ARTICLES

The role of forest as carbon sinks in post-glacial Lithuania

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Biological resources in a regional system are of extraordinary importance. It is an object of the activities of different sectors of the economy and a sensitive indicator of environmental changes. The dynamics of biological resources in ecosystems and their productivity over the post-glacial period have been investigated by the method of analogies.

On the basis of the correlation between the vegetation productivity and average annual air temperature and the average annual precipitation quantity the annual vegetation productivity has been calculated. There have been also derived the curves of vegetation productivity and phytomass accumulation for the territory of Lithuania over the whole post-glacial period.

Consequently it is possible to infer that in the whole post-glacial period the Lithuanian regional system possessed the highest index (320 t/ha of the phytomass and 12 t/ha of the annual increment) of sustainability during the Atlantic chronozone. Later it weakened till the middle of this century (34 t/ha and 7.5 t/ha, respectively).

Due to a considerable increase in forest cover of the territory and in the production of forest the process of the biomass accumulation significantly intensified over the last four decades. In Lithuanian forest nearly 200 million tons of CO_2 (2.9 t ha^{-1} per year) were additionally accumulated.

Key words: biomass, forest, productivity, sustainability, CO_2.

Introduction

The biomass and the process of its accumulation characterise sustainability of regional ecosystem. All ecological factors forming the process of life are associated with vegetation and organic substance created by means of photosynthesis. In ecosystems the organic substance exchange is a continuous process. After the death of producers and consumers the reducers decompose the organic substance into water, carbon dioxide and other chemical elements. Thus, the organic substance exchange is maintained. Because of man's economic activity this process is severely distorted.

The aims of investigation were the following:

- to assess the dynamics of the phytomass and its increment in quantitative parameters in the post-glacial period;

- to assess man's activity related changes in the phytomass over the last two millennia;

- to investigate the changes of the phytomass and its increment in Lithuanian forest over the last century and to assess its role as carbon sinks.

The dynamics of biological resources in the ecosystems and their productivity in Lithuania over the post-glacial period have been investigated by the method of analogies (Basalykas, 1977; Kabailienė, 1979;

Bumblauskis et al., 1995, 1996). In accordance with the effect of climate on plants the post-glacial period has been divided into 7 chronozones. The processes and factors influencing the biological productivity in this period have been extrapolated according to the current laws of vegetation development and, vice versa, vegetation is considered as an indicator of climate.

The changes in the phytomass and its increment over the last millennium were assessed using the historical data on land use and reforestation. The effect of the phytomass on the carbon sequestration was calculated in two ways: through the balance of the increment and decomposition of the phytomass in the ecosystems and through variation in the phytomass resources.

The productivity of vegetation in the post-glacial period

After the glacial period on the territory of Lithuania the first plants appeared 13,200 years ago. Over a period of 3,000 years the tundra type vegetation prevailed, which was attributed to Arctic and sub-Arctic chronozones. Forests appeared at the beginning of the preboreal chronozone nearly 10,000 years ago. Vegetation developed further in different climatic conditions. It resulted in variation in vegetation productivity. At the onset of the Atlantic chronozone productive broad-leaved forests spread throughout Lithuania. Due to colder climate the conversion of these forests to coniferous and mixed forests occurred.

On the basis of the correlation between the vegetation productivity and the average annual air temperature and the average annual precipitation quantity the annual vegetation productivity has been calculated.

The results presented in Table 1 are very similar. The annual phytomass increment determined for the chronozones according to vegetation zones and the average annual air temperature or according to vegetation zones and the average annual quantity of precipitation, correlates well (the coefficient is higher than 0.9).

Man's activity related changes in vegetation productivity

On the territory of Lithuania man's activity has been traced since the late glacial period. In the Mesolithic and Neolithic periods the effect of this activity was intangible. Forests and land were melted by fire for expanding pastures and arable land. Man started using wood in the Iron Age when cattle breeding and agriculture were rather intensive However, the territory was sparsely populated. Forest areas shrank slowly and the impact of man's activity on vegetation productivity was limited.

As a result of investigation conducted on the increment of the phytomass and its accumulation in different kinds of land, it has been found that phytomass accumulation is mostly affected by variation in land use. It has been determined that the total phytomass (t/ha) correlates well with forest cover of the territory and can be calculated according to the formula:

$$M = 320 \cdot (0,99 - e^{-0,006 \cdot A}),$$

where A refers to forest cover, %.

The data on changes in the area of land, covered by wood (by Prof. Matulionis) and the available data on the phytomass increment enabled a two-way analysis of variation in the phytomass over the last 1,200 years (Table 2) to be conducted.

There have been also derived the curves of vegetation productivity and phytomass accumulation for the territory of Lithuania over the whole post-glacial period (Fig. 1). From time immemorial till the middle of the subboreal chronozone the organic mass of vegetation which had been affected only by climatic changes accumulated normally. The influence of man was noted 2,000 years ago when he started ravaging forests. Consequently, the average quantity of the vegetation mass has decreased in the ecosystem of the Baltic region.

Table 1. The annual phytomass increment in chronozones and the reliability of its calculation

Chronozones	According to vegetation zones t/ha	According to the average air temperature t/ha	According to the annual quantity of precipitation t/ha	On average t/ha	The sum of the average deviation	Error ±	Reliability
Preboreal	7.0	7.1	7.3	7.1	0.53	0.127	high
Boreal	8.0	7.9	8.5	8.1	0.73	0.215	good
Atlantic	12.0	11.7	11.9	11.9	0.33	0.097	high
Subboreal	10.0	10.7	10.4	10.4	0.87	0.257	good
Subatlantic	10.0	9.8	10.1	10.1	0.67	0.198	good

Table 2. Variation in the phytomass over the last 1,200 years

Years	The number of people per 1 km²	Forest cover, %	The phytomass t/ha according to variation in land		The phytomass t/ha according to equations	
			Total	The annual increment	Total	The annual increment
1990	56	27.9	44.8	7.9	44.8	7.7
1980	54	27.6	38.0	7.7	41.4	7.6
1950	45	25.0	37.4	7.2	33.4	7.5
1900	37	24.0	33.8	7.9	30.0	7.5
1861	33	30.0	52.0	8.0	48.7	7.7
1500	19	42.0	87.9	8.2	85.4	8.0
1100	8	55.0	122.1	8.5	125.2	8.4
1000	7	61.0	142.1	8.7	143.6	8.6
800	7	73.0	175.1	8.9	180.3	9.0
On average			106.2	8.3	106.7	8.2

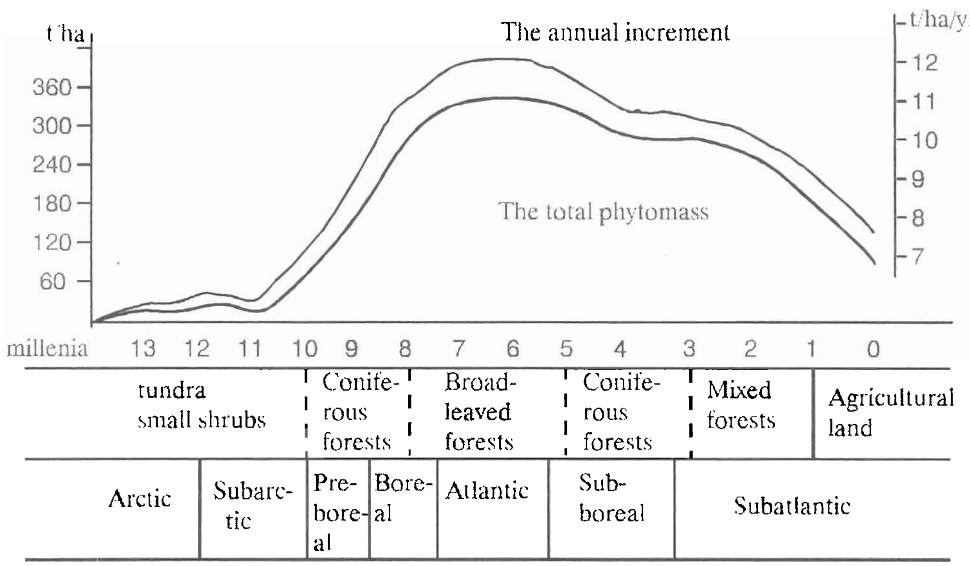

Fig. 1. Variation in the annual increment and in total quantity of the phytomass on the territory of Lithuania in the chronozones of the post-glacial period

The dynamics of changes in the phytomass resources of forests

In order to assess the dynamics of the phytomass increment of forests the correlation between the current volume increment of wood in stems and phytomass increment has been used. It is described by the following equation:

$$FP = 4.537 \cdot (SP \cdot b)^{0.5648} \qquad (R^2=0.80),$$

where *FP* is the phytomass increment, t/ha, *SP* refers to the current wood increment of stems, m³/ha, *b* is volume weight of absolutely dry wood, t/m³.

This equation is applicable to the main tree species in Lithuania. There is no essential difference between pine, spruce or birch stands. All experimental data distribute around the common resultant. Additionally, in publications (Kenstavičius, Brukas, 1984, 1993) characterising the forest fund the stand increment is presented by one value for all stands.

It has been determined that it is feasible to assess the total forest phytomass according to the stem volume and stand age. The following equations have been applied:

$F = 5.281 \cdot (ST \cdot b)^{0.6714} \cdot A^{0.0882}$
(for pine stands, $R^2 = 0.877$);
$F = 2.547 \cdot (ST \cdot b)^{0.7750} \cdot A^{0.1544}$
(for spruce stands, $R^2 = 0.941$);
$F = 3.458 \cdot (ST \cdot b)^{0.7742} \cdot A^{0.0665}$
(for birch stands $R^2 = 0.775$);
where *F* – the phytomass, t/ha (absolutely dry), *ST* – stem volume, m³/ha, *A* – age, years, *b* – volume weight of absolutely dry wood, t/m³.

For oak, ash and other stands, the following formulae have been used:

$F = M_2 \cdot b \cdot c$,

where *F* – the phytomass, t/ha (absolutely dry); M_2 – conversion coefficient established according to the measurement data (for soft broadleaved species – 0.61 and for hard broadleaved species – 1.22); *c* – stem volume, m³/ha; *b* – additional coefficient depending upon stem volume per hectare.

The equations show significant impact of stand age on the total phytomass: the less the stand age, the less is the total phytomass. The dynamics of the forest phytomass and its increment has been determined according to the presented equations and data on changes in the area, volume and their increment in the 20th century. In the period 1958-1993 a significant increase in the phytomass of forests was observed: an increase in the quantity of the phytomass per hectare comprised 40% (Fig. 2) and that in the total quantity of it - nearly 65% (Table 3). The phytomass increment over the same period varied less (Fig. 3). It holds for the increment per area unit, which augmented till - 1987 and amounted to 9.2 t/ha .

Table 3. Changes in the phytomass in all Lithuanian forests in 1958-1993

Stands	The phytomass in different years, mln/t			
	in 1958-1963	in 1966-1977	in 1978-1987	in 1993
Pine	71.7	78.7	98.8	106.5
Spruce	36.3	39.6	55.0	61.7
Birch	27.4	42.1	51.9	53.2
Oak	2.8	4.0	6.0	6.9
Ash	2.0	3.5	6.5	8.1
Alder	5.8	7.9	10.1	11.2
Aspen	9.0	8.9	7.5	6.6
Grey alder	2.1	5.6	6.3	6.0
Other stands	0.2	0.4	0.9	0.5
Total	157.4	190.8	243.1	260.7

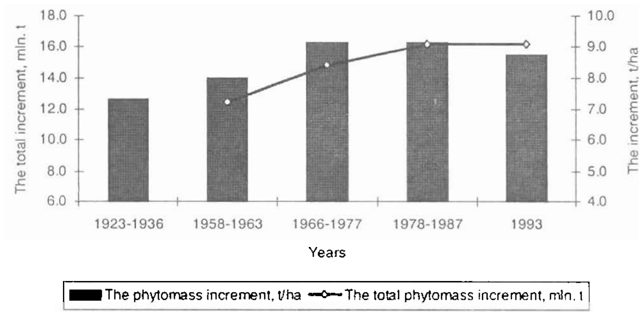

Fig. 3. Changes in the phytomass increment per 1 ha and in total phytomass increment in Lithuanian forests in 1923-1993

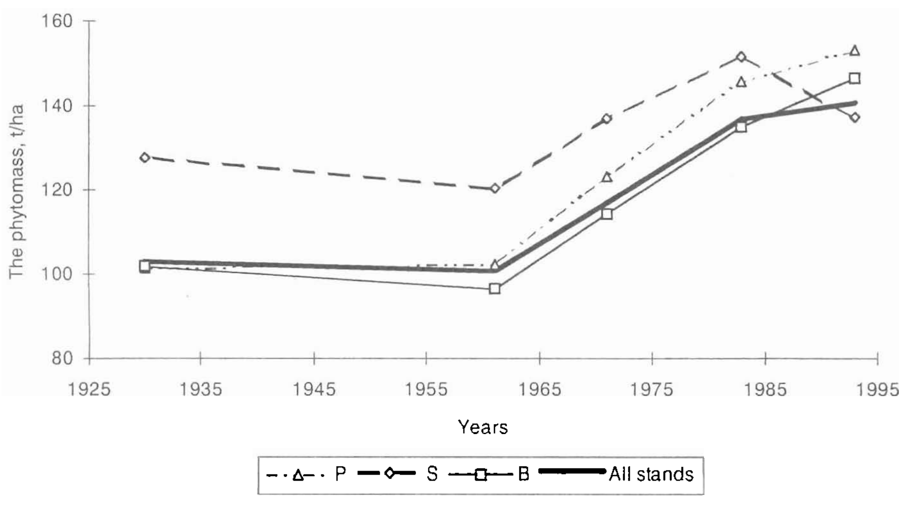

Fig. 2. Changes in the average quantity of the phytomass per hectare in stands of the main tree species (P - pine; S - spruce; B - birch) in Lithuania in the period 1930 – 1993

The balance of CO_2 assimilation of forest in the past and current feasibility of atmospheric self-purification

In the balance of CO_2 two factors are crucially important: CO_2 accumulation in the phytomass in the process of photosynthesis and its isolation in the atmosphere when mortmass decomposes. The dynamics of variation in phytomass calculated and the quantities of mortmass (litter, humus, peat, sapropel etc.) have been assessed rather precisely. That has permitted the dynamics of variation in the phytomass to be determined in the whole post-glacial period. Over the holocen period the balance of CO_2, and O_2 significantly exceeded 1.0 (Table 4).

Table 4. The balance of CO_2 and O_2 in Lithuania in the post-glacial period (10^6 t)

Creation of the organic mass	CO_2 consumption	Eduction of O_2	Decomposition organic mass	Eduction of CO_2	O_2 consumption
The phytomass of plants	337922	901126	Vegetation	337795	900786
Peat	413	1100	Peat	88	239
Bottom deposit	953	2541	Humus	233	559
Humus	466	1243	Litter	67	161
Litter	29	76	Fuel burning	369	984
Total	339783	906086		338552	902729

The effect of the phytomass on the balance of CO_2 has been assessed in two ways. The first one deals with the balance of the increment and the decomposition of the phytomass in the ecosystems. In the second way the effect of the phytomass on the balance of CO_2 is estimated according to variation in the phytomass resources. In this case the influence of the phytomass, and not that of the whole organic mass, is evaluated. Therefore, such a balance is partial. The impact of variation in the phytomass in this century on the balance of CO_2 has been assessed without analysis of mortmass decomposition, consumption of the phytomass and mortmass in man's economic activity (fuel burning, etc.).

For this, the data on variation in the phytomass, the quantity of C in it and the general physiological laws (Summary equation of photosynthesis) have been applied:

1. Chemical composition of phytocoenoses organic substance (the quantity of C). The data of many researchers allow us to assert, that carbon (C) in wood and bark comprises 48-52% from total mass of absolutely dry substance. It is accepted that C constitues on average 50% of absolutely dry substance mass.

2. Use of CO_2 for phytomass creating. By refering to the general physiological laws ($6CO_2+6H_2O = C_6H_{12}O_6+6O_2$) and to quantity of carbon in the forest phytomass it may be ascertained that for creating 1 kg of absolutely dry phytomass 1.84 kg of CO_2 is used.

The above data indicate that in the period 1958-1993 the phytomass of Lithuanian forests increased 103 million tons. Thus, over this period nearly 190 million tons of CO_2 were absorbed by the phytomass of the ecosystems or on average 5.4 million tons per year. In the agricultural ecosystems the phytomass accumulation practically does not occur. Therefore, its influence on CO_2 absorption is minimal. Variation in the phytomass increment determines only larger or smaller turnover of CO_2. The assessment of the effect of other types of the ecosystems (swamps, water basins, areas grown with brushes) on the CO_2 balance is almost infeasible. As the phytomass of these ecosystems is not abundant it is not significant in influencing the balance of CO_2.

Finally, looking back to the dynamics of CO_2 emission in Lithuania (Fig. 4) we see two main trends: drastic increase in emission starting from 1945 and decrease from 1988. The sequestration of CO_2 by forest was also increasing during the above time span due to nearly a two-fold increase in wood production (Table 3). But the gape between the emission and sequestration was still growing and achieved its maxima (38 mil. t/ CO_2) in 1988. Due to a general production decrease the fuel and energy consumption in Lithuania has diminished from 22.37 million tons of equivalent fuel (e.f.) in 1989 to 12.90 million tons of e.f. in 1993 (Zukauskas et al., 1996). For this reason the amount of CO_2 and other pollutant gas released has diminished twice. The gap between the emission and sequestration of CO_2 in Lithuania decreased. At present (1995-1997) in the regional ecosystem of Lithuania the balance of emission and absorption of CO_2 is nearly at zero level. Only a total of about 10 million tons of CO_2 yearly are emitted from the territory of Lithuania. This amount is 10-14 times less as compared to emission per capita or per sq. km^2 of West European countries.

Conclusions

1. The accumulation of the phytobiomass per time unit may be considered to be a perfect index of eco-

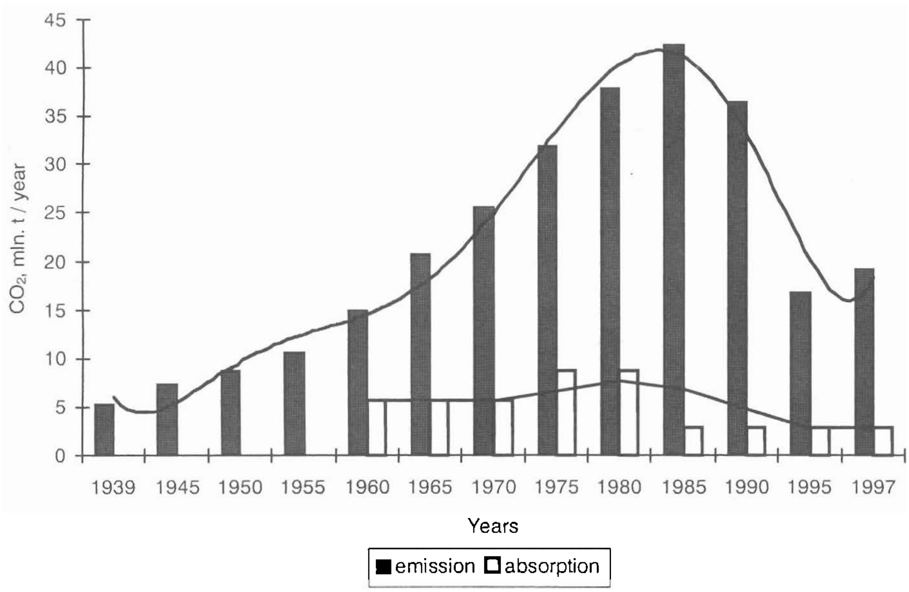

Fig. 4. Emission and sequestration of CO_2 in Lithuania in 1939-1997 (Mln. t/year)

system vitality while the quantity of the biomass being accumulated on an area may be regarded as a conditional index of sustainability of a regional system.

2. In the whole post-glacial period the Lithuanian regional system possessed the highest index (320 t/ha of the phytomass and 12 t/ha of the increment) of sustainability during the Atlantic chronozone. It weakened from the onset of the Atlantic chronozone till the middle of this century (34 t/ha and 7.2 t/ha respectively).

3. Due to a considerable increase in forest cover of the territory of Lithuania and in the production of forest and agriculture the process of biomass accumulation significantly intensified over the last four decades. Sustainability of the regional ecosystem augmented too: in 1993 the phytomass amounted to 50 and its increment about 8 tons per hectare.

4. Over the last fourth decades in the phytomass of the forest ecosystems nearly 200 million tons of CO_2 were additionally accumulated or 5.5 million tons annually. It means that Lithuanian forest over this period has additionally accumulated 2.9 t ha^{-1} per year which remarkably decrease the gap between the emission and sequestration of CO_2.

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РОЛЬ ЛЕСОВ В ПОГЛОЩЕНИИ CO_2 НА ТЕРРИТОРИИ ЛИТВЫ ОТ ПОСЛЕЛЕДНТКОВОГО ДО НАСТОЯЩЕГО ВРЕМЕНИ

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Резюме

Исследовалась динамика прироста и накопление фитомассы на прротяжении всего послеледникового периода на территории Литвы. Применена методика аналогов. По влиянию климата на растений, послеледниковый период разделен на 7 хронозон.

На основе корреляционных связей между продуктивностью растительности, среднегодовыми температурами и осадками расчитана продуктивность растительности и накопление биомассы. Определены связи между лесистностью территории и средних объемах биомассы. Установлено, что в атлантической хронозоне, когда на территории теперешней Литвы преобладали широколиственные леса, годовой прирост фитомассы достигал в среднем 12 $т/га^{-1}$ сухого вещества при средних ее запасах 320 $т/га^{-1}$. С проявлением активности человека на протяжении двух последних тысячилетий лесистость территории Литвы снижалась, средние объемы фитомассы сократились, достигнув минимума в середине нашего столетия (лесистость – 20%, фитомасса – 33-37 $т/га^{-1}$). Благодаря облесительным работам по созданию 0,5 мил. га новых лесов и нестованию запаса во всех лесах в условиях выборочного хозяйства, запасы в лесах увеличивались от 162 мил. $м^3$ (1958) до 347 мил. $м^3$ (1996). Таким обpазом за последние 40 лет в лесах Литвы дополнительно было аккумулировано 190 мил. т CO_2. В настоящее время, благодаря двойному сокращению эмиссий, баланс CO_2 в территориальной системе "Литва" улучшился и, при дополнительном увеличении лесистости, имеет тенденцию достижения нулевой отметки.

Ключевые слова: фитомасса, хронозоны, CO_2, лесистость, запас, баланс.