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Estimation of biomass and carbon stock of components of subalpine birch forest of Georgia

G. Vachnadze*, Z. Tiginashvili*, G. Tsereteli**, B. Aptsiauri*

*Vasil Gulisashvili Forestry Institute of Tbilisi State University, **Micheil Sabashvili

Institute of Soil Science, Agrochemistry and Melioration Kakha Bendukidze campus, 240,

David Aghmashenebeli Alley, Tbilisi, 0159, Georgia

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ABSTRACT

In Georgia birch is spread in the mountain subalpine belt on the altitudes 1,800 - 2,250 m above sea level, mostly in the form of subalpine sparse crooked forests of Litvinov birch (*B.litwinowii* A.Dol), as well as common birch (*B.verrucosa* Ehrh). The paper considers the biomass (2,628.5 Gg) of the forest stand and the subordinate layer (young, undergrowth, a living cover of the forest) of the subalpine birch forests and carbon stock (1,298.5 Gg C), sequestered in it, their distribution by age groups and fractions of the forest. The carbon stock of dead organic mass (dead standing trees and fallen dry branches, dead forest cover). Mean annual increment of carbon in 63,781 ha of subalpine birch forests of Georgia.

Keywords: forest stand, age group, fraction, young, undergrowth, living cover, dead cover, soil.

*Corresponding author: G. Vachnadze, E-mail address: givi.vachnadze@gmail.com

Introduction

Today the biological productivity of forests is determined as their main characteristic that taking into account the global change determines processes in forest ecosystems and is used in ecological monitoring, simulation of forest productivity [1-3], estimation of a diversity of forest structure, and forest cover, carbon sequestration of forests [4-8].

The biological productivity of forests is determined by climatic factors, but there are also ontogenetic, cenotic, edaphic, and other factors of its variability [9]. Biological productivity varies according to the horizontal as well as the vertical zoning of the Earth. There is a statistically significant increase in both above-ground biomass and net primary product in birch forests from the north (middle taiga) - 113 Mg·ha⁻¹ to the south (broadleaf and steppe sub-zone) - 225-283 Mg·ha⁻¹,

but further southward (Caucasus and Asia Minor regions) the total biomass of birch forests decreases to 56 Mg·ha⁻¹ [9, 10].

Climate change with the tendency of warming on Earth has caused the raising of the upper boundary of the spread of forest species in the mountains. Analysis of aerial photographs and landscape photographs, as well as a description of the upper forest line, revealed that between 1956 and 2005, during the last 50 years, the composition and structure of the northern Ural Mountains changed and the forest line has raised by 40 meters [11, 12]. Data from space in the Caucasus Reserve revealed a raising tendency of the upper limit of the distribution of subalpine deciduous forests.

The growing threat of global warming on Earth has significantly increased the role of the forest as one of the important reservoirs for the absorption and sequestration of atmospheric carbon in the gaseous

interchange process of carbon. In this regard, the determination of carbon stocks sequestered from the atmosphere by subalpine forests, including subalpine birch forests, is a very topical but little-studied issue and requires proper attention. Their study is important in terms of both vegetation dynamics of the upper forest line in the mountains and their biosphere role.

The subalpine forests of Georgia are represented by crooked, sparse groves and shrubs. Their species composition includes the following plant formations: beech, maple, birch, pine, spruce and fir (Western Georgia) and evergreen azalea groves, Pontic azalea thickets, junipers.

Birch (*Betula*) is a representative of the boreal zone of forest vegetation in the northern hemisphere. In Georgia, in conditions of moderate climate, it is spread in the mountain subalpine belt, on altitudes from 1,800 m to 2,250 m above sea level in the form of subalpine sparse groves and crooked trees (crooked trunk is a result of prolonged exposure of a large mass of snow on birch trunks and rooting of decumbent trunks on the ground). The climate is cold, with short cool summers and harsh long winters. The average annual temperature is 3.2-4.1°C. The duration of the vegetation period is three to four months. Subalpine birch forest is a forest formation that is above all other formations in the mountains. It is an important biogeographical element of the upper forest line in the mountains.

The subalpine belt of Georgia by its environmental conditions and vegetative cover is heterogeneous. Geobotanists [13-19] distinguish two sub-belts in the subalpine belt: the lower sub-belt, which extends from 1,800 m to 2,200-2,300 m above sea level, the vegetation of which is complex and is represented by beech trees (*Fagus orientalis* Lipsky), highland maples (*Acer trautvetter* Medw.), highland oak woods (*Quercus macranthera* F. et M.), rowan (*Sorbus caucasigena* Kom.) in the form of sparse groves and crooked trees of Litvinov birch

(*Betula Litvinowii* A. Doluch.). In Eastern Georgia (in conditions of semi-dry climate) Sosnovski pine (*Pinus sosnovskyi* Nakai.) is added to them, and in Western Georgia (in conditions of moderately humid climate) alpine oaks are replaced by spruce and fir groves (*Picea orientalis* L., *Abies nordmanniana* (Stev.) Spach).

The upper sub-belt of the subalpine belt, up to altitudes 2,200-2,500 m above sea level, is represented by mesophilic high-grass formations and evergreen azalea groves, in the form of bound thick undergrowth.

Five types of birch grow in Georgia. Medvedev birch (*B.medvedewii* Rgl) grows in the upper mountain belt and subalpine crooked forests in Adjara-Guria; also in the Lesser Caucasus [13, 20], Megrelian birch (*B.megrelica* D. Sosh) is the endemic species of Kolkheti, is also found in the forests of Samegrelo and Svaneti; Radde birch (*B. raddeana* Trantzy) - in the central and eastern part of the northern slopes of Caucasus. All three species of birch are spread in small areas. Litvinov birch (*B.litwinowii* A. Dol) is the most spread species, widely represented on the slopes of the Caucasus and southern highland mountains, as well as common birch (*B.verrucosa* Ehrh). Their distribution areas coincide with each other [21]. In Georgia, subalpine birch forests are often mixed with single trees or small groups of rowan (*Sorbus caucasigena* Com. et Gatch), highland oak (*Quercus macranthera* F.et M.), and on relatively moist slopes - mountain maple (*Acer trautvetteri* Medw.), in western Georgia, not infrequently, crooked beech. Litvinov birch is characterized by good seed regeneration on open slopes, covered with stones and loose rocks, where it forms sparse stands; it also well regenerates by sprouts.

During the forest inventory, the arboreal areas and timber volumes in Georgia are presented in a form of cumulative birch - Litvinov birch forests, as the most common species. The total area of birch forests is 63,781 hectares, with a timber volume of 3,105.4 thous. m³ (Tab. 1).

Table 1. Distribution of areas and timber volume of birch forests spread in Georgia by age groups, ha/thous.m³, as of Jan. 1, 2003,*

Area/ stock, ha/ thous. m ³	Age group, ha/thous. m ³					Total average increment, thous. m ³	Average age, yr.
	Young, I-II cl	Average age	Ripening	Mature and older than mature			
				In total	In their number, oldest		
63,781	845	40,510	11,156	11,270	617	64.8	46
3,105.4	14.5	1,554.8	678.6	857.5	67.1		

*Unified registration of the Georgian State Forest Fund has not been conducted since 2003. Currently, since 2017, a complete inventory of Georgian forests is being underway with the support of the German government.

OBJECTIVES AND METHODS

a) determination method of biomass and carbon stock of the forest stand

Phytomass and carbon stock in birch cenoses were assessed by the conversion-volume method [22, 23]. The conversion-volume coefficient is the ratio of phytomass ($B - \text{Mg} \cdot \text{ha}^{-1}$) of a separate fraction of the forest (stem, branch, leaf, root) to the volume of stem wood (with bark) ($M - \text{m}^3 \cdot \text{ha}^{-1}$).

First, the wood biomass was determined by the equation $B_{\text{st}} = M_{\text{st}} \times D$, where B_{st} is the biomass of timber (with bark) in tons, M_{st} is the stem volume in m^3 , and D is the basic density of birch (for birch $D = M_o / V_{\text{wet}} = 0,56 \text{ t/m}^3$)

The method is based on the state materials of forest inventory. The data on areas of birch forests and volume of timber (stem), for different age groups, have been found according to the available materials of forests management and the “United Indices of Inventory of Forest Fund” of the Forestry Department of Georgia [24] and also according to the Guidelines for Effective Management for the Forestry Sector [25] and the Guidelines of the National Greenhouse Gases Inventory [26].

We do not have any birch timber evaluation tables or biomass database in Georgia, therefore, in the percentage distribution of biomass of birch forest fractions, we use the “conversion ratios”, converting timber volumes to the biomass of the forest fractions of the birch forests in the southern zone of Russia [22].

The mean annual increment in biomass volume of subalpine birch forests was determined by the ratio of living biomass of the forest stand and the subordinate layer for the average age of the forest, with the formula:

$$G = B_{\text{total}} / A, \text{ where}$$

G – mean annual increment of the total biomass of birch forest, $\text{Mg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$;

B_{total} - living biomass of birch forest (without leaf and forest grass cover), Mg . According to research materials;

A – average age of birch forests, year. From materials of inventory.

b) determination method of biomass and

carbon stock of the subordinate layer of the subalpine birch forest

Inventory materials include: species composition of young growth and undergrowth on sample areas and their number; dominant species of living soil cover, percentage of its coverage; thickness of dead soil cover and the degree of coverage, but their biomass and sequestered carbon stock that is of interest to us, are not available. The mentioned issue has been studied on the example of the Lagodekhi State Reserve, where subalpine forests are distributed in the subalpine belt of the southern slopes of the Greater Caucasus from 1,800 m to 2,200 m above sea level. The area of subalpine forests has been greatly reduced due to prolonged and strong anthropogenic impact on the forest (unsystematic felling, uncontrolled grazing of livestock in the forest). Only small groves and fragments of crooked birch groves and birch-rowan groves reach the natural upper forest line (about 2,500 m above sea level) [20]

We have used the results, obtained in the research according to the 2013 grant of Shota Rustaveli National Scientific Foundation of Georgia: “Determination of carbon (C-CO_2) stocks sequestered in the vegetative cover of Lagodekhi State Reserve” on subalpine birch forests [27]. In the Lagodekhi Reserve, birches are represented by crooked trees of Litvinov birch (*Betula litwinowii*) and they occupy 128 ha, with a small timber volume - 23 thous. m^3 . 8 sample areas are taken there, each with an area of 1000 m^2 . Also, 6 sample areas from the inventory materials were analyzed.

In determining the total phytomass of the forest, it is necessary to evaluate the biomass and carbon stock sequestered in all the morphological components of the forest: the forest stand, undergrowth, young growth, living soil cover, as well as dead soil cover, dead standing trees, and fallen deadwood. Species composition, number, and dendrometric indicators were determined on the sample areas. Average model trees were selected, from which average samples of stem and branch (leaf) were taken to determine biomass, taking into account their number per hectare.

Living and dead soil cover was described on the sample areas. The type, thickness, and degree of coverage of the dead soil cover were determined.

Biomass of living soil cover and carbon sequestered in it were determined by weight method of grass mass mowed on discount areas (1×1 m), taking into account the moisture content and the percent of coverage of grass cover. The stock of biomass of dead soil cover was determined by drying the samples (number 10) taken by metal molding blocks ($25 \times 25 \times 20$ cm) on the sample areas to absolute dry weight; by converting their average weight per hectare and the percent of coverage of dead cover.

c) determination method of the biomass of organic substances and volume of sequestered carbon in soils of subalpine birch forests

Morphological description of soil cuts taken from the sample areas was performed; Soil density was determined in samples taken from genetic horizons [28-31]. Granulometric and chemical analyzes have been performed; according to these characteristics, the stock of organic matter in the soil was determined by the formula:

$$C_{soil} = a \times 10\,000 \times b \times p/100, \text{ where}$$

C_{soil} – humus stock, t/ha

a- thickness of soil layer, m

b- density of soil layer, g/cm³

p- humus content, %

RESULTS AND ANALYSIS

1. Estimation of biomass and carbon dioxide stock in the forest stand of the subalpine birch forests

One of the important issues in the study of the regularity of development of forest biogeocenoses is the assessment of phytomass and carbon stocks of all forest components and its fractions; distribution of stocks by age groups; increase the carbon capacity of forests; maintaining climate resilience by slowing down the ongoing warming process on the planet. The results of scientists working on this issue are reflected in the publications [32-37].

The stock of biomass of the forest stand in the forest and the amount of carbon sequestered in it directly depends on the species composition of the forest, the age of the forest, the taxation frequency, the quality class - in total, on timber volume. Using cameral treatment of field materials, inventory materials, and appropriate Tables, the biomass and carbon stocks in subalpine birch forests are determined by forest age groups and regions (Table 2) and forest fractions and age groups (Table 3).

Table 2. Biomass and carbon stock of the birch forests of Georgia by age groups and region (B/C in Gg)

Territorial forestry service (region)	Total area/stock ha/thous. m ³	Age group, B/C					In total
		Young	Average age	Ripening	Mature	Older than mature	
Eastern Georgia							
Kakheti	3 384	-	33.85	17.84	36.48	1.91	90.08
	119.4	-	16.89	8.9	18.2	0.95	44.94
Kvemo Kartli	85	-	0.79	-	0.44	-	1.23
	1.6	-	0.39	-	0.22	-	0.61
Mtskheta-Mtianeti	14 159	0.88	201.94	165.66	215.43	-	583.91
	775.5	0.43	100.72	82.67	107.47	-	291.29
Shida Kartli	8 188	0.61	188.34	56.22	56.96	34.42	336.55
	439.9	0.3	93.93	28.06	28.41	17.18	167.88
Samtskhe-Javakheti	6 428	1.22	67.95	64.89	145.55	3.89	283.5
	379.3	0.61	33.89	32.38	72.6	1.93	141.41
In total, East. Georgia	32 244	2.71	492.87	304.61	454.86	40.22	1 295.27
	1 715.7	1.34	245.82	152.01	226.9	20.06	646.13
Western Georgia							
Imereti	29	0.17	1.03	-	-	-	1.2
	1.5	0.09	0.51	-	-	-	0.6
Guria				is not spread			
Racha-Lechkhumi-Kvemo Svaneti	4 098	0.17	61.62	10.86	15.49	10.72	98.86
	128.6	0.09	30.73	5.42	7.72	5.34	49.3

Samegrelo-Zemo Svaneti	24 857	8.74	611.28	173.81	103.57	0.07	897.47
	1 160.8	4.33	304.87	86.73	51.66	0.04	447.64
Abkhazia A.R.	2 343	0.52	62.17	2.06	1.54	-	66.29
	84.1	0.26	31.01	1.02	0.77	-	33.06
Adjara A.R.	210	0.35	0.87	6.75	2.94	-	10.91
	14.7	0.17	0.43	3.37	1.47	-	5.44
In total, West. Georgia	31 537	9.95	736.97	193.48	123.54	10.79	1 074.73
	1 389.7	4.94	367.55	96.549	61.62	5.37	536.04
Georgia	63 781	12.66	1 229.84	498.09	578.4	51.01	2370
	3 105.4	6.28	613.37	248.56	288.52	25.44	1 182.17
Percentage distribution of carbon		0.5	51.9	21.0	24.4	2.2	100

The total area of the subalpine birch forest in Eastern Georgia is 32,244 hectares, with a biomass supply of 1,295.27 Gg, with the largest share coming from the Dusheti region of Mtskheta-Mtianeti Forest Service - 13,976 ha, with a biomass supply of 570.12 Gg. The total biomass supply of Mtskheta-Mtianeti birch forests was determined at 583.91 Gg, carbon stock - 291.29 Gg, which is 45.1% of the total biomass and 52.1% of the carbon stock of birch forests of Eastern Georgia. In the birch forests of Eastern Georgia, the average aged (492.97 Gg) and mature (9,454.86 Gg) stands are dominant. In the subalpine birch forests, the biomass of the older than mature and young birch forests is small, sometimes of insignificant quantity.

In Western Georgia, the birch forests are

spread on 31,537 hectares. 78.8% of them (24,857 ha) accounts for Samegrelo-Zemo Svaneti region: in particular, 15,604 ha for Upper Svaneti and 9,041 ha - Lentekhi district. The total biomass supply of birch forests of Samegrelo-Zemo-Svaneti is 897.47 Gg with 447.64 Gg of carbon sequestered in them. The birch forests of Adjara A.R. are characterized by the smallest area (210 ha) and consequently with the smallest biomass - 10.91 Gg, but are distinguished by high productivity, 52.0 t/ha per unit area when the supply of the rest of the region was 34.1 t/ha. The average age stands prevail in birch forests by biomass supply and carbon stock - 51.9%. The biomass supply is small in two age groups of birch forests: young growth (0.5%) and older than mature (2.2%).

Table 3. Distribution of biomass supply and carbon stock of birch forests of Georgia by fractions and age groups (B/C in Gg)

Age group, duration, year	Total area/stock ha/thous. m3	Fractions, B/C				
		Stem	Branch	Leaf	Root	In total
Young 1-20	845	7.19	1.75	1.05	2.67	12.66
	14,5	3.6	0.88	0.47	1.33	6.28
	% of biomass	57 %	14 %	8 %	21 %	100 %
Average age 21-50	40,510	838.04	97.96	31.08	262.76	1 229.84
	1,554.8	419.01	48.98	14	131.38	613.37
		68 %	8 %	2 %	21 %	100 %
Ripening 51-60	11,156	363.73	41.4	9.5	83.46	498.09
	678.6	181.86	20.7	4.27	41.73	248.56
		73 %	8 %	2 %	17 %	100 %
Mature 61-80	10,653	418.43	55.95	13.4	90.62	578.4
	788	209.22	27.97	6.03	45.3	288.52
		73 %	10 %	2 %	16 %	100 %
Older than mature 80 and >	617	36.9	4.93	1.19	7.99	51.01
	69.5	18.45	2.46	0.52	4.01	25.44
		73 %	10 %	2 %	16 %	100 %

In total	63,781	1 664.29	201.99	56.22	447.5	2 370
	3,105.4	832.14	100.99	25.29	223.75	1,182.17
Percentage distribution of biomass		70.2	8.5	2.4	18.9	100 %

In determining the biomass supply and carbon stock in forest ecosystems, special importance is given to the morphological-structural distribution of individual forest fractions by fractions [12, 22, 32, 38, 39], modeling their dynamics [37]. Percentage distribution of fractions and the number of their stocks are mainly determined by forest species composition, genetic-morphological characteristics of the species [40, 41], as well as the age structure of the forest, forest density, climatic-soil conditions [12, 37, 42-44].

The percentage of biomass distribution of fractions in the total biomass of the subalpine birch forests of Georgia significantly differs from all other deciduous trees. The biomass share of the stem of crooked birches in total biomass is 70.2%, which is 7-12% higher than in other deciduous trees. And the share of biomass supply of branches in total biomass is about 2 times smaller and amounts to 8.5%, instead of 16% for other deciduous trees on average. The share of leaf biomass is high, which amounts to 2.4% of the total biomass, in other deciduous trees its supply is in the range of 1.5-2.1% [41, 45-47].

The biomass supplies of their fractions in the subalpine birch forests of Georgia are very small. This is due to the harsh living environment of the subalpine birch forests. Their supplies are the smallest compared to other deciduous species. For example, the average supply of total biomass in birch forests is 2,370 Gg (37.2 Mg·ha⁻¹). Their biomass supply of stem is 26.1 Mg·ha⁻¹, of a branch - 3.2 Mg·ha⁻¹, of a leaf - 0.9 Mg·ha⁻¹, and of root biomass - 7.0 Mg·ha⁻¹. The biomass supplies of other deciduous fractions are significantly higher. For comparison, biomass supplies of beech forests are the highest. Their total biomass is 191.3 Mg·ha⁻¹. According to the fractions, their supplies are: stem - 121.0 Mg·ha⁻¹; branch - 31.0; leaf - 3.0; root - 36.3 Mg·ha⁻¹ [47]. The biomass supplies and carbon stocks are also high in the other deciduous species spread in the subalpine zone. The highest is the biomass of highland oaks, their supply is 95.0 Mg·ha⁻¹. According to the fractions, their supplies are: stem - 59.4 Mg·ha⁻¹; branch - 15.9; leaf - 2.0; root - 17.7 Mg·ha⁻¹. The biomass of highland maple fractions is also high: total biomass - 91.4 Mg·ha⁻¹, in their number stem - 56.7 Mg·ha⁻¹; branch - 14.4;

leaf - 3.3; root - 17.0 Mg·ha⁻¹ [6, 7, 22, 27, 41].

The total biomass of birch forests growing on 63,781 hectares in Georgia has been determined at 2,370.0 Gg. They store 1,182.17 Gg of carbon, which corresponds to 4.33 Tg of CO₂ absorbed from the atmosphere.

2. Estimation of biomass and carbon stock in the subordinate layer of birch forests of Georgia

The vegetative cover of the subordinate layer plays a central role in the formation of the structure and composition of the forest ecosystem. Its participation and abundance provide the basic elements of biodiversity [48, 49], metabolism [50-53] and forms the future timber structure and diversity [54-56].

According to the data available in the forest sources, the rates of biomass and carbon stocks of young growth, undergrowth, and living soil cover in the forest vary greatly [46, 54-59]. Species composition of young growth and undergrowth in the subordinate layer, their quantity and biomass indicators depend not on the timber supply of the stand, but mainly on forest species composition, forest fruiting period, degree of crown closure (light factor), on the conditions of the locality of plant growth - environmental conditions in which the phytocenosis developed. The same can be said about the species composition of the living soil cover and the degree of their coverage in the forest. Therefore, their biomass and carbon stock values are highly variable over time and are related to environmental conditions. The range of change in the number of their biomass supplies per hectare is very wide, from a few kilograms to several tens of tons. Therefore, the rate of biomass supplies and carbon stocks of young growth, as well as of undergrowth and living soil cover is not a constant value.

It should be noted that the generalization of the data of biomass and carbon stocks of the **subordinate layer** - young growth, undergrowth, living soil cover, obtained at the study of birch forests on such a small area of 128 hectares and one location (on the example of Lagodekhi Reserve) on birch forests spread in Georgia (especially for the conditions of Western Georgia) does not give convincing results. Thus, we consider it necessary to continue research in this direction on subalpine forests, including subalpine birch forests, to

correct the data for the subordinate layer obtained by us (as the forest element most sensitive to the changing environmental conditions of the forest), to make them more precise.

In determining the living biomass and sequestered carbon stocks in the subordinated

layer of the forest, we used the weighted average values of the young growth and living soil cover of biomass supplies obtained in the study in the pilot birch forests selected by us in the form of reference values (coefficients); accordingly, their coefficients are 0.1 and 0.395 Mg·ha⁻¹.

Table 4. The biomass and carbon stock of the subordinate layer of birch forests of Georgia B/C in Gg

Young growth			Undergrowth		Living cover			Subordinate layer		
above-ground	below-ground	Total	above-ground	below-ground	above-ground	below-ground	Total	above-ground	below-ground	Total
4.47	1.92	6.39	-----	-----	14.82	10.37	25.19	19.29	12.29	31.58
2.01	0.87	2.88	-----	-----	6.67	4.67	11.34	8.68	5.53	14.21

The phytocenological structure of the subordinate layer of subalpine birch forests is highly peculiar.

Biomass and carbon of young growth. Subalpine birch forests are represented by pure stands. Their renewal is mainly vegetative, with a root collar. Thus, in the subalpine birch forest, the young growth is usually represented by young birch, it is seldom mixed with single young trees of highland maple and highland oak. The levels of biomass and carbon for young growth of the subalpine birch forests spread in Georgia on 63,781 ha are not high. Their stocks are 6.39 and 2.88 Gg, respectively. Their stocks per unit area are small and amount to: biomass - 0.1 Mg·ha⁻¹, carbon - 0.045 MgC·ha⁻¹.

Biomass and carbon of undergrowth. The Caucasian rhododendron (*Rhododendron caucasicum*) is distributed in the undergrowth in the form of small fragments, blueberry (*Vaccinium myrtillus*), as well as rowan (*Sorbus aucuparia* L.) are found. The total biomass supply in the pilot crooked undergrowth of birch forests is so insignificant that it is permissible to ignore them [25].

Biomass and carbon of living soil cover. It is noteworthy that there is a strong development of high grassland living cover in the subalpine forests, mainly in the plain areas, in the uncultivated grounds in the forest. High grassland is dominated by Alpine dock (*Rumex alpinus* L.), heartleaf oxeye (*Telekia speciosa*), ragwort (*Senecio rhombifolius*), Sosnowsky's hogweed (*Heracleum*

sosnowskyi), also common aconite (*Aconitum orientale*), rough comfrey (*Symphytum asperum*) [60-62]. The biomass supplies in the living soil cover of birch forests of Georgia amounts to 25.19 Gg, with 11.34 Gg of sequestered carbon. Their stocks per unit area are 0.395 Mg·ha⁻¹ and 0.178 Mg C·ha⁻¹, respectively.

The carbon dioxide - 52.11 Gg (0.817 Mg CO₂·ha⁻¹) - is absorbed from the atmosphere by the subordinate layer (young growth, undergrowth, living soil cover) of subalpine birch forests of Georgia, this value is bound in 31.58 Gg·ha⁻¹ (t / ha) of biomass in the form of 14.21 Gg of carbon (Mg C·ha⁻¹).

3. Estimation of the biomass of dead organic substance and carbon stock in birch forests of Georgia

Dead standing and fallen biome. Biomass supplies in the dead standing and fallen biome of the subalpine birch forests were not recorded in the inventory materials, so for its determination, we used the coefficient for calculation of pristine forests from the total forest biomass, proposed by the working group of climate change experts [26], according to which the mass, as well as carbon stocks in dead standing and fallen deadwood, should be 23.7 Gg and 11.85 Gg of C, respectively (see Table 5).

Dead soil cover. In the subalpine birch forest, there is a dead cover 2-4 cm thick, its biomass supply is up to 319.85 Gg (5.02 Mg·ha⁻¹), and it contains 127.94 Gg (2.01 Mg C·ha⁻¹) of carbon, which corresponds to 469.16 Gg of carbon absorbed from the atmosphere. (see Table 5).

Table 5. Biomass of dead organic substance and carbon stock in birch forests of Georgia (B/C in Gg)

Area/stock ha/thous. m ³	Dead standing and fallen deadwood	MgC·ha ⁻¹	Dead forest cover	MgC·ha ⁻¹	In total	MgC·ha ⁻¹
63,781	23.7	0.37	319.85	5.02	343.55	5.39
3,105.4	11.85	0.19	127.94	2.0	139.79	2.19

The total biomass and carbon stock of dead organic matter in the subalpine birch forests are 343.55 and 139.79 Gg, respectively. Here, the carbon bound in the organic matter of dead standing and fallen mass is very small 11.85 Gg of C, and carbon bound in the dead organic mass is only 8.5% of the total carbon stock. None of the species are cut in the subalpine birch forests, thus, the formation of dead standing and fallen timber here is a result of a natural, self-thinning process.

4. Mass of dead organic substance and carbon

Table 6. The total humus and carbon stock in the mountain-forest-meadow soil of subalpine birch forests of Georgia (B/C in Gg)

Area, ha	Humus stock		Carbon stock		Absorbed carbon dioxide	
	Mg·ha ⁻¹	Tg	Mg·ha ⁻¹	Tg	Mg·ha ⁻¹	Tg
63,781	227.18	14.49	131.54	8.39	482.43	30.77

The mountain-forest-meadow soils developed under the subalpine birch forests are strongly humous. In the whole soil profile, according to the genetic horizons of the soil (soil depth is 0-58 cm on average), the average weighted supply of organic matter is high, amounting to 14.19 Tg (227.18 Mg·ha⁻¹) on average. 8.39 Tg of carbon (131.54 Mg C·ha⁻¹) is bound in it, which corresponds to 30.77 Tg of carbon dioxide (482.43 MgCO₂·ha⁻¹) absorbed from the atmosphere.

stock in the soil of birch forests of Georgia

Typical mountain-forest-meadow soils are formed in the crooked subalpine birch and beech forests and under the sparse maple groves of Georgia. Soils are characterized by undifferentiated profile, low and medium depth, acid reaction of the whole profile, low degree of saturation, high humus [63-66].

Average values of soil organic matter (humus) obtained by granulometric and chemical analysis of soil samples in pilot birch forests are given in Table 6.

5. Accumulated carbon stocks in the total biomass of birch forests of Georgia by pools

In sequestration of the atmospheric carbon, forest formations are considered to be the most powerful carbon pool. There are three main pools of carbon in the forest: I – in the form of living biomass, II – dead organic matter, and III – soil. Table 7 shows the amount of carbon sequestered in carbon pools and their percentage distribution by pools.

Table 7. Carbon stocks in subalpine birch forests of Georgia by pools

I In living biomass	1,196.38 Gg	18.76 MgC·ha⁻¹	12.30 %
a) forest stand	1,182.17 Gg	18.54 Mg C·ha ⁻¹	
b) subordinate layer	14.21 Gg	0.22 Mg C·ha ⁻¹	
II In dead organic mass	139.79 Gg	2.19 Mg C·ha⁻¹	1.44 %
a. dead standing and fallen deadwood mass	11.85 Gg	0.19 Mg C·ha ⁻¹	
b) dead forest cover	127.94 Gg	2.0 Mg C·ha ⁻¹	
III In organic substances of soil	8,390.0 Gg	131.54 Mg C·ha⁻¹	86.26 %
Total carbon stock	9,726.17 Gg	152.49 Mg C·ha ⁻¹	100 %

According to carbon pools in the subalpine birch forests, from total biomass, only 12.3% (18.76 MgC·ha⁻¹) accounts for I - living biomass, II - 1.4% (2.19 Mg C·ha⁻¹) accounts for dead organic matter, III - soil organic matter 86.3%

(131.54 Mg C·ha⁻¹). The percentage distribution of their stocks differs markedly from that of both Georgia [47] and European forests (excluding Russian forests) [67].

Carbon stocks by pools

	I – Living biomass	II – dead mass	III – soil
Georgian forests	78.0 MgC·ha ⁻¹ 34.2 %	8.8 MgC·ha ⁻¹ 3.5 %	142.3 MgC·ha ⁻¹ 62.3 %
European forests	63.9 MgC·ha ⁻¹ 35.7 %	18.6 MgC·ha ⁻¹ 10.6 %	96.6 MgC·ha ⁻¹ 53.9 %
Subalpine birch forests of Georgia	18.76 MgC·ha ⁻¹ 12.3 %	2.19 MgC·ha ⁻¹ 1.4 %	131.54 MgC·ha ⁻¹ , 86.3 %

6. Mean annual increment of biomass and carbon in subalpine birch forests. When considering the process of gas exchange in the forest, it is important to determine the annual volume of atmospheric carbon absorbed by the living forest biomass.

Below, the rates of mean annual increment in biomass and carbon stocks of the forest stand and subordinate layers of the subalpine birch forest, their above-ground and below-ground layers (without leaf and living forest grass cover) are given in the form of a Table.

Table 8. Mean annual increment of biomass and carbon stock of subalpine birch forests (Mgha⁻¹yr⁻¹)

Forest forming species, average age, area, ha	Forest layer	Living biomass and carbon stock, Gg	Mean annual increment of living biomass and carbon stock, Mgha ⁻¹ yr ⁻¹		
			above-ground	below-ground	In total
Subalpine birch forest, average age 46 yr. 63,781 ha	Forest stand	2,313.78	0.636	0.153	0.789
		1,156.88	0.318	0.76	0.394
	Subordinate	6.30	0.003	0.002	0.005
		2.84	0.0014	0.0006	0.002
	In total, phytocenosis	2,320.08	0.639	0.155	0.794
		1,159.72	0.319	0.077	0.396

According to the forest inventory materials, the average annual age of subalpine birch forests in Georgia is 46 years. In the subalpine zone, birch forests developed during the vegetation period of 3-4 months are characterized by low productivity. We have determined the total volume of live biomass and carbon stock in the forest stand and subordinate layer of birch forests at 2,320.08 Gg (36.38 Mgha⁻¹) and 1,159.72 Gg (18.18 MgC·ha⁻¹). This does not include carbon bound in their leaf biomass, it is considered to be scattered as soon as it falls. The same can be said for the living (herbage) cover of the forest [25].

The mean annual increment of biomass and carbon stock of subalpine birch forests is not high (Tab.8). The values of mean annual increment of biomass and carbon stocks of forest stand and subordinate layer are small, especially, of the subordinate layer. The mean annual increment is: for the biomass of forest stand - 50.3 Gg·yr⁻¹; carbon - 25.15 GgC·yr⁻¹; and the subordinate layer, respectively - 0.32 GgC·yr⁻¹ and 0.14 GgC·yr⁻¹. Taking into account the unit area, the mean annual increment in carbon stock sequestered in the biomass of the forest stand and subordinate layer of the subalpine birch forests was 0.394 Mg

C·ha⁻¹·yr⁻¹ and 0.002 Mg C·ha⁻¹·yr⁻¹, respectively.

The forest ecosystem as a result of photosynthesis not only absorbs carbon dioxide from the atmosphere but at the same time, releases free oxygen in the atmosphere.

95.37 GgCO₂·yr⁻¹ (1.5 MgCO₂·yr⁻¹) of carbon dioxide is absorbed annually from the atmosphere during the gas exchange process on 63,781 hectares of subalpine birch forests in Georgia, while 69.4 GgO₂ (1.09 MgO₂·ha⁻¹·yr⁻¹) of oxygen are released.

CONCLUSION

The percentage distribution of biomass and carbon in the individual fractions of the birch forests differs significantly from all other forest forming deciduous trees of Georgia. The share of carbon sequestered in the stem biomass of the subalpine birch forests is 70.4% of the total biomass, which is 7-12% greater than in other deciduous trees, and that of a branch is 2 times smaller and amounts to 8.5%, instead of 16% for other deciduous trees on average. The leaf carbon stock is high, with a share of 2.2% of the total stock. In other deciduous trees, its stock is in the range of 1.5-2.0%. However, the total stock of birch forests per unit area is the smallest compared to other deciduous trees. The average biomass supply in birch forests is 37.2 Mg·ha⁻¹. The biomass supplies of a stem are 26.1 Mg·ha⁻¹, of a branch - 3.2 Mg·ha⁻¹, of a leaf - 0.9 Mg·ha⁻¹, and of a root - 7.0 Mg·ha⁻¹, which is due to the harsh living conditions of the subalpine birch forests.

The principle of percentage distribution of fractions of forest woody species was mainly determined by the genetic-morphological structure formed during their evolutionary development. The difference between biomasses of the tree fraction by species is small, not substantial. The differences are mainly due to the forest density, more precisely to the degree of crown closure.

In total in Georgia, the total supply of above-ground and below-ground biomass of the forest stand of subalpine birch forests growing in Georgia on area 63,781 ha with the age 46 years was determined at 2,370 Gg. The carbon stock sequestered there is 1,182.17 Gg C (18.53 MgC·ha⁻¹), which corresponds to 4.33 Tg CO₂ (68 Mg CO₂·ha⁻¹) absorbed from the atmosphere.

The phytocenological structure of the subordinate layer of subalpine birch forests

is highly peculiar. It can be said that in the subalpine birch forest formations (especially in crooked birch forests) the undergrowth is not developed. Neither biomass nor carbon stocks of young growth are high – the biomass is 6.39 Gg (0.1 Mg·ha⁻¹) and carbon – 2.88 Gg (0.045 MgC·ha⁻¹), but the biomass of herbal cover and carbon sequestered in it are high. Accordingly, their stocks are: 25.19 Gg (0.395 Mg·ha⁻¹) and 11.34 Gg C (0.178 MgC·ha⁻¹).

The stocks of atmospheric carbon in Georgian birch forests by pools are presented as follows: carbon sequestered in living biomass - 18.76 MgC·ha⁻¹, which is 12.3% of the total carbon stocks; in dead organic matter - 2.19 MgC·ha⁻¹, 1.4%; in the soil - 131.54 MgC·ha⁻¹, 86.3%. Their total stocks in all pools of birch forests are 9.73 TgC (152.5 MgC·ha⁻¹).

In the harsh climatic conditions of the subalpine zone, mean annual increments of living biomass and carbon stocks of 46-year-old subalpine birch forests developed during the short vegetation period are small. The mean annual increment in carbon stock sequestered in the biomass of the forest stand and subordinate layer of the subalpine birch forests was 0.394 MgC·ha⁻¹·yr⁻¹ and 0.002 MgC·ha⁻¹·yr⁻¹, respectively. The average annual increase in carbon deposited in the living biomass of 63,781 hectares in Georgia is 25.29 MgC·yr⁻¹ (0.396 MgC·ha⁻¹·yr⁻¹). The mean annual increment of carbon sequestered in the living biomass of the subalpine birch forests growing in Georgia on the area 63,781 ha, amounts to 25.29 MgC·yr⁻¹ (0.396 MgC·ha⁻¹·yr⁻¹).

The volume of carbon dioxide absorbed annually from the atmosphere during the gas exchange process in the phytocenoses of subalpine birch forests in Georgia is 95.37 GgCO₂·yr⁻¹ (1.50 MgCO₂·ha⁻¹·yr⁻¹); the volume of the released oxygen is 69.40 GgO₂·yr⁻¹ (1.09 MgO₂·ha⁻¹·yr⁻¹). The mentioned data are the lowest in comparison to the deciduous forests in Georgia.

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