Dependence of phytomass on environmental factors: Case study of Georgia's landscapes

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Abstract

Aim: Prior works had documented the diversity of Georgia's landscapes according to the phytomass. Paper aims to study relationship between phytomass and environmental factors for each landscape in Georgia.

Methodology: This research is based on the concept of analysis and synthesis of landscapes elaborated by Prof. Beruchashvili. The research is based on the field works accomplished by science-research Lab of Tbilisi State University, to study the state of the environments with RS methods in the long-time period. The work is based on the analysis of complex-geographical description of approximately 600 field plots. These plots cover the whole spectrum of landscapes of Georgia, starting from the plains through high-mountainous alpine and sub-nival landscapes. Most of these plots are described during summer period, allowing us to compare them.

Results: During research, the following parameters were identified: The landscapes of Georgia differ with their amounts of phytomass. Phytomass abundance (500 t ha^{-1}) is typical to the middle-mountain landscapes with the prevalence of beech-dark coniferous forests, while the minimum is typical to semi-desert and high-mountain subnival landscapes. It was established that the highest productivity of phytomass is common to the middle-mountain forest landscapes of Western Georgia with dominating beech-dark coniferous forests with an average amount of $15\text{-}20 \text{ t ha}^{-1}$ annually. The productivity of phytomass was also high in the middle-mountain forest landscapes with dominating beech trees. As a result of the study, the number of phytomas and their territorial distribution within the territory of Georgia and their connection according to environmental factors were determined. Besides, the optimum of environmental factors revealed, maximum accumulation of certain phytomass is being accumulated.

Interpretation: This study indicates that phytomass abundance is affected by different environmental factors in different landscapes. In future, it would be beneficial to analyze phytomass changes on the background of changing environmental factors.

Key words: Environmental factors, Georgia landscapes, Landscape approach, Phytomass, Vegetation

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Introduction

Estimation of vegetation biomass (Phytomass) is essential for determining the status and flux of biological materials in an ecosystem to understand the ecosystem (Anderson, 1970; Bargali *et al.*, 1992; Bargali and Singh 1995). Phytomass (vegetation biomass) is a state variable, resulting due to accumulation of net primary productivity in all parts of live vegetation through time (Song *et al.*, 2013). Phytomass estimation is critical for carbon cycle modeling and climate change mitigation programs (Laurin *et al.*, 2014). Much research in recent years has focused on the phytomass study or study of phytomass in different regions or landscapes of Georgia. Beruchashvili (1995) reported phytomass in the landscapes of Caucasus at a level of high taxonomic units (sub-class, types, and sub-types).

Analysis of long-term field work showed that phytomass in landscapes of Georgia is better studied in mountain landscapes than lowlands because most of the stations (meteorological, hydrological) are located in lowlands and foothills and the single environmental research center is located in lowland. The above-mentioned concept is directed and approved mostly for the study of mountainous territories.

Georgia's mountain landscapes are also unequally studied. Some of the landscapes have become the subject of special studies, namely, the middle-mountain forest landscapes with numerous beech trees (Nikolaishvili, 1994). Secondly, more attention has been paid to the forest landscapes. The number of field plots – the mountain landscapes make 87% of all landscapes, proves this. The estimation of phytomass allows us to identify general regularities in different environments and trends of their changes (Thakkar *et al.*, 2017). The relationship between phytomass abundance and environmental factors is described in various studies (Sun *et al.*, 2013). Mostly they are focused on an example of one or two landscape. In view of the above, in this study relationship between phytomass and environmental factors for each landscape in Georgia.

Materials and Methods

This research is based on the concept of analysis and synthesis of landscapes elaborated by Berouchashvili (1983). This concept enables conducting detailed description, analysis and spatial-temporal assessment of natural components. Its main value is to study conditions of natural-territorial complexes (NTC), peculiarity of structure and functionality and the degree of anthropogenic transformation, development of landscape spatial-temporal prognostic models, etc.

The research is based on the field works accomplished by the science-research Lab at Tbilisi State University during 1977-2005 (Nikolaishvili, 2009). A field survey was conducted on 600 plots, which covered almost the whole spectrum of landscapes of

Fig. 1 : Distribution of field plots according to the regions of Georgia: 1. Racha-Lechkhumi-Kvemo Svaneti; 2. Shida Kartli; 3. Kvemo Kartli; 4. Apkhazeti; 5. Kakheti; 6. Samegrelo-Zemo Svaneti; 7. Imereti; 8. Mtkheta-Mtianeti; 9. Samtskhe-Javakheti; 10. Achara and 11. Guria.

Georgia, from the plains through high-mountainous alpine and sub-nival landscapes. In total 9 from 14 types, 17 from 22 subtypes and 41 from 72 genera. Most of the field plots were performed during the summer period. t ha^{-1} was selected as a measurement unit. The number of field plots was nearly same in the eastern and western parts of the country. However, there was difference in their quantities in lowlands and uplands among the regions too (Fig. 1).

Results and Discussion

Dependence of phytomass on climate : In general, mountain landscapes are greatly influenced by air temperature, while the plain landscapes (in eastern and western parts of Georgia) are greatly influenced by precipitation. However, the degree of anthropogenic transformation is also important. On the whole, the maximum amount of phytomass (500 t ha^{-1}) is typical to the middle-mountain landscapes with the prevalence of dark coniferous forest (Tediashvili, 1987). They are followed by middle-mountain forest landscapes with abundant beech forests ($300\text{--}500 \text{ t ha}^{-1}$) (Nikolaishvili, 1994) and the low-mountain Colchic landscapes rank third (with $250\text{--}300 \text{ t ha}^{-1}$) (Beruchashvili, 1995; Tediashvili, 1987). The lack of phytomass is common to high-mountain sub-nival and nival, as well as semi-desert landscapes in Eastern Georgia, with $1\text{--}2 \text{ t ha}^{-1}$ and less (Table 1).

Table 1 demonstrates that phytomass abundance in the mountain forest landscapes ($200\text{--}300 \text{ t ha}^{-1}$ and more) is mainly typical to the landscapes with precipitation over $750\text{--}800 \text{ mm}$. However, the climate is not the only indicator of phytomass abundance in the mountain forest landscapes. According to Matchavariani and Nikolaishvili (2015), two other circumstances are also very important: a) the average amount of phytomass is relatively lower where the annual precipitation is close to minimum, *i.e.* around 700 mm . Most mountain forest landscapes in Eastern Georgia are of this type. The average amount of phytomass in the lower mountains was $175\text{--}200 \text{ t ha}^{-1}$,

Table 1 : Average amount of phytomass by landscapes of Georgia (Nikolaishvili, 2009)

Landscapes	Annual precipitation (mm)	Average amount of phytomass (t ha ⁻¹)	Interval of variation of phytomass (t ha ⁻¹)
Plain and foothills of Western Georgia	800 - 3000	140	75 - 400
Plain and foothills of Eastern Georgia	300 - 800	25	5 - 75
Low mountain with dry scrublands (shibliak, frigan) and steppes of Eastern Georgia	400 - 650	50	15 - 40
Low-mountain forest of Western Georgia	1000 - 3000	190	80 - 500
Low-mountain forest of Western Georgia	800 - 1400	165	100 - 500
Middle-mountain forest (with prevalence of beech forest) of Western Georgia	1000 - 2300	400	175 - 500
Middle-mountain forest (with prevalence of beech) of Western Georgia	750 - 1000	300	65 - 400
Middle-mountain forest (with prevalence of beech-coniferous forest) of Western Georgia	900 - 2500	400	75 - 800
Middle-mountain forest (with prevalence of coniferous forest) of Eastern Georgia	700 - 1400	300	100 - 400
Upper-mountain forest of Western Georgia	1200 - 1500	100	75 - 150
Upper-mountain forest of Eastern Georgia	700 - 1200	120	75 - 125
Middle-mountain with meadow-steppes, dry scrublands (shibliak, frigan)	400 - 650	20	15 - 25
High mountain steppes of Southern Georgia	500 - 700	15	5 - 25
High mountain subalpine of Western Georgia	1000 - 1600	20	10 - 75
High mountain subalpine of Eastern and Southern Georgia	600 - 1400	20	15 - 40
High mountain alpine of Western and Southern Georgia	1000 - 1600	5	1 - 10
High mountain alpine of Eastern Georgia	1000 - 1400	5	1 - 10
High mountain sub-nival and nival	1200 - 3000	1-2	1 - 5

Table 2 : Maximum amount of phytomass in conformity of elevation

Landscapes	Elevation (m)	Amount of phytomass (t ha ⁻¹)
Foothills with steppes, dry shrublands (shibliak, frigan) of Eastern Georgia	900 - 1000	50 - 80
Low-mountain forest (with prevalence of beech forest) of Western Georgia	600 - 750	> 400
Middle-mountain forest (with prevalence of beech forest) of Western Georgia	1200 - 1400	> 450
Middle-mountain forest (with prevalence of beech) of Eastern Georgia	1200 - 1400 (1800)	> 300
Middle-mountain forest (with prevalence of beech-coniferous) of Western Georgia	1400 - 1800	> 500
Middle-mountain forest (with prevalence of coniferous) of Eastern Georgia	1600 - 2000	> 500
Upper-mountain forest	1700 - 1750	> 150

300 t ha⁻¹ in the middle mountains and 80-90 t ha⁻¹ in the upper mountains, while 260, 360 and 100 t ha⁻¹ in Western Georgia, respectively, b) phytomass abundance was fixed where precipitation was maximum (500-600 mm) during the vegetation period (May-November). This is one of the reasons for the mountain forest landscapes in Western Georgia having more amount of phytomass than it does the landscapes in Eastern Georgia. The only exception is the Caucasus landscapes in Kakheti.

Dependence of phytomass on terrain : It is evident from the results that terrain greatly affects the amount of phytomass, especially elevation. However, within the limits of the landscape taxonomic unit, the relationship between the elevation and the amount of phytomass is not very stable. There are landscapes with different amount of phytomas at same elevation.

Distribution of phytomass depending on elevation is different in different landscapes of Georgia. From Table 2, it can be seen that some landscapes do not show even the signs of such a relationship, while others show certain regularities. Some botanical works consider distribution of high-humidity and strong forests at certain elevation. For example, Ketskaveli (1959) talks about the spatial distribution of vegetation cover in the middle mountain zone. He pointed out that high-humidity beech forests are spread at 1000-1700 m, while at higher altitude they are diminished and the height of trees does not exceed 15-20 m.

The maximum phytomass (over 300 t ha⁻¹) in the middle-mountain forest landscapes with the prevalence of beech forests was fixed at 1200-1400 m a.s.l in Eastern Georgia. Within the limits of Great Caucasus in Kakheti, its maximum (over 450 t ha⁻¹) was fixed at 1000-1800 m a.s.l. and at 1200-1400 m a.s.l. in

Colkheti (Nikolaishvili, 2009). High-productive landscapes up and below these altitudinal steps are relatively rare.

Phytomass abundance in the low-mountain forest landscapes of Western Georgia was typical at 600-750 m. However, such high-productive landscapes have limited distribution in the above-mentioned landscapes and are found only in unassailable areas and areas with minor anthropogenic transformation. As for low-mountain landscapes of Eastern Georgia, no relationship between elevation and the amount of phytomass is fixed here. There are no spatial regularities of high-productive landscapes fixed with these landscapes. First, the landscapes with the amount of phytomass of 250-300 t ha⁻¹ were rare and second, they were spread at different elevation.

The change in the amount of phytomass depending on the elevation is relatively evident in the middle-mountain beech-dark coniferous and upper-mountain forest landscapes. In the first case, the relationship between the elevation and the amount of phytomass was directly proportional, while in the latter case the relationship was inversely proportional. The middle-mountain beech-dark coniferous landscapes had much more altitudinal range than the lower mountains, making on average 400-500 m or more. Most of them were spread in Western Georgia at 1000 (1500) – 1800 (2000) m a.s.l. and received almost equal and highly intense humidification over the year. Therefore, as logic suggests, high amount phytomass must be typical to full altitudinal spectrum here. However, the landscapes with the amount of phytomass up to 350-400 t ha⁻¹ were spread at higher elevation, over 1200-1400 m a.s.l. As for the maximum amount of phytomass (over 500 t ha⁻¹), they are usually typical to the upper limit of landscapes. This can be explained by the fact that at high hypsometric steps these landscapes have preserved their original condition.

Different relationship between the amount of phytomass and elevation is seen at the upper-mountain forest landscapes. The relationship was is inversely proportional, i.e. the amount of phytomass decreased as elevation increased. Phytomass abundance (150 t ha⁻¹) was found at 1700-1750 m a.s.l., its average amount (50-100 t ha⁻¹) was found at 1800-1950 m a.s.l., and lack of phytomass (50 t ha⁻¹ and less) is found at 1950-2100 m a.s.l. This can be explained by severe climate conditions and reduced duration of productive stexes typical to high hypsometry of landscapes. However, this peculiarity is evident in the areas with little or hardly any anthropogenic transformation. Even in terms of intense anthropogenic impact, the amount of phytomass was little and all over the hypsometry the phytomass was found. Generally, no relationship was fixed between the elevation and amount of phytomass in high-mountain subalpine landscapes. Here, at the upper limit, on 1800-2300 m a.s.l., different amount of phytomass (15-40 t ha⁻¹) was found.

In the majority of cases, there was no direct relationship between the slopes and the amount of phytomass. First it was

linked to the degree of anthropogenic transformation of the area. Forest was better preserved over steeper slopes (20-30° or more), which was hard to access or cultivate. Consequently, the landscapes over the steep surfaces had great amount of phytomass as compared to slightly sloping surfaces. It appears that, when determining the relationship between the slope degree and the amount of phytomass, the degree of anthropogenic transformation should be considered.

As evident from Fig. 2, the average amount of phytomass over the slopes with 35-45° was 160 t ha⁻¹ in the low-mountain forest landscapes; it was 260 t ha⁻¹ in the middle-mountain forest landscapes and 135 t ha⁻¹, in the upper-mountain forest landscapes. It appears that, the optimal conditions for phytomass abundance was over the slopes was higher than 10-30°.

It is evident from the results that phytomass abundance was affected by the slope aspect. In terms of less anthropogenic transformation, more amount of phytomass was typical to the slopes of the northern and western aspect due to better humidity. Displayed in Fig. 3 relatively fewer amount of phytomass was found over the slopes with southern and southeastern aspect as a result of high insolation and resultant drier slopes. This was peculiar to most Georgian landscapes. For instance, phytomass in the piedmont Colchic landscapes differed depending on the slope aspect, thus, showing a sharp difference from low-mountain forest and middle-mountain forest landscapes of Western Georgia. In addition, the average amount of phytomass over the slopes with the northern and western aspect in Western Georgia was 250 t ha⁻¹, it was only 25 t ha⁻¹ in Eastern Georgia. The situation was similar with the slopes of southern aspect where the amount of phytomass was 100-125 and 10-15 t ha⁻¹, respectively. An exception is the mountain forest landscapes within the limits of Caucasus in Kakheta with frequent landscapes with great amount of phytomass (more than 300 t ha⁻¹) over the slopes with the eastern and southern aspect.

This indicates that phytomass should be analyzed depending on both, slope degree and aspect at the same time. Generally, over the slightly inclined slopes, the aspect difference between them was usually less, while over the steep slopes and

Fig. 2 : Average amount of phytomass in conformity of steepness of slopes.

Fig. 3 : Average amount of phytomass in conformity of slope aspect: 1: Middle-mountain erosion-denudation landscapes with beech, hornbeam-oak (*Quercus iberica*), hornbeam forest and postforest meadows and shrubs; 2: Upper-mountain erosion-denudation, partially paleo-glacial landscapes with birch or pine and oak (*Quercus pontica*) forest; 3: High mountain subalpine denudation and paleo-glacial landscapes with combination of meadows, tall-herb communities, elfin woods (beech and birch) and thickets.

those with average inclination, the average amount of phytomass in the landscapes over the slopes with the southern aspect was twice as less as over the slopes with the northern or western aspect.

Dependence of phytomass on soil properties : Phytomass abundance is highly affected by soil properties. It is not disputable that there is a certain link between the amount of phytomass and soil depth. However, this relationship is not simple or definite. Rather, it is quite weak with middle-mountain forest landscapes with dominant beech forests where brown forest soils dominate. These soils mostly have average strength (60-80 cm), poorly differentiated profiles and average humus-content (at 15-20 cm depth), with intense accumulation of organic substances and high stone content at some locations. As compared to the soils of other landscapes, they are more homogenous complicating their use for intra-landscape indication. However, certain assumptions can be made in this respect. In particular, if the strength of soil does not exceed 40 cm, the landscapes with little amount of phytomass are more common. Usually, under such terms, the amount of phytomass is not more than 300 t ha⁻¹. The situation is different at locations where soil strength is more than 40 cm. Under such terms, the landscapes with quite a great range of the amount of

phytomass are spread. The amount of phytomass at some locations was more than 500 t ha⁻¹ and less than 100 t ha⁻¹ at other locations. In addition, phytomass abundance (more than 500 t ha⁻¹) are fixed only when soil strength exceeds 50 cm (Nikolaishvili, 1996).

This kind of relation was more evident in the eastern part of middle-mountain forest landscapes, where there was a proportional relation between the amount of phytomass and soil strength. A similar situation was observed with the karst substrate in the middle-mountain forest landscapes. Here, even on the soils with little strength, there are landscapes with great amount of phytomass and on the contrary, landscapes with little amount of phytomass over strong soils are quite common.

The same is true with other mountain forest landscapes. Unlike the middle-mountain forest landscapes, the vegetation cover in the low-mountain forest landscapes is diversified and it is presented by forest sierozems, forest weakly unsaturated sierozems, and brown podzolic and brown forest soils. Their physical-chemical conditions are very different. The relationship between the amount of phytomass and soil strength in these landscapes is common both in the eastern and western parts. In terms of minor anthropogenic transformation, the amount of phytomass increases respectively (Nikolaishvili and Matchavariani, 2010).

The relationship between the amount of phytomass and the soil depth was not fixed in the upper-mountain forest landscapes. The only thing we can say for sure is that where the soil strength does not exceed 40 cm, the landscapes with little amount of phytomass (less than 100 t ha⁻¹) are common. The landscapes with little amounts of phytomass may be also found on the soils of different ranges (20-80 cm). The reasons may be different. The upper-mountain forest landscapes are located on the upper hypsometric step of the forest cover limit. They are subject to a significant impact by snow avalanches changing the structure and reducing the strength of the vegetation cover. At such locations, the landscapes with no forest often change the forest landscapes, while the soil strength remains almost the same. In addition, due to anthropogenic transformation of these landscapes because of their use as pastures and hay-fields, the areas of landscapes were also reduced. All this contribute to the reduced amount of phytomass (Matchavariani and Nikolaishvili, 2015).

Soil moisture greatly affects the type of landscapes and phytomass abundance. Generally, an increase in soil moisture results in the increase in the amount of phytomass. Phytomass abundance can be fixed in the mountain forest landscapes of Georgia provided the average soil moisture is at least 25-30%. For the Western Georgia's landscapes, this number must be even higher making 30-40%.

Another important criterion to identify the patterns of territorial distribution of phytomass is distribution of soil moisture. Usually, phytomass abundance is found where soil moisture is high not only in the upper soil horizon, but also across its whole profile. Most important is to identify the soil moisture in 30-cm-deep layer (Nikolaishvili and Chikhradze, 2017). In the middle-mountain forest landscapes with domination beech forests, phytomass more than 300 t ha⁻¹ are found on 30% isoline of soil moisture at 30 cm depth, and where 20% isoline runs at 80 cm depth or more. Similar condition was observed with low-mountain forest landscapes. Soil moisture higher than 60 or 70% in its upper, 10-15-cm-deep layer virtually, does not determine the amount of phytomass (Nikolaishvili and Machavariani, 2010).

Different peculiarities were identified with the piedmont and upper-mountain landscapes. Phytomass abundance was fixed in the landscapes of piedmont steppe, where 30% soil isoline runs at 15-20 cm depth. In addition, there is another necessary condition implying that 40% soil moisture must not run near the surface, but at least at the depth of over 15 cm. Under such terms, sparse arid forests, or shibliak developed with the average phytomass of 125-150 t ha⁻¹. Where 30% isoline runs at the depth of 15-20 cm, the amount of phytomass did not exceed 50 t ha⁻¹ and was only 20-25 t ha⁻¹ (Matchavariani and Nikolaishvili, 2015).

Dependence of phytomass on vegetation : Phytomass abundance is greatly influenced by vegetation. This is particularly well seen with forest landscapes. As illustrated in Fig. 4, phytomass abundance was observed in the middle-mountain forest landscapes (450-460 t ha⁻¹ on average) where the beech content is 80% or with the content of dark coniferous forests of 20-30% (Nikolaishvili et al., 2015). Particularly, the presence of spruce and fir was notable. These plants have long vegetation period. Unlike hardwood plants, they do not spend energy for leafing or weathering. As a result, they have high productivity. The amount of phytomass is much less at locations where hornbeam, ash trees, aspen, cornel, etc. dominate.

If the content of beech exceeded 90%, then the average amount of phytomass in the middle-mountain forest landscapes of Western Georgia with dominant beech was 450 t ha⁻¹, it was 460 t ha⁻¹ in Caucasus of Kakheti and 250-260 t ha⁻¹ in Eastern Georgia's middle-mountain forest landscapes. The amount of phytomass in pure beech landscapes (where the content of other species is less than 10%), was 360 t ha⁻¹; it was 450 t ha⁻¹ in Western Georgia and 460 t ha⁻¹ in Kakheti Caucasus. It is clear that the growth of the amount of beech phytomass is followed by the increasing total amount of phytomass and vice versa.

The total content of beech in the middle-mountain forest landscapes of Caucasus is 60%. This indicator is little for Georgia, as the specific weight of fir and spruce is increasing. As for species such as maple, aspen, lime, ash tree, cornel. etc., the

Fig. 4 : Phytomass amount and vegetation relation, landscapes with dominant plant: (1) Colchic plain and foothills; (2) Plain and foothills of Eastern Georgia; (3, 4) Low-mountain forest; (5, 6, 7) Middle-mountain forest (with prevalence of beech forest); (8, 9) Middle-mountain forest (with prevalence of beech-coniferous); (10, 11) Upper-mountain forest.

maximum amount of phytomass is fixed in the landscapes, where the amount of beech phytomass is 75-100 t ha⁻¹. If the amount of beech phytomass is more than 100 t ha⁻¹, the amount of phytomass of the above-listed species is significantly small. The relationship between the amounts of beech and dark coniferous forest phytomass is almost similar. In particular, if the amount of beech phytomass is 100 t ha⁻¹, then the amount of fir and spruce phytomass is 25(50)-150(175) t ha⁻¹.

The directly proportional relationship between the height of the vegetation cover and the amount of phytomass is quite clear in the forest landscapes. A sharp growth in the amount of phytomass is observed at locations where the height of the trees reaches 20 m. In case of greater strengths (over 25 m), the amount of phytomass does not increase any more, but stabilizes. The landscapes with the maximum values of phytomass (over 400 t ha⁻¹) are common where the height of trees is 22-32 m or more.

Distance between the trees has great influence on bio-functioning processes, as it determines the penetration of sunrays and, therefore, the intensity of bio-functioning processes.

Mean distance between the trees was calculated by using the following equation:

$$L = S / N - d \quad (1)$$

Where, L is the mean distance between the trees, S is the size of the study area (km²), N is number of trees and d is the tree trunk diameter (m). Phytomass abundance was fixed in the mountain forest landscapes (200-500 t ha⁻¹) with 3-5 m mean distance between the trees. As for the landscapes with the mean distance between the trees of less than 3 m, or more than 5 m, the amount of phytomass was minimal.

The mean distance between the trees in the middle-mountain forest landscape was 3-5 m. 45% of total phytomass was found in this kind of landscapes. Same situation was found in low-mountain forest landscapes, where phytomass abundance was fixed in the landscapes with 4-5m mean distance between the trees. The situation was different in the upper-mountain forest landscapes. In the landscapes with dominant beech forests, the amount of phytomass was high, while the mean distance between the trees was 5-6 m or more. Different situation was in the upper-mountain forest landscapes with dominant beech and maple. The mean distance between the trees was less. Due to small diameter of the trees; however, their density was high. Clearly, this peculiarity was observed even in terms of minor anthropogenic transformation.

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