Above-ground Biomass in Young Grey Alder (*Alnus incana* [L.] Moench.) Stands

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Abstract

Presented is a method for estimating the amount of leafless naturally moist above-ground biomass in one-to-five-year-old untended naturally grey alder regenerating stands with the respective values calculated by using easy-to-measure stand parameters like the average height and the number of stems (root suckers, stool shoots, coppice, or saplings) per unit area. An equation is proposed for estimating the amount of biomass in one-to-five-year-old grey alder growth: biomass (M) is calculated as a function of the average stem height (H_v) and the number of stems (N) per ha: $M = 0.0536 \cdot H_v^{2.2516} \cdot N, (R^2=0.905;\ P<0.05)$.

The biomass of untended young grey alder stands is calculated from the average stem height of H_v=0.8-4.8 m in one-year-old and five-year-old stands, respectively, with the number of stems per 1 ha ranging from 10,000 to 100,000.

The calculations show that, with the average stem height in one-to-five-year-old grey alder stands increasing only by 0.1m, the amount of above-ground biomass increases by an average of 30%, provided the number of stems per ha is the same; in case the number of stems is by 10,000 larger, the biomass increase is by 40%.

The research shows that the amount of naturally moist biomass in one-to-five-year-old untended grey alder stands is uneven with the variations depending on stand age and stem dimensions.

The amount of biomass in untended grey alder stands depending on the stand density varies in a fairly wide range: from 0.9 $t \cdot ha^{-1}$ to 7.7 $t \cdot ha^{-1}$ ha in one-year-old stands; from 2.2 t ha^{-1} to 23.6 $t \cdot ha^{-1}$ in two-year-old stands; from 5.2 $t \cdot ha^{-1}$ to 28.9 $t \cdot ha^{-1}$ in three-year-old stands; from 7.3 $t \cdot ha^{-1}$ to 57.4 $t \cdot ha^{-1}$ four-year-old stands; from 15.2 $t \cdot ha^{-1}$ to 64.4 $t \cdot ha^{-1}$ per ha in five-year-old stands.

Key words: grey alder, biomass, average height, number of stems per ha, natural regeneration, coppice, saplings

Introduction

In recent decades the researchers give increasing attention to the management and use of renewable natural resources for biofuels as a substitute for fossil fuels. In the boreal forest zone the fast-growing grey alder (*Alnus incana* (L.) Moench) may be conveniently used for both timber and fuelwood. In the climatic conditions of Latvia the standing volume of cultivated grey alder stands at the age of 25–30 years may amount to 250–400 m^3 ha^{-1}, of which stemwood suitable for conversion into roundwood assortments makes 50–70% (Daugaviete and Daugavietis 2008). Grey alder as a species usable for producing biomass in short-rotation plantations is renowned for a number of advantages: 1) high productivity and short rotation period (Sennerby-Forsse 1986, Johansson 1999, Pregent and Camire 1985, Saarsalmi et al. 1992, Siren et al. 1984, Tullus and Uri 1998, Tullus et al. 1995, Uri et al. 2009, Uri and Tullus 1999, Vares 2005, Daugaviete and Daugavietis 2007, Miezīte 2008, Daugaviete and Daugavietis, 2008); 2) no need for additional site improvement because of symbiotic nitrogen fixation in the soil (actinomycete *Frankia*) (Johansson 1999, Uri et al. 2002, Saarsalmi et al. 1992, Uri 2001, Uri et.al. 2002) 3) high resistance to unfavorable climatic conditions as well as pests and diseases (Ozols and Hibners 1927, Avotiņš 1962, Kundziņš 1969, Mūrnieks 1948, Mūrnieks 1950, Daugaviete 2006, Daugaviete and Ūsīte 2006); 4) ability to produce coppice growth, thus considerably reducing the restocking and stand protection costs (Rytter et al. 2000, Daugaviete et al. 2009, Kundziņš 1937); 5) relatively simple stand management (Daugaviete and Daugavietis 2007).

The share of grey alder stands has been significantly increasing in Latvia since the thirties of the previous century up to the first decade of the 21st century due to intensive natural afforestation of abandoned agricultural lands (Ozols and Hibners 1927, Avotiņš 1962, Daugaviete and Ūsīte 2006, Daugaviete 2009). In 2008, according to the data of the Central Statistical Bureau of Latvia (www.csb.gov.lv), the area under gray alder is 310,200ha, which accounts for 11.4% of the total forest area.

The standing volume in Latvia's grey alder stands is as high as 41.5 million m³. The wood of grey alder is mainly used as fuelwood, and for producing chipped wood, packaging materials, and charcoal. Some researchers believe that the biomass of grey alder may in the nearest future become a significant resource for biofuels (Pregent and Camire 1985, Sennerby-Forsse 1986, Saarsalmi et al. 1992, Granhall and Verwijst 1994, Tullus and Uri 1998, Tullus et al. 1995, Uri and Tullus 1999, Uri 2001, Uri et al. 2002, Uri et al. 2003, Uri et al. 2009, Vares 2005).

In the Nordic countries, intensive investigations on the use of grey alder and willow (*Salix* spp.) for producing wood chips are under way since the 1980-90s.

A three-year-old grey alder plantation is experimentally found to have accrued up to 34 $t \cdot ha^{-1}$ of dry woody biomass (DM) (air-dry biomass of the moisture content 20–25%) with no additional expenses for fertilization (Siren et al. 1984, Sennerby-Forsse 1986).

In the Nordic and Baltic countries, a number of scientists have made estimates of the biomass production by grey alder stands (Saarsalmi et al. 1992, Rytter et al. 2000, Granhall and Verwijst 1994, Johansson 1999, Tullus et al. 1998, Uri et al. 2002, Uri et al. 2003, Uri et al. 2009), using regression equations with one or two variables which are obtained in sample plots, mainly the d. b. h., tree height, and the stand's average diameter or basal area.

To calculate the dry biomass of a single tree, the Estonian scientists V. Uri and H. Tullus (Uri et al., 2002) used the following allometric function:

$$Y = a \cdot x^{b}, \quad (1)$$

where *Y* – dry mass of tree, g; *x* = d·h (*d* – tree root collar diameter, cm; *h* – tree height, m); *a* and *b* – constants.

As to the biomass calculations for grey alder V. Lazdāns (www.lvm.lv) suggests the following equation for calculating the amount of above-ground biomass:

$$Yi = b_0 \cdot x_i^{b}, \quad (2)$$

where *Yi* – tree biomass (kg); *xi* – tree height (m); b_0=0.039; b_1=3.059; R^2=0.79, at the tree height 1.6 m<H<10.0 m.

In Latvia, to estimate the above-ground biomass of untended grey alder stands, O. Miezīte (Miezīte 2008) recommends using regression equations with a single variable, namely the d. b. h. or stand's basal area. However, it is hardly possible to determine the d. b. h. for one to five year old stems as the height for many of them is below 1.3 m.

A study carried out at the Latvian State Forest Research Institute "Silava" shows that at the juvenile stages of naturally regenerating grey alder stands the age and density are the variables that count rather than the d. b. h. which for one-year-old grey alders is practically nonexistent. Therefore, the biomass calculations based on a single tree by using such variables as the d. b. h., $d_{1.3}$, or basal area, g, fail to show the actual amount of above-ground biomass in young naturally regenerating grey alder stands up to the age of five years.

The objective of the given study is to develop a practicable method and an empirical equation for estimating the amount of above-ground leafless biomass of natural moisture in untended grey alder stands aged from one to five years.

The following tasks were set forth to achieve this goal:

- Developing a practicable method for obtaining the input data for calculating the amount of biomass in untended grey alder stands aged from 1 to 5years.
- Developing an empirical equation for calculating the amount of leafless above-ground biomass of natural moisture in untended grey alder stands aged from 1 to 5 years, using the height and the number of trees per ha as the variables.

The given study is as a part of the State Research Programme "Development of technologies for cultivating deciduous trees in forest and non-forest lands to provide consumers with forest resources".

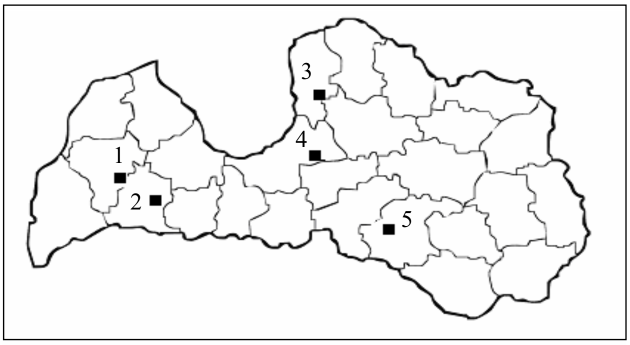

Figure 1. Locations of sample plots
1 – 56°33.392 N;021°50.401E; 2 – 56°31.462 N; 022°43.177E; 3 – 57°26.413 N;024°43.147E; 4 – 56°59.916 N;024°41.203E; 5 – 56°17.345 N;025°13.743E

Material and methods

For the present study 15 one-to-five-year-old clear-felled grey alder cutovers (felling sites of 2003/2004–2008/2009 winter months), where natural regeneration was well under way, were selected, and in each age group the biomass for the stands of the size at least 1 ha was determined (Fig. 2). The species composition of the young growth was as follows: 10 grey alders$_{1-5}$ + bird cherry, osier, and other undergrowth shrub species.

In the young growth of grey alder, circular sample plots of 1m in radius (3.14m²) were established after

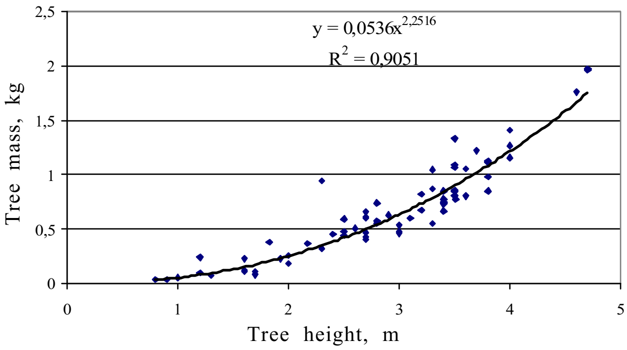

Figure 2. Correlation between the tree mass and height

every 10m by using the transect method. The sample plots (a total of 145 in this study) make up 3% of the total experiment area. For all grey alder shoots diameter D_{rc} (cm) and height H (m) were measured at the height of 10 cm above the root collar. The diameter was measured by using a caliper (HAGLOF, Sweden; accuracy ±0.1 cm), the height was determined with a measuring pole (SK SENSHIN Japan; accuracy ± 1 cm). Each shoot was cut down, defoliated and weighed by using the KERN scales with an accuracy of ±2 g, and the biomass (stem + branch mass) of each stem was determined. A total of 1,500 stems were measured and weighed. The sampling was done from September to November when the growing season is at its close.

The number of trees per 1ha is calculated by using the formula:

$$N = \frac{n_1 + n_2 + n_3 + ...n_x}{n_{pl}} \bullet 3185, \qquad (1)$$

at the sample plot radius R = 1m, where

n_1, n_2, n_3...n_x – number of trees in individual sample plots,

n_{pl} – number of sample plots.

The average stand height is calculated by using the formula:

$$H_v = \frac{h_1 + h_2 + h_3 ... h_n}{h_1 \cdot n + h_2 \cdot n + h_3 \cdot n + ... h_n \cdot n}, \qquad (2)$$

where H_v – average stand height, m

h_1, h_2, h_3...h_n height of shoots measured in sample plots, m

n – number of repetitions.

The age of each stem was determined by counting the growth rings.

As a part of our research, a comparison of two previously proposed equations for calculating the biomass of grey alder was done, namely, those of V. Uri (Uri 2001, Uri et al. 2003) and V. Lazdāns (www.lvm.lv), where the amount of biomass is calculated by using two variables – the tree root collar diameter and height (Uri 2001), and the tree height (www.lvm.lv).

The mathematical data processing and reliability calculations were made in the *Microsoft Office Excel 2003* environment by using the methods of mathematical statistics with the SPSS software (Arhipova and Bāliņa 2006) used for calculating the averages, standard deviations, and the relative error.

The relationship between the tree mass and the average height in 1-5 year-old grey alder stands were analyzed statistically, using the Power correlation and regression analyses. The allometric function is significant, the significance level $P<0.05$.

Results and discussion

Previous and recent studies on the course of natural regeneration of grey alder show that a fresh growth of its shoots up plentifully on the cutovers logged in winter (Kundziņš 1969, Kundziņš 1937, Docītis 1953, Viļums 1955, Mūrnieks 1948, Mūrnieks 1950, Daugaviete et al. 2009). In different forest types the number of shoots in one-year-old grey alder dominated natural growth ranges from 33,360 per ha^{-1} in the Vr *Oxalidosa* to 220,000 per ha^{-1} in the Ap *Mercurialiosa mel.* site type. Grey alder makes up from 67% (Gr *Aegipodiosa* and Vr *Oxalidosa*) to 95% (Dm *Hylocomiosa*) of the total number of young shoots. In the site types Vrs *Myrtilloso-polytrichosa*, Grs *Drypteriosa,* and Ap *Mercurialiosa mel.* one finds also a strong undergrowth of other tree and shrub species. With the shoots growing and the competition among them getting tougher, the number of trees per unit area decreases with age. In two-year-old grey alder growth the number of stems decreases: in Gr *Aegipodiosa* site type on average by 16%, in Ap *Mercurialiosa mel* by 46%, in Dm *Hylocomiosa* by 30%, in Vr *Oxalidosa* by 25% (Daugaviete et al. 2009). Later on, in three-, four- and five-year-old growth the number of grey alder stems goes down on average by 15–20% compared to the previous year, while under favorable microclimate (light, humidity, etc.) grey alder continues to develop basal shoots.

Data comparison between the present study and those reported by the Swedish (Rytter et al. 2000) and Estonian (Uri et al. 2003) researchers, show that in Sweden the number of grey alder shoots decreases on average by 20% already in the second growing season, and by 37% in the third, compared to the initial number of shoots per hectare. In Estonia, too, in grey alder stands aged from 2 to 6 years as a result of competition the number of stems falls by 11%-38%, respectively (Uri 2001).

Observational data show the distribution of grey alder stems per unit area in young naturally regenerating untended stands to be highly uneven due to the effect of various factors (light, competing vegetation of other tree species and herbaceous, strip-roads for vehicle movement, etc.). The number of trees varied from 0 to 30 and more per sample plot (3.14 m²).

In one-to-five-year-old untended young grey alder stands the stem age, too, is a variable to be taken into account, since not all the trees are cut down during logging, and grey alder tends to develop basal shoots as soon as there are suitable light and humidity conditions (Table 1).

Table 1. The number of stems and classification by age of 1 to 5 year-old naturally regenerating cutovers by grey alder

Stand age, yrs.	Number of stems per ha	Classification by age of measured stems, %				
		1 yr.	2 yrs.	3 yrs.	4 yrs.	5 yrs. and above
1	70 000	76	19	5	-	-
2	56 000	25	63	7	6	-
3	44 100	21	28	32	10	9
4	38 500	13	21	24	37	5
5	35 000	7	16	16	27	34

The research results show that the amount of biomass in young grey alder stands may be estimated with a sufficient reliability by measuring the average height and the number of stems because it is impossible to determine the d. b. h. for one- and two-year-old shoots, normally 0.8–1.3m high.

The field data obtained in this study show that during the first five years of growth there have been significant variations in the height, root collar diameter, and mass of grey alder stems (Table 2).

Table 2. Average parameters of grey alder stems aged 1-5 years (average±st.deviation)

Stand age, yrs.	Root collar diameter, cm	Stem height, m	Stem mass, kg	Number of measurements
1	0.91±0.21	1.38±0.45	0.066±0.058	372
2	1.67±0.42	2.5±0.58	0.33±0.13	328
3	2.49±0.59	3.04±0.64	0.72±0.35	315
4	2.94±0.63	4.38±0.64	1.32±0.61	275
5	4.07±0.53	4.81±0.54	2.09±0.72	210

After data processing and biomass estimation as a function of the average tree height, it has been concluded that there is a strong positive correlation between the average height and stem mass (R^2= 0.905) (Fig. 2).

The amount of biomass of grey alder per 1ha is calculated by using the allometric function (3):

$$M = 0.0536 \cdot Hv^{\,2.2516} \cdot N, \qquad (3)$$

where M – above-ground biomass of tree stems, kg·ha^{-1}; H_v – average stem height, m; N – number of stems per 1 ha.

It is found that there is a weak positive correlation between the root collar diameter and tree biomass (R^2= 0.3894) (Fig. 3). In further biomass calculations, a formula with the average stem height per unit area as a variable was used as the basis.

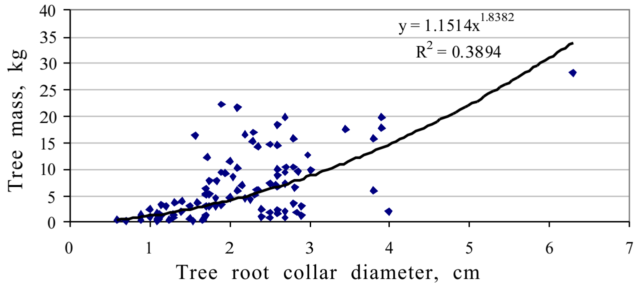

Figure 3. Correlation between the tree mass and tree root collar diameter

The results demonstrate that, with the average stem height increasing only by 0.1m, the amount of above-ground biomass increases on the average by 30%, provided the number of stems per ha remains the same; in case the number of stems was by 10,000 higher, the amount of biomass increased by 40%. The average values for the amount of biomass, grouped by the number of stems per ha (e.g. 10,000-15,000 stems·ha^{-1}), differ by ±20% (Table 1). The estimated biomass amount does not differ from the actual one by more than 2.8–5.0%.

Based on our research data regarding the average stem parameters in one-to-five-year-old grey alder stands (Table 2), as well as taking into account the corresponding average number of stems per ha (Table 1), we found that the amount of naturally moist biomass in untended one-to-five-year-old grey alder stands varies in fairly wide range, from 0.7 t·ha^{-1} to 70.4 t·ha^{-1}, at the average stem height H_v=0.9m to H_v=5.0m and the average number of stems (Table 3). The calculation results for the most typical stands (number of stems per ha 20,000 -80,000) are presented in Table 3.

The data obtained in this study are comparable with those of the Finnish (Saarsalmi 1992), Swedish (Telenius 1999, Granhall and Verwijst 1994) and other researchers, where the total biomass of a two-year-old grey alder stand is 8–10 t ha^{-1} DM; four-year-old – 32 t ha^{-1} DM; five-year-old – 31 t ha^{-1} DM, which partly agrees with the results of our research, taking into consideration that the biomass moisture content of naturally dry grey alder wood is 20–25%.

If the stand biomass is calculated by using formula (1) due to Uri and Tullus (Uri et al. 2002), based on the measurements of root collar diameter and tree height, the amount of naturally dry biomass in grey alder stands aged 1 to 5 years is lower by 42% on average compared to the results of our study, where we distinguished between naturally moist biomass and dry biomass. These data demonstrate that under different climatic conditions the amount of biomass in

Table 3. Above-ground biomass of untended naturally regenerating young grey alder stands (age 1-5 yrs.), $kg \cdot ha^{-1}$

Number of stems / H_v, m	20000-25000	25100-30000	30100-40000	40100-45000	45100-50000	50100-55000	55100-60000	60100-65000	65100-70000	70100-75000	75100-80000
0.8	731	893	1136	1379	1542	1704	1866	2028	2191	2352	2514
0.9	953	1164	1482	1799	2010	2221	2433	2644	2856	3067	3280
1	1208	1476	1878	2280	2548	2816	3084	3739	3618	3888	4156
1.1	1498	1669	2329	2827	3159	3492	3824	4156	4488	4821	5488
1.2	1820	2226	2832	3438	3842	4246	4651	5055	5459	5863	6267
1.3	2182	2666	3391	4117	4601	5085	5568	6052	6563	7020	7504
1.4	2578	3150	4008	4865	5436	6008	6580	7152	7723	8295	8867
1.5	3011	3679	4681	5686	6350	7018	7686	8353	9020	9684	10357
1.6	3482	4254	5413	6571	7343	8115	8888	9660	10432	11204	11976
1.7	3991	4876	6204	7531	8416	9320	10186	11071	11956	12841	13726
1.8	4539	5546	7055	8565	9572	10578	11585	12591	13598	14604	15611
1.9	5128	6265	7970	9676	10813	11950	13087	14224	15361	16498	17635
2	5754	7030	8944	10858	12134	13410	14686	15962	17238	18514	19790
2.1	6424	7849	9985	12122	13547	14971	16396	17820	19245	20669	22086
2.2	7132	8714	11086	13458	15040	16621	18203	19784	21366	22947	24529
2.3	7883	9631	12253	14875	16623	18371	20119	21867	23619	25367	27115
2.4	8677	10601	13487	16373	18297	20221	22145	24039	25960	27882	29803
2.5	9511	11620	14784	17947	20056	22165	24274	26387	28496		
2.6	10391	12695	15151	19607	21911	24215	26519	28823	31127		
2.7	11313	13822	17584	21347	23856	26364	28873				
2.8	12278	15001	19084	23168	25891	28613	31336				
2.9	13286	16232	20651	25070	28016	30962	33911				
3	14342	17522	22292	27062	30242	33421	36601				
3.1	15439	18863	23998	29133	32557	36007	39406				
3.2	16585	20263	25779	31295	34973						
3.3	17774	21715	27626	33538	37479						
3.4	19009	23224	29547	35869	40084						
3.5	20292	24792	31541	38290	42790						
3.6	21621	26415	33606	40797	45141						
3.7	22546	28095	35744	43392	48491						
3.8	24419	29834	37955								
3.9	25892	31633	40244								
4	27409	33487	42603								
4.1	28976	35401	45039								
4.2	30593	37377	47550								
4.3	32257	39409	50138								
4.4	34021	41503	52802								
4.5	35734	43657	55542								
4.6	37464	45872	58360								
4.7	39410	48148	61256								
4.8	41323	50486	64230								
4.9	43287	52885	67282								
5.0	45301	55346	70413								

grey alder stands differs, as in Estonia the average grey alder stem dimensions and mass in the respective age groups are less than in Latvia.

By using the allometric function (2) developed by V. Lazdans (www.lvm/lv) for estimating the above-ground biomass of grey alder, and comparing the data with those obtained by using our function, we notice that after formula (2) the amount of biomass in young grey alder stands of the corresponding age is by 39-40% larger. This is because in the given study the sample trees were mainly chosen in ditch and roadside areas, where the crown biomass is larger than for the trees appearing on naturally regenerating cutovers or abandoned agricultural lands.

Conclusions

In untended young naturally regenerating grey alder stands, the stem age and number per ha is irregular with significant variations in individual stem dimensions. To calculate the potential yield of biomass it is necessary to develop methods for estimating the amount of above-ground biomass in similar irregular stands.

The method of using small sample plots for determining the stem height and number and estimating, following the measurement data, the amount of above-ground biomass by allometric function is proposed.

For determining the amount of biomass in one-to-five-year-old grey alder growth, tree root collar measurements do not provide the required accuracy, as the calculated average root collar values and the stem weight per unit area show a weak positive correlation, $R^2=0.389$.

For biomass estimations, an accurate stem height measurement is more significant than determining the number of stems per ha. Variations in the average tree height only by 0.1m results in a 30% increase in the amount of above-ground biomass, while following the number of stems per unit area a similar increase in stand biomass is achieved provided the number of stems is by 7,500 higher.

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НАКОПЛЕНИЕ БИОМАССЫ В МОЛОДНЯКАХ СЕРОЙ ОЛЬХИ (*ALNUS INCANA* [L] MOENCH)

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Резюме

В статье приводятся результаты исследований процесса восстановления и накопления биомассы в молодняках серой ольхи возрастом с 1 до 5 лет на зимних вырубках насаждений ольхи.

Показано, что ольха на зимних вырубках восстанавливается очень интенсивно и количество деревьев, в основном корневых побегов в первом году, достигает 33 600 -220 000 шт·га$^{-1}$ и на втором году снижается на 16-46%, а в последующие годы - на 15-20% ежегодно. Густота насаждений на различных участках вырубки существенно отличается, что затрудняет оценку объемов биомассы традиционными методами таксации, поскольку нет возможностей определения $d_{1..3}$ в возрасте 1-2 года. Высота деревьев в насаждениях также значительно отличается.

Основной задачей исследований являлась разработка методики определения надземной свежезаготовленной биомассы без листьев (далее биомассы) серой ольхи на основе легко замеряемых параметров деревьев и насаждений. На основании измерений высоты, диаметра корневой шейки, возраста и массы 1500 деревьев и количества деревьев на круглых пробных площадях размером 3.14 мІ (радиус 1 м), было установленно, что массу дерева с большой вероятностью можно расчитать как функцию высоты дерева по формуле м =0.0536 $\cdot H_v^{2.2516}$ (RI=0.9051), а биомассу насаждения в кг·га$^{-1}$ по формуле $M=0.0536 \cdot Hv^{2.2516} \cdot N$, где N – количество деревьев на га, определенное как среднее по учету количества деревьев на отдельных пробных площадях. Пробные площадки размещаются по трансекте лесосеки на расстоянии 10-15 м, количество площадок должно соответствовать 3% площади лесосеки.

Количество биомассы составляет от 0.9 до 7.7 т·га$^{-1}$ в однолетних и от 15.2 до 64.4 т·га$^{-1}$ в пятилетних молодняках серой ольхи.

Ключевые слова: серая ольха, биомасса, молодняк