transform total production into net production in Turkey was found to be at a similar level. Although the broad-leaved forests have lower NPP and GPP, they have a two percent higher the CUE value.

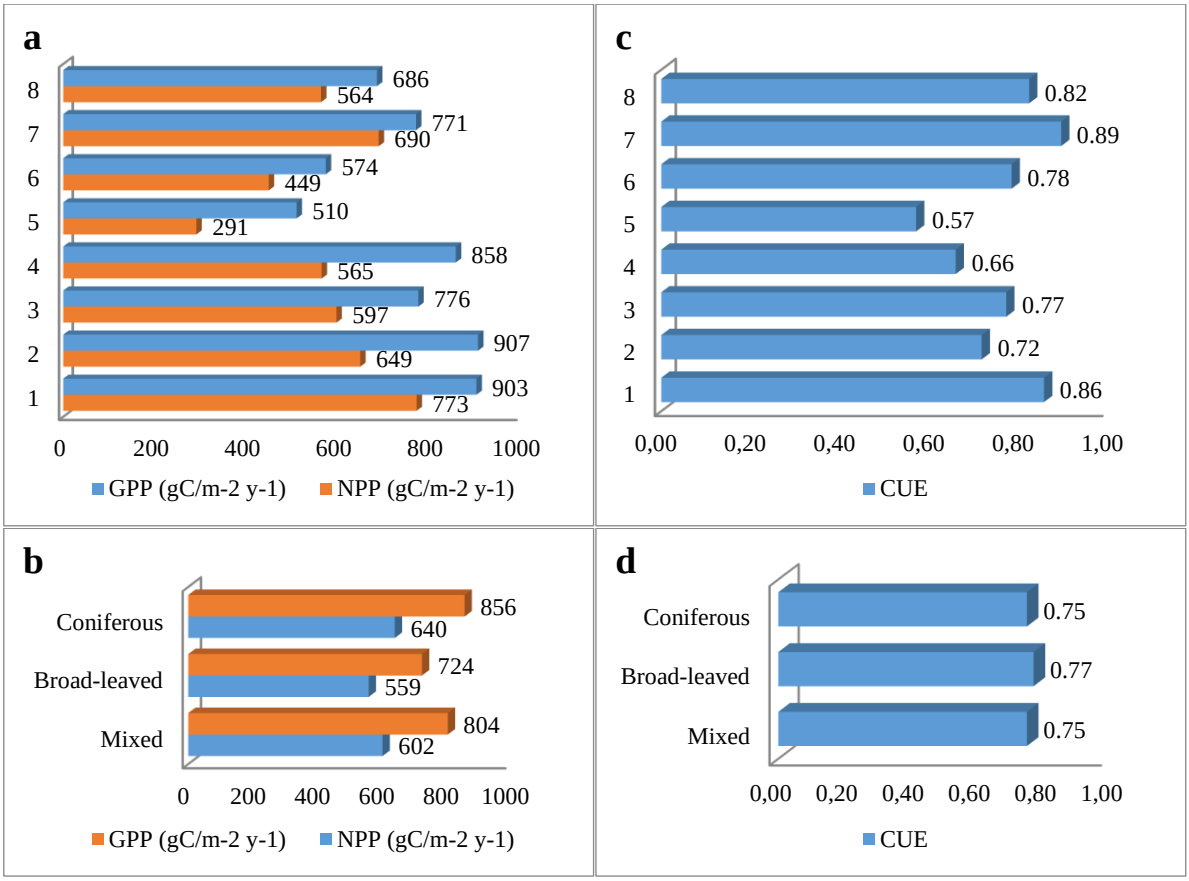
Table 3. Net primary productivity, gross primary productivity and carbon use efficiency values of forest types of Turkey

Forest type	NPP (gC / m^{-2} y^{-1})	GPP (gC / m^{-2} y^{-1})	CUE
Coniferous	640	856	0.75
Broad-leaved	559	724	0.77
Mixed	602	804	0.75

Table 4. Net primary productivity, gross primary productivity and carbon use efficiency values of coniferous, broad-leaved and mixed forest in different ecoregions of Turkey

Region	Forest type	NPP (gC / m^{-2} y^{-1})	GPP (gC / m^{-2} y^{-1})	CUE
Marmara Transitional Region	Coniferous	751	909	0.83
	Broad-leaved	791	902	0.88
	Mixed	776	899	0.86
	Mean	773	903	0.86
Aegean Geographical Region	Coniferous	638	912	0.70
	Broad-leaved	641	887	0.72
	Mixed	669	922	0.73
	Mean	649	907	0.72
Mediterranean Transitional Region	Coniferous	596	813	0.73
	Broad-leaved	587	726	0.81
	Mixed	609	790	0.77
	Mean	597	776	0.77
Mediterranean Geographical Region	Coniferous	622	872	0.71
	Broad-leaved	524	859	0.61
	Mixed	549	844	0.65
	Mean	565	858	0.66
Southeastern Anatolian Transitional Region	Coniferous	277	507	0.55
	Broad-leaved	329	531	0.62
	Mixed	267	493	0.54
	Mean	291	510	0.57
Eastern Anatolian Region	Coniferous	463	581	0.80
	Broad-leaved	434	577	0.75
	Mixed	451	564	0.80
	Mean	449	574	0.78
Black Sea Climatic Region	Coniferous	665	750	0.89
	Broad-leaved	756	835	0.91
	Mixed	648	729	0.89
	Mean	690	771	0.89
Inner Anatolian Region	Coniferous	608	746	0.82
	Broad-leaved	527	640	0.82
	Mixed	556	672	0.83
	Mean	564	686	0.82

The NPP, GPP and CUE of forest types were evaluated for eight ecoregions in Turkey (Table 4, Fig 3). Among the regions, the highest mean NPP was found in the Marmara Transitional Region (773 gC / m^{-2} y^{-1}) and the lowest mean NPP in the Southeastern Anatolian Transitional Region (291 gC / m^{-2} y^{-1}). The highest and lowest mean GPP were found in the Aegean Geographical Region (907 gC / m^{-2} y^{-1}) and Southeastern Anatolian Transitional Region (510 gC / m^{-2} y^{-1}), respectively. When the ecoregions and forest types were compared, the highest NPP was found in the broad-leaved forests in the Marmara Transitional Region (791 gC / m^{-2} y^{-1}). The highest GPP was found in mixed forests in the Aegean Geographical Region (922 gC / m^{-2} y^{-1}). The lowest NPP (267 gC / m^{-2} y^{-1}) and GPP (493 gC / m^{-2} y^{-1}) were detected in mixed forests in the Southeastern Anatolian Transitional Region. It has been determined that the most effective region and forest type in converting total production to net production was the broad-leaved forests in the Black Sea Climatic Region (CUE=0.91). When the mean values between the regions were compared, the highest CUE value was found in the Black Sea Climatic Region (0.89), and the lowest value in the Southeastern Anatolian Transitional Region (0.57).



Ecoregions of Turkey: 1- Marmara Transitional Region, 2- Aegean Geographical Region, 3- Mediterranean Transitional Region, 4- Mediterranean Geographical Region, 5- Southeastern Anatolian Transitional Region, 6- Eastern Anatolian Region, 7- Black Sea Climatic Region and 8- Inner Anatolian Region

Fig 3. Net primary productivity and gross primary productivity of (a) ecoregions, (b) forest types and carbon use efficiency values of (c) ecoregions and (d) forest types of Turkey

The spatial distribution of the CUE values of Turkish forests was shown on the map (Fig 4). It has been determined that the CUE value was above 0.6 in the northern strip of Turkey. The CUE value was lower especially in the southern regions of Turkey. The variation in CUE values may be due to the mean temperature differences in the regions. The mean annual temperature in the southern regions is higher than in the northern regions. In the southern regions, the increased temperature also increases the respiration in the trees, and respiration also causes material loss and reduces NPP (Clark et al., 2003; Bulut, 2021). With an increase in temperature, water loss increases and soil moisture decreases, too. Therefore, another factor that has a reducing effect on NPP in the southern regions is the water deficit (Zhao et al., 2005; Brohan et al., 2006). In the study, the NPP:GPP ratio (CUE) was lower in the southern regions of Turkey as a result of increased respiration, water deficit and decreased NPP content.

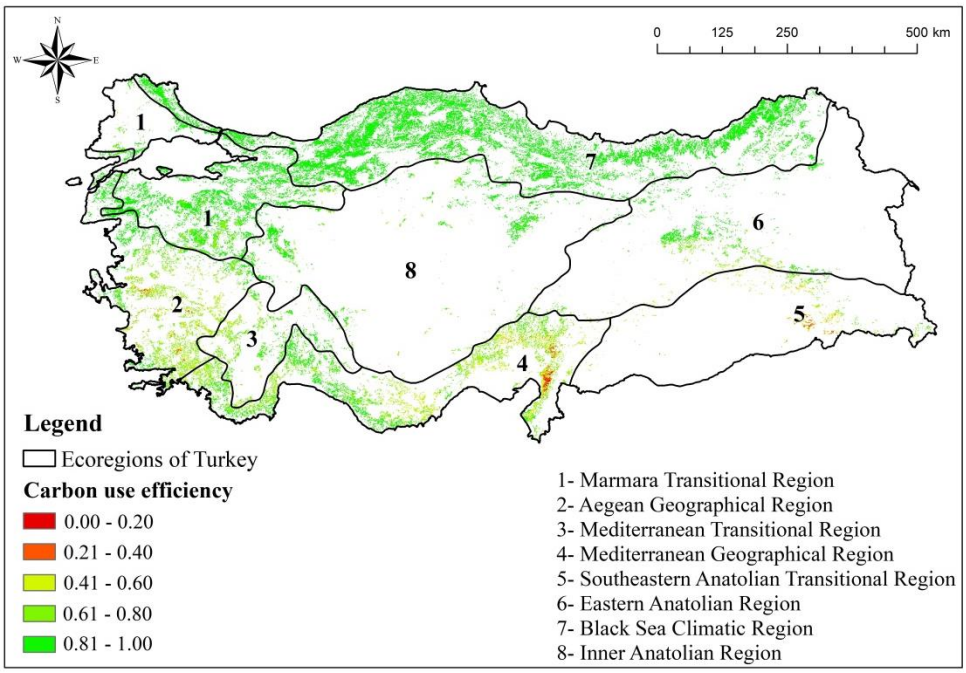


Fig 4. Spatial distribution of carbon use efficiency by ecoregions in Turkey

4. Conclusion

In this study, the NPP, GPP and CUE values of coniferous, broad-leaved and mixed forests in Turkey were determined, and also evaluated in terms of different ecoregions. It has been determined that the forest type with the highest mean NPP and GPP was coniferous forests. There was no significant difference between forest types in terms of CUE. However, differences were determined between forest types in ecoregions. The mean CUE value for forests of Turkey was found to be 0.78. In ecoregions, mean CUE values varied between 0.57 and 0.89. According to the findings, it has been determined that the CUE value was not constant but varied especially in regions that differ in ecological terms. The data in this study were satellite-based data and not based on field measurements. However, considering the difficulties in measuring and determining these data, satellite-based data is also very effective and widely used for the interpretation of these data in large areas. It is especially used to understand the carbon cycle and its dynamics on a global scale. In modeling studies, it is recommended that the NPP and GPP be based on field measurements and disseminated in different environmental conditions in order to reach more clear and reliable data for CUE. Thus, net carbon budgets can be determined precisely, the carbon released by respiration in forests can be revealed, and the ability of forests to transform total production into net production can be interpreted.

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