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Remote Sensing of Leaf Biomass Production in Deciduous Forests - Rhodope Mountains, Southeast Europe

KEYWORDS: foliage biomass, broadleaf deciduous forests, Rhodope Mountains, SLA, LAI, MODIS, CORINE, DEM

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ABSTRACT *Production of leaf biomass by broadleaf deciduous forests in the Rhodope Mountains, Southeast Europeis studied. Leaf biomass is estimated based on LAI/FPAR data product of spectroradiometer MODIS on board of the satellites Terra and Aqua (NASA). The relationship between leaf area index (LAI) and specific leaf area (SLA) is used to determine the leaf biomass production of the broadleaf forest. Assessment of the SLA is based on in situ measurements and literature data for widespread broadleaf species - hornbeam, oak and beech. To determine the geographic distribution, location and altitude of forest tree species on the territory were used: CORINE land cover (2006) and ASTER GDEM V2 (2011)products.*

INTRODUCTION

Leaf biomass is about 3-4% of the above-ground biomass of trees, but the allocation ratio NPP_{leaf}/NPP is 0.25- 0.30 [1]. Apart from being a carbon stock, leaf biomass is a major supplier of nutrients in the soil and increases its fertility and the primary productivity of forest ecosystems. Foliage of some forest tree species contains a large quantity of proteins, starches and fats, making it valuable forage for feeding wildlife.

The present study analyses the net primary production (NPP) of leaves (NPP_{leaf}) in deciduous forests of the Rhodope Mountains, based on measurements of leaf area index (LAI) with MODIS spectroradiometer (NASA) on board of the Terra and Aqua satellites during 2010.

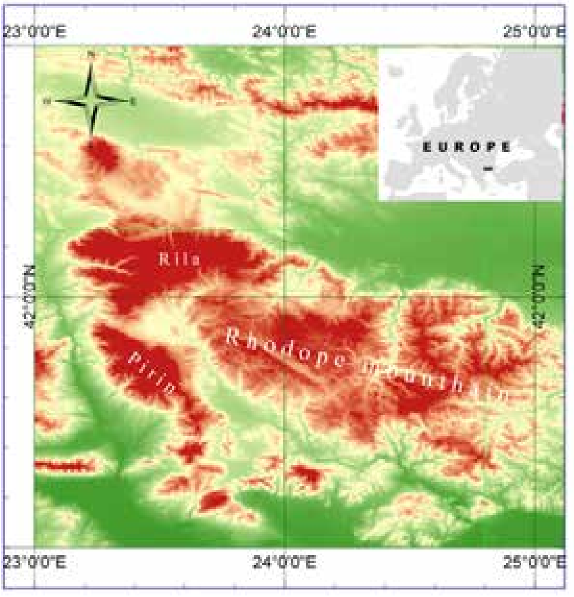
DATA AND METHOD

The Rhodope Mountains are situated in Southeastern Europe, with over 83% of its area in Bulgaria and the remainder in Greece. The mountains are about 240 km long and about 100 to 120 km wide. The altitude of the region varies from 300 to 2191 m.a.s.l. (Mt Goliam Perelik).

The Rhodope Mountains are highly diverse, both in terms of plant species and vegetation typology. Low elevations (300 - 800 m.a.s.l.) are dominated by mixed broadleaf deciduous forests: Quercus dalechampii T. Ten., Quercus pubescens, Quercus Virgiliana, Carpinus betulus L., Ostrya carpinifolia, Carpinus orientalis Mill., Populus tremula L., Acer pseudoplatanus L., Fraxinus ornus L., Acer platanoides L., Corylus avellana L and evergreen Juniperus oxycedrus, while at high altitudes (above 800 m.a.s.l.) Fagus sylvatica, Pinus sylvestris and Picea abies are dominant. The natural forest vegetation zones in Rhodope Mountains (EFA, 2011) are:

1. Lower hilly plain foothill belt of deciduous oak trees (0-700m.a.s.l.).
1.1 Plain and hilly sub-belt of deciduous oak and xerothermic forests (0-500m.a.s.l.)
1.2. Hilly foothill sub-belt of mixed deciduous forests (500-700m.a.s.l.)
2. Middle mountain belt of beech and coniferous forests (700-2000m.a.s.l.).
2.1. The low mountain sub-belt of oak, beech and fir forests (700-1200m.a.s.l.).
2.2. Middle mountain sub-belt of beech, fir and spruce forests (1200-1700m.a.s.l.)
2.3. High mountain sub-belt of spruce forests (1700-2000m.a.s.l.)

Figure 1: Rhodope Mountains (Aster GDEM 2)



Leaf biomass. Leaf biomass productivity of deciduous forests is found using the relationship between leaf area index LAI, and specific leaf area SLA:

$$LMD=\frac{LAI}{SLA}=\frac{\dfrac{m^2(\text{leaf area})}{m^2(\text{graund area})}}{\dfrac{m^2(\text{leaf area})}{kg(\text{leaf mass})}}$$

LMD- leaf mass density, [$kg.m^{-2}$]

Leaf area index. The study is based on an analysis of the LAI/ FPAR MODIS, NASA data sets (ESDT: MCD15A2) [2]. The data are composited every 4 days at 1km resolution.

Based on CORINE land cover 2006 (CLC2006) raster data (100m resolution), we retrieved only the pixels classified as Forest and semi natural areas/Forests/Broad-leaved forest class covered a territory of 2066 km^2. Broadleaf deciduous forests in other CLC2006 classes, as Mixed forest, Heterogeneous agricultural areas, Scrub and/or Herbaceous vegetation associations are not the subject of this study.

The LAI value, which we use to determine the productivity of deciduous broadleaved forest, is calculated as LAI = $LAI_{max} - LAI_0$, LAI_0 acts as a background component and accounts LAI for evergreen coniferous forest and shrubs during dormancy period DJFM (winter).

Specific leaf area (SLA) [m^2kg^{-1}] was measured for the dominant deciduous broad-leaved species in the region: hornbeam, oak, beech. Samples of 500-600 healthy, fresh leaves of dominant species were collected from 10 plots located at different altitudes from 400 to 1300 m.a.s.l. (see Table 1). Groups of 10-15 leaves were scanned with a high resolution scanner. Software was developed to determine the leaf area of the scanned leaves. Then the leaves are dried for 48 hours at 65°C. Dry leaf mass was measured with an accuracy of 0.01g

Leaf mass density (LAD) of mixed forests. Much of the deciduous forests in the Rhodope Mountains are mixed: oak and xerothermic forests (up to 700 m.a.s.l.), oak and beech forests (between 700 and 1200 m.a.s.l.). Monodominant beech forests occur only above 1200 (1200- 1700 m.a.s.l.). In the Greek part of the Rhodope the zone of mixed deciduous forest is more blurred and mixed forests of Quercus petraea, Carpinus orientalis, Fagus sylvatica reach 1200- 1300 m.a.s.l.. Here, Fagus sylvatica can be found in the highest parts of the mountains up to 1800 m.a.s.l. [3]. Therefore, within a pixel, we can find different plant species and in order to define leaf biomass it is necessary to define Composite SLA (CSLA) per pixel. Let on the territory scanned within the i-th pixel, there be n-forest tree species, each with specific leaf area SLA_k (k=1...n). Then the composite SLA of i-th pixel is $CSLA_i=\Sigma\omega_{ki}SLA_k$ where ω_{ki} is the part of the area (100ha) occupied by the k-th species in percents. To determine the ω_{ki} we used the distribution of the dominant species in the EFA forest zones and subzones [4], data form Regional Forest Directorate- Plovdiv, Bulgaria and literature data. Due to the lack of research on the spatial distribution of forest tree species on the Greek territory of the Rhodopes, we assume that the stratification of forest species in the Greek part of the Rhodope Mountains is similar to that in the South Borderside -Arda forest subarea. Then leaf mass density in the i-th pixel- LMD_i, is calculated as $LMD_i = LAI_i/CSLA_i$

RESULTS AND DISCUSSION

The SLA in Rhodope Mountains varies greatly both between the different species and among a given species' representatives (Table 1). This variability has been registered by other researchers too. Bartelink [5] determined that for Fagus sylavatica the average SLA is 17.2$m^2.kg^{-1}$ and SLA is increasing in the direction from the top of the tree to the base of the crown, at the summit SLA varies between 0.8 and 1.2$m^2.kg^{-1}$ while at the base of the crown it is ~ 30 to 34$m^2.kg^{-1}$. Castro-Díez J. et al. [6], examined structural reasons for the variation in the leaf mass per unit area (LMA, $g.m^{-2}$) and the variations of the leaf structure on 52 European tree species grown in controlled conditions. They established that for bushes SLA=20.16$m^2.kg^{-1}$, for trees SLA = 24.0$m^2.kg^{-1}$, for Fagus sylvatica SLA=26.8$m^2.kg^{-1}$. For trees of the genus Querqus – Q. cerris, Q. petraea, Q. robur and Q. suber they found that SLA=19.2m^2kg^{-1}.

Table 1: Measured SLA of dominant species in Rhodope Mountains

Species	Date	Altitude, m.a.s.l.	SLA, m^2/kg dry leaves
F. sylavatica	10.5.2011	400-700	25.4194
F. sylavatica	15.5.2011	400	17.0997
F. sylavatica	15.5.2011	1000	37.0469
F. sylavatica	26.6.2011*	600-1100	15.8634
F. sylavatica	27.7.2011*	1000-1300	14.9148
Q. petraea	10.5.2011	300	8.8982
Q. petraea	15.5.2011	400-500	16.8190
Q. petraea	26.6.2011*	400-600	14.8541
Q. petraea	27.7.2011*	400-500	11.5189
C. betulus	10.5.2011	300-400	14.8196

*) very dry and hot weather

Meier & Christoph [7] examined beech forests in southern Saxony, northern Thuringia and southwestern Saxony-Anhalt (Central Germany). They found that SLA = 21.4 $m^2.kg^{-1}$ (S. E. = 0.48) in 2003 and 19.9 $m^2.kg^{-1}$ (SE = 0.52) in 2004. The surveyed sites were located at 300-400m.a.s.l.. Bouriaud at al. [8] examined SLA on the basis of analysis of beech leaves collected during the autumn litterfall. They also established that SLA strongly varied- 15.0 to 32.0 $m^2.kg^{-1}$ from one location to another.

The measured values of the SLA over the studied territory are: 22.07m^2kg^{-1} (beech), 13.02 m^2kg^{-1} (oak) and 14.82 m^2kg^{-1}(hornbeam). As can be seen, our results for the SLA are closed to those presented above.

On the basis of the analysis of the collected literature data [9]: Carpinus betulus (4 sources), Fagus sylvatica (15 sources) and Querqus (12 sources), we can make the following assessments:

SLA = 21.925 $m^2.kg^{-1}$ (Carpinus betulus)
SLA= (21.85 ± 4.65) $m^2.kg^{-1}$ (Fagus sylvatica)
SLA = (13.73 ± 3.85) $m^2.kg^{-1}$(Querqus)

In order to obtain the NPP_{leaves} we have considered the following three scenarios: 1-st variant our measurements in 2011 (Table 1), 2-nd variant- literature sources data above and average of the two variants (Table 2). Carbon content in the leaves has been taken from literature [9], for the two main tree groups - the families Fagaceae and Betulaceae.

Table 2: SLA and carbon in leaves of dominant species (1-st variant – measured data; 2-nd variant-literature data)

Species	SLA, $m^2.kg^{-1}$			carbon*
	1-st variant	2-nd variant	average	%
Carpinus	21.92	14.82	18.37	46.7
Querqus	13.73	13.02	13.375	44.65
Fagus	21.85	22.07	21.96	44.65

*) carbon contents in percentage of dry leaf mass

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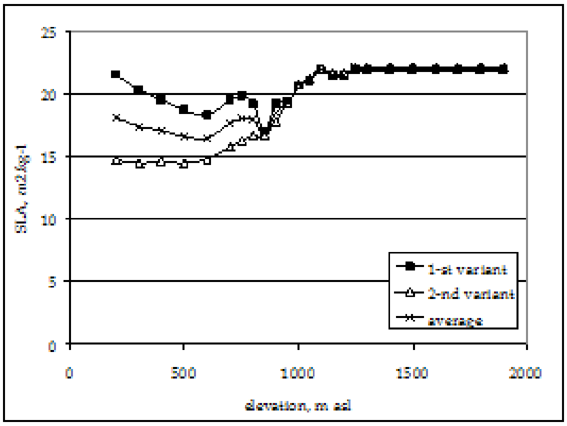
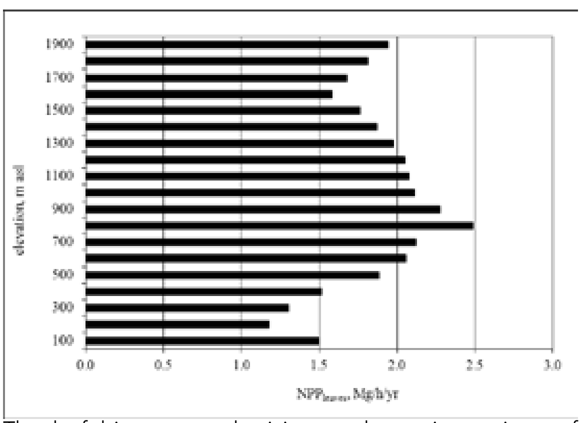
On the basis of CLC2006 data and the data for identifying and mapping of forest habitat types and the composition of plant communities [4], we have obtained altitude profiles of composed SLA (CSLA) and composite carbon contents in percentage of dry leaf mass (Figure 2). As can be seen, CSLA varies strongly in mixed forests, which will affect the estimates of the production of leaf biomass, and the accumulated carbon in forest ecosystems. At an altitude of over 1000 m.a.s.l. deciduous forests are monodominant beech forests and then CSLA = SLA(beech forests).

Figure 2. Composite SLA, (m^2kg^{-1}) with elevation (m.a.s.l.) in Rhodope Mountains in different scenarios



The NPP_{leaves} distribution with elevation, calculated by CSLA is shown in Figure 3. The highest productivity is that in mixed forests, located between 700 and 1200m.a.s.l., where mixed deciduous forests of oak and beech produce on average 2.4$Mg.ha^{-1}yr^{-1}$ dry leaf mass (Table 3). This exceeds by 29% the productivity in the sub-zone of deciduous oak and xerothermic forests (0-500m.). The average NPP_{leaves} in the broadleaf deciduous forests on the territory of the Rhodopes Mountains is 2.14$Mg.ha^{-1}$.

Figure 3: NPP_{leaves}, $Mg.ha^{-1}yr^{-1}$ with elevation.



The leaf biomass productivity on the entire territory of Rhodope Mountains is ~ 442$Gg.yr^{-1}$ and the carbon in the leaves is ~ 202$Gg.yr^{-1}$. So the quantities of leaf biomass and carbon on an annual basis are impressive. The produced leaf biomass is highest in the mixed forests of oak and beech between 700 and 1200m.a.s.l. ~ 198Gg and stored carbon here is 89.65Gg.

The annual production of beech forest in the mid-mountain zone (700-2000 asl.) is about 12% higher compared to that of oak and hornbeam forests between 0 and 700 m.a.s.l.

Table 3. NPP_{leaves} in broadleaf forests, Rhodope Mountains, (2010)

Elevation, m.a.s.l.	Foliage biomass, Mg/ha		
	1-st variant	2-nd variant	Averaged variant
0- 500	1.48	1.98	1.69
500- 700	2.16	2.68	2.39
700-1200	2.35	2.45	2.40
1200-1700	1.99	1.97	1.98
1700-2000	1.98	1.96	1.97
Average	2.01	2.30	2.14

There are no studies on the productivity of leaf biomass in mixed forests of beech, oak and hornbeam. Therefore, to assess our results, we have used data on the productivity of monodominant broadleaf forests. The average leaf biomass production over 23 beech stands in Europe [10] is 2.878 $Mg.ha^{-1}$ and it ranges from 1.2 $Mg.ha^{-1}$ for young beech stand (10 years old, 16 815 $trees.ha^{-1}$) to 4.7 $Mg.ha^{-1}$ (100 years old forest, 1200 $trees.ha^{-1}$). Based on research conducted in two beech stands in Balkan Mountains, Bulgaria, 100 years old forest, Garelkov[11] found that the production of foliage is respectively 2.9$Mg.ha^{-1}yr^{-1}$ and 4.7$Mg.ha^{-1}yr^{-1}$. Dimitrova at al. [12], studied beech tree communities in Vitinya, Petrohan1 and Petrohan2 forest stands, Western Balkan Mountains, Bulgaria. They found that the collected leaf litterfall is: 2.80$Mg.ha^{-1}yr^{-1}$ (Vitinya), 2.51 $Mg.ha^{-1}yr^{-1}$ (Petrohan1) and 2.70 $Mg.ha^{-1}yr^{-1}$ (Petrohan2). As seen the obtained values are comparable to our estimates of NPP_{leaves} = 2.63$Mg.ha^{-1}yr^{-1}$ for monodominant beech forests in Rhodope Mountains. Blaj & Chifu [13] determined the leaf biomass production in Carpinus betulus, Quercus robur and Tilia tomentosa associations in Romania. The average leaf biomass production for Carpinus betulus is 1.480 $Mg.ha^{-1}$ and 2.017Mg. ha^{-1} for Quercus robur, which are very close to our estimates on the territory of Rhodope Mountains: 1.349 $Mg.ha^{-1}$ (Carpinus) and 1.920 $Mg.ha^{-1}$ (Querqus).

CONCLUSIONS

The results presented here show that MOIDIS LAI/FPAR data products can be successfully used to determine the leaf biomass productivity over large territories, which is very difficult to achieve with ground-based measurements. We note that in NPP algorithms of NASA, SLA of broadleaf forests is 26.2 m^2kg^{-1} (BPLUT parameters [14]) and does not depend of their composition. This results in a 12 % error in assessments of NPP_{leaves} and carbon content.

The detailed information on the spatial distribution of forest tree species (CLC2006) on the territory of a pixel (100ha), and observations on their development in terms of leaf area index, increases the accuracy of estimates of leaf production and atmospheric carbon storage.

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The Corine land cover 2006 data was downloaded from European Environment Agency. http://www.eea.europa.eu/ data-and-maps

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