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Peter Lakida, Sten Nilsson, and Anatoly Shvidenko

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IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Telefax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

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Peter Lakida
Ukrainian National Agrarian University, Kiev, Ukraine

Sten Nilsson,
and Anatoly Shvidenko
International Institute for Applied Systems Analysis,
Laxenburg, Austria

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Foreword

This is the time Siberia's forest sector has recently gained considerable international interest. IIASA, the Russian Academy of Sciences, and the Russian Federal Forest Service, in agreement with the Russian Ministry of the Environment and Natural Resources, signed agreements in 1992 and 1994 to carry out a large-scale study on the Siberian forest sector. The overall objective of the study is to focus on policy options that would encourage sustainable development of the sector. The goals are to assess Siberia's forest resources, forest industries, and infrastructure; to examine the forests' economic, social, and biospheric functions; with these functions in mind, to identify possible pathways for their sustainable development; and to translate these pathways into policy options for Russian and international agencies.

The first phase of the study concentrated on the generation of extensive and consistent databases for the total forest sector of Siberia and Russia. The study is now moving into its second phase, which will encompass assessment studies of the greenhouse gas balances, forest resources and forest utilization, biodiversity and landscapes, non-wood products and functions, environmental status, transportation infrastructure, forest industry and markets, and socio-economic problems. This report, by Dr. Lakida from the Ukrainian State Agricultural University in Kiev and Professors Nilsson and Shvidenko from the study's core team, is a contribution to the analyses of the topic of greenhouse gas balances. The reason for studying the phytomass characteristics for the investigated region is that limited information is available on the phytomass fractions for Siberia.

Abstract

Regression equations for fractions of forest phytomass have been developed for European Russia (including the Urals). These equations are based on available data and findings given in publications (962 sample plots have been examined). The analyses cover pine, spruce, oak, birch, beech, aspen, alder, and lime species. Together these eight species constitute some 95% of the tree cover of the forested areas in European Russia. The equations allow us to evaluate the ratio between the weight of phytomass fractions and growing stock by species, age classes, and site indexes. Application of the phytomass results to the Forest State Account (FSA) data (1988) gives an estimate of a total (living) phytomass in the forest ecosystems of forested areas of European Russia (166 million hectares of forested area, 20.28 billion m^3 of growing stock) of 15.47 petagrams (Pg) of dry matter (which corresponds to a density of 9.32 kg/m^2). The total carbon pool is estimated to be 7.64 Pg of carbon (C) with an average density of 4.60 kg C/m^2 in 1988. Sensitivity analyses of data and methods show that the results of the equations probably underestimate the values for phytomass and carbon by about 5%. Total phytomass in the forest vegetation of forested areas based on the 1993 FSA inventory is estimated to be 16.94 Pg (with an average density of 10.36 kg/m^2) and the total C content is estimated to be 8.37 teragrams (Tg) (with an average density of 5.03 kg/m^2). Changes in the total forest phytomass of the forested areas during the 1966–1993 period were estimated to be 4.73 Pg (or about 174 Tg of dry matter per year), and the carbon content increased by 2.34 Pg. Thus, between 1966 and 1993 European Russian forests were a net sink for carbon and stored and absorbed an average of about 87 Tg of C annually.

1. Introduction

Data on phytomass (i.e., organic matter in the living vegetation of forest ecosystems in the form of dry matter) and on the dynamics of phytomass are crucial in many ecological investigations on different spatial and temporal scales (for example, studies on carbon budgets or sustainable forest management). However, Russia is one of the countries that do not include phytomass measurements in forest inventories. Therefore, empirical regional models must be developed to estimate changes in phytomass.

In the framework of the Siberian Forest Study, which is under development by the International Institute for Applied Systems Analysis (IIASA), in cooperation with several Russian scientific institutions, numerous detailed data bases and corresponding geographical information system (GIS) components have been generated [about 80 megabytes (Mb) of information on some 4000 forest enterprises of the former Soviet Eurasian territory]. The data on forest productivity include results from field measurements of separate regions, experimental data from different publications, and information from scientific archives. All data in the data bases have been examined and checked and questionable materials have been excluded from the analyses presented in this paper.

Aggregated estimations of the amount of phytomass in the Russian forests based on 1988 Forest State Account (FSA) data were recently published in Alexeev and Birdsey (1994), Isaev *et al.* (1993, 1995), and Kolchugina and Vinson (1993). The first two publications used average values for the ratio between phytomass fractions and the growing stock of the dominant species disseminated over different ages. Although all three studies used similar methods and the same initial FSA data, they present results that, to some extent, contradict one another. For the vegetational forest ecosystem phytomass in Russia, Isaev *et al.* (1993) give an estimate of 5.16 Mg C/m^2 for Russia and Kolchugina and Vinson (1993) report an estimate of 6.27 Mg C/m^2. Alexeev and Birdsey (1994) estimate that phytomass in the forests of the former USSR is 3.63 Mg C/m^2, whereas Isaev *et al.* (1995) present an estimate of 4.55 Mg C/m^2 for the same region.

The overall objective of this paper is to generate a set of regression models that can produce estimations of the vegetation phytomass of forest ecosystems in European Russia; these estimations can then be used in various ecological analyses. We have used the equations to generate estimates of the amount of phytomass and its dynamics over the period from 1966 to 1993.

In 1988, forested areas in European Russia (all forests independent of the form of management) totaled about 166 million ha, and the growing stock (total volume of stemwood over bark of living trees) was reported to be 20.28 billion m^3 (data from the 1988 FSA). Species composition and productivity of forests vary significantly over the territory studied. Details of the species composition of the forested area in European Russia are presented in *Tables 1* and *2*; the data are grouped according to nine economic regions (Goscomles, 1990, 1991). The average age of all forests under state forest management (covering about 82% of the total forested area) was 80 years in 1988 (98 years for coniferous stands, 73 years for hard deciduous stands, and 43 years for soft deciduous stands).

Phytomass models were developed for pine, spruce, oak, beech, birch, aspen, alder, and lime species, which make up about 95% of all forested areas and constitute 97% of the total growing stock of stands with a dominance of these species in European Russia (Goscomles, 1990). Pine and spruce species cover about 65% of the forested area in European Russia.

Table 1. Forested areas in European Russia (including the Urals) by economic region in 1988.

	Area, thousand hectares			
		Species		
Region	Total	Coniferous	Hard deciduous[1]	Soft deciduous[2]
Pre-Baltic	266.5	95.8	52.6	118.1
Northern	76,048.2	60,835.8	–	15,212.4
Northwestern	10,387.5	5,333.5	9.7	5,044.3
Central	20,328.5	8,977.2	526.2	10,825.1
Volgo Vyatsky	13,309.2	6,901.3	388.4	6,019.5
Central Chernozymny	1,469.3	415.7	729.8	323.8
Povolshsky	4,772.5	1,159.0	1,508.5	2,105.0
North Caucasus	3,663.5	414.2	2,719.5	529.8
Ural	35,753.0	19,205.7	963.2	15,584.1
Total	165,998.2	103,338.2	6,897.9	55,762.1

Source: Goscomles (1990).
[1]Beech, oak, hornbeam.
[2]Aspen, birch, alder, lime

Table 2. Growing stock in European Russia (including the Urals) by economic region.

	Growing stock, million m^3			
		Species		
Region	Total	Coniferous	Hard deciduous	Soft deciduous
Pre-Baltic	39.4	14.3	9.0	16.1
Northern	7,599.2	6,427.7	–	1,171.5
Northwestern	1,625.1	879.2	1.2	744.7
Central	3,041.5	1,467.8	70.8	1,502.9
Volgo Vyatsky	1,787.0	993.7	47.4	745.9
Central Chernozymny	183.1	62.5	87.4	33.2
Povolshsky	572.9	171.2	141.3	260.4
North Caucasus	579.5	88.5	438.5	52.5
Ural	4,850.1	2,883.0	106.4	1,860.6
Total	20,277.8	12,988.0	902.0	6,387.8

Source: Goscomles (1990).

2. Method and Data

The models for estimating the dynamics of the forest ecosystems phytomass components were developed according to methods and technique described in Lakida *et al.* (1995). The objective during the model development phase was to employ FSA data in the equations. This meant that equation parameters should correspond to the FSA data (species, age, site indexes, etc.). As described by Lakida *et al.* (1995), the most appropriate way to use this data to produce phytomass estimation is to employ relative values linked to the growing stock.

For each experimental stand the ratio of a forest vegetation phytomass fraction (milligrams of dry matter for each cubic meter of green growing stock) was calculated according to

$$R_{v(fr)} = M_{fr} \; / \; V_{st} \; , \qquad (1)$$

where M_{fr} is the weight of a phytomass fraction in megagrams (Mg), and V_{st} is growing stock in cubic meters (m^3).

The following phytomass components were included in the analyses: $R_{v(f)}$ – foliage (needles); $R_{v(br)}$ – branches (wood and bark of the crown branches); $R_{v(st)}$ – stems (wood and bark of the stems); $R_{v(bl)}$ – understory phytomass (forest floor vegetation + undergrowth + bushes); $R_{v(bl)}$ – belowground forest stand phytomass.

The total phytomass of the forest ecosystem vegetation [$R_{v(tot)}$] was calculated as the sum of the components listed above.

In the search for adequate analytical model forms, we used the method of the multiple regression analysis adopted specifically for forest biometric calculations (Shvidenko and Yuditsky, 1983). The parameters that were statistically examined included age (*A*), average diameter (*D*), average height (*H*), site index (*B*), relative stocking (*P*), and growing stock (*V*) of stands. In nearly all cases, the parameters *A* and *B* influenced the results (at the 0.05 significance level). The impact of growing stock (*V*) was usually significant if the site index (*B*) was excluded from the equation and insignificant if the site index was included in the equation. Taking into account the weight of the different variables and the structure of the information available in FSA data, we used age (*A*) and site index (*B*) as the independent variables in the multiple equations. The site index was used to estimate the average height corresponding to Orlov's scale. *Table 3* gives the average height of seed origin stands at the age of 120 and of vegetative stands at age 60.

Table 3. Site class indexes by Orlov and corresponding average stand height.

	Site index by Orlov										
Origin of stands	Id	Ic	Ib	Ia	I	II	III	IV	V	Va	Vb
Seed	47	43.0	39	35.0	31	27.0	23	19.0	15	11.0	7
Vegetative	39	35.5	32	28.5	25	21.5	18	14.5	11	7.5	4

Three types of equations were used to estimate phytomass:

$$= \qquad (2)$$

$$= \qquad (3)$$

$$= \qquad (4)$$

where *A* is the average age of a stand in years; *B* is the site index class (data from *Table 3*); and a_1, a_2, a_3 are regression coefficients.

Table 4. General characteristics of data used in analyses.

	Number of tests plots					
		Separate phytomass components				
Species	Total	Foliage	Branches	Stem	Roots	Understory
Pine	515	485	464	485	203	20
Spruce	181	157	156	157	35	14
Oak	147	129	129	129	22	8
Beech	18	18	18	18	–	–
Birch	36	20	20	20	8	8
Aspen	37	30	30	30	3	4
Alder	23	23	23	23	8	–
Lime	5	5	5	5	1	–
Total	962	867	845	867	280	54

Selection of equations was based on the amount of experimental data available, the statistical criteria of equations, and the distribution of residuals. The most acceptable results were derived from equation (2). Equation (4) was used if the experimental data were quantitatively unsatisfactory.

We compared the results of analyses with and without a site index as an independent variable in the equations. Evidently, the use of the average site index for the total European Russian forests can generate a systematic error of 15–20% for separate regions. This is because the average site indexes differ from region to region, for example, the average site index for pine forests in the Arkhangelsk *oblast* is in the IV.5–IV.7 range, whereas the average site index for the pine forest in the Moscow*oblast* is in the I.6–II.0 range.

The initial experimental data were cross-checked and validated, and some of the data were excluded in the final analyses for the following reasons:

1. The results reported did not provide sufficient information about the inventory parameters of stands or phytomass parameters used in the equations (Balykov *et al.*, 1989; Gutman and Uspensky, 1987; Papezh and Bugayov, 1988).

2. The measurement results were only given for the fresh (green) state of phytomass (Babich, 1989a; Bugayov *et al.*, 1988, 1989; Bugayov and Onischenko, 1987; Babich and Travnikova, 1990).

3. The field data were not sufficient (from the viewpoints of statistics or methodology) to provide reliable estimates (Babich and Vasiljev, 1992; Bugayov and Mamonov, 1986).

The data which were included in the final analyses for the dominant forest species in European Russia and which were used in the calculations were derived from 962 test plots (for details see *Table 4*, Appendix 1, and the references). The data include inventory characteristics of experimental stands and phytomass measurements. Unfortunately, available data do not completely reflect the dynamics of phytomass parameters of the dominant species in all regions of the European Ural. Thus, for the missing parameters, data describe similar stands in the

Baltic countries, Belarus, and Ukraine were used in the final analyses (Lakida *et al.* (1995). The data are detailed in Appendix 1.

3. Regression Equations

The results of the modeling efforts are presented in *Table 5*. *Figure 1* illustrates the graphic representation of the equation results for the phytomass fraction of pine needles, and *Figure 2* presents the equation results for branches.

The results were validated in three steps. First, accuracy and adequacy were controlled by statistical methods based on the significance of multiple nonlinear correlation coefficients (*Q*) and the probability dustributions of residuals. Second, the results were checked against results presented by Utkin (1994). This latter study contains average phytomass ratios based on experimental data for pine, spruce, larch, birch, and aspen species according to four age groups (young, middle-aged, premature, and mature stands) in three zones of the boreal and temperate forests of Russia (northern, central, and southern). The averages calculated by Utkin (1994) were based on field measurements from some 1200 sample plots for all of Russia. No statistical analyses were made by Utkin in the cited report, so only aggregated averages can be reported from those data. Third, we used available data from other publications to validate the results (Alexeev and Birdsey, 1994; Isaev *et al.*, 1995). Unfortunately, in these reports, the ratios are reported either for Russia as a whole or for aggregated geographical zones. For the validation of the results we used average site indexes as entry parameters.

Q (nonlinear correlation coefficient) values are dependent on species, phytomass fractions, the natural variation of the forests, as well as other factors. The general conclusion is that the accuracy of the equations presented in *Table 5* is satisfactory. The analyses of the probability distributions of the residuals (we considered the first four moments of the empirical distributions for estimating the type of empirical distribution of the residuals) showed that all equations have nonsystematic errors (at the 0.05 significance level) and are adequate for all ranges of the variable values. The results from these analyses correspond significantly with published data, as a rule within limits ±10–20%, excluding some species and fractions which have not been measured adequately.

4. Estimates of Forest Phytomass and Carbon

By using the data of the 1988 Forest State Account of Russian forests and the results from the models of forest phytomass dynamics, we have calculated the phytomass of the forest vegetation on forested areas in European Russia (including the Urals). The analyses consider not only the forests under state forest management, but all forests.

A complete set of parameters needed for the calculations was available for the 131.7 million ha of forested areas under state forest management; these areas make up 79.3% of the total forests. For the rest of the forested areas (4.5 million ha of long-leased forests, 23.8 million ha of colkhozos and sovkhozos forests, and 5.5 million ha of forests managed by other ministries and agencies), the distributions of area and growing stock by age and/or by site indexes were assumed to be the same as those of species groups growing in forests under state management in a given ecoregion.

The calculations were carried out for dominant species because detailed species composi tion is only available for mature and overmature stands. A detailed species composition would

Table 5. Estimated coefficients of the equations for the forest phytomass fractions of the dominant tree species in European Russia.

Ratio	Number of test plots	Equation type (see page 3)	Coefficients				
			a_0	a_1	a_2	a_3	Q
Pine							
$R_{v(f)}$ (foliage)	485	2	60.95	-1.072	-1.162	0.004	0.79
$R_{v(br)}$ (branches)	464	2	17.03	-0.812	-0.932	0.006	0.75
$R_{v(st)}$ (stemwood)	485	2	0.232	0.253	-0.069	-0.003	0.56
$R_{v(bl)}$ (belowground)	203	3	0.383	0.063	-0.469	–	0.41
$R_{v(us)}$ (understory)	20	2	217.7	-1.726	-0.999	0.023	0.68
Spruce							
$R_{v(f)}$	157	2	704.2	-1.477	-1.293	0.012	0.79
$R_{v(br)}$	156	2	55.05	-1.001	-0.974	0.009	0.68
$R_{v(st)}$	157	2	0.564	-0.075	-0.068	0.002	0.32
$R_{v(bl)}$	35	2	3.017	-0.583	-0.324	0.005	0.32
$R_{v(us)}$	14	2	444×10^{3}	-1.940	-3.398	0.020	0.82
Oak							
$R_{v(f)}$	129	2	102.5	-1.286	-1.256	0.010	0.86
$R_{v(br)}$	129	2	111.4	-0.378	-1.631	0.002	0.79
$R_{v(st)}$	129	2	0.629	-0.049	-0.006	0.002	0.30
$R_{v(bl)}$	22	2	0.027	-1.379	1.736	0.023	0.92
$R_{v(us)}$	8	2	427×10^{-6}	4.137	-2.910	-0.058	0.80
Beech							
$R_{v(f)}$	18	2	547.4	-1.671	-1.391	0.012	0.92
$R_{v(br)}$	18	2	8.085	-1.277	-0.242	0.029	0.51
$R_{v(st)}$	18	2	0.251	0.199	0.086	-0.004	0.94
Birch							
$R_{v(f)}$	20	2	110.0	-1.348	-1.356	0.014	0.95
$R_{v(br)}$	20	2	2.545	-1.758	0.190	0.048	0.71
$R_{v(st)}$	20	2	0.453	-0.528	0.351	0.019	0.58
$R_{v(bl)}$	8	3	0.694	-0.063	-0.272	-0.009	0.99
$R_{v(us)}$	8	2	415.7	0.116	-2.610	-0.025	0.78
Aspen							
$R_{v(f)}$	30	2	9.176	-1.216	-0.839	0.012	0.78
$R_{v(br)}$	30	2	4.121	-1.028	-0.651	0.031	0.75
$R_{v(st)}$	30	2	0.515	-0.128	0.001	0.005	0.25
$R_{v(bl)}$	3	4	-0.785	–	–	–	0.71
$R_{v(us)}$	4	4	-1.131	–	–	–	0.74
Alder							
$R_{v(f)}$	23	2	137.0	-1.976	-1.377	0.047	0.98
$R_{v(br)}$	23	2	0.878	-0.678	-0.474	0.023	0.73
$R_{v(st)}$	23	2	1.693	-0.048	-0.422	0.004	0.65
$R_{v(bl)}$	23	2	576.2	-1.559	-1.452	0.042	0.66
Lime							
$R_{v(f)}$	5	3	1684	-0.951	-2.432	–	0.82
$R_{v(br)}$	5	3	1069	-0.349	-2.471	–	0.54

$R_{v(st)}$	5	3	21.60	-0.058	-1.097	–	0.35

The equations are valid for age $10 \le A \le 120$ for deciduous species and for $10 \le A \le 200$ for coniferous of the site index of $Ib \ge B \ge Vb$ (i.e, $47 \ge H \ge 7$ *m* for stands of seed origin and $39 \ge H \ge 4$ *m* of stands of vegetative origin. *H* is the average height of a stand at 120 and 60 years, respectively).

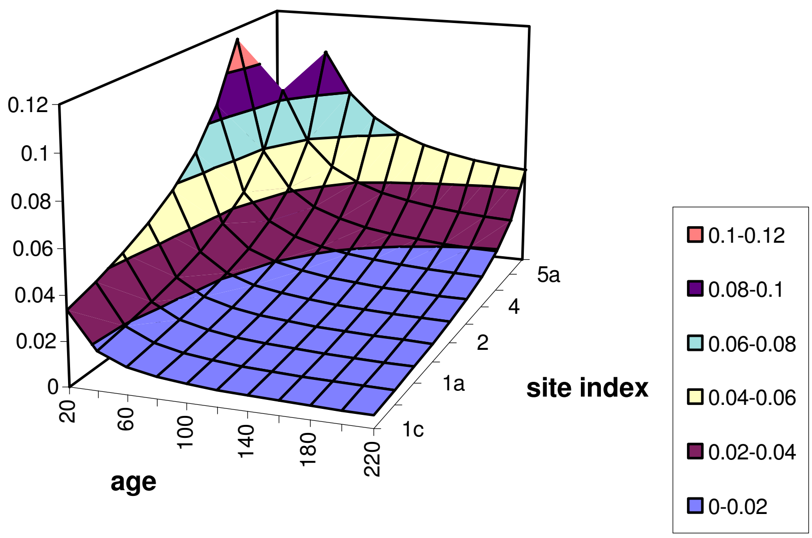

Figure 1. R_v(f) for pine.

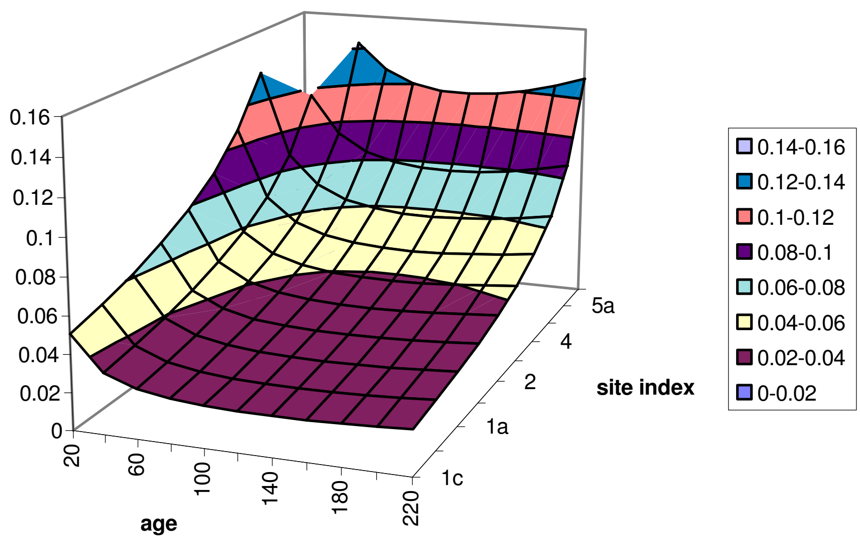

Figure 2. R_v(br) for pine.

probably result in similar findings as the proportions of coniferous and soft deciduous species in hard deciduous stands are very small, and the proportions of coniferous species in soft deciduous forests and soft deciduous species in coniferous forests are roughly the same as those in the growing stock.

We used average site indexes for regions for the dominant forest species for the regional calculations. The codes for the site index classes of coniferous, hard deciduous, birch, and lime were applied according to the site index scale for seed origin stands. For aspen and alder the site index for vegetative origin stands was used.

The estimates for missing species and phytomass fractions inside a region were derived from estimates from regions with similar compositions, taking into account geographical distribution, forest growth conditions, and qualitative wood parameters.

The results of the phytomass and carbon content for forested areas are presented in *Table 6* according to region. To calculate the carbon content we used average coefficients for conversion of the dry matter phytomass fractions to carbon content, namely, 0.50 for wood and 0.45 for green parts (Matthews, 1993).

6. Discussion and Conclusion

The total amount of phytomass of the forest vegetation in the forested areas of European Russia in 1988 was estimated to be 15.47 Pg of dry matter. Wood constituted 84.9% of the total vegetation phytomass (stemwood, 59.3%; crown branches, 9.6%; and roots 19%). Understory made up only 6.0%. About 90% of the total phytomass was aboveground, and another 10% was belowground. The average density of the forest vegetation phytomass was 9.32 kg/m^2, but the regional variability was rather high, from 8.46 in the northern region to 13.99 kg/m^2 in north Caucasus. The average phytomass density in coniferous forests was somewhat less (8.21 kg/m^2) than the total average; this is because, on one hand, there are large areas of low productive stands in the north of European Russia, but, on the other hand, a high extent of harvests of mature and overmature coniferous forests in the region. Total carbon fixation was estimated to be 7.64 Pg, with an average density of 4.60 kg C/m^2; the density ranges between 4.16 to 6.96 kg C/m^2.

Many studies report a high proportion of decaying stems in mature and overmature stands in European Russia especially in the north and in mountainous regions (e.g., Chertovsky *et al.*, 1974; and Chibisov, 1974). For our calculations we needed to estimate the amount of decaying wood at the destructive stages. This information is not available from the forest inventory. In 1988 the growing stock in mature and overmature stands was 6.68 billion m^3 in coniferous forests, 0.27 million m^3 in hard deciduous forests, and 2.18 billion m^3 in soft deciduous forests. Based on studies of the wood quality in mature and overmature forests (Moshkaljov, 1984; Voinov, 1986; Shvidenko *et al.*, 1987; and Dzebisashvili, 1992) and expert assumptions, we estimated that 0.25 billion m^3 of wood were destroyed by decay. This amount constitutes about 1.2% of the total growing stock and is within the limits of the systematic errors of the Russian forest inventory data. Thus, we have not calibrated the data presented in *Table 6* for decaying wood.

The average ratio between the total phytomass and the growing stock is estimated to be 0.763 [Mg of dry matter per 1 m^3 of fresh (green) stemwood]. The corresponding ratio for carbon is

Table 6. Phytomass and carbon content of the forest vegetation in forested areas of European Russia.

Species group and total	Phytomass component, Tg: Foliage	Crown wood	Stem wood	Roots	Under-story	Total	Phyto-mass density, kg/m^2	Carbon content: Total, Tg	Density, kg/m^2
Pre-Baltic									
Coniferous	0.9	1.0	5.7	1.9	0.5	10.0	10.42	4.9	5.14
Hard deciduous	0.2	1.2	5.2	1.2	0.2	7.9	15.03	3.9	7.48
Soft deciduous	0.3	0.8	7.4	2.6	0.6	11.7	9.90	5.8	4.91
Total	1.3	3.0	18.4	5.6	1.2	29.6	11.10	14.7	5.50
Northern									
Coniferous	490.9	631.5	3002.0	1022.9	381.2	5528.5	9.09	2720.6	4.47
Hard deciduous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soft deciduous	34.7	59.2	503.5	186.9	123.4	907.8	5.97	446.0	2.93
Total	525.6	690.7	3505.5	1209.9	504.6	6436.3	8.46	3166.6	4.16
Northwestern									
Coniferous	36.7	53.2	365.3	110.4	27.1	592.6	11.11	293.1	5.50
Hard deciduous	0.0	0.2	1.0	0.2	0.0	1.4	14.85	0.7	7.39
Soft deciduous	11.7	35.0	352.1	108.0	24.0	530.8	10.52	263.6	5.23
Total	48.4	88.4	718.4	218.6	51.1	1124.9	10.83	557.5	5.37
Central									
Coniferous	63.9	87.5	598.4	178.5	42.9	971.1	10.82	480.2	5.35
Hard deciduous	1.3	9.3	40.9	9.7	1.2	62.4	11.86	31.1	5.90
Soft deciduous	25.9	66.3	686.7	233.6	52.6	1065.1	9.84	528.6	4.88
Total	91.0	163.1	1326.0	421.7	96.8	2098.6	10.32	1039.9	5.12
Volgo Vyatsky									
Coniferous	43.4	60.5	408.6	122.9	32.6	668.0	9.68	330.2	4.78
Hard deciduous	0.9	6.8	28.2	6.4	0.9	43.2	11.12	21.5	5.54
Soft deciduous	14.8	34.4	346.9	116.5	27.9	540.5	8.98	268.1	4.45
Total	59.1	101.6	783.7	245.8	61.5	1251.7	9.40	619.8	4.66
Central Chernozymny									
Coniferous	2.1	3.4	25.7	6.6	2.9	40.7	9.80	20.1	4.84
Hard deciduous	1.8	13.2	50.4	9.9	2.0	77.3	10.59	38.4	5.27
Soft deciduous	0.6	1.2	14.8	5.4	0.8	22.8	7.04	11.3	3.50
Total	4.5	17.8	90.9	21.9	5.7	140.8	9.58	69.8	4.76
Povolshsky									
Coniferous	5.4	8.8	71.0	18.3	7.3	110.8	9.56	54.8	4.73
Hard deciduous	2.9	24.3	83.3	14.5	4.2	129.2	8.56	64.2	4.26
Soft deciduous	5.3	4.5	118.9	38.3	6.2	173.2	8.23	86.0	4.09
Total	13.6	37.5	273.2	71.2	17.7	413.1	8.65	205.0	4.30
North Caucasus									
Coniferous	4.0	5.6	36.7	11.3	2.6	60.2	14.53	29.8	7.19
Hard deciduous	7.2	86.4	252.1	54.3	9.9	410.0	15.07	204.1	7.51
Soft deciduous	1.3	1.8	27.3	10.0	1.9	42.2	7.97	21.0	3.96
Total	12.5	93.8	316.1	75.6	14.4	512.4	13.99	254.9	6.96
Ural									
Coniferous	143.7	193.8	1186.0	374.4	93.1	1991.0	10.37	983.7	5.12
Hard deciduous	2.0	18.8	65.2	11.9	2.9	100.8	10.47	50.2	5.21
Soft deciduous	39.7	81.0	884.9	284.2	76.3	1366.1	8.77	677.2	4.35
Total	185.4	293.7	2136.1	670.5	172.2	3457.9	9.67	1711.1	4.79
Total and average	941.3	1489.5	9168.4	2940.9	925.2	15465.3	9.32	7639.3	4.60

0.377 Mg C/m^3. The latter indicator provides the information needed to estimate the development of the phytomass content if the dynamics of the growing stock is known. The dynamics of the growing stock can be obtained from the FSA for the 1966–1993 period (Goscomles SSSR, 1968, 1976, 1982, 1986, 1990; FSFMRF, 1995). Earlier it was shown that the FSA data are, to some extent, biased and that this bias is due to inventory methods used (Shvidenko *et al.*, 1996). Results from the estimations of the dynamics of both the officially reported growing stock and the dynamics adjusted by the technique discussed by Shivdenko *et al.* (1995) are presented in*Table 7.*

Table 7. Dynamics of the phytomass and carbon content of the European Russian forests during 1966–1993.

Indicator	Years 1966	1973	1978	1983	1988	1993
	Data of official statistics					
Forest fund, million ha	202.3	206.3	199.8	199.8	207.4	209.3
Forested area, million ha	161.3	158.6	163.5	164.4	166.0	166.5
Forested area of state forest mngmt, million ha	130.7	133.3	134.6	135.9	136.7	136.9
	Forested areas					
Growing stock, billion m^3	17.00	17.40	18.70	19.30	20.30	21.10
Total phytomass, Pg	12.97	13.28	14.27	14.73	15.47	16.10
Carbon content, Pg	6.41	6.56	7.05	7.28	7.64	7.95
	Reconstructed dynamics for forested areas					
Growing stock, billion m^3	16.00	17.00	18.30	19.90	21.40	22.20
Total phytomass, Pg	12.21	12.97	13.96	15.18	16.33	16.94
Carbon content, Pg	6.03	6.41	6.90	7.50	8.07	8.37

From *Table 7* it can be concluded that between 1966 and 1993 phytomass increased by 3.13 Pg (an annual average increase of 116 Tg) and carbon increased by 1.54 Pg (an average of 57 Tg C/year). Our reconstruction gives values that are about 30% higher: the phytomass increase is estimated to be 4.73 Pg (174 Tg C/year) and carbon content increase is estimated to be 2.34 Pg (or 87 Tg C/year).

A comparison of the estimated amount of phytomass reported in this study with estimates presented by Alexeev and Birdsey (1994) shows that this study's estimates are 0.45 Pg C (5.9%) higher than the latter study's estimates. A comparison between the values calculated for the reconstructed dynamics of this study and those from the Alexeev and Birdsey (1994) study shows even larger differences: 10.9% for 1988 and 14.1% for 1993. The ratio $R_{v(tot)}$ calculated from the Alexeev and Birdsey (1994) study is 0.354 Mg C/m^3 (which is 6.1% lower than the results reported in this paper). Isaev *et al.* (1995) estimated that is 0.43 for all Russian forests. Kolchugina and Vinson (1993) used the value of 0.53 Mg C/m^3 determined by Sampson (1992) for marketable wood in US forests (which is quite different from the stemwood presented in the FSA). This latter value results in a significant overestimate of the total phytomass for total Russian forests [the average C density reported by Kolchugina and Vinson (1993) for all of Russia was 6.27 kg C/m^2 versus 3.63 kg C/m^2 given by Alexeev and Birdsey (1994)]. Isaev *et al.* estimate the C density of the Russian forests to be 5.16 (1993) and 4.55 (1995) kg C/m^2. The average C density estimated in this study for European Russia is 4.60 kg C/m^2.

Taking into account the structure of the calculations and the specifics of the initial data, there are no formal methods which could be applied for the estimation of the statistical errors of the overall results. Sensitive analysis based on "what … if" auxiliary calculations gives a probable standard error of about ±7–8%.

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Appendix

The experimental data
(European Russia)