

***Field and remote sensing research in the
development of mathematical models for predicting
and managing mountain-forest-steppe landscapes***

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Интеграционный проект №4
**«Информационные технологии, математические
модели и методы мониторинга и
управления экосистемами в условиях
стационарного, мобильного и
дистанционного наблюдения»**

Integration Project № 4
**“Information technology, mathematical models and
methods for monitoring and management of
ecosystems in stationary, mobile and remote
observations”**

Виноградов Б.В., Черкашин А.К., Горнов А.Ю., Кулик К.Н.
Динамический мониторинг деградации и восстановления пастбищ
Черных земель Калмыкии//Проблемы освоения пустынь.-1990, № 1,
С.10-19.

Vinogradov B.V.; Cherkashin A.K., Gornov A.Yu., Kulik K.N. Dynamic
monitoring of degradation and restoration of pastures in the Black Lands
of Kalmykia // Probl-Desert-Dev. New York, N.Y. : Allerton Press. 1990,
N1, p. 7-14.

Pasture and climate degradation



Natural and artificial restoration

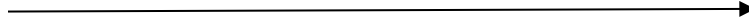


Stages of pasture degradation

Pasture and climate degradation



Natural and artificial restoration



Stages of pasture degradation

The model describes the dynamic process of desertification - the transition of land area from one state to another state in condition of the degradation of pastures and natural recovery:

$$\begin{cases} \dot{s}_1 = -\alpha_1^0 s_1 + \alpha_2 s_2 + v_2 + v_3 + v_4 \\ \dot{s}_2 = \alpha_1^0 s_1 - \alpha_2^0 s_2 + \alpha_3 s_3 - \alpha_2 s_2 - v_2 \\ \dot{s}_3 = \alpha_2^0 s_2 - \alpha_3^0 s_3 + \alpha_4 s_4 - \alpha_3 s_3 - v_3 \\ \dot{s}_4 = \alpha_3^0 s_3 - \alpha_4 s_4 - v_4 \end{cases}$$

where $s_i(t)$ - the amount of land being in the moment t on the i

-th stage of degradation (nondestroyed, little destroyed ets) in % of total area,

216000 ha, $(\alpha_i^0, \alpha_i) = (\alpha_i^0, \alpha_i) (s_1, s_2, s_3, s_4, v_2, v_3, v_4, N_b)$

- the coefficients of the intensity of the degradation of pastures and its recovery,

v_2, v_3, v_4 - control values, the rate of phytomelioration annual events to restore the land at time t (% pa),

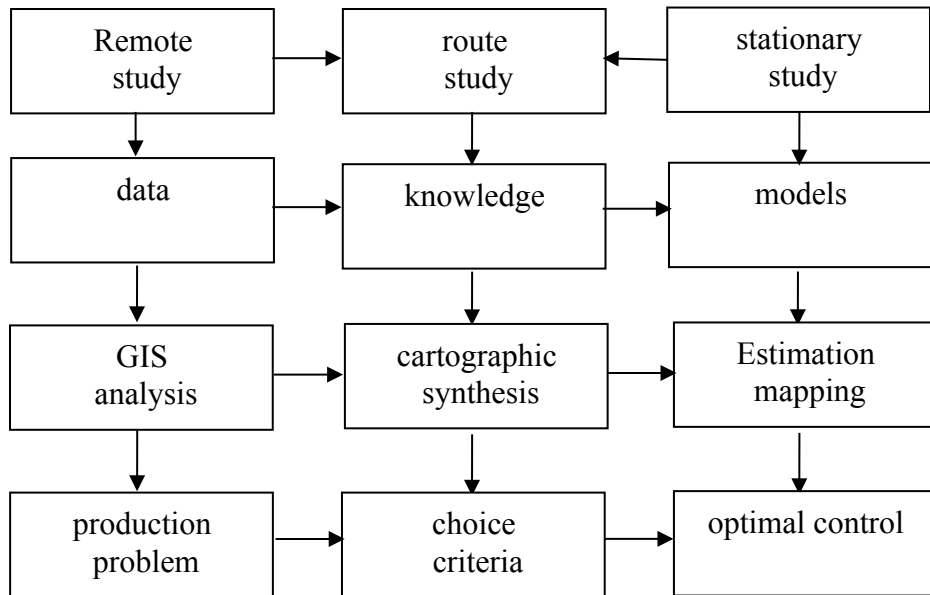
- pasture load.

N_b The task management function is the balance of the profits from sheep farming and costs on the restoration of land:

$$I(u) = \int_0^{20} \left[a \cdot N_b(t) - \sum_{i=2}^4 b_i v_i(t) \right] dt$$

“Information technology, mathematical models and methods for monitoring and management of ecosystems in stationary, mobile and remote observations”

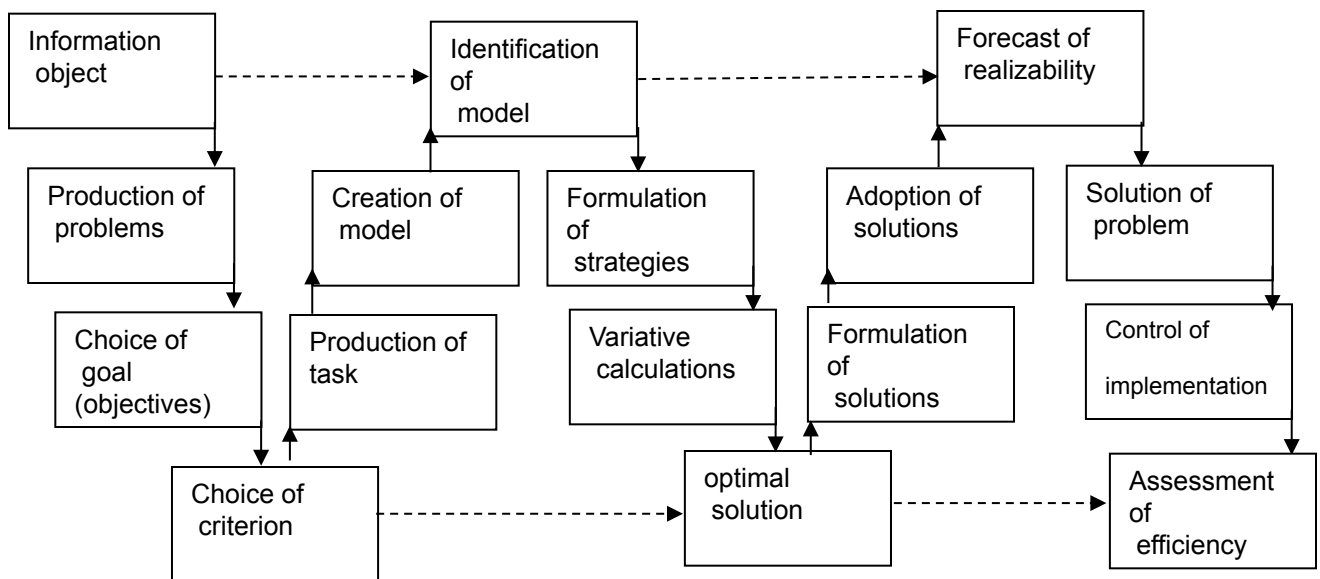
scheme of studies



Research Objectives

- The development of GIS assessment of model plots in territory;***
- The creation and identification of a mathematical model of the transformation of mountain forest steppe landscapes influenced by anthropogenic factors and climate change.***

Periodic system of systems analysis procedures



Stages of Systems Analysis: Choosing the best solutions at different stages

*Stages of
Systems
Analysis*

objects

problems

Objectives

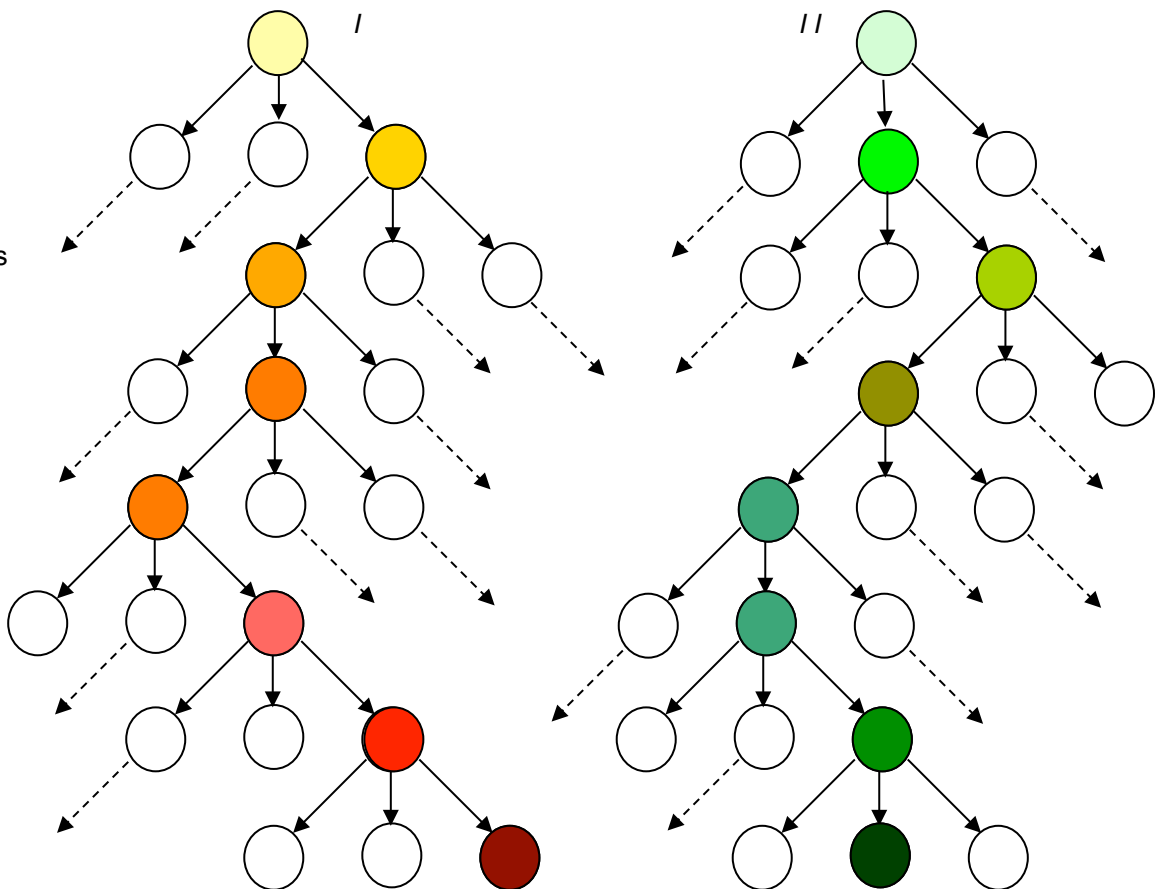
Criteria

Tasks

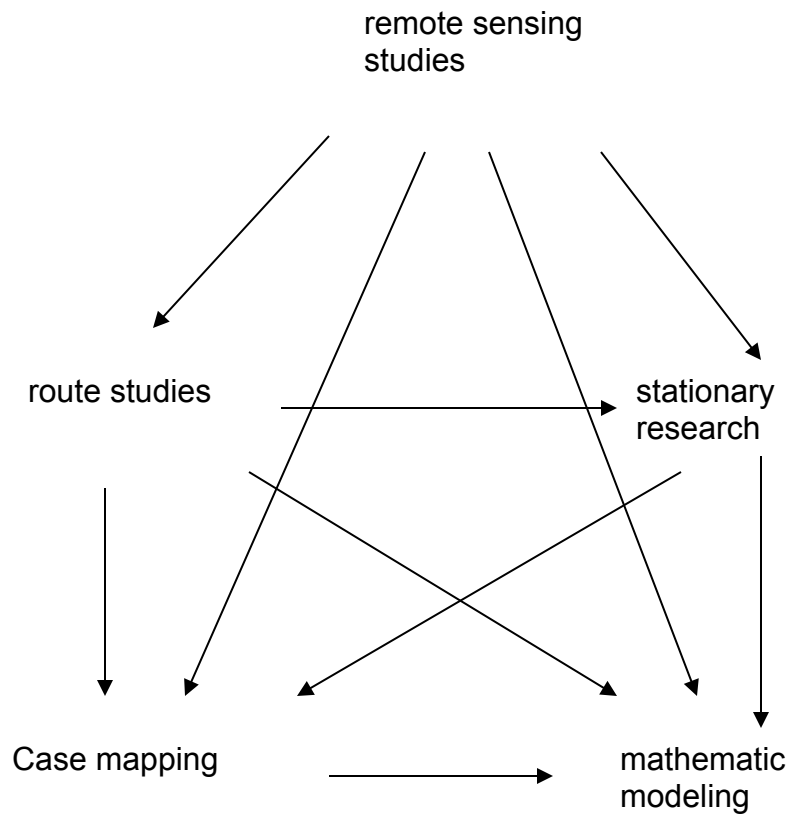
models

metods

Solutions



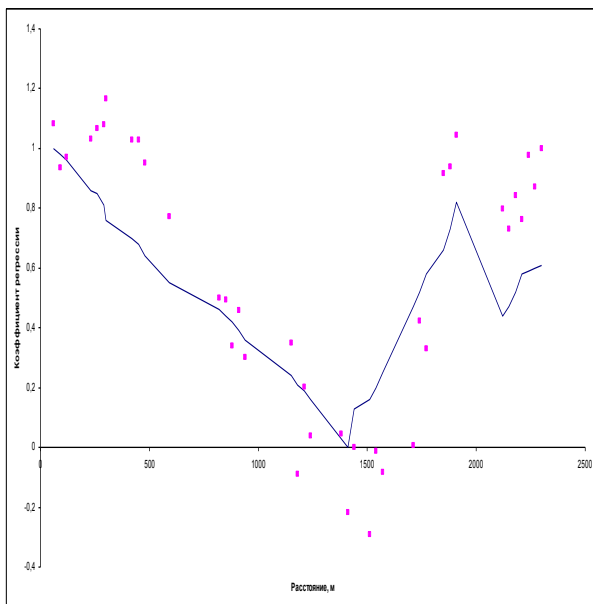
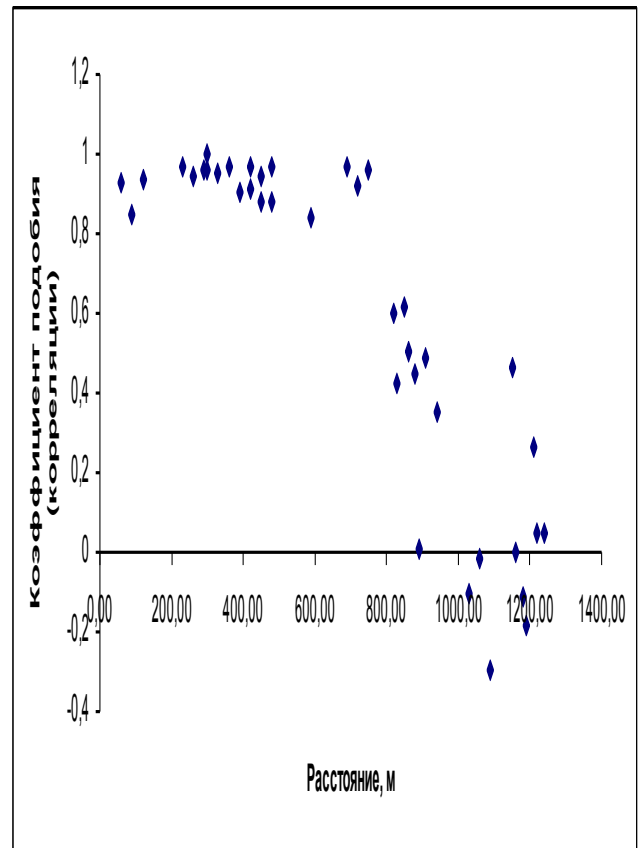
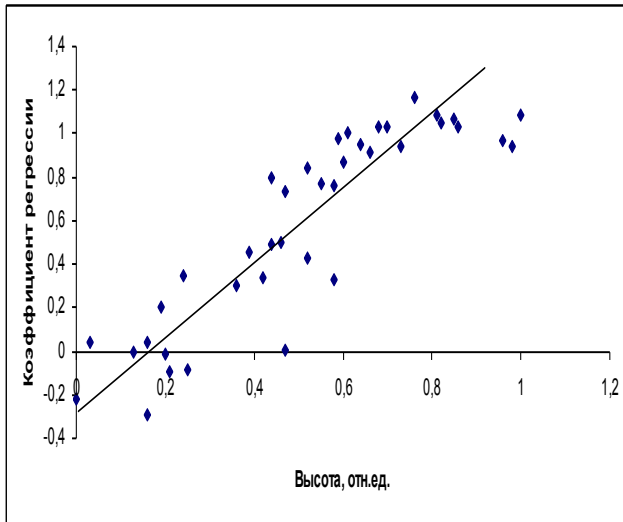
Commutative diagram of flows of information

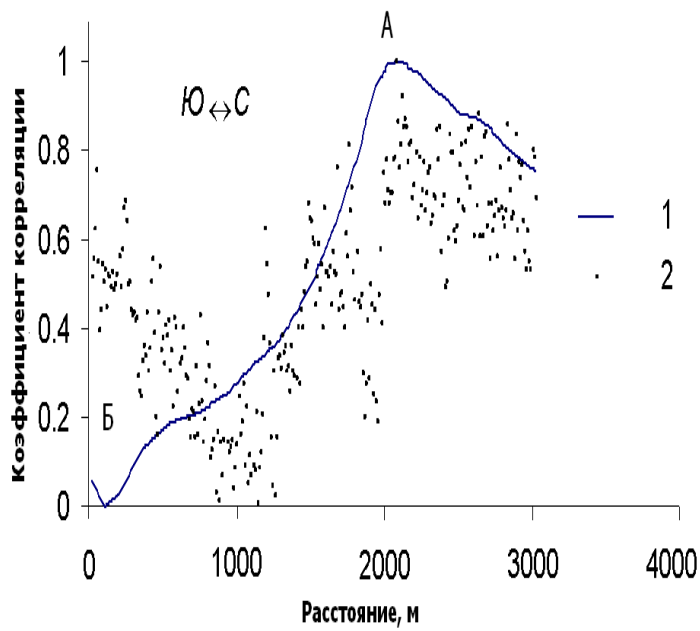


At satellite imagery interpretation and compilation of landscape map for the study area were used:

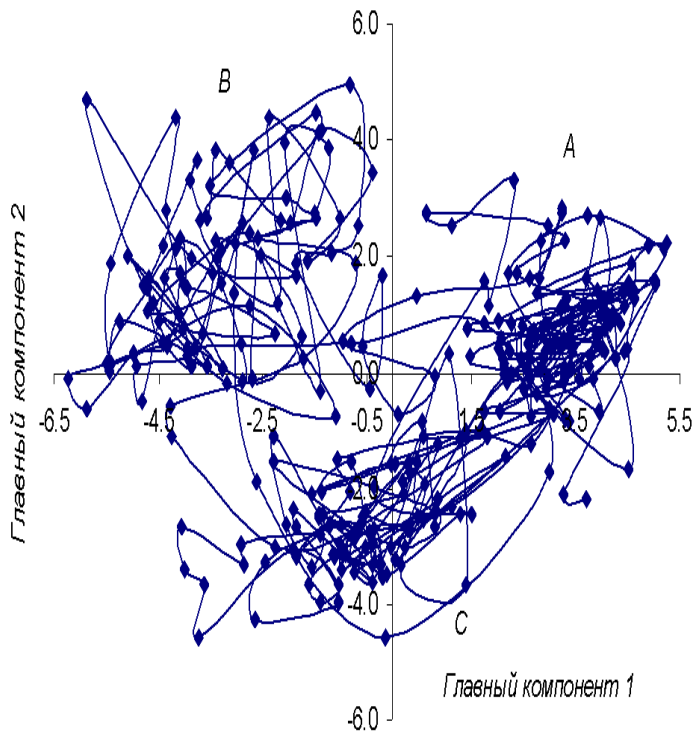
- *топографическая карта территории М 1: 100 000,*
- *цифровая модель рельефа,*
- *космические снимки Landsat за разные сезоны и годы,*
- *материалы советско-монгольской комплексной экспедиции 1970-1973 гг.*
- *тематические карты мелкого масштаба: растительности, кормовых угодий, почв, ландшафтов*
- *материалы собственных маршрутных исследований 2008-10 гг.*
- *материалы стационарных исследований Института 1970-2008 гг.*

Relationship of coefficients of similarity for set of characteristics of geosystems with the height According to Angara taiga transect data





Соответствие изменений относительной высоты (1) и коэффициента корреляции (2) связи БГЦ для Южного Прибайкалья. А, В – высотные зоны. Compliance of changes of the relative heights (1) and the correlation coefficient (2) for BGC links for the Southern Baikal region. A, B - altitude zone.



BGC location in space of the first and second eigenvectors. The points correspond to the BGC, the line - their sequence on the transect. BGC Group: A – at watershed, B - the slopes, C – low part of slopes.



Маршрутные исследования в прибре



Территориальное сочетание гольцовых, горно-таежных и гор







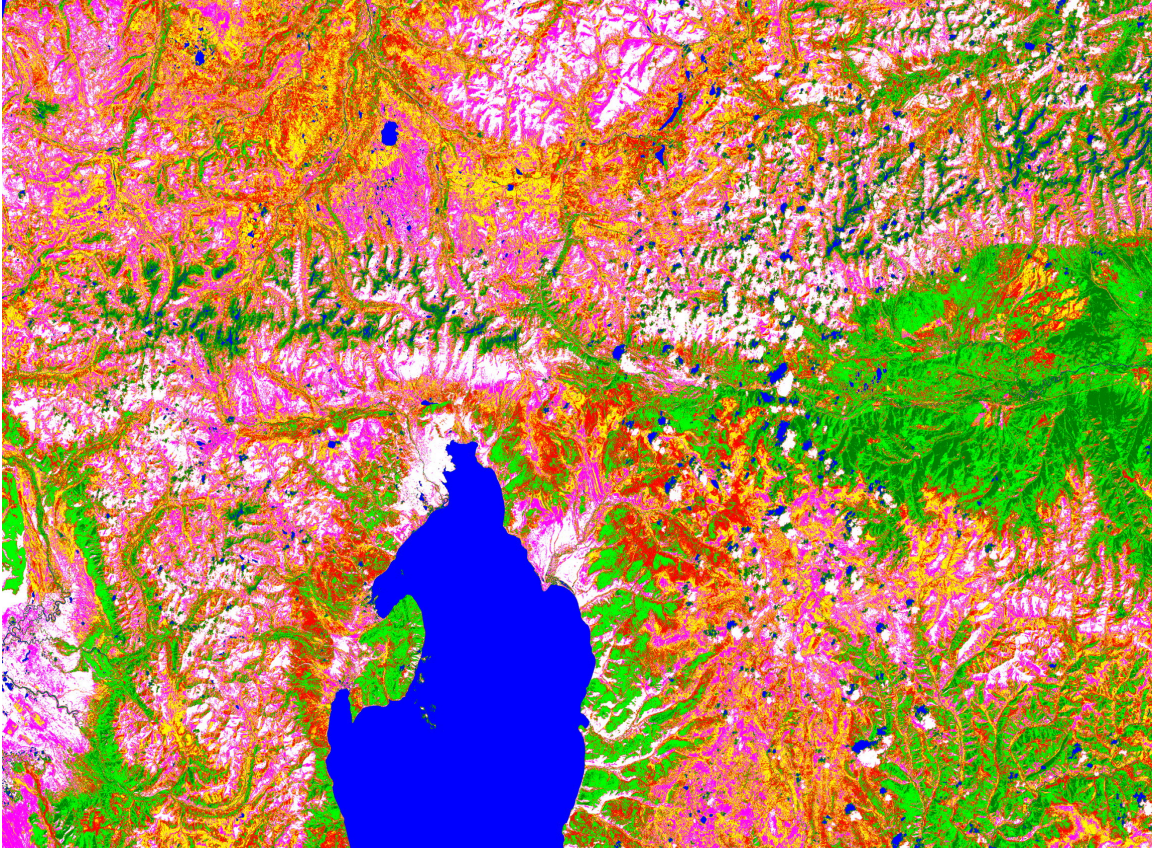


Рубка лесов и нарушение почвенного



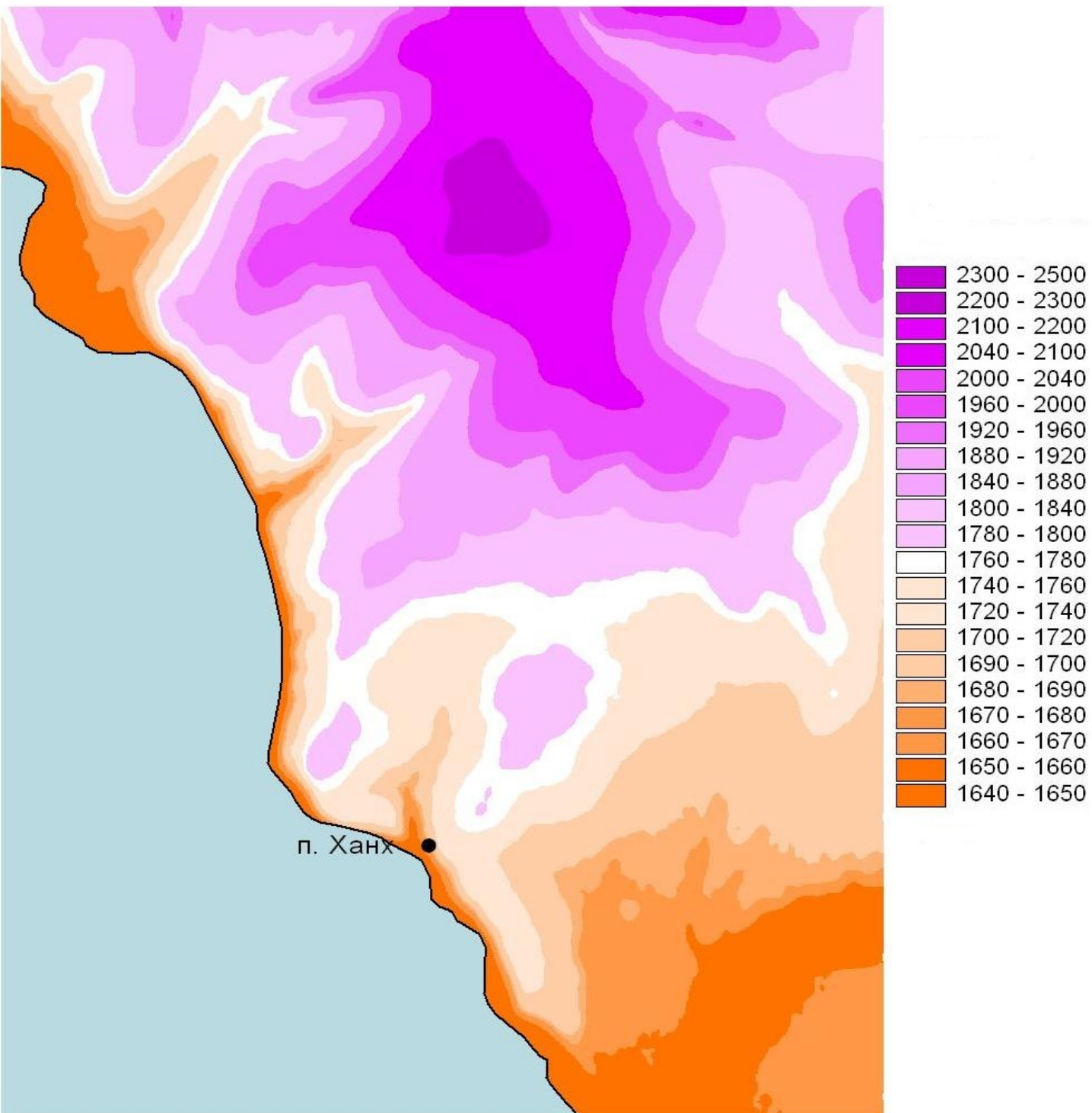
Мертвопокровн

Remote data

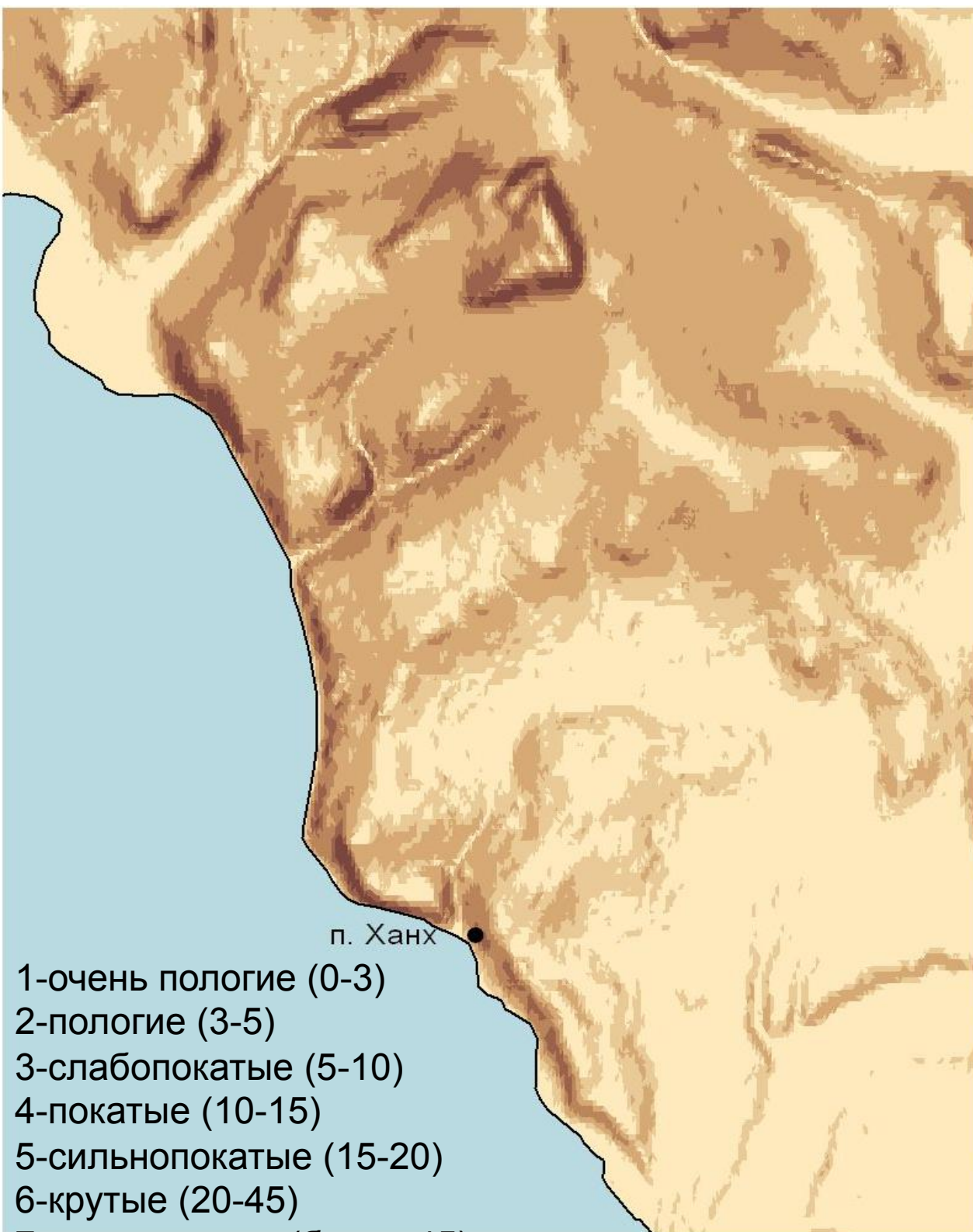


The northern part of the lake
Hovsgol (Mongolia)
with surrounding areas

height distribution



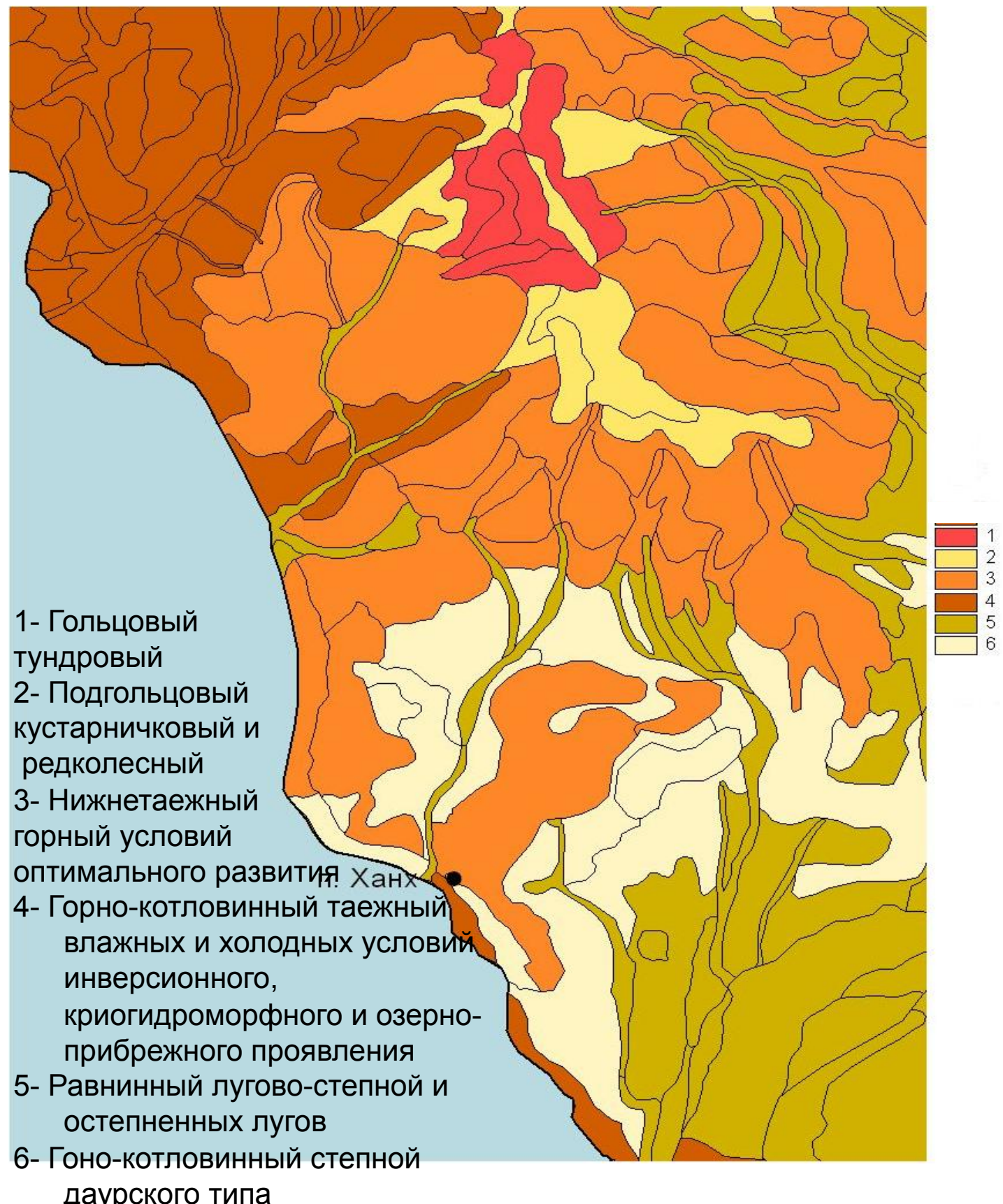
steepness of the slopes



Determination of boundaries of homogeneous plots (Landsat, dotted border, isolated by the method of calculating the Jacobian determinant)

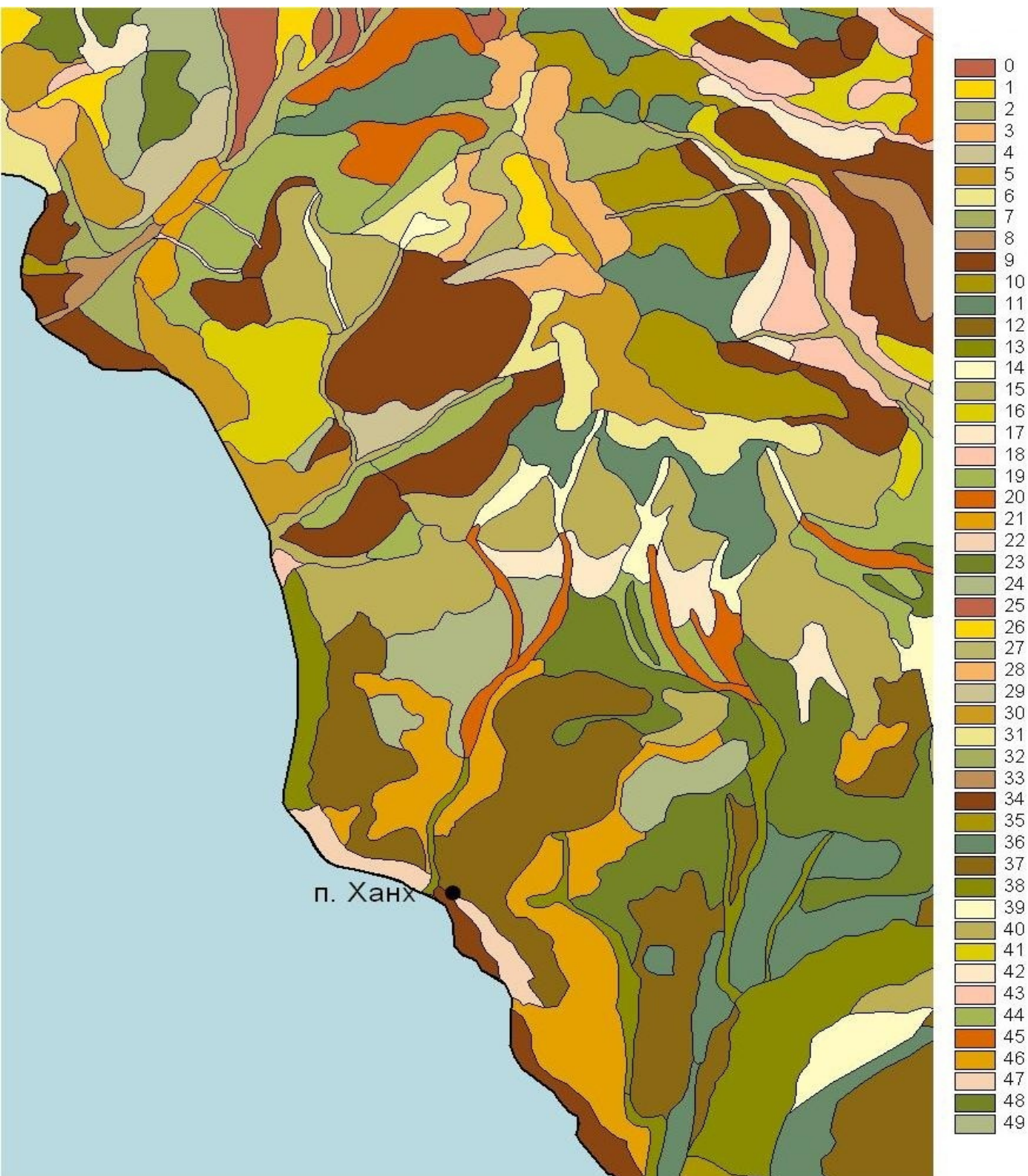


Geoms



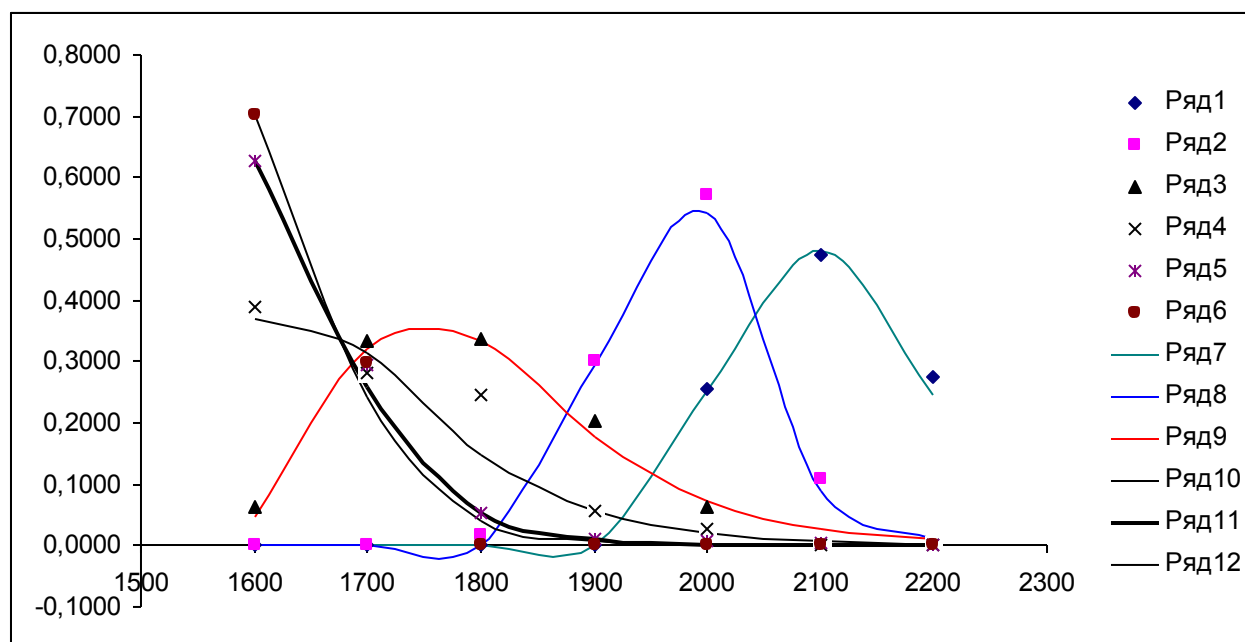
Landscape map of the key area

M:1:50 000

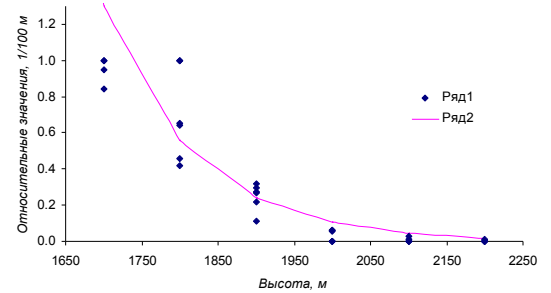
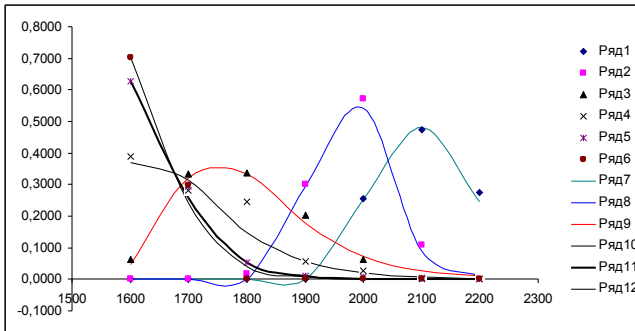


Main characteristics of the distributions of Geom area at altitudinal gradient

i	Геом	ρ_i	x_{mi}	p_{mi}	β_i
1	<i>Гольцовый тундровый</i>	0.021	2080	0.49	-0.0122
2	<i>Подгольцовый</i>	0.041	1953	0.79	-0.0215
3	<i>Нижнетаежный горных условий оптимального развития</i>	0.337	1750	0.37	-0.0101
4	<i>Нижнетаежный горно-котловинный условий редуцированного развития</i>	0.199	1630	0.39	-0.0106
5	<i>Североазиатский степной</i>	0.280	1600	0.62	-0.0171
6	<i>Центральноазиатский степной</i>	0.122	1600	0.70	-0.0191



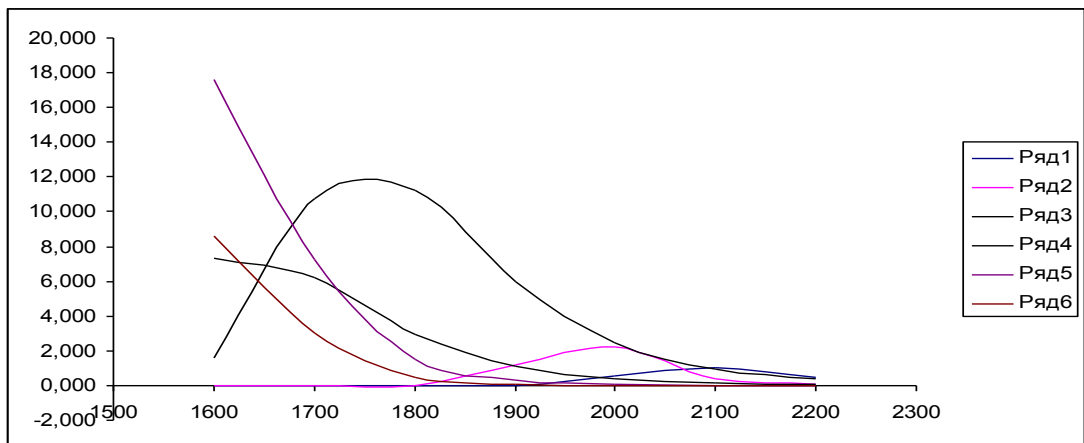
The distribution of Geom area on height



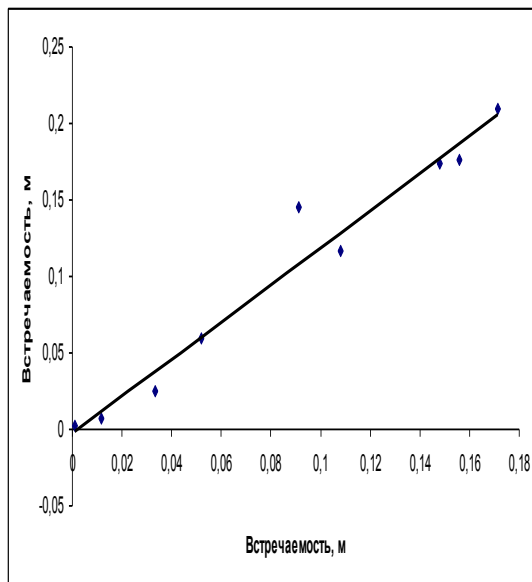
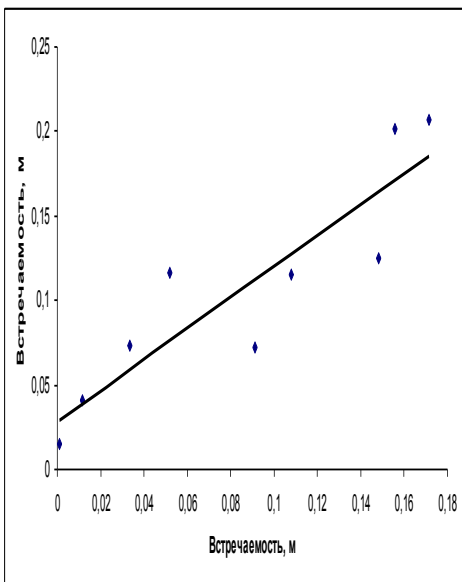
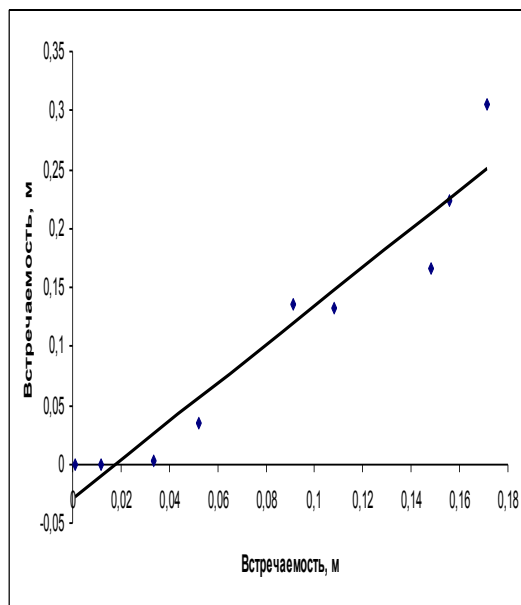
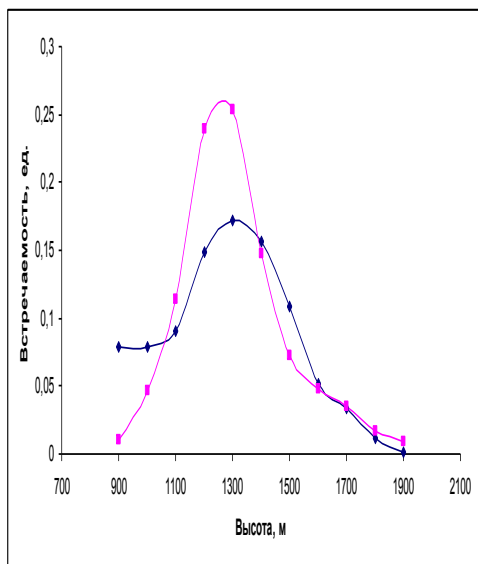
$$\frac{p_i(x)}{p_{mi}} = e \exp(-\beta_i(x - x_{mi})) \exp[-\exp(-\beta_i(x - x_{mi}))]$$

$$\frac{P_i(x)}{p_{mi}} = \exp[-\exp(-\beta_i(x - x_{mi}))]$$

$$a_i(x) = e \exp(-\beta_i(x - x_{mi}))$$



linear relationship of different distributions of geom on occurrence taking into account the displacement of the modal values (coincidence of modes).



Substantiation of the mathematical model of the dynamics of the ecosystems in logarithmic terms of the existence of unrealized potential

$$E(x) = -\ln P(x) = -\ln P(x + x_0)$$

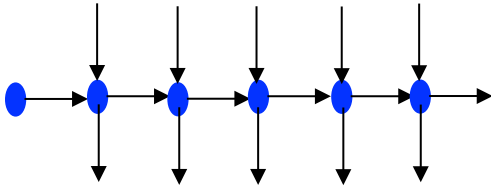
$$\frac{P(x)}{P_{m1}} = \frac{P(x + x_0)}{P_{m2}} \quad P_j(x) = \int_0^x p_j(\xi) d\xi$$

$$\frac{\Delta E(x)}{\Delta x} = a[E(x + \Delta x) - E(x)] = 0, \quad a = 1 / \Delta x$$

Balance the equation for the potential values

$$\frac{\partial E(t, x)}{\partial t} + v \frac{\partial E(t, x)}{\partial x} = 0$$

Flow models - Continuity equation

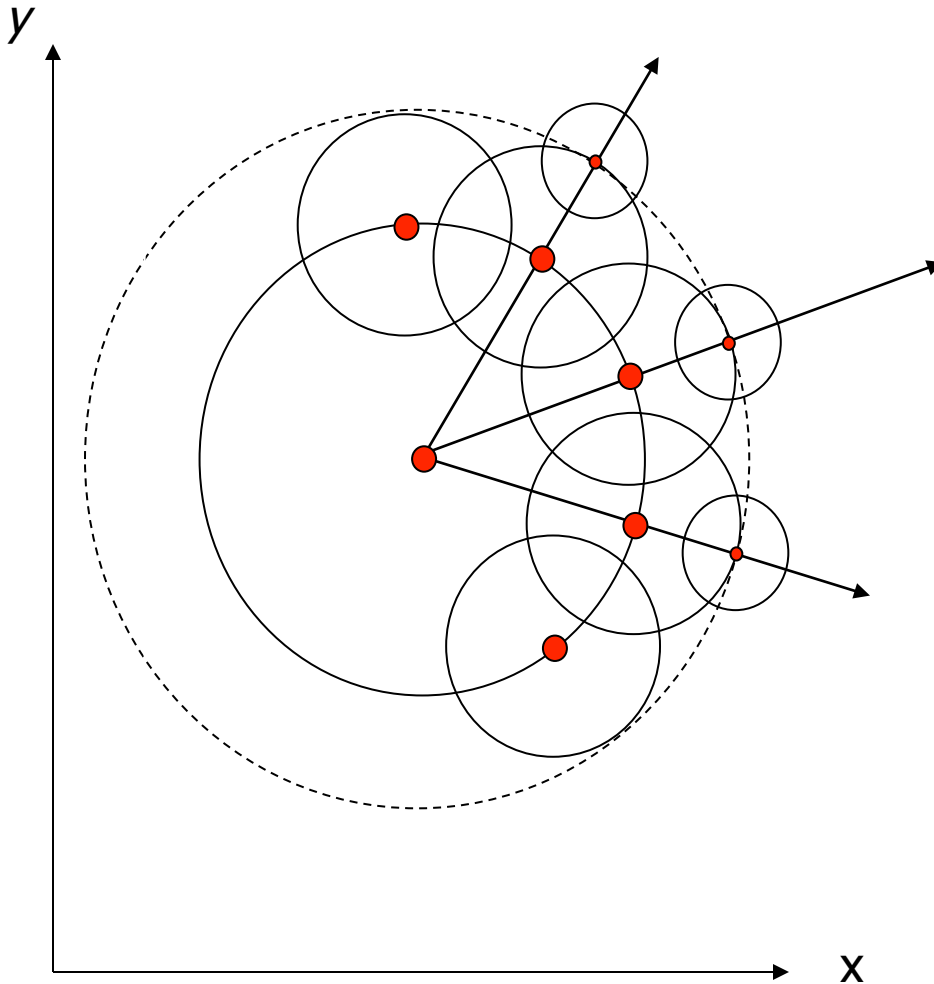


$$\frac{\partial z}{\partial t} + \operatorname{div} \vec{v} z = 0,$$

$$\operatorname{div} \vec{v} z = z \operatorname{div} \vec{v} + \vec{v} \operatorname{grad} z = z \frac{\partial v_x}{\partial x} + z \frac{\partial v_y}{\partial y} + v_x \frac{\partial z}{\partial x} + v_y \frac{\partial z}{\partial y}$$

$$v_x \frac{\partial z}{\partial x} + v_y \frac{\partial z}{\partial y} = K z(x, y)$$

Distribution of wave fronts (analog of Huygens law)

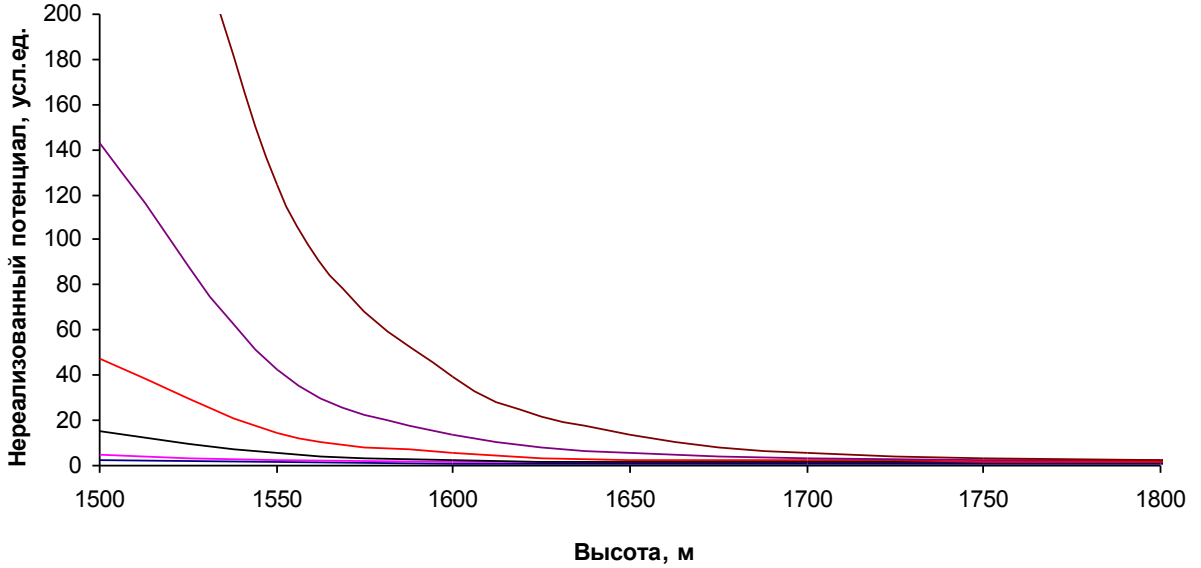


Rationale for the dynamic model

$$P(x, y) = \rho(y) \exp[-\exp(-\beta(y)(x - y))]$$

$$E(x, y) = -\ln P(x, y) = -\ln \rho(y) + \exp(-\beta(y)(x - y))$$

$$\frac{\partial E(x, y)}{\partial x} = -\beta(y) \exp(-\beta(y)(x - y)) = -\beta(y)[E(x, y) - E_0(y)] \quad E_0(y) = \ln \rho(y)$$



Изменение нереализованного потенциала с высотой. Большие значения соответствуют экосистемам с большей характерной высотой (высотной характеристикой)

$$\begin{aligned} \frac{\partial E(x, y)}{\partial y} &= \frac{\partial \rho(y)}{\partial y} \frac{1}{\rho(y)} + \exp(-\beta(y)(x - y)) \left[\beta(y) - \frac{\partial \beta(y)}{\partial y} (x - y) \right] = \\ &-k + \left[\beta(y) - \frac{\partial \beta(y)}{\partial y} (x - y) \right] [E(x, y) - E_0(y)] \\ \frac{\partial \rho(y)}{\partial y} \frac{1}{\rho(y)} &= \frac{\partial E_0(y)}{\partial y} = -k. \end{aligned}$$

The distribution function of ecosystems in the territory (reliability function)

$$P(x, y) = \rho(y) \exp[-\exp(-\beta(y)(x - y))]$$

где

x – состояние (высота местоположения) системы
с характеристикой y ;

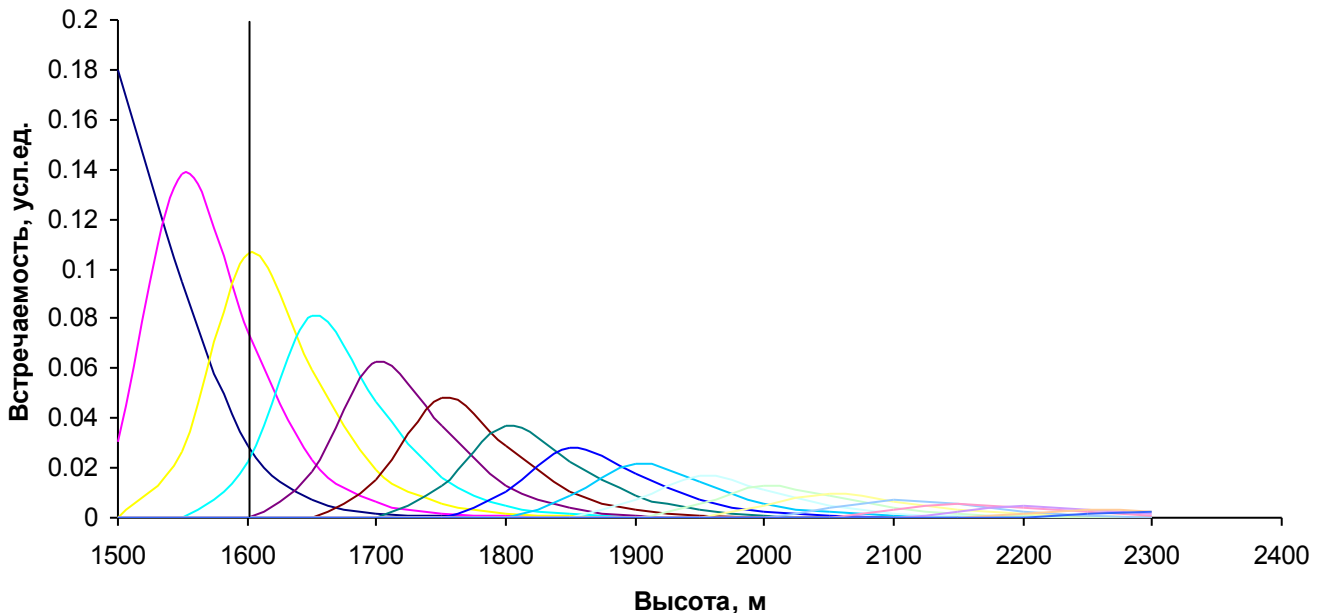
$\rho(y)$ – доля площади экосистемы в ландшафте.

$$\rho(y) = \rho(y_0) \exp(-k(y - y_0))$$

The value of y is the value of the distribution mode

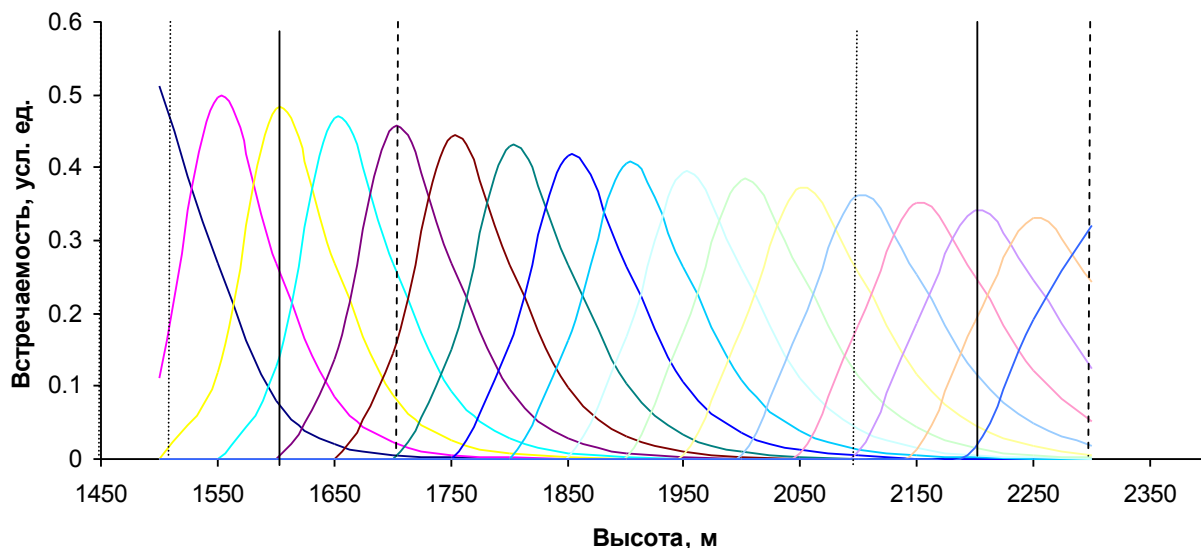
$$p(x, y) = \frac{dP(x, y)}{dx} = \rho(y) \beta(y) \exp(-\beta(y)(x - y)) \exp[-\exp(-\beta(y)(x - y))]$$

$$\beta(y) = ep_m(y) / Dx$$

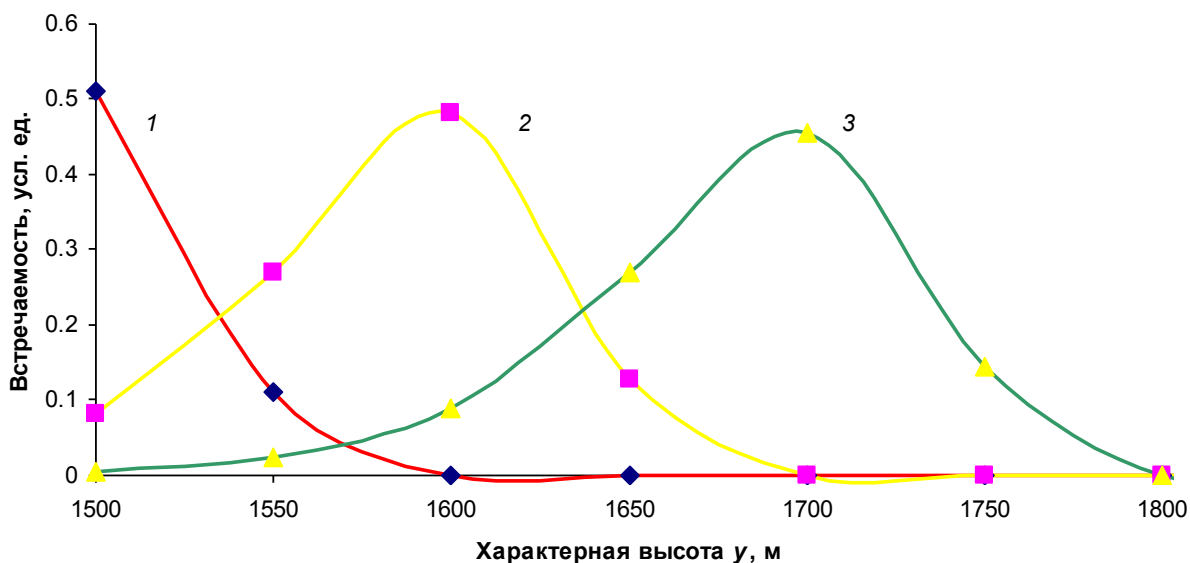


Распределения площади экосистем по высоте с шагом $\Delta x = \Delta y = 50$ м с учетом горного рельефа. Вертикальной линией показана нижняя высотная граница региона.

The scheme of forecasting changes in the distribution of ecosystems in the warming and cooling of the climate



Распределения площади экосистем по высоте с шагом $\Delta x = \Delta y = 50$ м с учетом горного рельефа. Вертикальными линиями показаны нижняя и верхняя высотная граница региона в современную климатическую эпоху. Пунктирные линии демонстрируют условное смещение высот при похолодании, точечные – при потеплении климата.



Спектр распределения площади экосистем по характерной высоте y (без учета горного рельефа) в современную климатическую эпоху (2), при потеплении (1) и при похолодании (3) климата

The partial differential equation

$$v_x \frac{\partial E(x, y)}{\partial x} + v_y \frac{\partial E(x, y)}{\partial y} = vk - vu(x, y) + Kv\beta(y)(x - y)(E(x, y) - E_0(y))$$

$$\frac{\partial E(t, x, y)}{\partial t} + v \frac{\partial E(t, x, y)}{\partial x} = k[v - u(t, x, y)], k = 0,0047$$

$$E(t, x, y) = -\ln \rho(y + x_t) + \exp(-\beta(y)(x - x_t - y)), x_t = \int_0^t v(\xi) d\xi = vt, v = \text{const}$$

$$\rho(y + x_t) = \rho_0 \exp(-k(y + x_t)) = 405.41 \exp(-0,0047(y + x_t)),$$

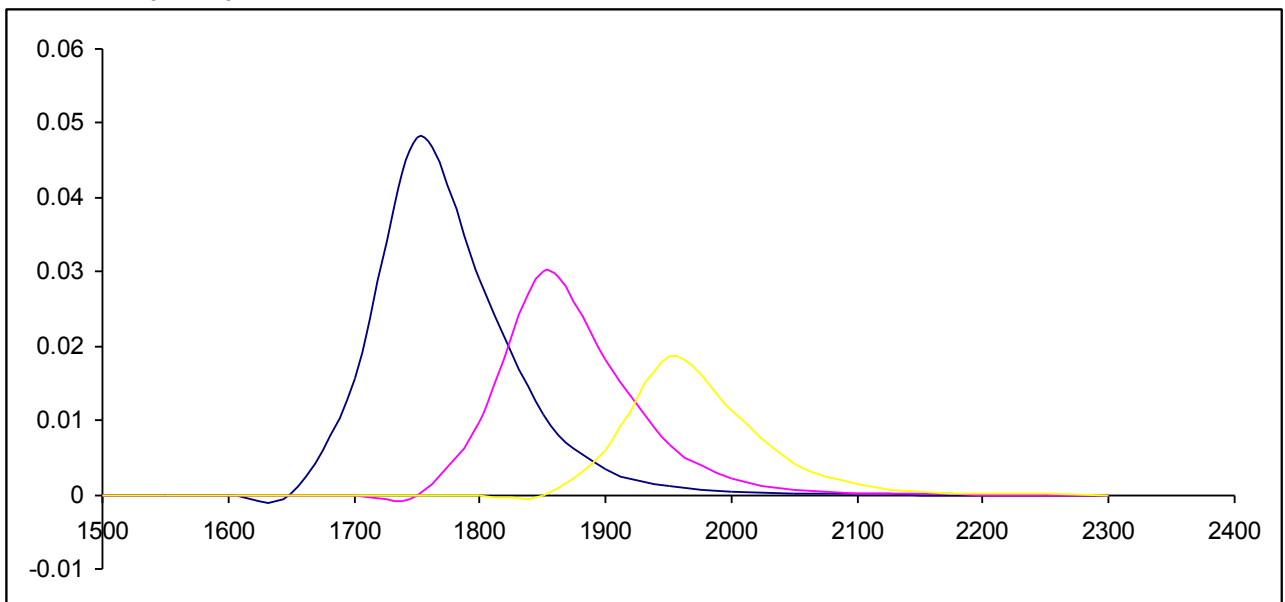
$$\beta(y) = \beta_0 \exp(-Ky) / Dx = \exp(1) \cdot 1,22 \exp(-0,00058y) / 100$$

$$v = a \frac{dN}{dt} = 0,35 \frac{dN}{dt}, x_t = \int_0^{N(t)} 0,35 \frac{dN}{dt} = 0,35(N(t) - N_0) = 0,35(N(t) - 116).$$

$N(t)$ - пастбищная нагрузка, голов скота на кв. км. Равномерная по территории.

Граничные значения (в расширенном горно-степном поясе).

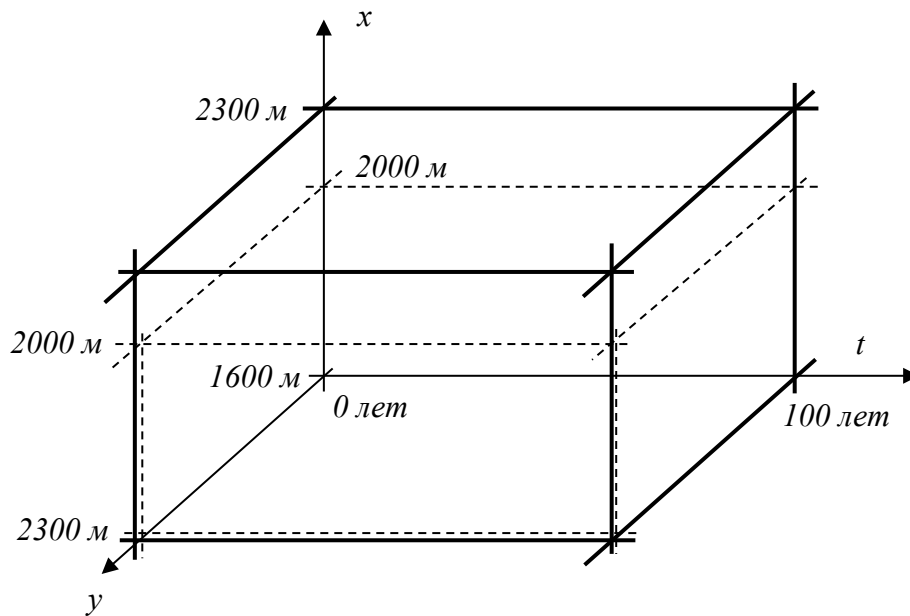
$x_0 = y_0 = 1500$ м и $x_m = y_m = 1800$ м.



Изменение распределения площади экосистемы со временем с учетом особенностей горного рельефа

The functional defines income, expenses and losses per unit area

$$J = \iiint \{ [E(t, x, y) - E(0, x, y)]^2 - cv(t) + Cu(t, x, y) \} dx dy dt$$

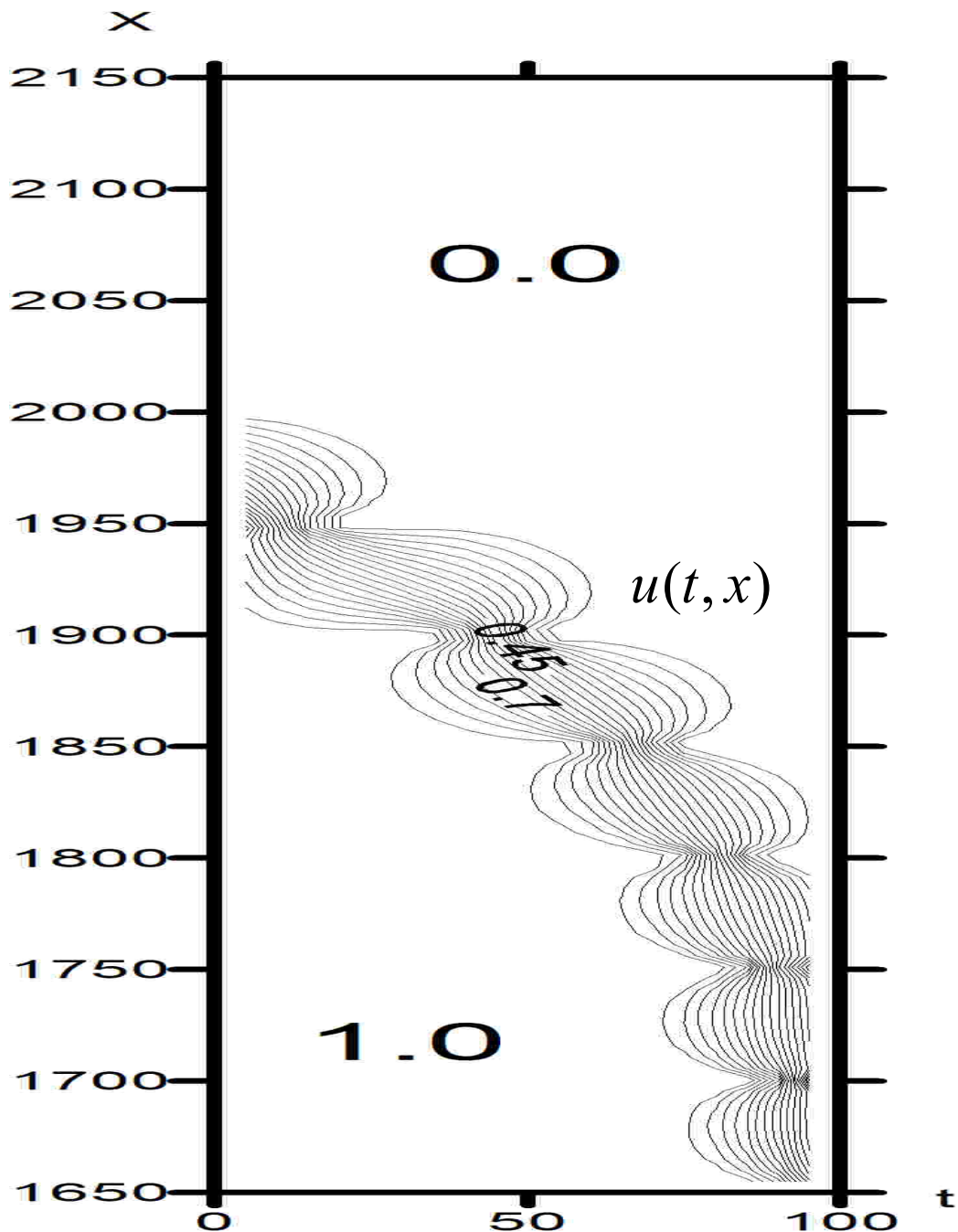


The equation changes in the structure of the landscape taking into account the heterogeneity of the territory

$$\frac{\partial E(t, x, y)}{\partial t} + v \frac{\partial E(t, x, y)}{\partial x} = kv - ku(t, x, y), k = 0,0047$$

$$0.5 \leq v(t) \leq 1 \quad 1.5 \leq N(t) \leq 3$$

Optimal control strategy



управление

$v(t) = 0.5, t \in [0, 95.30]$, затем 1

Results and conclusions

- ***Equation on changes in landscape structure of the ecosystem is justified in the form of a mathematical model of the change of their states under the influence of variations in climate and grazing impact taking in account the heterogeneity of mountainous terrain.***
- ***The task of optimal control of grazing load and ameliorative measures to facilitate the recovery areas is stated.***
- ***Оптимальное управление землепользованием с ограничением по времени имеет релейный характер с поддержанием на минимуме пастбищной нагрузки и максимуме мелиоративных мероприятий в течение большого срока эксплуатации горных степей.***
- ***Optimal time-limited control of land use has relay property and is to maintain load at a minimum and a maximum of pasture reclamation activities during the long time usage of mountain steppes.***



Спасибо