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RELATIONSHIP BETWEEN MENSURATION AND DECODING INDICES OF PINE STANDS OF I AND IA BONITET

The article provides a brief analysis data of remote sensing and advanced software for processing, a brief review of the basic regularities and relationships between mensuration and deciphering characteristics of forest stand. The technique of performance of works to lay mensuration and deciphering stratum and forest inventory, the relationship between mensuration characteristics and indicators of forest canopy in pure pine stands of I and Ia growth classes is investigated.

Introduction. During the past decade, modern digital methods and technologies of information processing have been actively developing in the forestry management of Belarus. In the Republican unitary enterprise "Belgosles" a digital photogrammetric station Photomod and modern smallware are implemented to process the remote sensed data, such as ENVI, ScanEx, ERDAS IMAGINE and others. In such a way, digital technologies have been replacing processing of old-fashioned aerial and satellite photography using simple equipment and visual analysis.

The implementation of geo-information systems and digital photogrammetric stations opens up new opportunities for mensuration decoding, and the use of stand formation regularities and relationship between mensuration and decoding indices allows to determine the main mensuration characteristics of forest stands.

Satellite images are used in the process of forest management, the share of satellite photography made 5% in 2011 and 10% in 2012. In the present time digital materials of aerial and satellite photography find ever-growing use in forest monitoring, estimation of forest health and changes caused by human economic activities and inclement weather conditions, that's why it's necessary to work out new methods of interpretation of digital images.

On the 22nd of July, 2012, a Belarusian remote sensing satellite was launched. It can help to provide the industries of the Republic of Belarus with satellite photo-data that can be used to complete tasks of urban planning, geodesy, land management, agriculture and forestry management. In this regard it's a vital task to work out new methods of numerical and qualitative evaluation of forestry data along with estimation of forest changes.

The goal of this work is to investigate relationships between mensuration characteristics and indicators of forest canopy in pure pine on the high-resolution digital satellite images with use of dedicated software and technologies of geo-information systems (GIS).

Main part. During estimation of stands using methods of measurement interpretation of aerial and satellite images it's possible to obtain only a part of stands canopy indicators. That's the reason why in 1924 a question of a relation between crown sizes that can be seen on the images and other indices that can't be seen, such as breast height diameter, arose. At a later stage the researches were conducted in order to determine the relations not only between crown diameter Dc and breast height diameter db, but also between crown diameter, tree height and crown length. Researches showed that crown diameter to the fullest extent is related to breast height diameter (correlation coefficient 0.7–0.9). Relation between crown diameter, tree height and crown length is somewhat below (correlation coefficient 0.5–0.6) [1].

There is not only simple relationship between mensuration and decoding indices of forest stand and canopy, but also multiple relationships, for example between breast height diameter, height and density db = f(h, D), or between breast height diameter, height, crown diameter, crown density and bonitet db = f(h, D_c, D_c, bonitet), which are simulated with help of different correlation equations or have a form of graphs, nomographs, tables, including these of growth course updated by decoding indicators (h, D_c, D_c, lc, h_{Dc}, h_{Cc}) [2].

I.M. Danilin has equaled relationships between db, h и D of forest stands of some forest-forming species of Siberia [2]. The equation of relationship for a pine of II bonitet looks like:

$$d_m = 4.791 + 0.749\,h + \\ + 0.022\,h_m^2 - 4.616D - 1.353D^2, \qquad (1)$$

where h – tree height, m; h_m – forest stand mean height, m; D – stand density.

On the basis of crown diameters that were measured on the images and correlation equations it's possible to determine breast height diameter, height and length of crowns, and other characteristics.

Investigation of canopy regularities helps to learn the forest nature better. Crown shape, size and length have a real impact on trees growth and development. That's why the investigation of regularities of crown and canopy structure, along with characteristics of their images, will allow to determine mope precisely all the mensuration indices during the interpretation of images.

Among the scientists who investigated regularities and relationships between mensuration and

decoding indices of forest stands there were G.G. Samoylovich, I.D. Dmitriev, V.I. Sukhih, I.M. Danilin, N.I. Baranov, A.S. Ageenko, I.T. Trunov and others.

Pine stands of Baranovichsky, Byhovsky, Ivatsevichsky, Smolevichsky forestry stations of I and Ia bonitet, where 56 circular plots were established in 22 measurement plots using GPS receiver Garmin 60C, were taken as the objects of research. Digital colour satellite images, made in 2007 from Quickbird space satellite, with resolution 0.6 m, made in red, green and infra-red ranges (RNIRG) were used to conduct measuring interpretation.

Mensuration characteristics in the plots were determined according to the data of random enumeration measurement by laying out circular plots (CP) of constant radius. The number of circular plots of constant radius that is necessary to determine mensuration characteristics depended on density and area of the plot. Radius in different plots varied from 9.8 to 17.8 m, according to stand density and mean diameter.

During the mensuration of CP of constant radius a systematic sampling was used. Within the boundaries of survey plot CPs were laid out on an evenly-spaced diagonal pattern. The CP center coordinates were determined with the help of GPS-receiver Garmin 60C. The boundaries of CP were established with help of ultrasonic height-range finder VERTEX IV. Complete enumeration with diameters measurement was carried out in the boundaries of CP in two directions (North-South, West-East) using metal caliper graduated in 1 mm. During the complete enumeration the trees were divided into opened, partially closed and closed according to participation in canopy-forming.

Tree height, tree height till crown's maximum diameter and tree height till crown ending were measured with the help of ultrasonic height-range finder VERTEX IV at the five closest to the center trees. Crown diameter was measured in biaxial-oriented directions (1 – the largest crown diameter, 2 – perpendicular to it), besides, crown density and shape were classified according to G.G. Samoylovich.

Measurement methods, worked out for digital images with the use of specific software and geo-informational systems (ENVI and Quantum Gis), were applied during the decoding of pine stands' satellite images [3, 4].

Mathematics and statistics methods were used for the obtained data processing.

The models of relationship between tree diameter, stand mean diameter and other mensuration indices for bonitet I and Ia were made according to the data, obtained in the program Statgraphics when analyzing multiple regression parameters.

The analysis of measurement data of stand and its canopy was conducted firstly for bonitet I and Ia. The difference between the obtained equals wasn't significant, that's why further the data were combined.

The relationships between trunk diameter and mensuration characteristics, such as tree height, stand mean height, age, crown diameter, stand density, crown density, total basal area etc. were investigated. Consequently excluding not significant variables according to Student's t-test (Table 1), a following multiple regressions equal was obtained:

$$d_m = 3.74950D_c + 0.70263h - 0.00604N. \quad (2)$$

Table 1

Values of independent Student's t-test variables for-calculation a treediameter

parametres	*t*-Student's
D_c	16.7699
h	15.8916
N	–7.37411

There is a graphical model of relationship between trunk diameter, tree height and stand density according to the equal (2) on the Fig. 1.

Coefficient of determination (R2) makes 98.59%; standard square error of equal (Se) – 2.9171; Fisher's F-score – 6492.09.

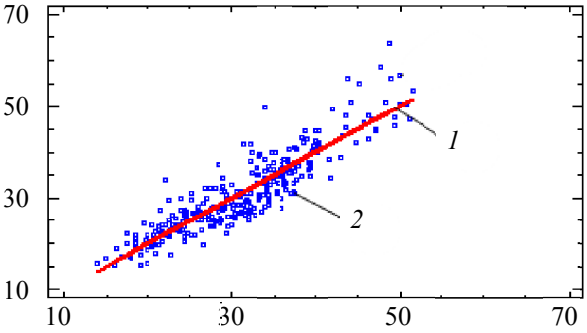

Fig. 1. Calculated (1) and measured (2) values of tree diameters

During the investigation of relationship between stand mean diameter and stand canopy (table 2), the best results were demonstrated by the following function:

$$D_{\text{m}} = -6.52007\, D_{\text{cm}} + 0.923253\, D_{\text{cm}}^2 + 5.29728\, L_{\text{tree}} + 27.3359\, P_{\text{s}}^2, \quad (3)$$

where D_{m} – is a stand mean diameter, cm; D_{cm} – is a mean crown diameter of canopy, m; L_{tree} – mean distance between trees, m; P_{s} – density of canopy.

Table 2

Values of independent Student's t-test variables for calculation a tree medium diameter

parameters	*t*-Student's
D_{cm}	–18.0861
D_{cm}^2	17.8456
L_{tree}	46.5218
P_{s}	24.4315

The determination coefficient (R2) makes 99.90%; standard square error of equal (Se) makes 0.7619; Fisher's F-score makes 68624.21.

There is a model of relationship between stand mean diameter, crown mean diameter, mean distance between trees and canopy density according to the formula (3) in Fig. 2.

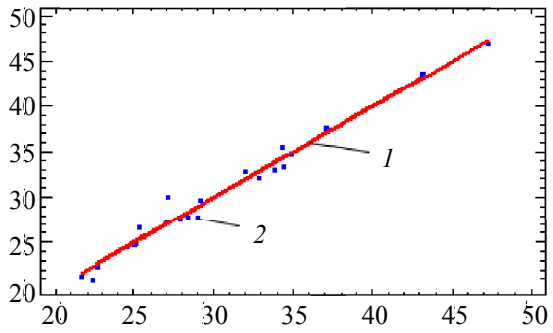

Fig. 2. Calculated (*1*) and measured (*2*) values of tree diameters

Conclusion. The results of researches correspond with the results of other authors' investigations of relationship between mensuration indices of forest stand and its canopy.

The tightest relationship is observed between diameters of definite trees, crown diameters, height and density, which is confirmed by high determination coefficient (98.59%), and between stand mean diameter, crown mean diameter, mean distance between trees and canopy density (the determination coefficient makes 99.90%).

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