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Geodistributed analysis of forest phytomass: Subcarpathian voivodeship as a case study

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Abstract. An approach to the implementation of spatial inventory of greenhouse gas sinks and emissions in forestry sector is presented. The algorithms for disaggregation of official statistical data on forests at the regional level, and formation of geodistributed database using the digital map of land use are proposed. As an example the forests of Subcarpathian Voivodeship of Poland were investigated. This study presents the results of modeling the flow of carbon in forest phytomass taking into account different tree species composition, age class and other characteristics. The 'regional' coefficients for phytomass and carbon deposited were clarified taking into account regional specificity. Also an algorithm for determining aboveground and underground phytomass of tree by its stock and forests of different types has been created. The correlation between the total area and stock for each species of forest-forming stands was analysed. The multilayer digital maps of deposited carbon, and greenhouse gas emissions in forests of Subcarpathian Voivodeship were created. For the spatial inventory of forest phytomass the territory of voivodeship was divided into square areas 2x2 kilometers in size, and stock phytomass in each such elementary area has been analised. Acheaved results were verified using GIS technology, and forest inventory data.

Keywords: information technology, digital maps, GIS, IPCC methodology, forest inventory, deposited carbon.

INTRODUCTION

The processes of carbon absorption by forest ecosystems intensively studied by many scientists especially in European countries. Project 'Carbo Europe' initiated series of new projects, which were aiming to develop a methodology to better understand the processes and implementation of quantitative assessment and verification of carbon balance. A forest valuation study collected considerable experimental material on the biological productivity of forest plantations, established patterns of distribution biomass components [1]. However, studies have not enveloped all the diversity of forest ecosystems, the available data do not give a spatial representation of the distribution of phytomass and accumulated carbon. Therefore, there is a unique opportunity based on data the remote sensing and of terrestrial observation, and data of measurements to create an effective tool for Geoinformation spatial research of complicated processes of carbon deposition in forest ecosystems and carbon balance assessment. Such an tool would be extremely useful for decision-makers, landscape planners and managers.

Poland is one of the most forested European country. At present, the forest cover in Poland is around 9,164 thousand ha, which corresponds to 29.3% of the country [1]. Forest cover in different provinces varies from 21.2% in Łódź to 49.1% in Lubuskie. The last forest inventory was carried out by Biuro Urządzania Lasu i Geodezji Leśnej to order Dyrekcji Generalnej Lasów Państwowych, completed in March 2011. The research results obtained mainly based on data from sample plots laid in 2006-2010 and it was a continuation of the first large-scale inventory of all forms of ownership of forests (for the period 2005-2010) [1]. According to the data Central Bureau of Statistics in 2010 from the previous, the forest area increased by 33 thousand ha, and since 1995, forest area in Poland has increased by 365 thousand ha. Forest cover in Poland in 2001 was 28.5% (8.89 million ha). Over the past 50 years, it has increased by 7.7%, but has not yet reached the optimum level, which according to Polish experts should reach 33-34% [15]. The increase of total forest cover caused by afforestation of agricultural lands and natural process of afforestation. Stock of wood in the root was 1.73 billion m^3, the average current increase was 6.6 m^3/ha (in state forests - 8.5 m^3/ha). Average stock of wood per 1 ha for the last 35 years in state forests has increased from 145 to 211 m^3/ha in private and gmina forests - from 60 to 119 m^3/ha [1,10-12]. Increasing forest cover in Poland was a result of the introduction of "National Program of increasing the area of forests", developed by Forest Research Institute, adopted in June 23, 1995 by the Council of Ministers. The main goal of the program was to increase forest cover up to 30% by 2020 and up to 33% in 2050, and to ensure optimal spatiotemporal distribution of afforestation, creation of environmental and economic priorities and tools to accomplish it. The diagram (Fig. 1) shows the dynamics of change in forest cover of Subcarpathian Voivodeship in Poland within the program of increasing forest cover [12].

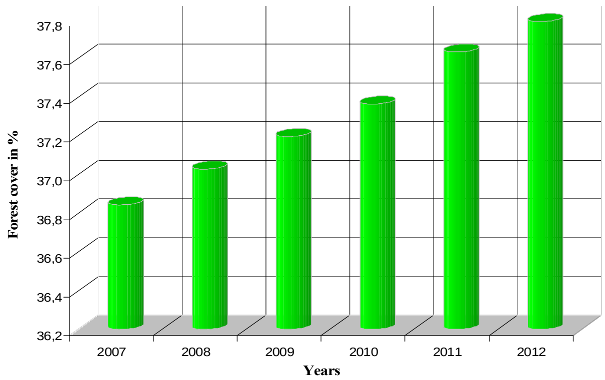

Fig. 1. Forests cover change in Subcarpathian Voivodeship, Poland (%)

Especially valuable natural forest ecosystems in Poland have certain protected status. In 2010 in Poland there were 1,441 nature reserves, including 671 forest, with total area of 61,000 hectares. It is usually highly productive old forests. The oldest and largest trees, which in 2010 totaled 10,800 units, have status of Nature Monument. Also in Poland there are national and regional landscape parks, which occupy 2.5 million ha, including 1.3 million hectares - wooded. In most cases, these forests are highly productive, they are protected, and the harvesting of wood is prohibited [14].

The objects of study in this article are the forests in Subcarpathian Voivodeship, Poland as reservoirs for deposited carbon. The subject of the study is to model the process of flow of carbon in phytomass of forest at different levels of spatial disaggregation from a single tree, to a stand level, and forest ecosystem level. The aim of the study was to develop GIS tools for spatial analysis and calculation of forest phytomass of carbon deposited in forests using statistics data, species composition, age class and other forestry valuation indicators. To achieve this goal the following tasks were:

- to develop the algorithms of estimation of aboveground and underground phytomass of a tree stem wood volume (stock) for forests taking into account different composition, age and site conditions;
- to clarify regional coefficients for phytomass and carbon deposited taking into account regional specificity;
- to form geodistributed databases and digital maps of forests as a result of spatial analysis of phytomass and deposited carbon.

METHODOLOGY

To determine phytomass and deposited carbon the methodology developed by the Intergovernmental Panel on Climate Change (IPCC) was used [7,18]. In these guidelines of National Greenhouse Gas Inventories the methods for estimating sources and sinks of CO_2 were proposed. National inventory should cover all forests, regardless of ownership and consider all forest activities ranging from growing plantations, implementing measures nature restoration care of forest crops, the workpiece firewood business and to use change [18]. According to the Guidelines, forest areas are divided into two subcategories, which have separate calculation methodologies: "forest land remaining forest land" and "non-forest land, converted to forest land". In the first case the lands that were forested for more than 20 years are considered. In the second case, the lands that were transferred to the forest area are considered, for a transitional period during which a change in carbon stocks due to land use changes takes place. By default, the length of the transition period is 20 years. The actual duration of the transition depends on the natural and ecological characteristics of a specific country or region, and may differ from 20 years [18].

The guidelines contain the methods for calculation of the the next reservoirs of carbon and other than CO_2 greenhouse gases:

- biomass aboveground and underground;
- dead organic matter (litter and wood overthrown);
- soil organic matter;
- other than CO_2 gases (CH_4, CO, N_2O, NO_x).

MAIN LEVELS OF GHG INVENTORY

IPCC Methodology recommends a three-tier general scheme for greenhouse gas inventory in the forest and land-use change. Methods of the first level are the simplest on the practical application. To evaluate emissions the appropriate formulas and parameters are used by default (for example, the value of emission factors and changes in reservoirs). When using this level of inventory, data on economic activity at the national level are needed. Nevertheless in many cases only data on the activities assessed at a higher, sometimes even global, level are available (for example, the rate of deforestation, statistics, global maps of land cover, etc.). Therefore these data usually include low spatial resolution [6,19].

At the second level the same methodological approach as for the first level can be used, but applied emission factors and data on changes in stocks must be derived from the data for a particular country or a particular region (they can be identified by the country, and for the most important categories of land). As a part of the second level more detailed data are typically used on the activities with higher temporal and spatial resolution, in order to conform to the designated coefficients for specific regions and specialized land use categories [18].

As a part of the third level the special methods are applied, including models and systems of measurements for cadastres, adapted to specific national conditions. They can use the results of repeated measurements, and data on the activities of a better definition, including data disaggregated to the regional level. The data on economic activity at the level of separate enterprise can be applied, or a level of basic areas of a certain size, for example, 5km × 5km can be used. These methods provide an inventory of the highest order to obtain estimates of the value of a higher degree of certainty than at lower levels of inventory [2, 6, 13]. Such methods and systems may include a full inventory of the sample in the field, repeated at regular intervals or based on GIS systems, data on age class, productivity of the stand, soils conditions and other. The information about the activities in the field of land use and management, which combines the results of several types of monitoring, is also under consideration. Plots of land on which there is a change of land use, can usually be controlled with time, at least statistically.

Plant biomass, including above and underground parts, is the main reservoir for the capture of CO_2 from the atmosphere. Between the atmosphere and terrestrial ecosystems large amounts of CO_2 are moved, primarily through photosynthesis and respiration [9, 23].

Annual change in carbon stocks for each category of land use is defined as the sum of the changes in each layer within this category: $\Delta C_{LU} = {}_i\Delta C_{LU_i}$, where ΔC_{LU} is the changes in stocks of carbon for any category of land use (LU), *i* denotes a specific layer or unit within this category of land use. That is, the annual change in carbon stocks for any given layer of land use categories is defined as the sum of changes in carbon stocks in all reservoirs:

$$\Delta C_{LU_i} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}, \quad (1)$$

where the subscripts denote the following carbon reservoirs: AB - aboveground biomass; BB – underground biomass; DW – wood overthrown; LI – litter; SO – soil; HWP – harvested timber. Specific emissions and removals of greenhouse gases (per hectare) vary depending on the characteristics of the land and other parameters, such as forest type, structure of plantation, current state of stand, and practice of management [16, 17, 22, 24]. An effective practice is to classify the forest areas by different subcategories with the purpose to reduce the variation in growth rate and other parameters of the forest, and to reduce an uncertainty [6]. National experts should use more detailed classification of forest lands, and regional factors estimation.

Sinks or depositions of carbon include the overall growth of biomass (aboveground and underground parts). Losses or removals of carbon include the billet of round timber, firewood, and losses from damage associated with fires, insects, diseases and other injuries also considered in the research. When such losses occur underground biomass is also reduced and converted into dead organic matter (MOU) [8, 20, 21]. Evaluation of changes in carbon reservoirs and stocks depends on the availability of data and models as well as the resources and opportunities to gather and analyze additional information [9, 23].

STUDY AREA, RESULTS AND DISCUSSION

Subcarpathian Voivodeship (‘Województwo podkarpackie’ in Polish) is located in the southeast of Poland between the rivers Vistula and San, the Sandomierz Basin and the foothills of the Carpathian Mountains. It shares borders with Slovakia in the South, and Ukraine in the East. Forest cover of Subcarpathian Voivodeship is one of the biggest in Poland and reaches 37.2%. The bigger share of forest cover has only Lubusz Voivodeship (48.9%). The area covered by forest in Subcarpathian Voivodeship is 663 797 hectares, and industrial wood supply is 194.7 million m^3, or 293.3 m^3/ha [4, 5]. In the southern, mountainous part of the region there are rich primeval forests of the Carpathian Mountains, dominated by mountain species: beech, fir and spruce (Fig. 2). The northern part of voivodeship is occupied by thick forests Sandomierz plain type. In the past, it was also dominated by beech and fir. Today, however, grows mainly pine, which was planted [3].

In terms of age structure in the Subcarpathian Voivodeship forests are predominant third and fourth age classes 25% and 21%, respectively. Little is left of seventh age class of forest, which are 120 years old and more. Distribution of forest area by age classes is presented in Fig. 3: 1 – not forested land, 2 – the first age class (up to 20 years), 3 – the second age class (21-40years), 4 – the third age class (41-60 years), 5 – the fourth age class (61-80 years), 6 – the fifth age class (81-100 years), 7 – the sixth age class (101-120 years), 8 – the seventh age class (over 120 years), 9 – KO forests, KDO, BP.

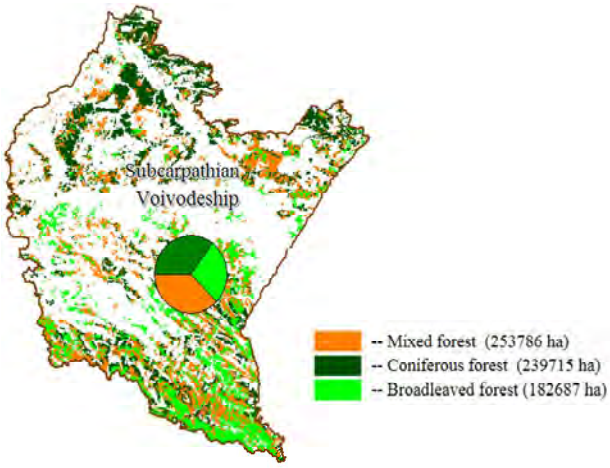

Fig. 2. Forest cover in Subcarpathian Voivodeship

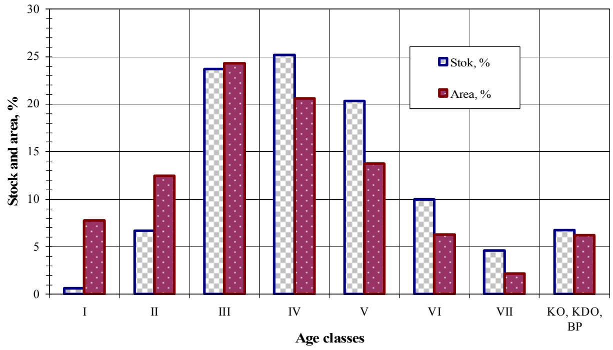

Fig. 4. Forest stands of different age classes, and forest phytomass formation

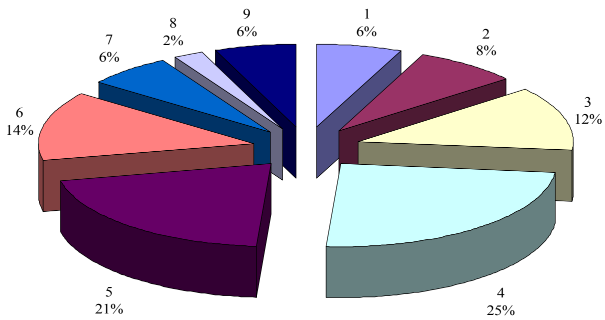

Fig. 3. Distribution of forest area by age classes

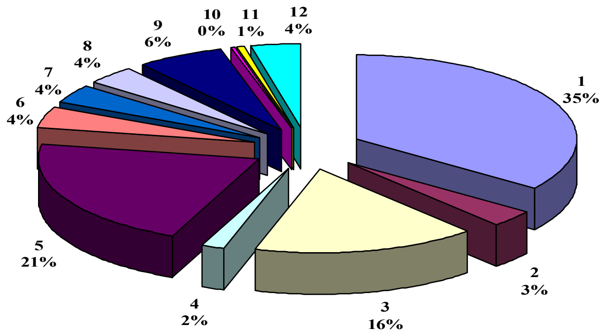

Fig. 5. Species composition of forests: 1 – pine, 2 – spruce (spruce), 3 – fir, 4 – other conifers, 5 – beech, 6 – oak, 7 – hornbeam, 8 – birch, 9 – alder, 10 – poplar, 11 – aspen, 12 – other deciduous

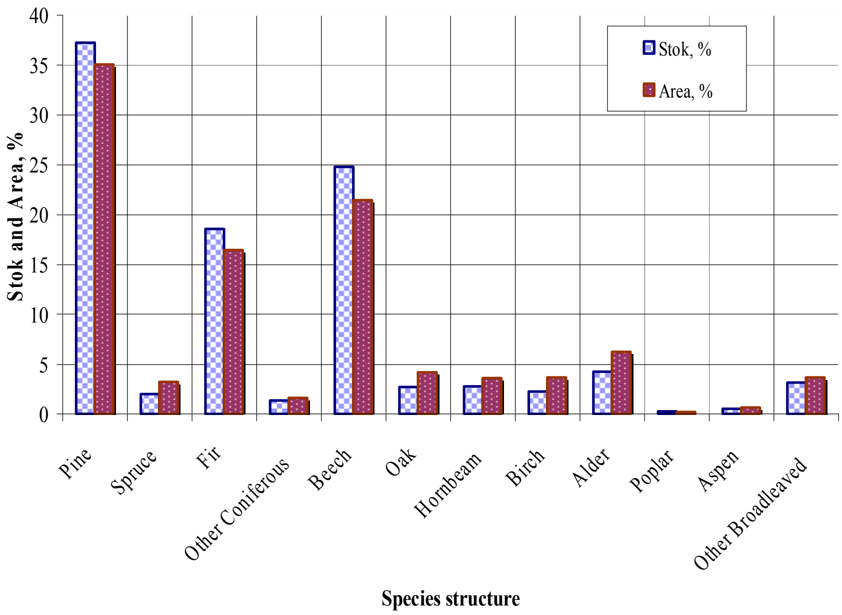

Fig. 6. Correlation between the total area and stock for each species of forest-forming stands

Share of different age classes in the formation of stem wood stock and, consequently, forest phytomass of Subcarpathian Voivodeship is shown on Fig. 4. Thus forest stands with III, IV i V age classes have the most significant impact. Young and old classes occupy a large areas of 7.75% and 12.47% of the total area covered by forest, but they make up a small proportion of forest phytomass 0.66% and 6.71%, respectively. Overmature forests VI and VII of age classes cover an area of 6.28 and 2.19%, and have a stake in forest phytomass 9.96% and 4.58%.

From 1945 to 2010 the Polish forest species structure changed significantly, in particular, the area of deciduous forest stands increased from 13 to 29.3%, but coniferous forest stands dominated and occuped 70.7% [1, 15]. In Subcarpathian Voivodeship share hardwood is much greater than in the whole of Poland and is 43.6%, while conifers occupy 56.4%. The predominant species here are: 35% – pine, 21% – beech, 16% – fir (Fig. 5). The northern part of the province is mostly flat, the south part is mountainous, there are 'islands' of preserved pine and beech forests. In the mountains mixed coniferous-deciduous forests are dominating.

The correlations between total area and stock for each species of forest-forming stands are different (Fig. 6). Thus, the area is covered with pine forests 35.6% of the total area covered by forests, and stem wood stock is thus 37.22% of the forests. Fir and beech occupy, respectively, the area of 16.43% and 21.44%, and the stock of phytomass -18.54% and 24.77%. At the same time, the breeds like spruce, oak, hornbeam, birch, and alder share space with 3.24%, 4.16%, 3.61%, 3.65%, 6.24%, and the share of the stock, respectively, 2.04%, 2.74%, 2.8%, 2.27%, 4.28%.

VERIFICATION OF RESULTS

Modern geoinformation technologies can be applied for analysis of forests using satellite sensing of the earth's surface, and aerospace and satellite images. Google Earth, and other tools for image viewing and analysis have means for measuring linear dimensions of forest areas: length, width, perimeter (Fig. 7) and area (Fig. 8).

The forest phytomass of Subcarpathian Voivodeship was defined according to the latest inventory [1, 11, 12], and digital maps of forests in Poland (Corine Land Cover, 2006). To verify this map the fragments of forests of Corine Land Cover map (see example in Fig. 9 and Fig. 11) were compared with actual satellite images of arrays of Google Earth (Fig. 10, and Fig. 12).

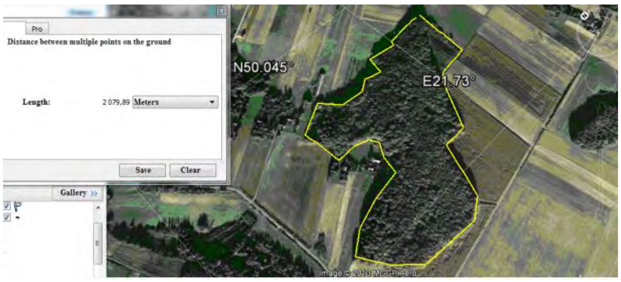

Fig. 7. Defining the perimeter of forest area

Fig. 8. Determination of parameters of forest areas for aerospace images

Fig. 9. Fragment of Corine Land Cover forest map with centroid coordinates E 22,017890º; N 49,551217 º

Fig. 10. Fragment of forest maps from Google Earth with the same coordinates

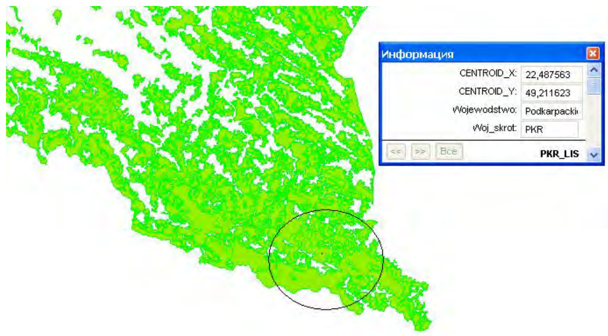

Fig. 11. Mountain forests in the Beskids (Corine Land Cover map)

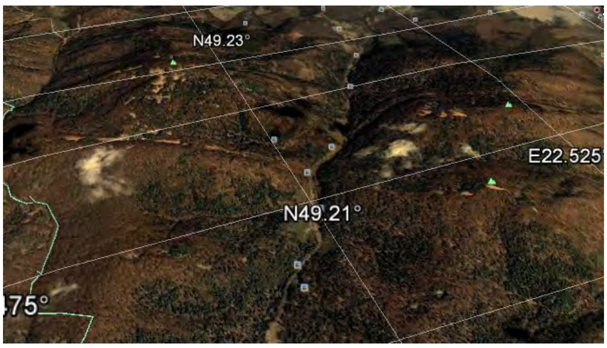

Fig. 12. Satellite image of Beskids mountain forests ;in Google Earth

As a result, the digital map of forest vegetation of Subcarpathian Voivodeship was created. This map comprise 2510 elementary areas, including 725 coniferous forests sections, 703 deciduous sections, 1082 sections of mixed forests (Fig. 2).

MODELING COMPONENTS OF BIOLOGICAL PRODUCTIVITY OF FOREST STANDS

All indicators of phytomass in the forest stand are closely connected to the trees growth and their thickness. Distribution of trees in thickness is the main indicator of forest valuation of forest stand through which all other parameters of forest stand can be estimated [17]. In this paper, modeling of components of biological productivity of forest stands are made using techniques borrowed from the literature [16, 17, 22, 24].

Based on data of the latest forest inventory in Poland, and taking into account data on areas covered with forests, reserves and stem wood in forests of Subcarpathian Voivodeship by forest-forming species (pine, spruce, fir, other conifers, beech, oak, hornbeam, birch, alder, poplar, aspen and other deciduous), age groups, and corresponding mathematical models of fixed components of plants phytomass, the total phytomass of forest was estimated (with division on species as well as age groups of forest-forming species) by formula:

$$M_{j,v} = M_{j,d,100^{-1}} \sum_{i=1}^{n} P_{j,i} * k_{j,i}\,, \qquad (2)$$

where: $M_{j,v}$ is the gross wood value of the j-th forest-forming species, which includes supply of industrial wood, green wood stock, and stock of underground biomass; $M_{j,d,100^{-1}}$ is 1% of the stock of commercial timber of the j-th species; $P_{j,i}$ is the percentage of trees of the i-th grade age in gross wood stock of the j-th species; $k_{j,i}$ is the factor which reflect the above-ground and underground part for the i-th age class, and $k_{j,i} = k_{dz,j,i} + k_{r,j,i}$; $k_{dz,j,i}$ is the coefficient, that reflect a part of green wood for the i-th class of age; $k_{r,j,i}$ is the coefficient, that reflect the proportion of underground part of wood in the i-th grade age; n is the number of classes of age in stands (in this case 7 age classes and forest KO, KDO, BP).

The total wood value of each province is calculated as:

$$M_w = \sum_{j=1}^{m} M_{j,v}\,, \qquad (3)$$

where: n is the number of major forest forming tree species, that are taken into account in determining stock of biomass (pine, spruce, fir, other conifers, beech, oak, hornbeam, birch, alder, poplar, aspen and other deciduous).

The data of forest inventory in Poland include information across all provinces about the area covered by forest, species composition, age structure, and reserves of timber. Moreover, these reserves of commercial timber in Poland includes the stem wood in the cortex (including firewood), and thick branches, suitable for firewood [11, 12]. To calculate the forest biomass, it must be also taken into account the stock of thin twigs, leaves, pine needles, so-called green wood, and underground parts of the tree or vine. The amount of green wood depends on the conditions of growth, breed, age, quality of locality, and other factors [9, 21]. In the literature [9, 16, 17, 20-24], the methods of calculation of the amount of woody green depend on other forest valuation parameters (diameter at breast height, the height, stock, breed, age, etc.).

IPCC Guidelines [7, 18] recommend the universal coefficients for calculation of woody green forests. However, these coefficients and estimation algorithms are fairly common and universal for different regions of the world, and eventually they do not take into account the specific characteristics of these regions. The proposed emission and absorption factors vary sometimes in a very wide range. Therefore, the task of refining and applying coefficients, specific to particular areas, is very useful.

Table 1. Above-ground biomass of forests (recommended by IPCC)

Type of forest	Overground biomass (tons of dry matter per ha)
Deciduous forests aged > 20 years	200
Deciduous forests aged ≤ 20 years	15
Coniferous forests aged > 20 years	150-200
Coniferous forests aged ≤ 20 years	25-30

Table 2. The ratio of underground biomass to aboveground biomass (R)

Aboveground biomass	R [roots, tons of dry matter / branches, tons of dry matter]
Overground biomass of conifers <50 t / ha	0,40 (0,21 - 1,06)
Overground biomass of conifers 50-150 t /ha	0,29 (0,24 - 0,50)
Overground biomass of conifers > 150 t /ha	0,20 (0,12 - 0,49)
Overground biomass of deciduous < 75 t /ha	0,46 (0,12 - 0,93)
Overground biomass of deciduous 75-150 t /ha	0,23 (0,13 - 0,37)
Overground biomass of deciduous >150 t / ha	0,24 (0,17 - 0,44)

Recommended by IPCC Guidelines, the coefficients of stock biomass for different types of forests in Europe are presented in Table 1. Table 2 contains the coefficients to calculate the mass of underground biomass particles [7,18]. These coefficients are used for the first level of inventory, they are approximate and vary widely.Here the forests are divided only into two age groups: under 20, and over 20 years, and two groups in composition: coniferous and deciduous. Phytomass accumulation in coniferous young growth is faster than in deciduous, and after 20 years slowly. Therefore, for more accurate inventory we can apply smaller division, by class of age, which is commonly used in forestry.

Determination of underground phytomass in forest the IPCC Guidelines propose to estimate by the amount of aboveground phytomass known, guided by a certain ratio (Table 2).Based on these recommendations, and taking into account the results of studies described in the literature [8, 9, 20, 23], the improved coefficients were applied depending on the mass of green wood on the breed, and age of trees (Fig. 13). Constructed trendlines for calculating the coefficients of underground proportion of pine and spruce, demonstrate how they decrease with increasing age class.

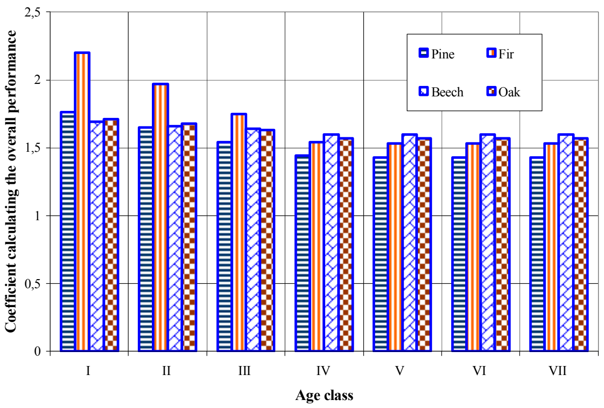

Fig. 13. Total underground and aboveground biomass of illiquid shares from age classes of forest stands

The root system of forest stands is little studied, and therefore various references present the different coefficients to calculate the biomass of the underground part of trees [8, 20, 21, 22, 24], which fluctuate within 14-35%. According to [17] the stock of wet, freshly dug roots, in the 22-year growth of pine is 19.6% of the aerial parts of the stand. The share of moist root system in the total weight of trees decreases with increasing of thickness, while the total weight of aerial parts increases. Thus, if the root system to the power of 12 cm is 19.2% of the total phytomass of trees, the extent 20cm its composition is reduced to 14.1%, at the same time there is a relative increase in phytomass aerial parts of trees from 80.8 to 85 9% [17].

Based on data of the latest forest inventory in Poland, especially data on area covered by forests, and stem wood in forests of Subcarpathian Voivodeship, the amount of total forest phytomass in province was estimated. The main indicators of silvicultural-forest valuation of forest-forming major species (pine, spruce, fir, other conifers, beech, oak, hornbeam, birch, alder, poplar, aspen and other deciduous species), the age groups, and mathematical models for calculation of the main components of phytomass were took into account. Within each forest area the species composition, and age group of forest stands were considered.

MODELING OF ANNUAL GROWTH

In determining the magnitude of growth in the forests of Poland the data of Banku Danych o Lasach [10] were used. This database contains information on the current increase of ten main forest-forming species, depending on the age classes, separately for each voivodeship. Current annual growth of trees of a certain species per unit area depends primarily on biological features the species and can vary by several times. For example, in the first age class the annual growth is 0.36 m^3/ha for hornbeam, 0.70 m^3/ha for oak, 0.80 m^3/ha for beech, 1.28 m^3/ha for pine, 2.73 m^3/ha for birch, and up to 4.66 m^3/ha for alder. At different ages, each species also has a different annual growth, such as pine in the second age class has 9.23 m^3/ha, in the third class has 8.09 m^3/ha, in the fourth class has 6.78 m^3/ha, and in the seventh class has 3.56 m^3/ha. Edaphic, phytopathogenic, and hydrothermal factors, light regime, stand age structure, length of growing season, landscape features and other factors affect the annual growth. Depending from the geographical location of the forests, the impact of separate factors can be different. For example, in Scandinavia the growth of forest stands are more limited by temperature than precipitation, in Poland, Romania and Italy more precipitation than temperature effects on the annual growth of forest stands [18].

Stand composition and age structure in each province were taken into account in calculating the average growth coniferous, deciduous and mixed forests:

$$Z_s = \sum_{l=1}^{L} z_l p_l / 100 , \qquad (4)$$

where: Z_s is the average increase; z_l is the average (taking into consideration age classes) increase of the l-th breed; p_n is the proportion of the l-th species in stand composition (%).

Similarly, the average growth of mixed forests was calculated, on the base of the share of coniferous and deciduous forests in voivodeship stand, i.e.:

$$z_m = \left(z_b p_b + z_c p_c\right)/100, \qquad (5)$$

where: z_m is the average growth of mixed forest; z_b is the growth of deciduous forests; p_b is the share of deciduous forests in forest stand of province (%); z_c is the growth of coniferous forests; p_c is the share of coniferous forests in forest stand of voivodeship (%).

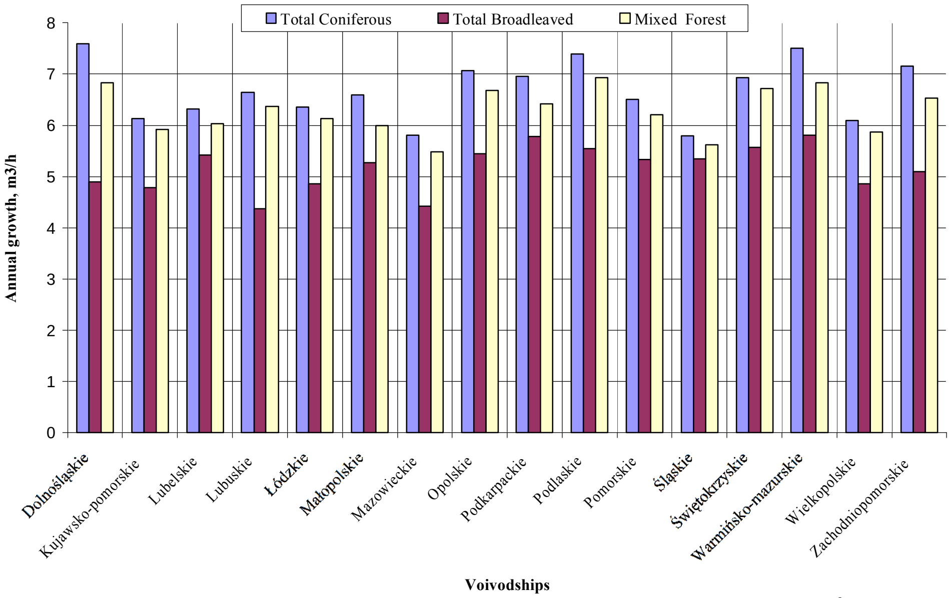

Fig. 14. Specific growth of wood in coniferous, broadleaf and mixed forests in the Polish provinces (m^3/ha)

Table 3. Main indicators of phytomass, and forest carbon deposited in Subcarpathian Voivodeship, 2010

Index	Value	Data unit
Area	17846,66	km^2
Forest	37,2	%
The area covered by forest	663797	ha
The area covered by coniferous forest	374240	ha
The area covered by deciduous forest	289557	ha
Gross industrial wood	194,68	million m^3
The gross volume of business softwood	115,21	million m^3
The gross volume of business hardwood	79,47	million m^3
Number of separate areas of forest on a digital map	2510	units.
The average stock of biomass per 1 hectare of forest	455,14	m^3/ha
The average stock of biomass of coniferous forests per 1 hectare	473,80	m^3/ha
The average stock of biomass of deciduous forests per 1 hectare	435,93	m^3/ha
Average stock of deposited carbon per 1 hectare of forest	115,35	t / ha
Average stock of deposited carbon per 1 hectare of coniferous forests	100,76	t / ha
Average stock of deposited carbon per 1 hectare of deciduous forests	134,22	t / ha
Gross stock of forest biomass	302,12	million m^3
Stock in absolutely dry biomass	153,14	million tons
Stock of deposited carbon in forest biomass	76,57	million tons

The diagram on Fig.14 presents the specific annual growth of coniferous, deciduous and mixed forests in Poland by voivodeship. The diagram shows that the largest annual growths are in coniferous forests of Lower Silesian (7.59 m^3/ha), Warmiano-Masurian (7.5 m^3/ha), and Podlaskie (7.39 m^3/ha) voivodeships. The largest growths of deciduous forests are in Warmian-Masurian (5.8 m^3/ha), and Subcarpathian (5.78 m^3/ha) voivodeship, and for mixed forests in Warmian-Masurian (6.86 m^3/ha) and Podlaskie (6.82 m^3/ha) voivodeship.

Fig. 15 shows the graphs of the current increase of the main forest-forming timber and classes ages. The highest productivity has spruce of II, III and IV classes of age (11.62, 16.42, 11.58 m^3/ha, respectively); fir of II, III classes of age (11.31, 11.38 m^3/ha); pine of II age class (9.23 m^3/ha). Among the hardwoods with the highest annual growth there are: beech of III age class, and poplar of II age class (9.24, 8.71 m^3/ha, respectively). However, due to the small amount of poplar (only 0.22%) within the stands of Subcarpathian Voivodeship, it has little effect on the average growth of

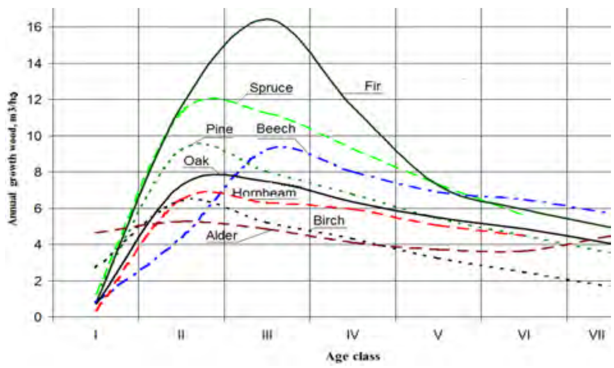

Fig. 15. Dependance of the growth on age classes for the main forest-forming rocks in Subcarpathian Voivodeship

deciduous forest in the province. Pine, beech and fir, which share in the composition of the stands is the largest (35.06, 21.44, 16.43%, respectively) [1, 4-6], have the most significant effect on annual growth.

SPATIAL INVENTORY OF FOREST PHYTOMASS

For the spatial inventory of forest phytomass the territory of voivodeship was divided into square areas 2x2 kilometers in size, and stock phytomass in each such an elementary area has been analised. This task was implemented using GIS technologies. Fig. 16 shows a map of forest of Subcarpathian Voivodeship superimposed on the grid with a size of 2x2 km. Achieved plots with coniferous, deciduous and mixed forests are marked in the same way as at Fig. 2.

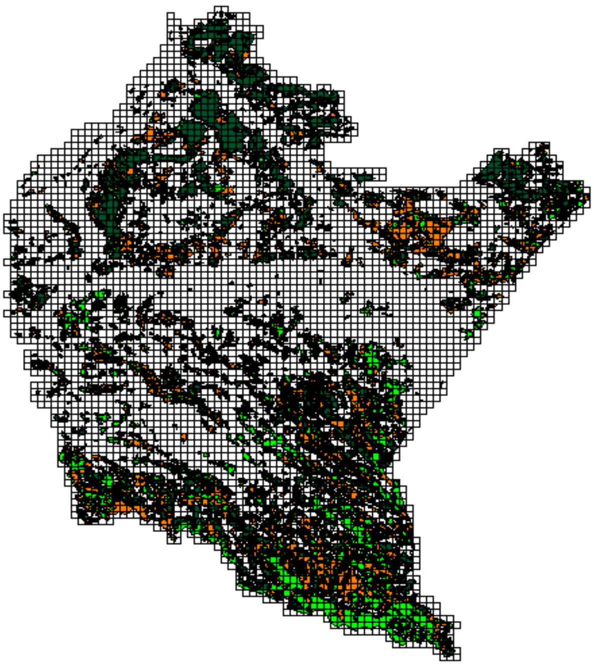

Fig. 16. Forest map of Subcarpathian Voivodeship with superimposed grid

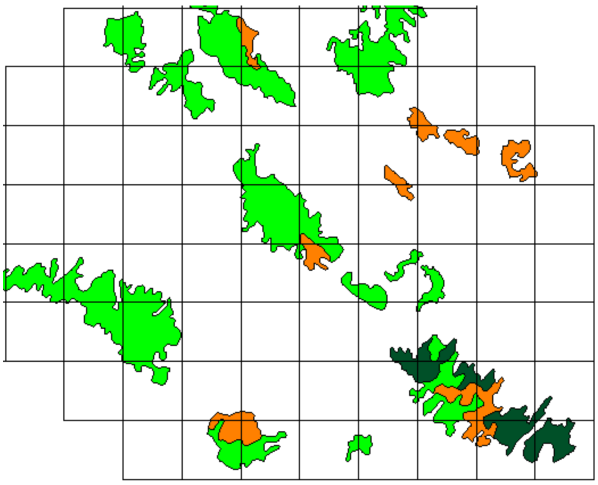

Fig. 17. Fragment of forest map with a net of 2 x 2 km

Table 3 summarizes the data on forests of Subcarpathian Voivodeship. It presents the results of an analysis of the main components of phytomass of forest stands, and evaluation of the deposited carbon.

CONCLUSIONS

Developed geoinformation tool gives a possibility to determine the geodistributed forest phytomass, and to analyse spatially the deposited carbon on the basis of statistical data, species composition, age classes, and other forest valuation indicators. An algorithm for calculation the aboveground and underground phytomass of tree by its stock, taking into account forests of different composition, age, and site conditions, has been created. Improved factors reflecting regional specificity were used for study of phytomass and deposited carbon. Geodistributed database and digital maps of forest vegetation, and map of deposited carbon in Subcarpathian Voivodeship in Poland have been developed.

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