DYNAMICS OF PHYTOMASS AND NET PRIMARY PRODUCTION OF RUSSIAN FORESTS IN 1961-1998: AN ATTEMPT OF AGGREGATED ESTIMATION

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Abstract

Aggregated estimates of the dynamics of phytomass and Net Primary Production (NPP) of Russian forests are presented for the period 1961-1998. The calculations for 1990 are based on detailed inventories, using data from the State Forest Account by ecoregions, available results of measurements and reference data on the productivity of forests which have been accumulated in Russia during the last decades. For 1990, the total amount of phytomass in forest ecosystems is estimated to be 66450 Tg (=10^{12} g) dry matter, or 32862 Tg C. Of the total amount of phytomass carbon, 78.0% of phytomass are above ground (including 6.2% green part and 71.8% woody part) and 22.0% are presented by roots. The NPP is estimated to be 3660 Tg dry matter per year or 1708 Tg C yr^{-1}. 75.4% of NPP are allocated above ground, and 49.0% of total NPP are in green parts. During the period 1961-1998, it has been shown that phytomass of forest ecosystems in Russia increased from 29.59 to 34.30 Pg (=10^{15} g) C, i.e. annual average accumulation of carbon in phytomass is estimated at 127 Tg C yr^{-1}. NPP, calculated as smoothed average for a 5 year period, increased from 1488 Tg C yr^{-1} in 1961 to 1735 Tg C yr^{-1} in 1998.

Introduction

Estimation of phytomass (i.e., all vegetation live organic matter at a definite moment) and Net Primary Production (amount of atmospheric carbon, transferred into vegetation tissues for a definite period) of forests for such a big and diverse country as Russia is a typical stochastic fuzzy problem. In order to minimize uncertainty of the results, we tried to follow the major principles of the holistic analysis of poorly organized systems, in particular, 1) to use to the possible extent all available information, 2) to use different independent estimations, 3) to provide all estimations using unified spatial, temporal and "thematic" basis, and 4) to apply all calculations, assumptions and expert estimates in the form of explicit algorithms. Taking into account the big seasonal variability of natural disturbances, the results for 1990 are given as an annual average for 1988-1992.

Materials and Methods

Initial information has been presented in the form of the Integrated Land Information System (ILIS) at the national (continental) scale. The ILIS comprises a number of the attributive DB: 1) available results of measurements of productivity of Russian forests (about 8000 sample plots and "semi-empirical" aggregations from publications and own measurements); 2) data from different inventories and surveys; 3) formalized and modified legends of different maps; 4) a set of auxiliary models; 5) data of state statistics of different nature and scales; and 6) different archives, in particular data, collected by N.I. Bazilevich. GIS components of the ILIS are presented by a number of digitized maps including landscape, soil, vegetation, land-use, phytomass, etc., maps at the scale from 1:1 tol:4 Mio. For georeferencing the forest polygons, the consecutive overlay of primary spatial units of vegetation, soil, land-use/land-cover and landscape maps has been provided. Then, the prototype of the forest map has been matched by ecoregions and administrative units with data of the State Forest Account (SFA) of 1993. Finally, we had about 15000 primary forest polygons on the forest map. For 1990 phytomass calculation, two methods have been used: 1) the method based on the SFA, and 2) the GIS based method. The results received by these methods differed by 1.5-3% for total phytomass and major fractions. Below we present the SFA based results as more precise and detailed. A special system of regression equations of phytomass fractions in relation to the SFA data has been developed for phytomass

estimation. NPP has been calculated by the GIS method using a set of auxiliary models designated to match the results of field measurements with numerical indicators of the SFA. Aggregated estimation of phytomass and NPP for 1961-1998 has been done based on regression equations and conversion coefficients of phytomass and NPP to aggregated forest inventory indicators.

Results and Discussion

Phytomass and NPP for 1990, aggregated by bio-climatic zones are presented in tables 1 and 2. Uncertainty, estimated by the modified error propagation theory and based on independent estimates by different methods, is estimated to be ±7% for phytomass and ±11% for NPP (*a priori)* confidential probability is at 0.85-0.90 (Nilsson et al., 2000).

Table 1

Distribution of phytomass of forests by bio-climatic zones in 1990

Zones	Area, x 10^6 ha	Phytomass, Tg		Density kg • m^{-2}	
		Dry matter	Carbon	Dry matter	Carbon
Polar desert	0.0	0.0	0.0	0.00	0.00
Tundra	3.8	109.2	53.5	2.86	1.40
Forest tundra & northern taiga	141.2	6,860.4	3,375.3	4.86	2.39
Middle taiga	455.0	41,590.4	20,586.7	9.14	4.52
Southern taiga	126.5	13,802.3	6,832.1	10.91	5.40
Temperate forests	26.5	3,318.1	1,635.8	12.53	6.18
Steppe	9.3	720.8	354.6	7.79	3.83
Semi-desert & desert	1.3	48.5	23.9	3.79	1.87
Non-vegetated area	0.0	0.0	0.0	0.00	0.00
Total	763.5	66,449.7	32,861.9	8.70	4.30

The distribution of the basic phytomass fractions is: stem wood over bark 60.2% of total phytomass, roots of trees 17.5%, crown wood 8.8%, understory including green forest floor 7.0%, and foliage 3.9%. Shrubs, as a separate category of forested area where closed forests are unable to grow, contain 2.6% of the total phytomass. The average carbon density *D* (total forest phytomass/forested area) for the whole country, European and Asian Russia is estimated to be 4.30, 5.07 and 4.09 kg C • m^{-2}, respectively. By aggregated fractions, 78.0% of total phytomass are allocated above ground, of which 71.8% are in woody parts and 6.2% are green parts. Coniferous dominated forests contain the major part of forest vegetation carbon (24,691 Tg C or 75.2%, of which 33.6% are in Larch forests, 16.7% in Pine, 14.3% in Spruce, 8.1% in Russian Cedar *(Pinus sibirica* and *P. korejansis*), and 2.5% are in Fir forests). Soft deciduous forests contain 6158 Tg C or 18.7% (by birch stands - 13.7% and aspen stands-3.6%). This means that about 92% of the phytomass of Russian forests are in stands dominated by 7 species. Only 3.4% of the total forest vegetational C are located in hard deciduous forests. Distribution of phytomass by age groups is as follows: young stands contain 5.2%, middle-aged stands 25.1%, immature 12.7%, mature 30.8, and overmature 26.2% of total phytomass of forest ecosystems of Russia.

Table 2

Distribution of NPP of forest ecosystems (Tg C yr^{-1}) in 1990 by aggregated fractions and bio-climatic zones

Zone	Area, x10^6 ha	Net Primary Production, Tg C yr^{-1}				Total, Tg C yr^{-1}
		green parts	woody parts	above ground	below ground	
Arctic vegetation	0	0	0	0	0	0.0
Tundra	3.8	3.1	1.0	4.1	2.4	6.5
Forest tundra and sparse taiga	141.2	107.6	46.4	154.0	80.5	234.5
Middle taiga	455.0	512.9	253.5	766.4	240.7	1007.1
Southern taiga	126.5	145.0	109.4	254.4	66.1	320.5
Temperate forests	26.5	45.9	28.9	74.8	16.2	91.0
Steppe	9.3	20.0	11.6	31.6	13.4	45.0
Semi desert & desert	1.3	2.0	0.4	2.4	0.8	3.2
Total	763.5	836.5	451.2	1287.7	420.1	1707.8

NPP of Russian forests is estimated to be 1708 Tg C C yr^{-1} in 1990 (table 2). The average NPP density is estimated to be 224 g C yr^{-1} m^{-2}, what is about 12% less than the average from 8 available estimates for the entire circumpolar boreal zone (Schulze et al., 1999, and others). NPP has an evident zonal gradient, from 171 g C yr^{-1} m^{-2} for forests situated in the tundra zone to 343 g C yr^{-1} m^{-2} for the zone of temperate forests. The independent estimate of above ground woody NPP by the increment evaluation differed by 6.4%.

Dynamics of major indicators of productivity of Russian forests are presented in table 3. In order to calculate phytomass dynamics, an expert system was used, which, among others, 1) eliminates systematic errors of forest inventory; 2) clarifies the relative phytomass data dependent upon forest inventory indicators; 3) includes a number of decision rules directed to decrease uncertainty of estimates. Due to our estimates, phytomass of the Russian forest ecosystem increased from 29.59 to 34.30 Pg C, or for 4.71 Pg C during the period 1961-1998. This means, that Russian forests accumulated phytomass on average 127 Tg C annually the during last 37 years. Two reasons are responsible for this process: 1) increase of forested area (for 78.8 million ha during the period), and 2) increase of phytomass density per unit area (from 4.254 to 4.431 kg C m^{-2}, or for about 4%), which is much more evident if comparisons are provided inside homogeneous (by species composition and age) groups of forests.

The increase of NPP of about 16% is explained, in addition, by the significant change of the age structure of forests, e.g., the share of mature and overmature stands decreased (by growing stock) during the period considered from 69.5 to 50% in European Russia, and from 75 to 59.5% in Asian Russia. The average NPP density changed insignificantly, excluding aboveground woody NPP.

Table 3

Dynamics of the major indicators of productivity in Russian forests for 1961-1998

Indicators	1961	1966	1973	1978	1983	1988	1993	1998
Data of the State Forest account								
Forest land, $xl0^6$ ha	848.1	863.0	862.1	872.3	880.5	884.1	886.5	882.0
Forested Area, $xl0^6$ ha	695.5	705.6	729.7	749.5	766.6	771.1	763.5	774.3
Growing stock volume, $xl0^9$ m^3	77.5	78.6	78.7	80.7	81.9	81.7	80.7	81.9
Dynamics of phytomass								
Phytomass - European part	6139	6712	6834	7484	7825	8344	8716	9131
Net annual increment		+115	+17	+130	+68	+104	+74	+83
Phytomass - Asian part	23451	23562	24000	24424	25736	25589	25003	25168
Net annual increment		+22	+63	+85	+262	-29	-117	+33
Phytomass - Russia totally	29590	30274	30384	31908	33561	33933	33719	34299
Net annual increment		+137	+80	+215	+331	+74	-43	+116
Net Primary Production	**1488**	**1521**	**1591**	**1652**	**1700**	**1717**	**1708**	**1735**
NPP density	**214**	**216**	**218**	**220**	**227**	**223**	**224**	**224**

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