CARBON STOCK AND DEPOSITION IN PHYTOMASS OF THE RUSSIAN FORESTS

A. ISAEV[1], G. KOROVIN[1], D. ZAMOLODCHIKOV[1], A. UTKIN[2], A. PRYAZNIKOV[1]

[1]*Centre for the Problems of Ecology and Forest Productivity of the Russian Academy of Sciences, Novocheriomuskinskaia str., 69, Moscow, 117418, Russia*
[2]*Institute of Forestry Science of the Russian Academy of Sciences, Uspenskoe, Moscow Region, 143030, Russia*

Abstract. Russian forests occupy an area of 771 Mha with a wood volume of 81.6×10^9 m^3. In this paper we estimate the carbon (C) storage and annual C deposition in living vegetation for stands of different age groups according to information in the Russian National Forest Inventory (NFI). Conversion of root C storage into phytomass was based on phytomass/storage ratios calculated from data from 1900 test areas in the different forest regions of Russia. We developėd these conversion ratios for different phytomass fractions, namely: stems, branches, roots and foliage, for different forest forming species. Of the total forest area (771 Mha), C storage in the living phytomass is 35.07 Pg C. Total annual C deposition in forest vegetation is estimated at 213.2 Tg C. We considered the role of the main forest forming species in the C cycle of the forest vegetation taking into account the actual structure of the Russian forests.

Keywords. RUSSIA, PHYTOMASS, CARBON, CONIFERS, CO_2, BOREAL FOREST.

1. Introduction

Russian forests occupy a considerable part of Eurasia and constitute about 21% of the global wood volume, including 57% of the most valuable coniferous species. The importance of the boreal forests has grown sharply with intensification of human pressure on the environment and deforestation in the tropical zone. Boreal forests are considered to be one of the most important components of the biosphere, exercising an influence on global ecosystem health and biodiversity. Boreal forests are comparable with the oceans in terms of global biosphere processes. Thus did G. F. Morozov, the founder of Russian forest science, call forests "Oceans of the Land".

Concern over global climate change, related to increasing atmospheric CO_2 and the enhanced greenhouse effect, has prompted detailed study of the carbon (C) balance in forest ecosystems. Russian boreal forests are an enormous repository of C in living phytomass, and in dead phytomass at different levels of decay including humus and peats.

According to current predicitons, global change will first and most strongly affect the Northern regions of the Taiga zone, which is mainly in Russia. It is impossible to solve the problems of global ecology without evaluating the potential role of Russian forests in the C cycle, both through quantitative description and mathematical simulation of the main C fluxes.

A large number of studies devoted to estimating C balance have been published in recent years. These studies can be divided into two groups: (1) studies based on the biological productivity of forest ecosystems and the areas of different forest types in ecoregions or other territorial complexes (Kolchugina and Vinson, 1993a,b,c; Kolchugina *et al.*, 1993); and (2) studies using the National Forest Inventory (NFI,

Water, Air and Soil Pollution **82**: 247–256, 1995.

1988) and ecosystem productivity data (Sedjo, 1992; Isaev, 1993; Isaev *et al.*,1993; Kolchugina and Vinson, 1993c).

This paper presents calculations based on data in the Russian NFI. The NFI is a unique data base including various information about Russian forests, including their age structures, species compositions, productivity and condition, at the local, regional and federal levels. The NFI does not contain information about phytomass and other components of C balance. For this reason we have developed several approaches to estimating the forest C cycle from the NFI. The purpose of this paper is to develop one approach suggested in the preceding paper (Isaev *et al.*, 1993) for estimating the C balance of Russian forests.

2. Methodology and Data Base

2.1. Data of the National Forest Inventory

Lands of the Russian National forest fund are divided into forest and non-forest lands (bogs, plough lands, pastures, glaciers, sands and other). The area of forest lands is 884.1 Mha; the area of non-forest lands is 298.5 Mha (Forest fund of the RSFSR, 1990). This paper considers only the forest lands.

Forest lands are divided into forested lands (771.1 Mha) and unforested lands (113.0 Mha), where forest is temporarily absent due to fire, harvest, sparse trees, or other causes.

In this paper we use information from the NFI relating to the distribution of areas and volumes of wood by age groups (young stands, middle aged, premature, mature and overmature) of the main forest forming species. The main forest forming species are: coniferous - pine (*Pinus sylvestris*), spruce (*Picea abies, P. obovata, P. ajanensis*), fir (*Abies sibirica, A. holophylla, A. nephrolepis, A. nordmanniana*), larch (*Larix sibirica, L. gmelinii, L. cajanderi, L. olgensis, L. kurilensis*), cedar pine (*Pinus sibirica, P. koraiensis*), dwarf siberian pine (*Pinus pumila*); hardwood - high stem (stands) and low stem (coppice) oak (*Quercus robur, Q. mongolica*), beech (*Fagus orientalis*), ash (*Fraxinus excelsior, F. mandshurica, F. sieboldiana, F. rhynchophyla*), stone birch (*Betula ermanii*); softwood - birch (*Betula pendula, B. alba* and other), aspen and poplar (*Populus tremula, P. nigra, P. alba, P. suaveolens, P. maximoviczii*), lime (*Tilia cordata, T. amurensis* and others).

The area and stocking data for stands of different age groups allows the reconstruction of the dynamics of the average stocks (m^3 ha^{-1}) and to determine the sizes of annual changes in the total stock of rootwood. In other words, it is possible to estimate C pools and fluxes taking into account the actual age structure and species composition of forests. This is particularly important in the Russian forest, with its enormous territories and different landscapes and ecological conditions.

2.2. Phytomass Data

We used the computer data base "Biological productivity of forest ecosystems" (Utkin *et al.*, 1994) as the second information source. This data base includes information about more than 1900 test plots established in the forests of Russia and neighbouring foreign countries. It includes the following main blocks: geographical situation, taxation characteristics of stands, phytomass, detritus production, annual litterfall and attrition. This data base is different from the Bazilevich (1993) data base in that it has a forestry orientation, so is easily compared with data in the NFI.

To calculate conversion ratios, we used stand stocking, age, and values of the different fractions of the stand phytomass.

2.3. Estimating Phytomass Carbon Storage

Phytomass and C storage estimates were derived from wood volume data and phytomass/rootwood ratios. Similar methods are widely used in forest inventories and to calculate C storage in different geographical zones (e.g., Johnson and Sharpe, 1983; Brown and Lugo, 1984; Brown *et al.*, 1989; Makarevsky, 1991; Sampson, 1992; Nabuurs and Mohren, 1994). Conversion ratios were calculated for different age groups of the main forest forming species for stems, branches, roots, and foliage.

Conversion ratios for dwarf siberian pine were calculated differently. We ascribed V. G. Kolischyk (1968) observations to *Pinus mugo*, and the observations in the mountains of central Japan of T. Kajimoto (1989, 1992, 1993) to dwarf siberian pine. This resulted in a new estimate of the C storage importance of dwarf siberian pine, lower than that of Isaev *et al.* (1993).

The total phytomass of each forest forming species was calculated by summing the wood stocks multiplied by the corresponding conversion ratios for each phytomass fraction for each age class.

The phytomass of lower layers was calculated from the stand species and age structure and average values (Mg ha^{-1}) of bushes and soil phytomass.

We equated average phytomass storage on the unforested lands with the phytomass storage of forest zone grasslands (Guricheva *et al.*, 1975). We excepted only areas designated as sparse wood, which in the Russian forest fund is mainly northern and montane sparse woods; its phytomass was assumed to be 20% of the phytomass of closed stands. We calculated C storage from the phytomass assuming 1 kg of dry mass of stems, branches and roots contains 0.5 kg of C, and 1 kg of dry mass of pine-needles, foliage and vegetation of lower layers contains 0.45 kg. Table I shows the ratio of phytomass C (including stems, branches, roots, foliage and vegetation of lower layers) to the wood stock for the age groups of stands of the main forest forming species.

2.4. Estimating Annual Carbon Deposition

The calculation of annual C deposition in the living phytomass of the forest ecosystems was based on the dynamics of areas and the average stocks of the main forest forming species. We assumed that the areas of young, middle aged and premature stands of each forest forming species were evenly distributed by age. For each species we determined fixed age group boundaries, corresponding to normal ages of cutting (Zagreev *et al.*, 1992). Then we calculated average stocks (m^3 ha^{-1}). We calculated annual accumulation of wood stocks (Q) for each forest forming species as follows:

$$Q = \sum_{j=0}^{m-1} \frac{S_j}{T_j} \left(W_{j+1} - W_j \right) \qquad [1]$$

TABLE I

Conversion ratios for phytomass carbon (Mg m^{-3}).

Species	Age groups			
	Young stands	Middle aged	Premature	Mature/Overmature
Pine	0.47	0.34	0.35	0.34
Spruce	0.55	0.37	0.36	0.38
Fir	0.39	0.32	0.27	0.29
Larch	0.51	0.48	0.52	0.51
Cedar	0.42	0.35	0.34	0.42
Dwarf Siberian pine	0.98	0.98	1.03	1.07
High stem oak	0.58	0.53	0.45	0.46
Low stem oak	0.89	0.54	0.62	0.73
Beech	0.47	0.51	0.49	0.49
Ash	0.51	0.50	0.42	0.43
Birch	0.48	0.41	0.37	0.37
Aspen, poplar	0.48	0.42	0.31	0.35
Lime	0.41	0.34	0.32	0.32
Other softwood	0.37	0.39	0.33	0.34

where m = number of age groups ($j = 0$ corresponding to the unforested area); S_j = area of age group j; T_j = temporary interval of group j; and W_j = average stock of the age group j.

Annual phytomass and phytomass C deposition was calculated with the applicable conversion ratios (Table I).

Unforested areas were divided into three groups for calculations of C depositon. The first group includes nursery, plantations, glades, and barrens. These areas will not transfer to the forested category. Annual C deposition for these areas was considered to be zero.

The second group includes areas where vegetation is a net C sink during stand regeneration. These are cuttings, burned areas, dead stands, etc; areas that will transfer to the forested category in the future. We considered the period of transition to the forested category to be 20 years, and that 30% of burned areas do not regenerate.

Sparse forests are in the third group. Calculation of C deposition for this group of forests is similar to that of stands with a crown closure density of 20%.

3. Results and Discussion

3.1. Carbon Storage and Deposition

The resulting estimates of C storage and deposition for Russian forests is given in Table II. The average C storage for Russian forest land is 41.1 Mg ha^{-1}, and the average annual deposition is 0.24 Mg ha^{-1} yr^{-1}. Coniferous and softwood species play the largest role in the C cycle in the Russian forests (Tables III and IV).

TABLE II

Carbon (C) storage and deposition in Russia by forest region.

Indicator	Covered with forests	Not forest-covered	Total
Area, Mha	771.1	113.0	884.1
C storage, Pg	35.07	1.25	36.32
C deposition, Tg	184.8	28.4	213.2

The distribution of the areas and volumes of wood of the main forest forming species (without bushes) is shown in Figure 1. Larch forest covers the largest area (42.4%). Together with other conifers (pine, spruce, cedar, fir) larch forests constitute 80.5% of the forested area. Softwood species cover 16.9% of the area. Hardwood species (oak, maple, ash and other) cover 2.6% of the area.

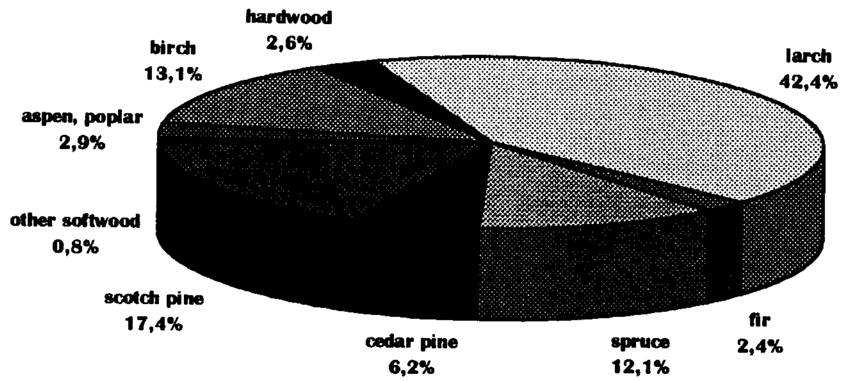
The distribution of wood volumes by species is similar to its distribution by area (Figure 1). Note that the per centage of cedar increases and of larch decreases. Cedar in Russia is mainly in old stands with large volumes (m^3 ha^{-1}) of rootwood. Larch forests grow mainly in the permafrost zone and have lower productivity.

The main C storage in living vegetation is concentrated in the larch, pine, spruce and birch forests (Figure 2). These forests account for 81% of the total C storage of the main forest-forming species. Consequently, the distribution of C storage in living forest vegetation corresponds to the distribution of these areas and stocks (Figure 1).

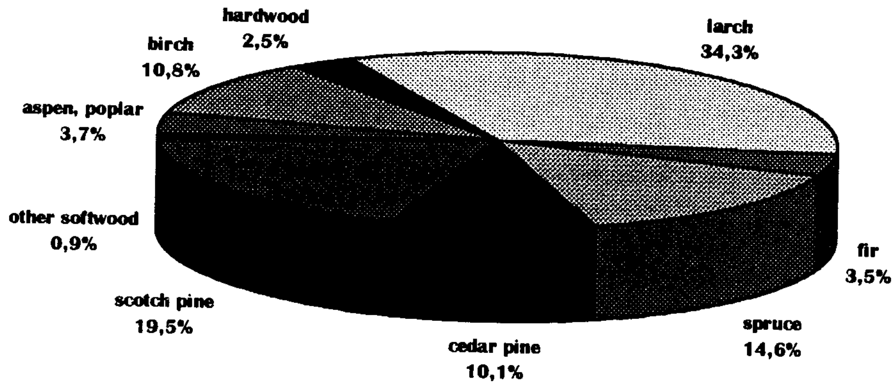
TABLE III

Indicators of phytomass stock and carbon (C) in forest vegetation.

Groups of species and land categories	Area		Wood volume		Total phytomass		C storage	
	Mha	%	10^9 m^3	%	Pg	%	Pg	%
Coniferous	568.0	74	65.78	81	55.77	79	27.79	79
Hardwood	18.5	2	1.99	2	2.42	3	1.21	3
Softwood	118.9	15	12.40	15	9.45	13	4.71	13
Other species	0.2	0	0.02	0	0.02	0	0.01	0
Bushes	65.6	9	1.45	2	2.74	4	1.36	4
Lands covered with forest	771.1	100	81.64	100	70.40	100	35.07	100
Lands not covered with forest	113.0	-	1.30	-	2.52	-	1.25	-
Forest lands	884.1	-	82.95	-	72.91	-	36.32	-

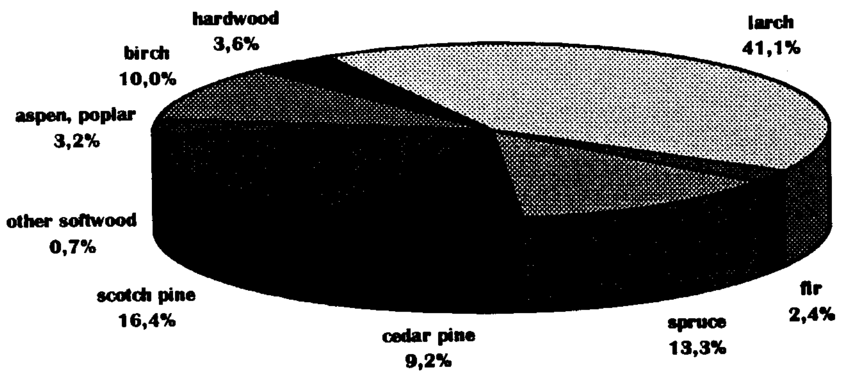


(a) Areas of forests (705.4 Mha)

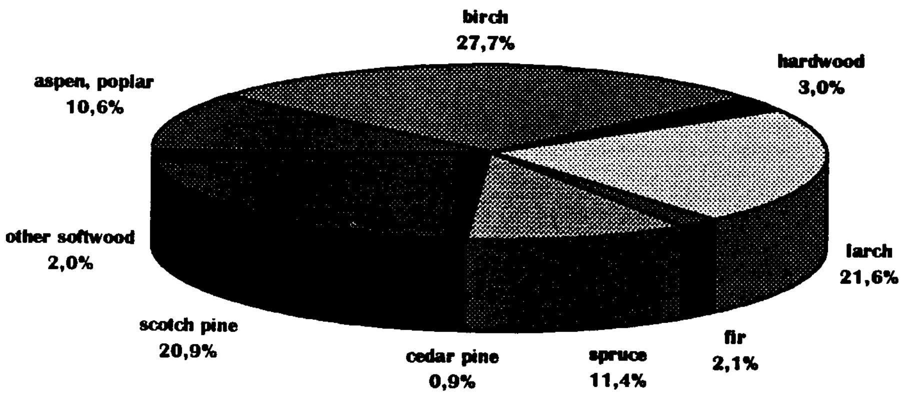


(b) Stem volume (80.17×10^9 m^3)

Fig. 1. Distribution of total area of Russian forests (a) and wood volumes (b) by main forest species.



(a) Carbon stock (33.7 Pg)



(b) Carbon deposition (183.0 Tg yr^{-1})

Fig. 2. Distribution of total carbon (C) storage in living phytomass (a) and average C deposition (b) for main forest species (without bushes).

The greatest annual C deposition is in birch stands, followed by aspen, then larch and spruce (Figure 2). The importance of aspen is greater, and that of conifers other than pine is lower. This is because deposition depends largely on the age structure of stands. Thus, prevalence of mature and overmature stands produces large C storage but low rates of deposition, whereas, prevalence of young and middle aged stands increases C deposition and reduces C storage. Thus the importance of aspen and birch increased in C deposition because of the prevalence of young and middle aged stands, formed on the enormous areas burned and harvested over the last fifty years.

Since, according to the NFI, conifers store less C in mature stands than in premature stands, then when these last will transfer to the older age group we will see negative values of deposition (Table IV).

3.2. Comparison of Different Estimates

The process of the regional and global estimation for the components of the C cycle is fraught with considerable methodological difficulties, whereas the significance of these estimates is very high. The only criteria to prove reliability of these estimates is coincidence with estimates by different investigators using different methods.

Comparison of the estimates of phytomass C storage (Table V) shows relatively close values for the forests of Russia. The differences can be explained by the use of different approaches and different conversion ratios. For instance, Kolchugina and Vinson (1993c) used the value of 0.53 Mg C m^3 to estimate a C pool of 50.2 Pg from the NFI. This value is recommended by R. Sampson (1992) for forests of the USA. According to our estimates, taking into account the species and age structure of the Russian forests, this value should be 0.43 Mg C m^3.

TABLE IV

Annual change in wood stock and carbon (C) deposition by groups of the main forest forming species.

Species group	Age group	Area ha	Change of stock 10^6 m^3 yr^{-1}	Deposition Tg C yr^{-1}
Conifers	Young	91.9		
	Middle-aged	107.5	185.3	82.0
	Premature	54.0	67.9	25.9
	Mature and overmature	314.6	-13.7	-4.0
Hardwood	Young	2.3		
	Middle-aged	4.6	5.1	3.4
	Premature	2.1	3.1	1.5
	Mature and overmature	9.5	1.1	0.6
Softwood	Young	25.4		
	Middle-aged	38.8	92.7	40.0
	Premature	13.6	62.9	24.8
	Mature and overmature	41.0	24.6	8.9

It is more difficult to compare annual values of C accumulation by the forests of Russia to those of the former Soviet Union (Table VI). Direct comparison of published values is impossible because they are significantly different in their content. The value of annual deposition is the increase in C storage in living phytomass. This value is a function of the current species and age structures of stands. The value "net ecosystem production (NEP)" is usually defined as the difference between "net primary production (NPP)" and "heterotrophic respiration (Rh)". Kolchugina and Vinson (1993b) considered NEP to be the total change of C storage in phytomass, mortmass, and soil organic matter, assuming this change to be effected only by natural processes. They considered "net increment of vegetation (NIV)" as the result of change in the quantity of C in phytomass and mortmass. The concept "net sink" is the net increase of C in all pools in the forest cover of fixed areas, excluding all emissions (fires, cuttings, etc.).

TABLE V

Estimates of carbon storage in forest phytomass.

Region	Area, Mha	Carbon pool, Pg	Source
Russia	771	39.8	Isaev *et al.*, 1993
Russia	771	35.1	This paper
Former USSR	800	46.3	Kolchugina and Vinson, 1993b
Former USSR	800	50.2	Kolchugina and Vinson, 1993c

Sedjo calculated C sequestration for the Former Soviet Union using the change in timber volume for the period 1973–1984. According to Sedjo's estimate, the annual change in timber volume was 400×10^6 m^3. According to our estimate, the corresponding value for the forested territory of Russia is 435×10^6 m^3. Sedjo's estimate of C sequestration is higher than ours essentially because it includes C deposition in mortmass and soil organic matter.

4. Conclusion

We consider the estimates of carbon (C) storage and deposition in the Russian forest vegetation given in this article as the completion of the first stage of research. In the future, based on this approach, we plan to develop estimates of NPP, mortmass, soil C, and other components of the C balance of the forest cover of Russia.

At present, calculations for separate zones, subzones and other large territorial landscape units, as well as for administrative/economical regions of Russia, are been done using similar methods. This approach will allow not only increased reliability of the estimates but also the standardization of estimates for different geographical regions in Eurasia. Carbon storage and deposition estimates for different parts of Russia are interesting from the perspective of "carbon capacity", and potential CO_2 emmissions. Studies relating to "carbon credits" are of current interest.

The approach demonstrated in this paper opens perspectives for long-term prediction of carbon fluxes taking into account the natural and anthropogenic dynamics of the forest fund. Building on this approach, we have begun to create complex mathematical models for forecast calculations.

TABLE VI

Estimates of different indicators of carbon accumulation. NEP is Net Ecosystem Production; NIV is Net Increment of Vegetation (see text).

Region	Parameter	Tg yr^{-1}	Source
Russia	Deposition	211	Isaev *et. al.*, 1993
Russia	Deposition	213	This paper
Former USSR	NEP	825	Kolchugina and Vinson, 1993b
Former USSR	NIV	780	Kolchugina and Vinson, 1993b
Former USSR	Net sink	485	Kolchugina and Vinson, 1993b
Former USSR	NIV	880	Kolchugina and Vinson, 1993c
Former USSR	Carbon sequestration	416	Sedjo, 1992

Acknowledgment

This study was supported by the project N 9404-13775-B of the Russian Fund of Fundamental Investigations.

References

Bazilevich, N. I.: 1993, *Bioproductivity of Northern Eurasian Ecosystems*, Nauka, Moscow, Russia, 295 pp.
Brown S., Lugo A. E.: 1984, *Science* **223**, 1290-1293.
Brown S., Gillespie A. J. R., Lugo, A. E.: 1989, *Forest Science* **35**(4), 881-902.
Forest Fund of the RSFSR (under accounting on the January 1, 1988): 1990, *Ministry of Forestry of the RSFSR*, 738 pp.
Guricheva N. P., Demina O. M., Kozlova G. I. *et al.*: 1975, *L. Nauka. Is.* **1**, 96-127.
Isaev A. S., Korovin G. N., Utkin A. I., Pryaznikov A. A., Zamolodchikov D. G.: 1993, *Forest Science* **6**, 3-10.
Isaev A. S.: 1993, *Piroda*, **7**, 18-21.
Johnson W. C, Sharpe D. M.: 1983, *Canadian Journal of Forest Research* **13**(3), 372-383.
Kajimoto T.: 1989, *Ecological Research* **4**(1), 55-69.
Kajimoto T.: 1992, *Ecological Research* **7**(3), 333-339.
Kajimoto T.: 1993, *Ecological Research* **9**(2), 193-204.
Kolchugina T. P., Vinson T. S.: 1993a, *Canadian Journal of Forest Research* **23**(1), 81-88.
Kolchugina T. P., Vinson T. S.: 1993b, *Global Biogeochemical Cycles* **7**(2), 291-304.
Kolchugina T. P, Vinson T. S.: 1993c, *Water, Air, and Soil Pollut.* **70**(1-4), 207-221.
Kolchugina T. P., Vinson T. S., Shwidenko A. Z., Dixon R. K., Kobak K. I., Botch M. S.: 1993, *Publications of the Academy of Finland*. **3**, 52-62.
Kolicshuk V. G.: 1968, *Forest Science* **4**, 28-38.
Makarevsky M. F.: 1991, *Ekologia* **3**, 3-10.
Nabuurs G. J., Mohren G. M. J.: 1994, Koolstofvoorraden En-vastlegging in Het Nederlandse Bos Nederlands Bosbouw Tijdschrift. **66**(4), 144-157.
National Forest Inventory: 1988, *VNIITZlesresurs M., CEPL RAN.*
Sampson R. N.: 1992, *Water, Air and Soil Pollut.* **64**, 83-120.
Sedjo R. A: 1992, *Ambio* **21**(4), 274-277.
Zagreev V. V., Sukhikh V. I., Shvidenko A. Z., Gusev N. N., Moshkalev A. G.: 1992, *In:* Kolos M.(eds.), Generally Union Norms for Forest Taxation, 495 pp.
Utkin A. I., Gylbe A. *et al.*: 1994, *In:* Bioproductivity of Forest Ecosystem Computer Data Base, Institute of Forestry Science of RAN- CEPL RAN, Moscow.