UDK 630*5:528.8

MAPPING OF PINE STANDS ABOVEGROUND BIOMASS USING 10 METER SPOT-5 SATELLITE DATA

D.V. Gilitukha ***PhD student*****[*]*****, P.I. Lakyda, Doctor of Agricultural Sciences, Prof., National University of Life and Environmental Sciences of Ukraine***

This paper presents the results of estimation and methodological approaches for modeling and aboveground biomass mapping using SPOT-5 satellite image (10 meters resolution). In particular, the mathematical models of quantitative indicators aboveground biomass were developed. The algorithm for processing and analysis of satellite imagery for mapping of output data was proposed.

Remote sensing data, SPOT-5 satellite data, above ground biomass, pine stands, vegetative indices, image classification.

On demand of now days there is implementation of new and effective methods such as remote sensing data (RS data) in aboveground biomass (AGB) assessment [1, 2, 7, 10]. This situation is caused by the modern requirements to adaptive forest management, forest protection, biodiversity conservation and mismatch of inventory work to actual changes in forest cover. The RS data is the more practical and cost-effective alternative to terrestrial methods, independent source of growing stocks volume (GSV) and AGB dynamic.

Aim of the study *is* to explore features and develop algorithm of spatial data processing and analyzing for mapping of AGB pine stands using 10 meter SPOT-5 multispectral satellite data.

Data and methods. We employ RS data received from the SPOT-5 sensor for 5 July, 2010 with 10 m spatial resolution. This image covers of the Boyarka forestry enterprise territory. The SPOT-5 data was obtained with «Planet Action» project support, launched in 2007 by Spot Image. [9]. Digital forest map that was

[*] Supervisor - Doctor of Agricultural Sciences, Prof. P.I. Lakyda

created on results of 2008 inventory data and Ukrainian forest inventory database of 2010 were used for selection of experimental parameters.

Primarily, methods for AGB estimating using 10 meter SPOT-5 satellite data were focused on the research of biophysical parameters and spectral characteristics of vegetation canopy. The models for AGB estimating were developed using the correlation relations terrestrial information about stock of AGB and vegetative cover structure [2]. According to the results of previous research [2, 3, 10], stands structure measured, such as stands age and tree height, was based on correlation with the vegetation indices and values of spectral brightness in different wavelengths.

An atmospheric correction of remote sensing data, such as compensation of atmospheric distortions caused by the water vapor and aerosols in the atmosphere provides full potential of satellite imagery and make possible to compare images taken from different acquisition dates and sensors [1].

Primarily, the coefficients of brightness in each spectral band should be converting to at-sensor spectral radiance ($L_{\lambda j}$). Calibration information has been presented in watts per square meter per steradian per micrometer W/(m^2·ster·μm) and is dimensionless and proportional to the number of radiation that falls on the sensor. The following formula for SPOT-5 image was used to calculate $L_{\lambda j}$ value.

$$L_{\lambda,j} = L_j / G + B, \qquad (1)$$

where L_λ – values of each pixel for j image band;

G and B - calibration coefficients that can be obtained from image metadata (PHYSICAL_GAIN and PHYSICAL_BIAS).

The atmospheric correction and conversion to surface reflectance were performed using the COST method by P.S. Chavez algorithm to eliminate the influence of different atmospheric factors [6].

Calculated vegetation indices (VI) characterize the relative estimation of vegetation properties. This data can be interpreted with ground parameters assistance (table 1).

1. Vegetation indices

Vegetation index	Formula for calculating
Normalized Difference Vegetation Index	*NDVI = (RED - NIR) / (RED +NIR)*
Normalized Difference Water Index	*NDWI = (NIR - SWIR) / (NIR + SWIR)*
Modified Normalized Difference Water Index	*MNDWI = (GRN - SWIR) / (GRN +SWIR)*
Normalized Difference Water Index of Mc Feeters or Green Index	*NDWIF = (GRN - NIR) / (GRN +NIR)*

Legend: NIR – spectral reflectance in the near-infrared regions; RED – spectral reflectance in the red regions; GRN – spectral reflectance in the green regions; SVIR – spectral reflectance in the mid-infrared regions.

Estimation of AGB is based on indexes that depend from vegetation period. The most stable meanings of NDVI were detected during maximum of foliate biomass development period. It is at the middle of vegetation period [2]. The models were built based on May images and it means that proper results can be received for the same period. That is why we decided to show spectral brightness of each band or vegetation indexes with the help of relative values (k_{vi}) using following equation:

$$k_{vi} = \frac{x_j - VI_{\min}}{VI_{\min} - VI_{\max}} \quad . \qquad (2)$$

So, we receive more correctly displayed trend of RS data distribution for research object. We could not make clear conclusion about RS data standardization and comparability for any period. Its accuracy depends on the image resolution and absence deciduous trees in pixel class.

The main attention was played to the selection of input research data and getting pixel value from each spectral channel. That procedure was done for homogeneous stands and forest mask of pine stands that was received during unsupervised classification.

Selection of the most characteristic pixel of each stands was carried out by grouping of pixel values for repetition rate and dipazonom ± 5% of stand mean value, assuming that they correspond to the mean forest structural parameters. We used models P. Lakyda for the calculation of the total stock of ABG of pine stands in Ukrainian Polissya region [3].

The software package ENVI 4.3, Statistica 8.0 and ArcGIS 10.1 was used for image processing and data analyzing.

Results. Considering the significant number of research data and a large dispersion of their values for the ABG biomass modeling we used the grouping initial data of their case weights for each stand height and the density parameters within the established classes. The variations of the each indicator did not exceed 15 %.

Significant stage of research work was to define independent variables. They should better describe the experimental data. Correlation analysis was done between AGB components, spectral reflectance characteristics and vegetation index within each pixel for definition of close relations between them (Table 2).

2. The correlation matrix of basic inventory parameters and satellite data analysis

Indicators	Vegetation indices				Basic inventory parameters				
	NIR	*NDWI*	*MNDWI*	*NDVI*	*P*	*D*	*A*	*H*	*M*
NIR	1,00	-	-	-	-	-	-	-	-
NDWI	0,79	1,00	-	-	-	-	-	-	-
MNDWI	0,74	0,62	1,00	-	-	-	-	-	-
NDVI	0,48	0,82	0,15	1,00	-	-	-	-	-
P	0,30	0,38	0,29	0,32	1,00	-	-	-	-
D	-0,80	-0,74	-0,65	-0,50	-0,49	1,00	-	-	-
A	-0,78	-0,75	-0,62	-0,52	-0,52	0,96	1,00	-	-
H	-0,85	-0,73	-0,69	-0,46	-0,42	0,95	0,92	1,00	-
M	-0,83	-0,68	-0,67	-0,41	-0,22	0,89	0,84	0,97	1,00
q_{stem}	-0,81	-0,69	-0,66	-0,42	-0,21	0,89	0,85	0,97	0,99
$q_{foliage}$	-0,33	-0,22	-0,17	-0,11	0,47	0,35	0,24	0,26	0,35
$q_{needles}$	-0,17	-0,08	-0,04	-0,02	0,58	0,18	0,08	0,07	0,18
$q_{branches}$	-0,80	-0,72	-0,62	-0,47	-0,38	0,98	0,91	0,91	0,86
Ph_{stand}	-0,81	-0,69	-0,66	-0,43	-0,21	0,90	0,86	0,97	0,99

Taking into account the significant relationship observed between AGB biomass (Ph_{stand}), components of stem biomass and stand height (*H*, m) (r=0,97); components of branches biomass and stand height (r=0,91). As the following stand height has close correlation with the brightness in the near-infrared spectral range

(*NIR*) (*r*=–0,85) and Modified Normalized Difference Water Index (*MNDWI*) (*r*=–0,73).

If to consider significant RMS error and variation of input parameters, further modeling of biomass individual components is useless.

Correlation beetling H and NIR, MNDWI, NDWI values is used as the basis for stock of AGB modeling because it has lower variation than mean diameter, age and GSV [3, 4].

Distribution of stand height and *NIR* values are characterized by the lowest dispersion and close to the exponential function. Graphic analysis of satellite imagery data distribution and forest parameters was as a basis for the models selection (fig. 1).

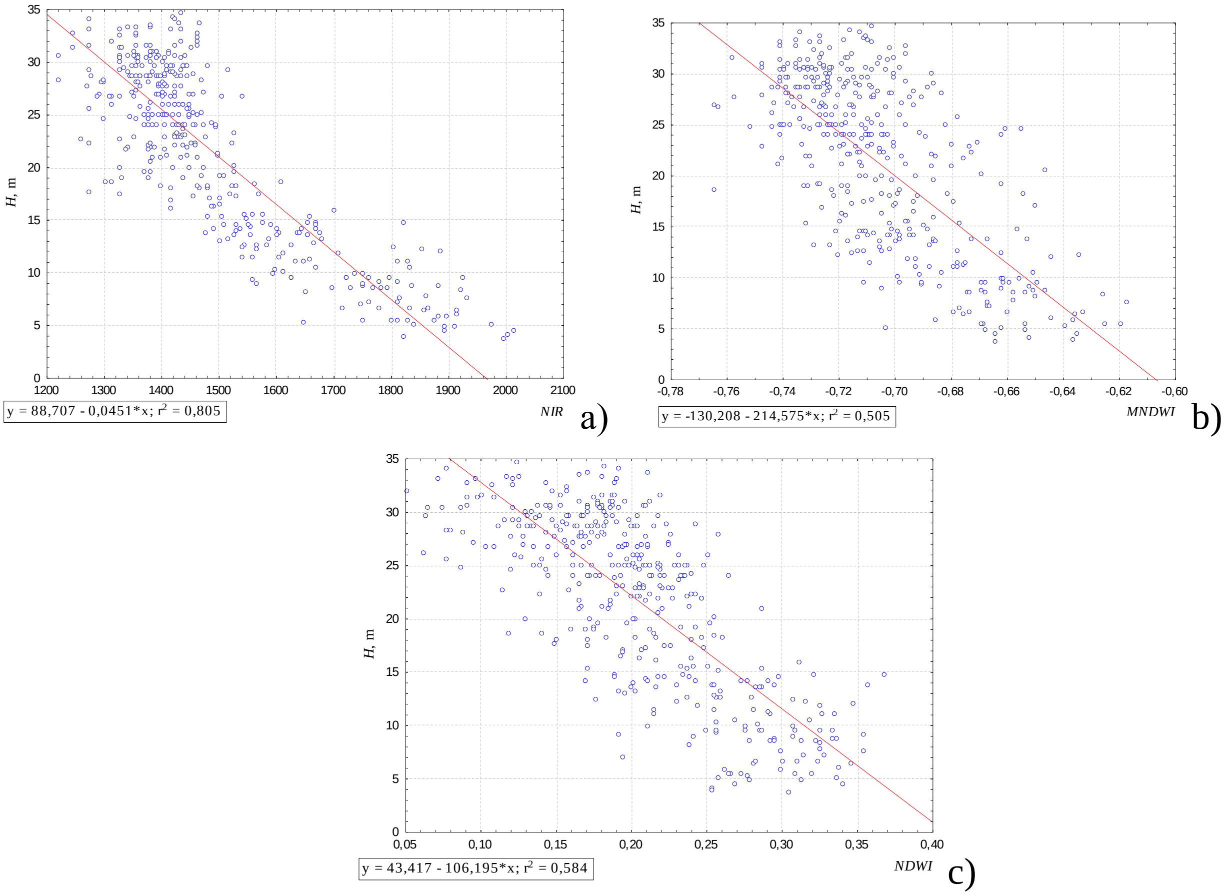

Fig. 1. Distribution of forest inventory parameters and values of vegetation indices (*a – between H and NIR, b – between H and MNDWI, c – between H and NDWI)*

After necessary calculations we got corrected model that describing dependent variable *H*.

$$H_{mod} = 52{,}140 \cdot \exp(-2{,}246 \cdot NIR - 0{,}209 \times NDWI). \quad (3)$$

High determination coefficients of ($R^2 = 0{,}78$) between *H and NIR* were obtained from assessment parametric structure of tropical forests by P. Propastin [10].

Dependence of Ph_{stand} and modeled height adequately is described by the following equation (4), as evidenced $R^2 = 0{,}78$.

$$Ph_{stand} = 21 + 247{,}2 \cdot (1 - \exp(-0{,}101 \cdot (H_{mod} - 4)))^{2{,}696}. \quad (4)$$

The RMS error (σ) of modeled indicators is 17 % (3,5 m) for height stand and 27 % (43 $t \cdot ha^{-1}$) for stock of AGB.

Efficiency equation used in the modeling stock of ABG from stand height was supported by graphical analysis (Fig. 2)

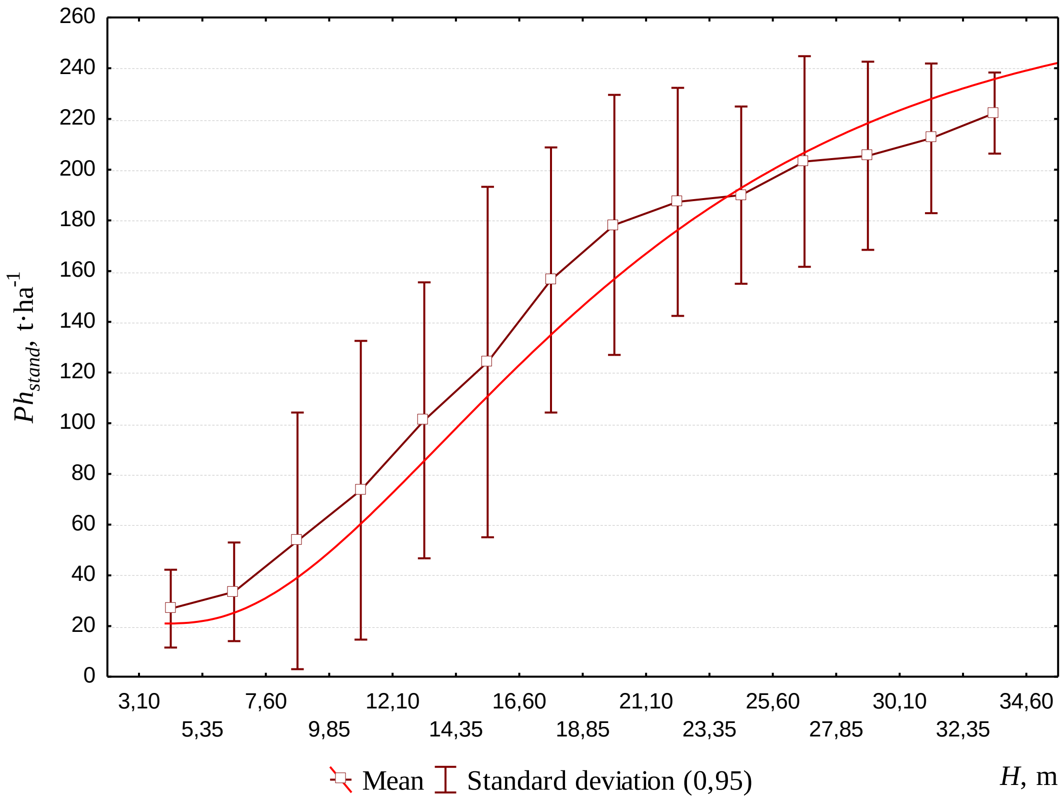

Fig. 2 - Distribution of mean values of aboveground biomass stocks and their deviations

As shown in Fig. 2, distribution of experimental parameters comparison with the modeled is unequal. The model trend line is within standard deviation and mostly close to average values. We should admit that modeled values of stock

AGB are characterized by large variance. Accuracy of assessment becomes lower with increasing of stock AGB. This situation can be associated with unequal of stands spatial structure. It was found that stock of AGB for each pixel (10×10 m resolution) depends on the gaps between trees crowns (crowns density) and phonological stage. In our opinion we should take into account crown closure because this indicator has significantly effect on their spectral brightness. Basing on literature sources, we know that middle-aged stands have tendency of relative stocking approach to density, while the mature and over mature stands have significant difference.

Comparative analysis of foreign studies results (Table 3) shows high estimation accuracy.

3. Analysis of aboveground biomass estimation methods using remote sensing data

The Methodology Author	Name and type of satellite	Spatial resolution	Accuracy of results definition
The methods are based on optical remote sensing data			
Developed of this research	SPOT-5	10 m at enterprise level	43 $t \cdot ha^{-1}$ 2 т· $t \cdot ha^{-1}$
A. Leboeuf, A. Beaudoin et al., 2007 [8]	QuikBird	0,61 m (aggregation to 30)	18 $t \cdot ha^{-1}$
R.J. Hall, R.S. Skakun et al., 2006 [7]	Landsat ETM+	30 m	53 $t \cdot ha^{-1}$
Xiaoyang Zhang, Shobha Kondragunta, 2006 [14]	MODIS (products: LAI, VSF and LandCover	1000 m at regional level	40 $t \cdot ha^{-1}$ 21 т $t \cdot ha^{-1}$
The methods are based on radar data (SAR)			
Svein Solberg, Rasmus Astrup et al., 2010 [12]	ALS (air-born laser) X-band	1,4 m	9-7 $t \cdot ha^{-1}$
Maurizio Santoro, Anatoly Shvidenko, Ian McCallum et al., 2006 [11]	ERS-1/2 C-band	25 m	45-75 $m^3 \cdot ha^{-1}$
Oliver Cartus, Maurizio Santoro, Josef Kellndorfer, 2013 [1]	ALOS PALSAR L-band	aggregation to 30 m 150 m aggregation to 1000 m at regional level	80 $t \cdot ha^{-1}$ 40 $t \cdot ha^{-1}$ 25 $t \cdot ha^{-1}$ 13 $t \cdot ha^{-1}$

Spatial interpretation of stock AGB deviation that calculated for RS data and P.I. Lakyda methodology is presented on Fig. 3 [3]. The ABG estimation was conducted at the level of one pixel (10x10 meters) for classified pine stands and was grouped for an individual stand by average value.

After compere analyzing was found that deviations of experimental and modeled data are more than 60 $t \cdot ha^{-1}$. This can be explained by heterogeneity of forest structure. However deviation of stands that have stock of AGB less than 250 $t \cdot ha^{-1}$ and modal RS 0,70-0,85 does not exceed 40 $t \cdot ha^{-1}$.

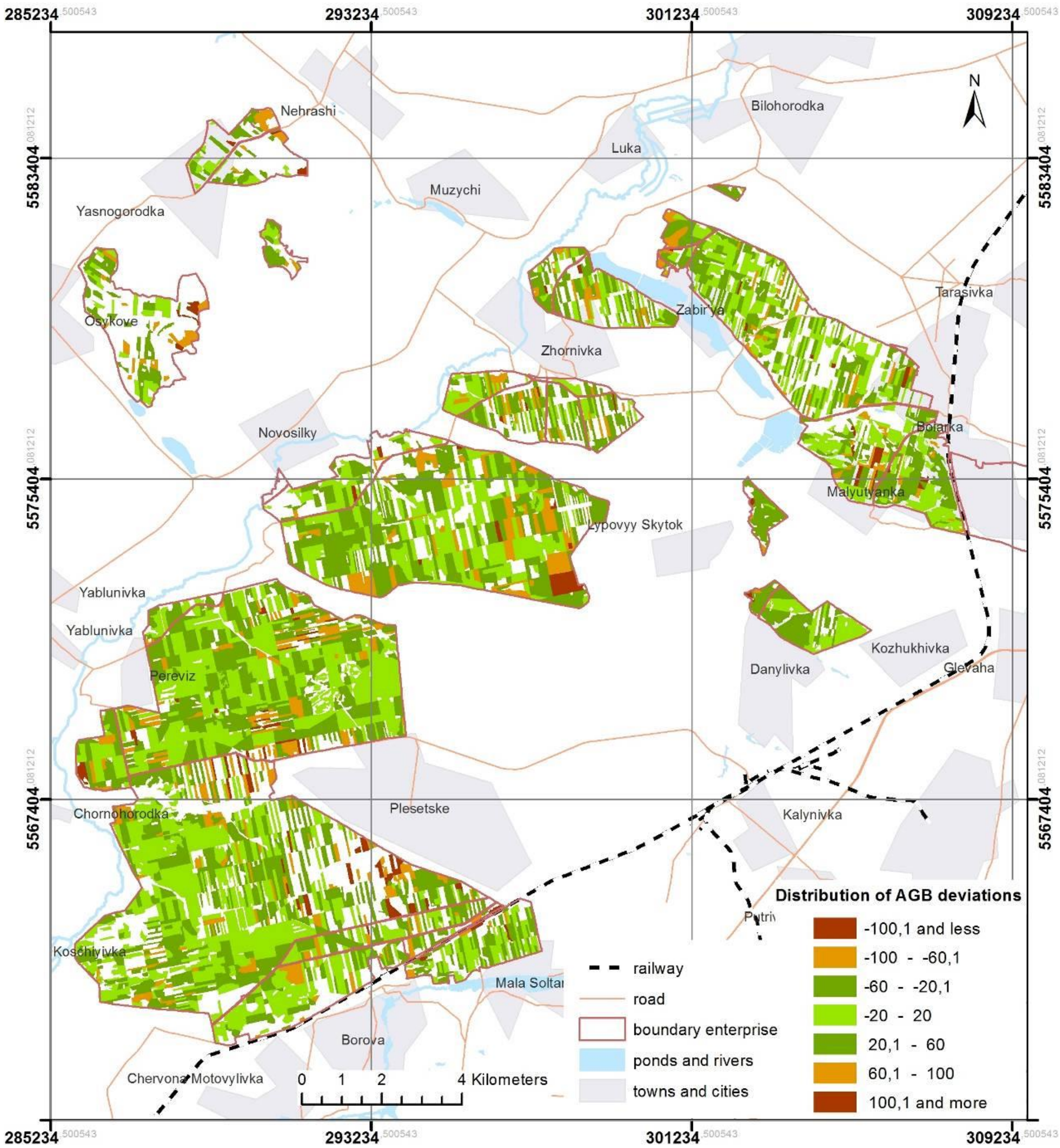

Fig. 3 - Spatial distribution of AGB models deviations

As show on the Fig. 3 estimation of AGB on a pixel level can lead to incorrect results. In this case AGB mapping should be based on average values for groups of similar pixels (i.e. segmented image). It should be noted that similar approach was used by R.J. Hall [7] and international project methodology of European biomass potential estimates– CEUBIOM [13]. Results of segmentation do not necessarily imitate traditional stands borders, but it is important to allocate part of stand with similar spatial structure and inventory parameters. Mean values of vegetation indices and spectral values that calculated for each segments will reduce variance and avoid significant errors that are characteristic for AGB estimated per pixel.

Conclusions

1. Methods of AGB mapping that were used in our work are based on reseregression analysis of pine stands spectral characteristics at different wavelengths, surface structure of vegetation cover and stands inventory parameters.

2. Results of processing and spatial information analyzing are contributes to sufficiently accurate models compared with foreign research, estimation stock of AGB and sands mensuration improvement.

3. Accuracy of AGB estimation using SPOT-5 image are significantly depends on stand structure and vegetation season. Segmentation of RS data was proposed for improvement quality of pine stands ABG mapping and identification of stand part with similar parameters.

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