Validation of vegetation type modeling at a local level using a moisture scale

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Abstract. This article shows a possibility of calculating types of vegetation cover according to climatic data and local landscape parameters. The variety of growing conditions of different relief forms is accounted for on the basis of a method of hydro-climatic calculations combined with moisture values of the L.G. Ramensky scale.

1. Introduction
In the study of plant communities it has long been noticed that vegetation is very sensitive to changes in the environmental factors. The determination of ecological amplitudes and optima for natural plant populations is extremely time-consuming [1]. During the transition from one equilibrium state to another, one must be able to predict possible changes in the vegetation cover as the primary source of food energy for humans.

In 1938, L.G. Ramensky [2], within the framework of applied geobotanical studies of hayfields and pastures, proposed a classification of locations depending on the influencing factors. He also developed a classification of habitats (a site with an inherent set of ecological regimes) in two grades: the degree and nature of moistening, as well as the chemistry of the soil (expressed as the richness of nutrients in a form that is accessible to plants, salinity) [2].

At present the following ecological scales are used to assess the ecological characteristics of plant habitats:

a) Amplitude ecological indicator values (scales) of L.G. Ramensky (Cy - moisture varies from 1 to 120);
b) Amplitude ecological indicator values (scales) of D.N. Tsyganov [3] contain 23 steps of moistening;
c) Targeted ecological indicator values of E. Landolt [4]. They were developed for plants of the flora of Switzerland and contain 5 steps of moistening;
d) Targeted ecological indicator values of H. Ellenberg [5] were developed for Central Europe and contain 15 steps of moistening.

Ecological scales allow performing ordination analysis of the position of plant communities on the axes of environmental factors. Such environmental ordination is used to confirm the ecological identity in determining the classification status of plant communities [6].

Ecological scales are used exclusively by botanists. In explicit form they are not suitable for modeling the dynamics of the hydrologic-climatic regime, that is, for water-balance studies on basic climatic and landscape characteristics.

We managed to solve this problem. We combined Cy - moisture by L.G. Ramensky [2] with the method of hydrological-climatic calculations (HCC method) of V.S. Mezentsev [7].

2. Methods
In accordance with the HCC method [7, 8], the evapotranspiration $Z$ is determined by the water equivalent of the evapotranspiration energy resources $Z_M$, the total watering of the active surface $H$
representing the sum of corrected precipitation $X$ and the soil water content change ($W_1 - W_2$) within the active layer during the calculation period, as well as the dimensionless parameters $n$ and $r$:

$$Z = Z_M \cdot \left[1 + \beta_H^{-rn}\right]^{-1/n}, \quad \text{where} \quad \beta_H = \frac{H}{Z_M} = \frac{X + W_1 - W_2}{Z_M}. \quad (1)$$

In the model, the water-physical properties of the soil are taken into account by the parameter $r$. It depends on the specific surface $S_0$ and the bulk weight $\rho$ of the active layer of the soil:

$$r = 1 + 0.01 \cdot S_0 \cdot \rho. \quad (2)$$

In these equations the parameter of landscape conditions $n$ includes the geomorphological conditions of runoff formation and reflects the ability of the active layer of the landscape to discharge excessive water through gravitation [8]:

$$n = 1.1 + \frac{W_T}{6.1}, \quad (3)$$

where $W_T$ is the wetness index determined in the SAGA (http://www.saga-gis.org) program or similar.

To take into account the local features, one should use the formula from [9]:

$$n = 2.5 + 0.22 \cdot \ln \frac{L_S}{\sqrt{i}}. \quad (4)$$

where $L_S$ is the slope length in km normalized to the distance between the contours equal to 10 m; and $i$ is the mean gradient of the slope between the contours, m/m.

To determine the most likely type of vegetation, it is necessary to understand that if a particular set of plant species flourishes, this indicates the existence of the necessary environmental conditions and the formation of appropriate soils. This is why the degree of moistening of the active evaporating soil layer is in complete harmony with the heat-energy resources.

It was shown above that the most informative quantitative characteristic of the plant component of ecosystems is $C_Y$ - moisture amplitude ecological indicator values (scales) of L.G. Ramensky. $C_Y$ - moisture can be associated with the soil (parameter $r$) and geomorphological (parameter $n$) components of the system through the relative humidity of the capillary rupture (as a fraction of the lowest moisture capacity of the soil) used in the HCC method [7]. The parameter $V_{PK}$ reflects the availability of moisture to plants and also, in conjunction with the plant nutrition conditions, determines the composition and structure of the vegetation cover.

To take into account the discrepancy between the real conditions and optimal conditions, a correction factor – a factor of humidifying ($\beta_H$) – is introduced, which over a long period is determined by the ratio of the corrected precipitation $X$ to the water equivalent of the evapotranspiration energy resources $Z_M$. According to the above, we managed to calculate $C_Y$ - moisture peculiar to a specific habitat [10]:

$$C_Y = 100 \cdot \beta_H \cdot V_{PK} = 100 \cdot \beta_H \cdot \left(\frac{r - 1}{r \cdot n + 1}\right)^{1/m}. \quad (5)$$

Flat landscapes are characterized by closed depressions in which the humidification will be substantially higher than in the catchment area. To take into account this local specificity, it is necessary to take into account the inflow of water into the central part of the depression from the catchment area:

$$\beta_{HLD} = \beta_H + \delta \cdot Y, \quad (6)$$

where $Y$ is the average long-term climatic runoff from the catchment basin, and $\delta$, the coefficient of lateral inflow, is determined from the ratio of the central part of the depression to the catchment area. Detailed investigations of the hydrological regime of closed depressions of the study area are presented in [11].
3. Results
The vegetation cover of the South Taiga was studied by us from 2011 to 2015. Application of the model to territories with closed depressions and centers of mire formation revealed a connection between the variety of forms and the size of depressions and their moistening regime. Table 1 presents $C_y$ - moisture values obtained by processing of the results of field botanical descriptions and modeled by the above method. For flat-bottomed valleys – centers of mire formation – the local conditions are most important, since this significantly improves the accuracy of modeling.

Table 1. Hydrological and environmental conditions in the central part of any type of depressions.

| Type of depressions | Coefficient $\delta$ | Parameter $r$ | Parameter $n$ | $C_y$ - moisture according to model calculations |
|---------------------|---------------------|---------------|---------------|-----------------------------------------------|
|                     |                     |               |               | without regard for local conditions           | taking into account inflow (Eq. (5)) | according to botanical descriptions |
| cone-shaped          | 0.03-0.06           | 2 - 2.4       | 2.8 ≤         | 74-78                                        | 71-81                                | 71-83                          |
| intermediate         | 0.06-0.125          | 2.4 - 2.8     | 2.8 - 3.2     | 78-83                                        | 81-89                                | 79-88                          |
| flat-bottomed        | 0.125-0.33          | 2.8 - 3.5     | >3.2          | 83-87                                        | 89-95                                | 85-93                          |

Determination of the type of vegetation cover by $C_y$ - moisture is possible according to Figure 1. To accurately determine the vegetation cover type, it is necessary to take into account the soil fertility-salinization.

In the central part of flat-bottomed valleys at the initial stages of swamping shrubby willow communities with sedges-marsh cinquefoils dominate. The same result is obtained with modeling taking into account the local conditions. Based on the simulation results without taking into account...
the local conditions, there must be *birch forests with sedges*, which contradicts the data of field studies.

The vegetation cover can be used as an indicator of significant ecosystem changes. The biocenotic mechanism of adaptation of ecosystems to external influences is manifested in the spatio-temporal dynamics of the vegetation cover.

In large flat-bottomed closed depressions, the most stable hydrological regime is observed. Such a regime promotes waterlogging and forms monotonous plant communities (shrubby willow communities with sedge-marsh cinquefoils, $Cy = 87-91$). In the cone-shaped depressions (bird-cherries communities, $Cy 68-82$), the most contrasting moistening regime is formed. Such a regime does not allow the formation of any specific type of vegetation. The most stable are the plant communities of wetlands (shrubby willow communities with sedge-marsh cinquefoils). The least stable are aspen and birch forests with mixed herbs and bird-cherries communities.

![Figure 2. The possible range of variability of $Cy$ (a) on the ideal peatland profile (b).](image)

![Figure 3. Long-term variability $\beta_H$ (Tomsk, Russia).](image)

Ecosystems in natural conditions are in a state of dynamic equilibrium of real-energy exchange. Such an exchange is well described by the $\beta_H$ - factor of humidifying of the period under study.

Calculations according to formula 4 show (Figure 2) that a possible structure of plant communities (characterized by $Cy$) can vary significantly. This is especially noticeable in the ecotones. The cause of significant fluctuations of $Cy$ - moisture is the variability $\beta_H$ - factor of humidifying. In reality, for a complete change of plant communities a long-term unidirectional change in the humidifying factor is needed. Judging by Figure 3, climatic preconditions for such changes are not observed.

The same conclusions were obtained in [12], where the absence of a significant climatic trend factor of humidifying was revealed. That is why in the south of Western Siberia shifts in the boundaries of vegetation zones to the expected 40-50 km have not yet been recorded.

4. Conclusions

The above-proposed model for calculating types of vegetation cover is very promising, especially for long-term forecasting in order to develop recommendations for rational use of plant resources. For example, by using predicted climatic values of temperature and precipitation or parameters of the
transformed natural conditions \((n \text{ and } r)\), we can calculate the moisture level \((C_y)\) and determine the corresponding type of the plant communities that will prevail under the changing conditions. To more accurately determine the type of vegetation cover, it is necessary to develop an algorithm for calculating the soil fertility-salinization.

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