{ Modeling forest dynamics

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Aim of research

- **Assessment** of the **forest resource development** in time (predict the results) **under the impact** of various **factors**.
- We investigate a corresponding model, giving the **parameters** of **natural dynamics** and **human impact, a SCENARIO**.
- A set of various scenarios forms **information for decision support**, e.g., choosing a management strategy that **combine economic efficiency** in the operation **with maintaining the ecological environment**.

Mathematical model

$$\frac{dS_N}{dt} = -a_{N0}S_N(t) + u_{non\,N}(t);$$

$$\frac{dS_0}{dt} = a_{N0}S_N(t) - a_{01}S_0(t) + u_{ncov\,0}(t) + u_{cut\,0}(t) - u_{non\,0}(t);$$

$$\frac{dS_i}{dt} = a_{i-1i}S_{i-1}(t) - a_{i\,i+1}S_i(t) - u_{non\,i}(t) - u_{ncov\,i}(t) - u_{cut\,i}(t),$$

where a_{ij} are the coefficients of transition from one category of land or age group to the next; S_N is the non-forest area;

S_0 is an area that is uncovered by forest;

Si is forest areas of different classes of age;

$u_{non\,i}$ is annual increase in non-forest area at the expense of other categories of land;

$u_{ncov\,i}$ is increase in the area uncovered by forest;

$u_{cut\,i}$ is the area of cutting, is subtracted only from the category of mature and over-mature forests, in other classes of age cutting is not carried out.

Anthropogenic impact assessment

The fires (43.7%), forest diseases (25.2%) and insect damage (16.2%) are the most important factors of destruction of forest resources, we take them into account in the model:

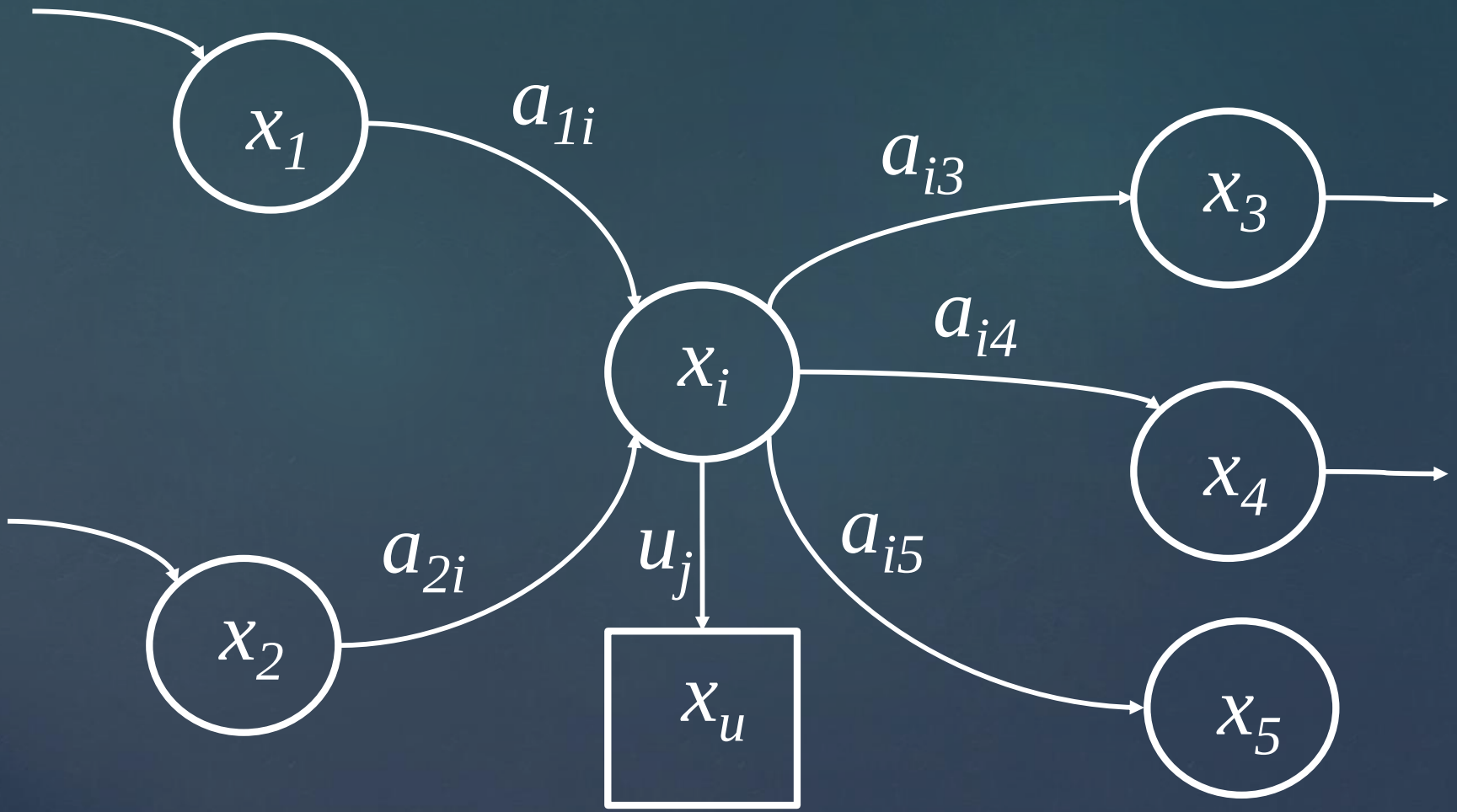
$$u_{ncov} = S_g + S_{nas} + S_b$$

The increase in non-forest area in the process of forest exploitation is as follows:

$$u_{non} = k_N \mathrm{V}N + \mathrm{V}S + \mathrm{V}R + \mathrm{V}G + \mathrm{V}Bl + \mathrm{V}Bv$$

Here k_N is the area of settlements per person, the remaining coefficients characterize the increase of forest population, ΔN, agricultural area, ΔS, recreational zones, ΔR, area of fields, ΔG, construction of linear objects, ΔBl, and maintenance of hydraulic structures, ΔBv.

Graph representation of the equation



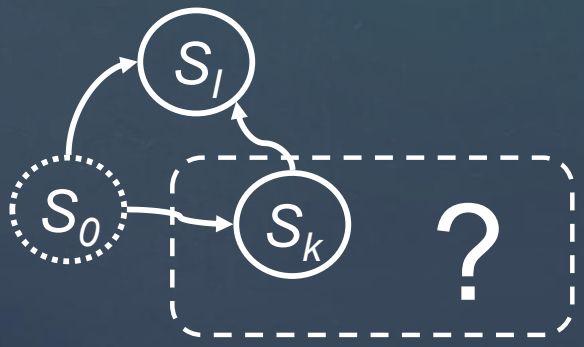
Knowledge Base

$\forall a,t_0$:*Problem(a,model_dyn),Progn(a,ten_year,*t_0*),*
GR(a,landscape),LT(a,forest) $\rightarrow$
$\exists m,S_0$:*MT(m,a,forest_res,*t_0*),*
State(m,S_0*,square(no_forest,*t_0*))*

fm ModelDeterm()=a:a,t0[Problem(a, model_dyn), Prognose(a, ten_years, t0),
Geosystem_Range(a, landscape), Landscape_Type(a, forest) >
e:m,s0[ModelType(m, a, forest_res, t0), State(m, s0, no_forest,
square(None, no_forest, t0))]];

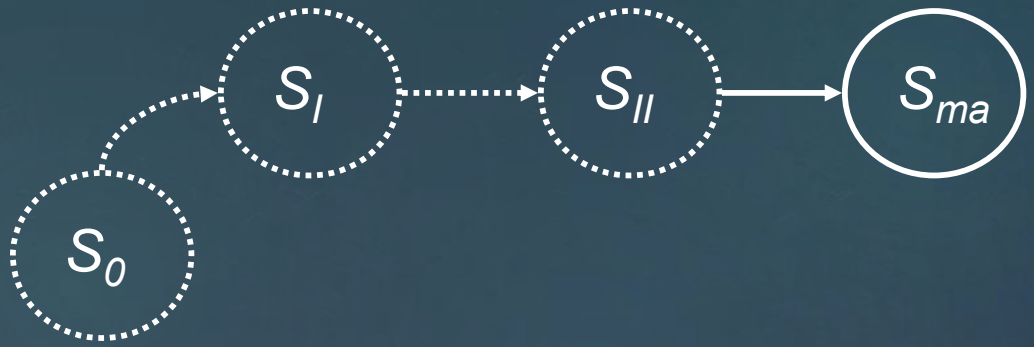
Forest occupies free areas

fm Cultures()=a:ck,m,a,t0,s1[ModelType(m,a,forest_res,t0), State(m,s1,mol1,square(ck,mol1,t0)), TakesPlace(a,forest_cultures,yes),culture_kind(k) > e:sk[State(m,sk,cult,square(ck,cult,t0)), DefineCultures(ck,square(ck,mol1,t0),Trans(m,sk,s1,trans_time(cult,mol1,ck,t0))]]



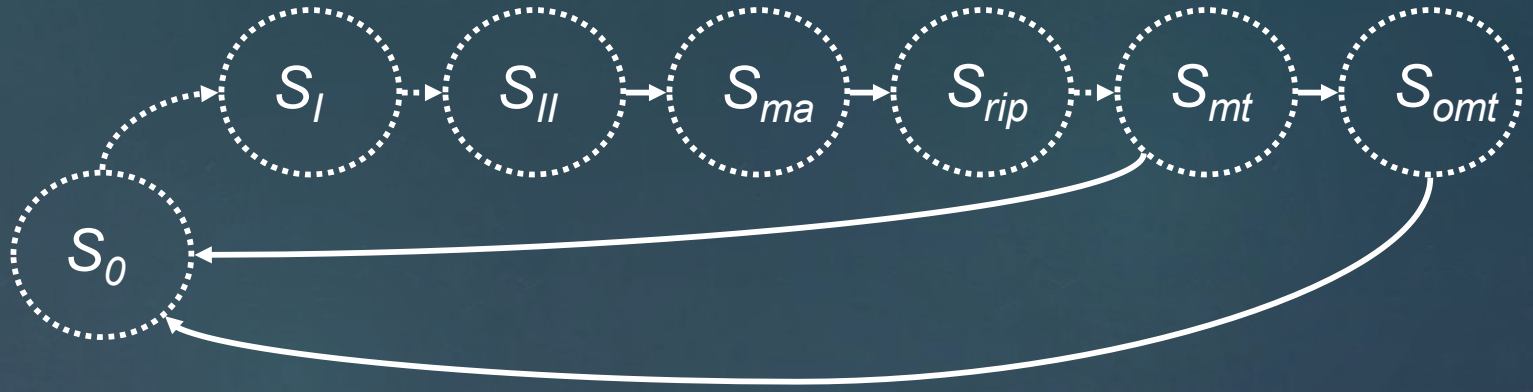
Reforestation activities ???

Forest growth (natural process)



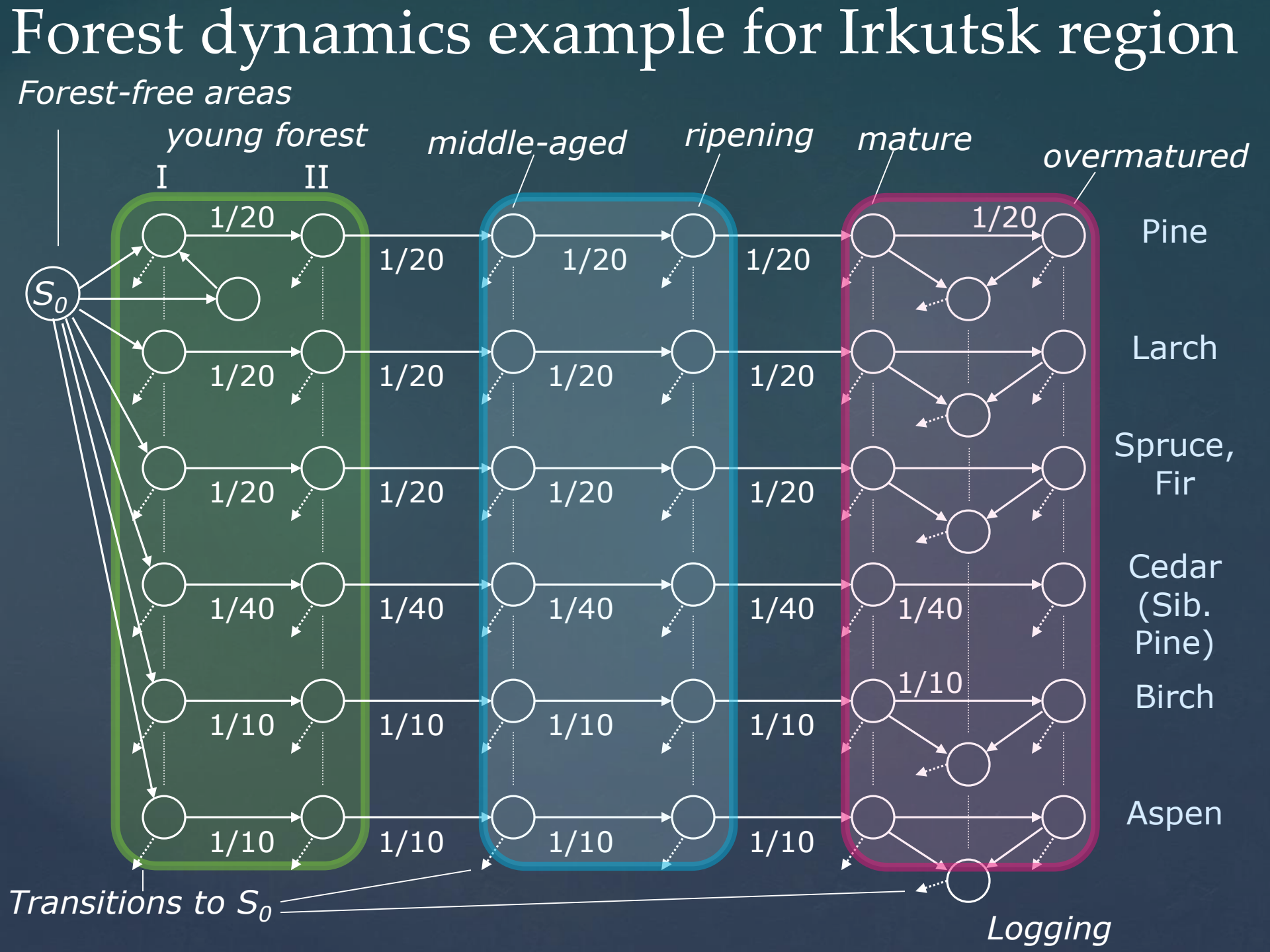
fm AToB()=a:m,t0,a,k,cl,cl1,s [
ModelType(m,a,forest_res,t0),tree_kind(a,k),
age_class(cl),after(cl,cl1), State(m,s,cl,square(k,cl,t0))>
e:s1[State(m,s1,cl1,square(k,cl1,t0)),Trans(m,s,s1,trans_time(cl,
cl1,k,t0))]]

Forest logging

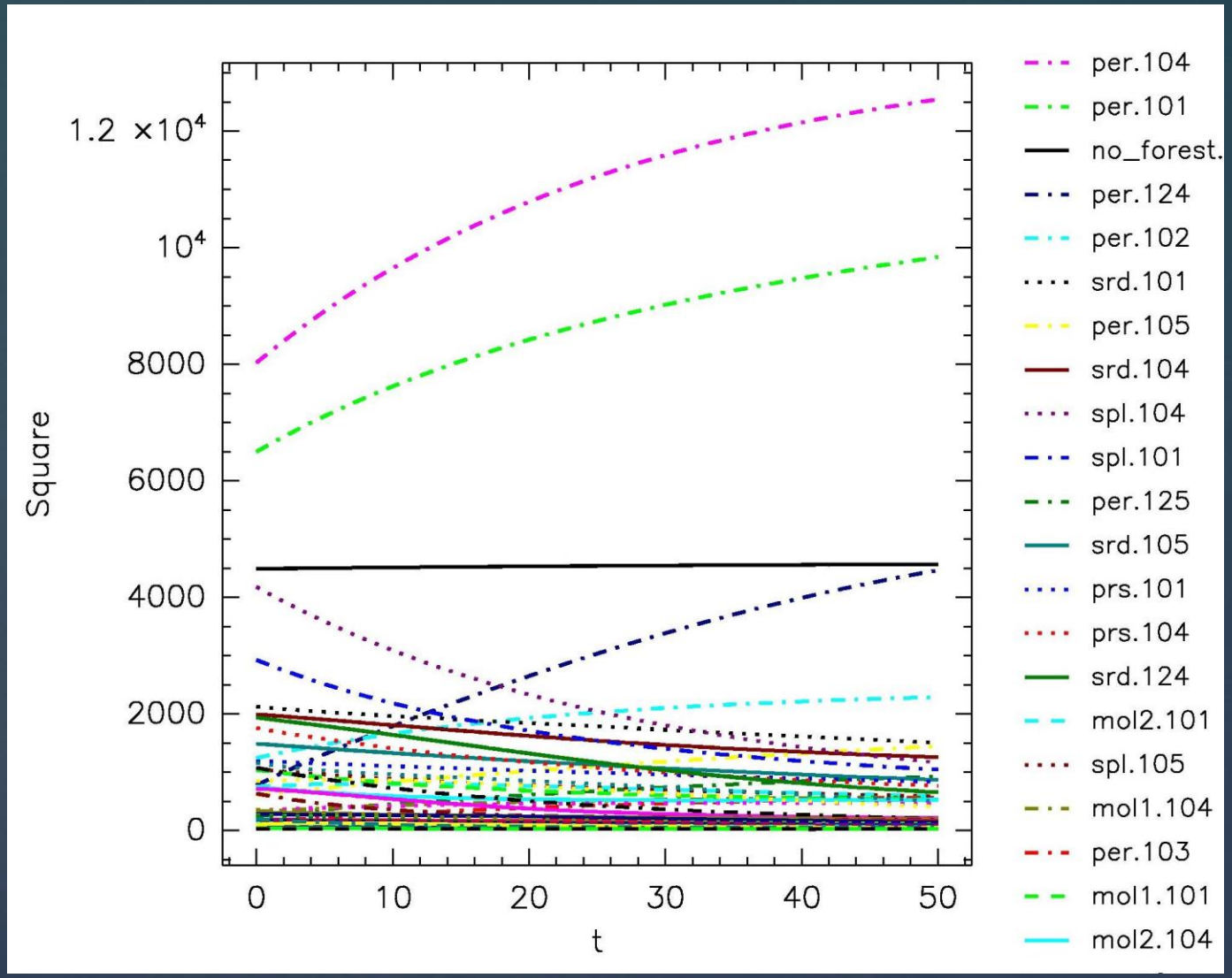


fm FiresProp()=a:m,a,t0,s,s0,name,sq,sq_no_forest,fi[
ModelType(m,a,forest_res,t0), State(m,s,name,sq),
State(m,s0,no_forest,sq_no_forest), FiresBaseIntensity(m,a,fi) >
Trans(m,s,s0,mul(fi, sq))].

Forest dynamics example for Irkutsk region

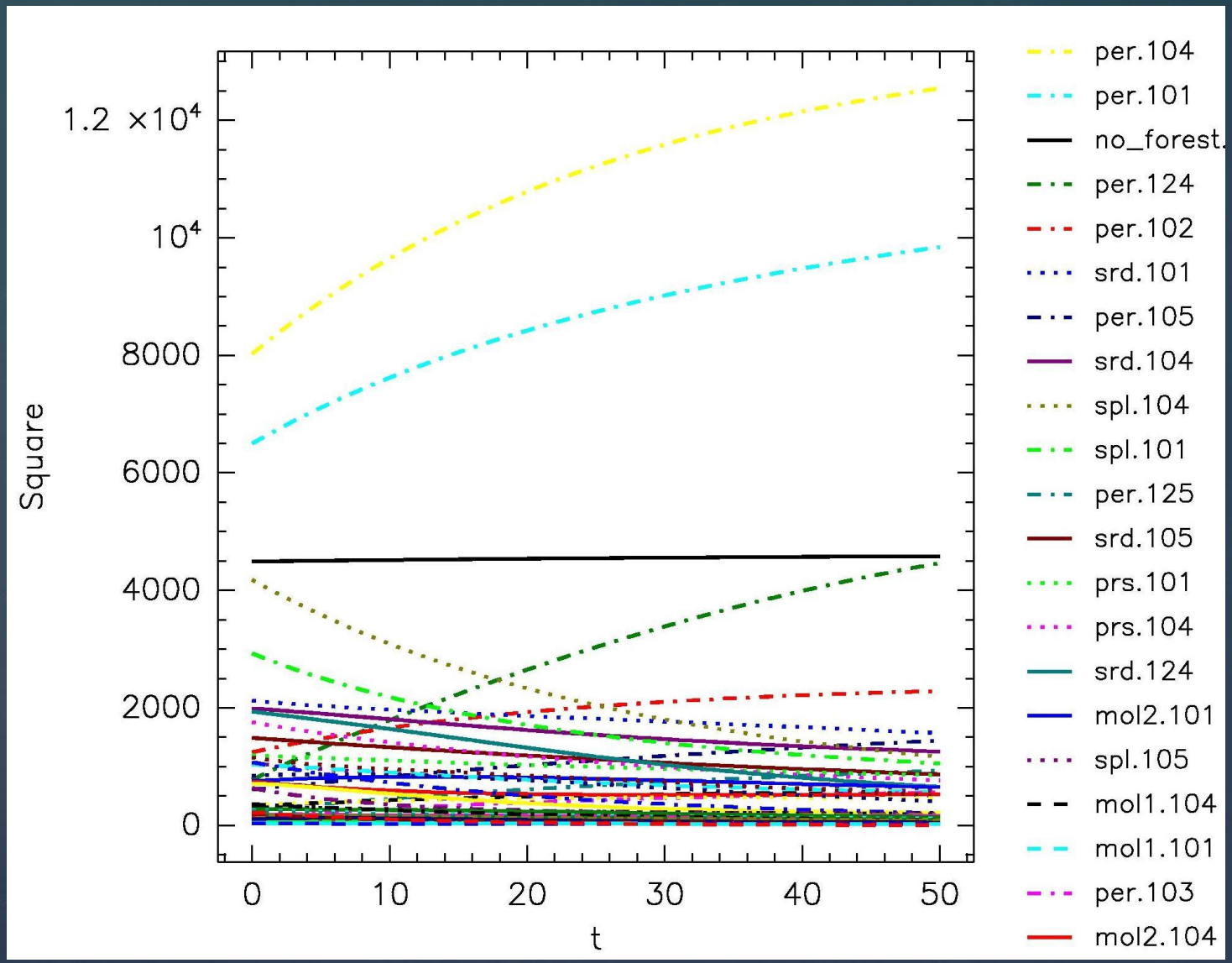


The natural dynamics **without reforestation** (植樹造林)

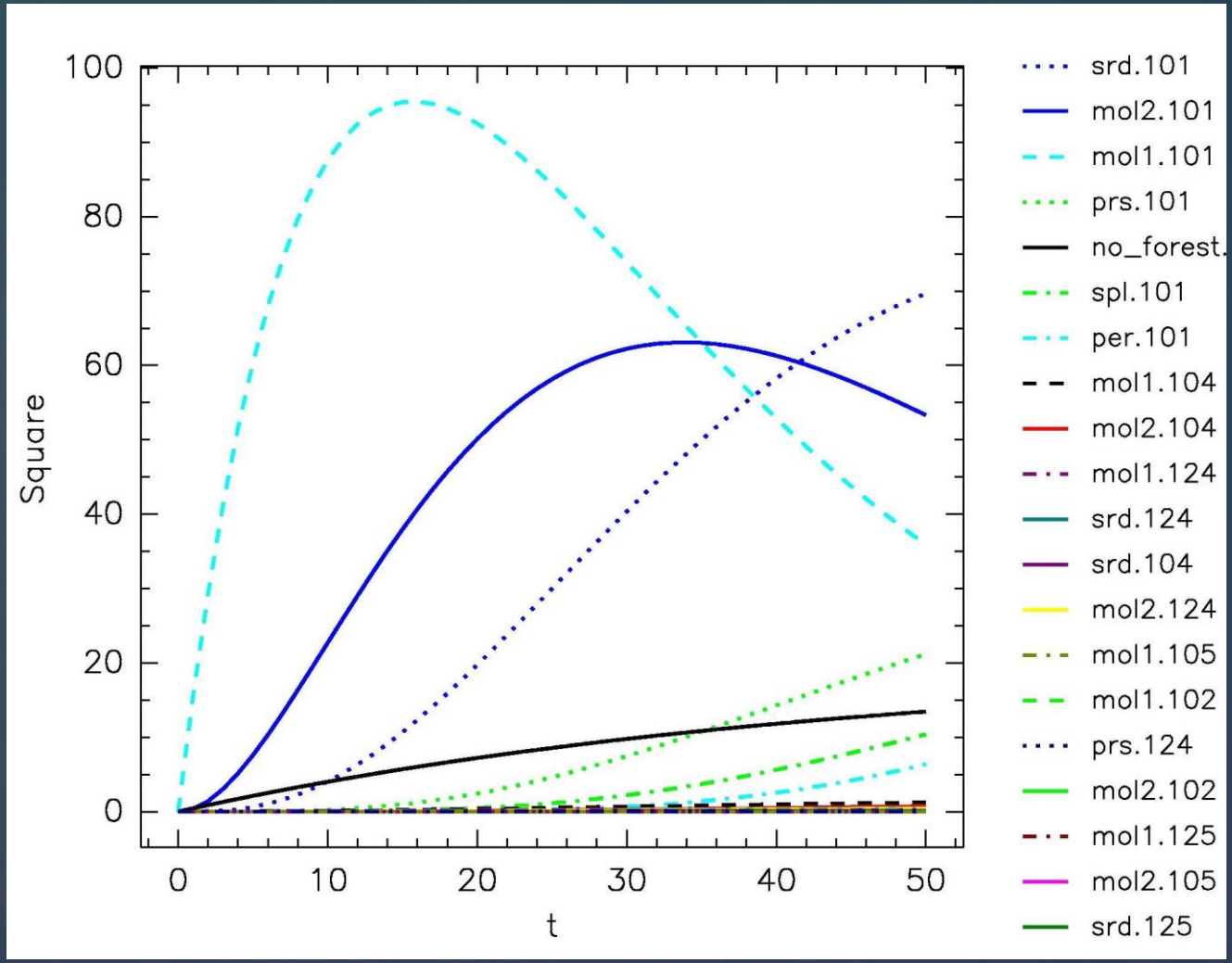


Numbers encode wood species.

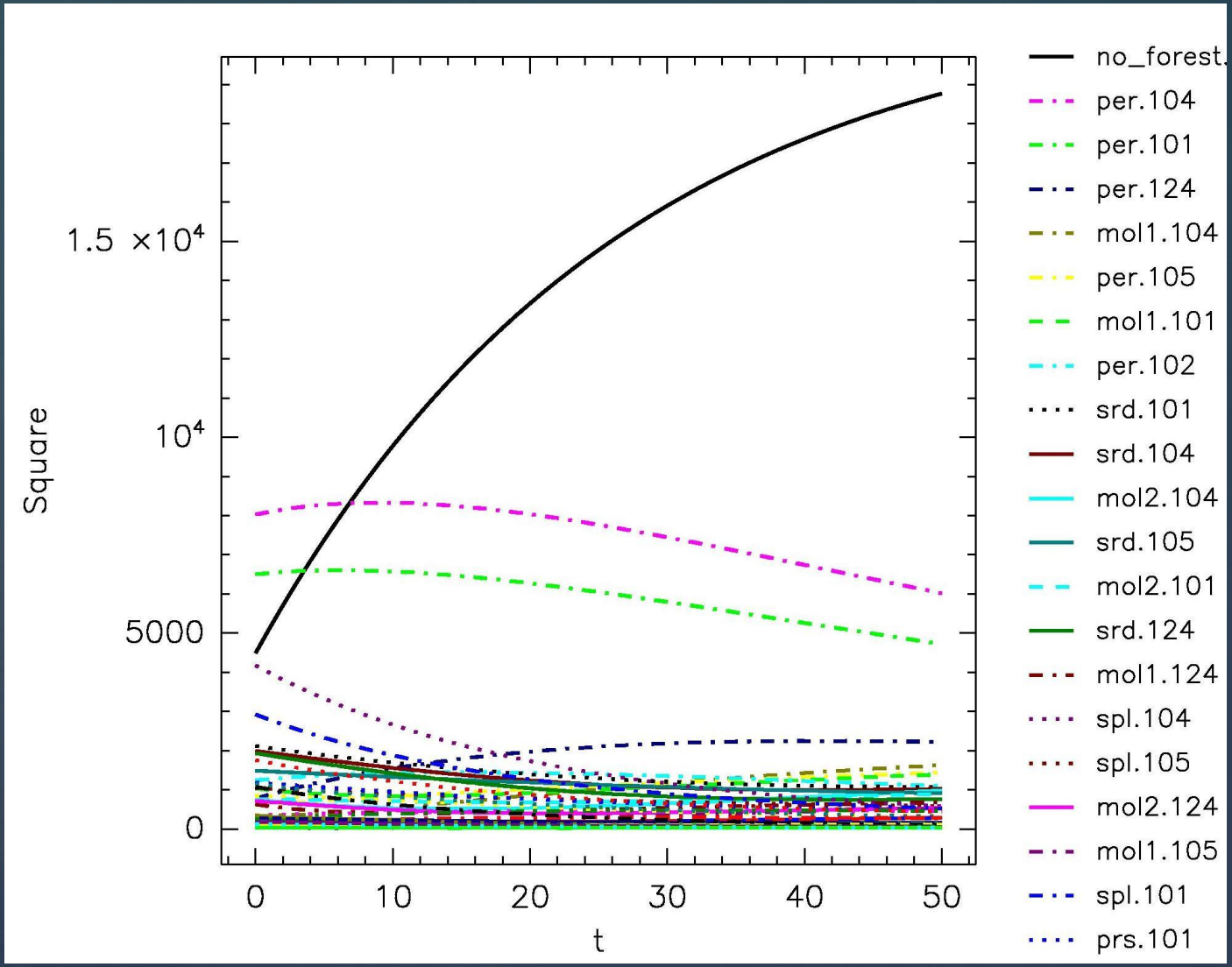
The natural dynamics with **reforestation** (植樹造林)



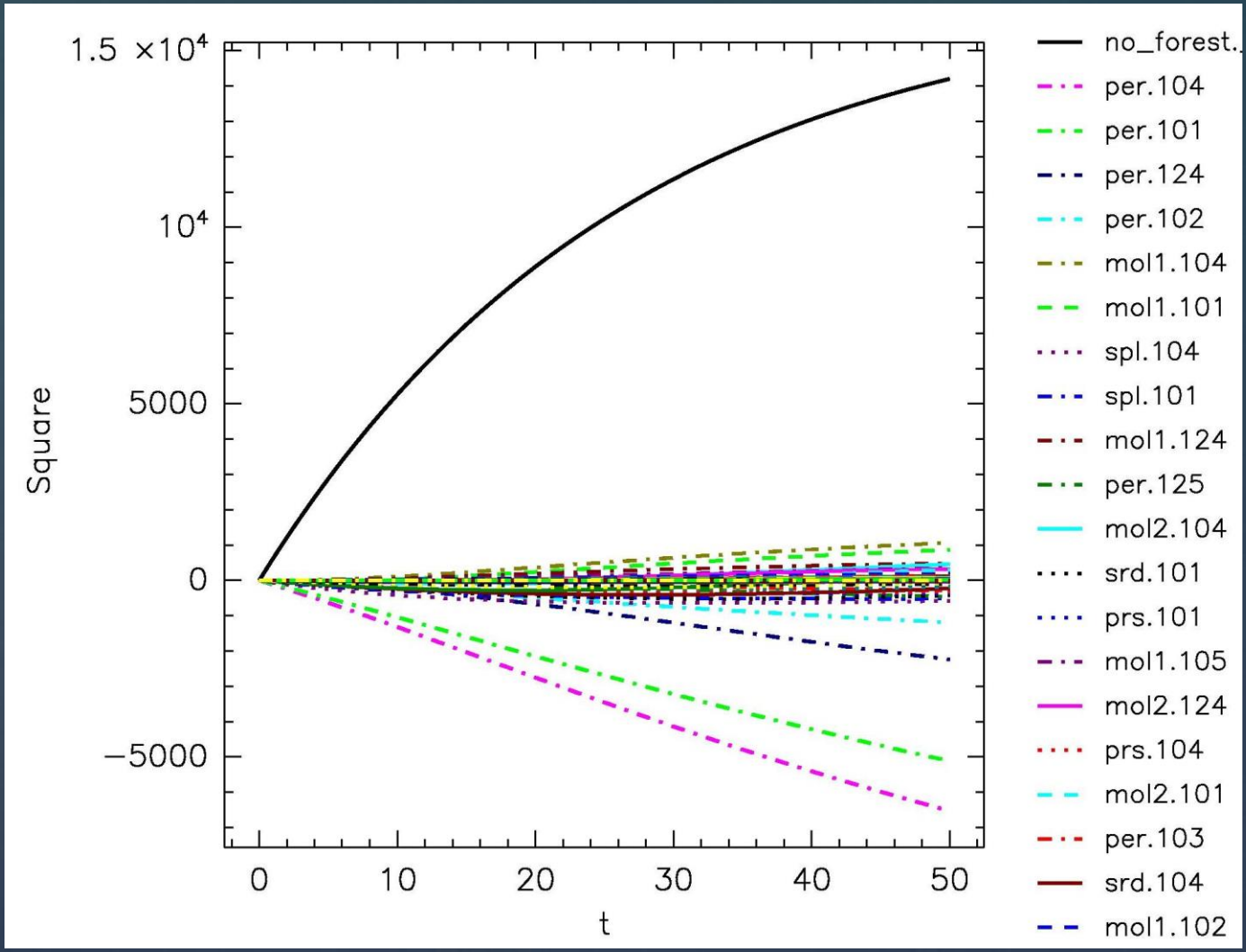
The **impact** of the **reforestation** to the forest dynamics



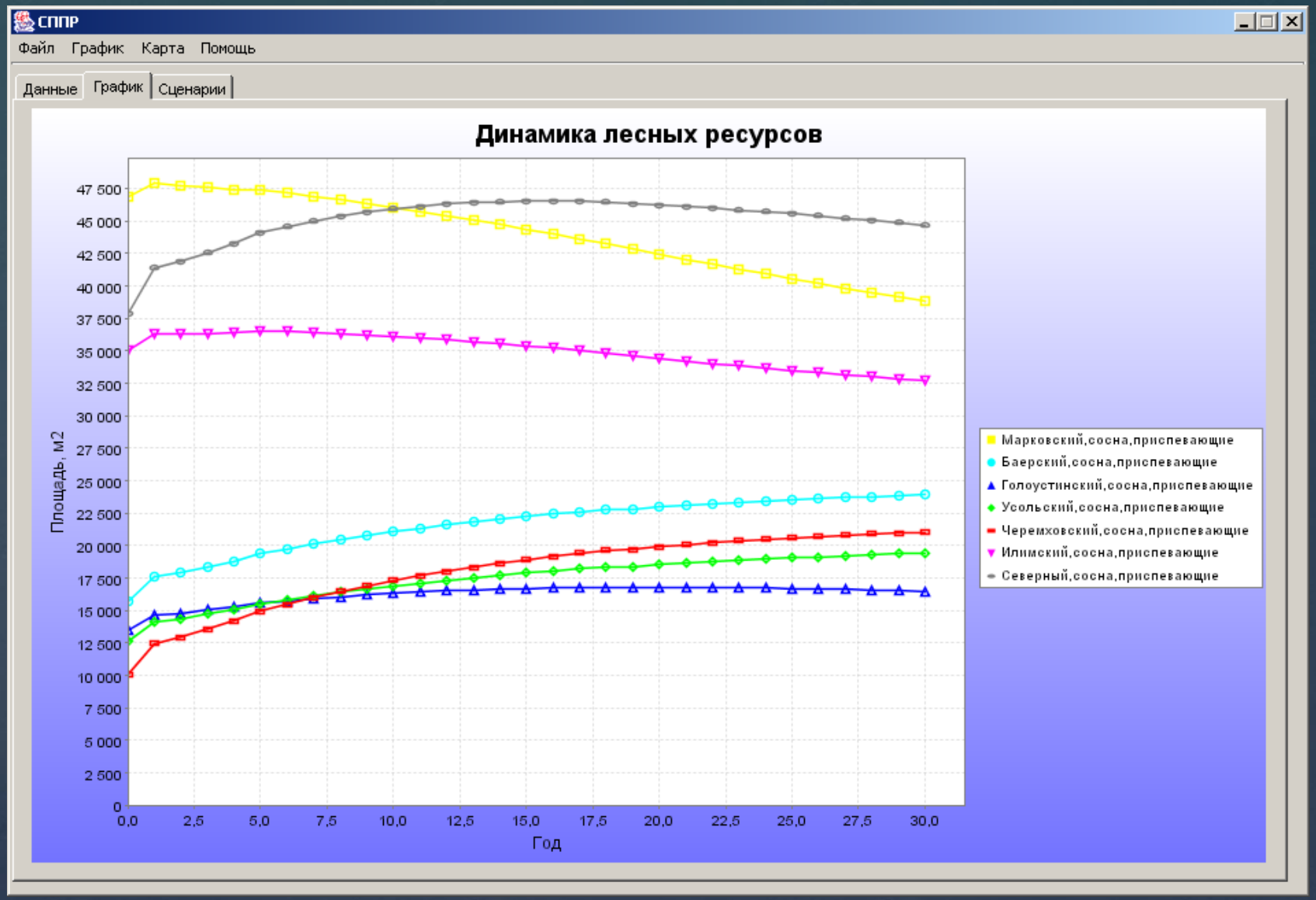
Intense **logging** (測井) without **reforestation**



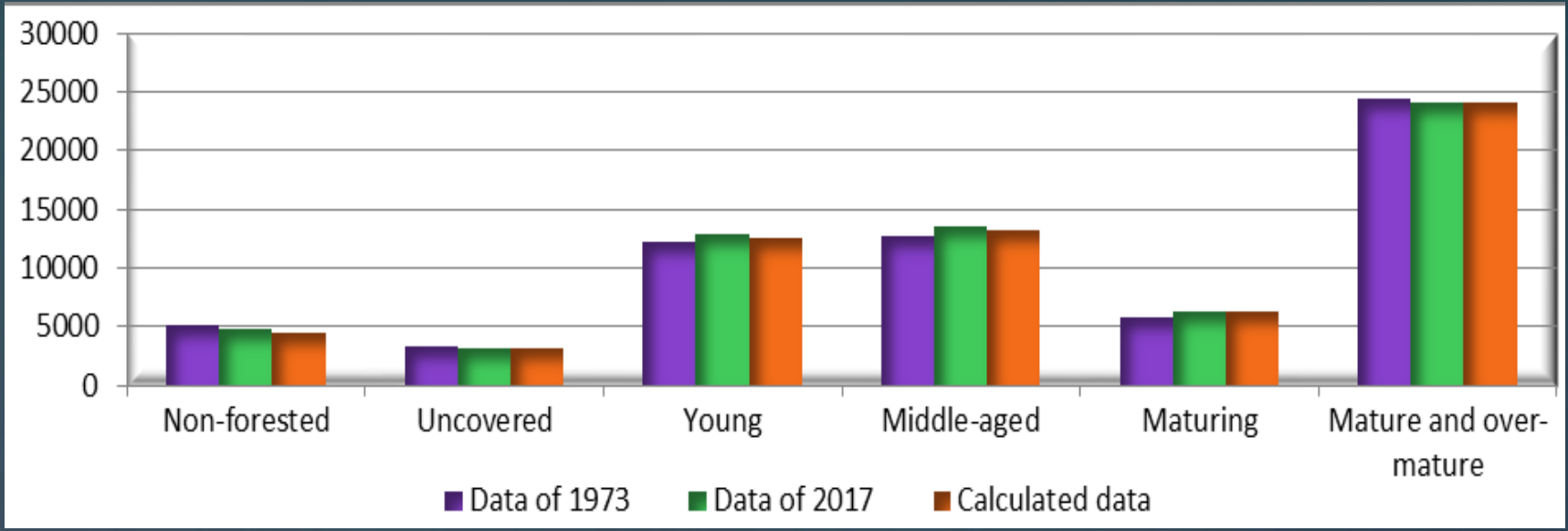
Impact of **logging with reforestation** to the natural forest dynamics



Forest dynamics forecasting for forestries (林業)



Verification of the model



Verification of the adequacy of the model and coefficients of transition a_{ij} calculation is done on the base of forestry input data of Baikal region for 1973. Input includes natural dynamics – the distribution of forest areas by age categories, anthropogenic use and adverse factors – volumes of cuttings, fires and forest plantations on the territory of 53 forest districts. Computations for the model were conducted for an interval of 45 years. The final results of the simulation were compared with the available data on forest areas for 2017, obtained from the official «Forest Plan of the Irkutsk Region».

Verification of the model

COMPARISON OF REAL AND CALCULATED DATA

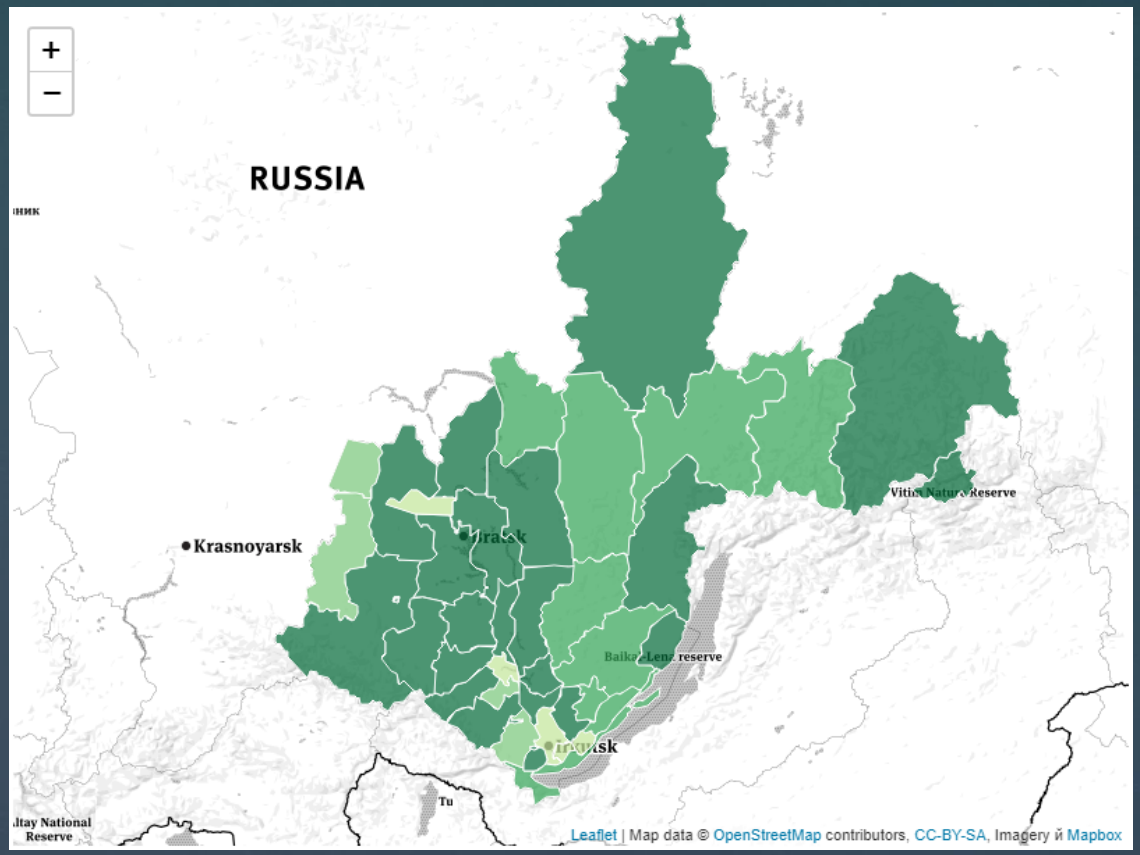
Area type	Actual data, years		Simulation	Error, %
	1973-1985	2017		
Non-forested	5108,223	4670,194	4401,66	5,75
Uncovered	3273,893	3032,455	3166,37	4,42
Young	12161,067	12847,546	12044,61	6,25
Middle-aged	12648,814	13411,571	13137,08	2,05
Ripening	5783,593	6170,173	6215,15	0,73
Mature and overmature	24444,429	24128,406	23089,60	4,3
Total	63420,02	64260,35	62054,47	3,43

The formula of the error is as follows:

$$E = \frac{|S_{calc} - S_{true}|}{S_{true}} * 100\%,$$

where S_{calc} is simulation data, S_{true} is actual data.

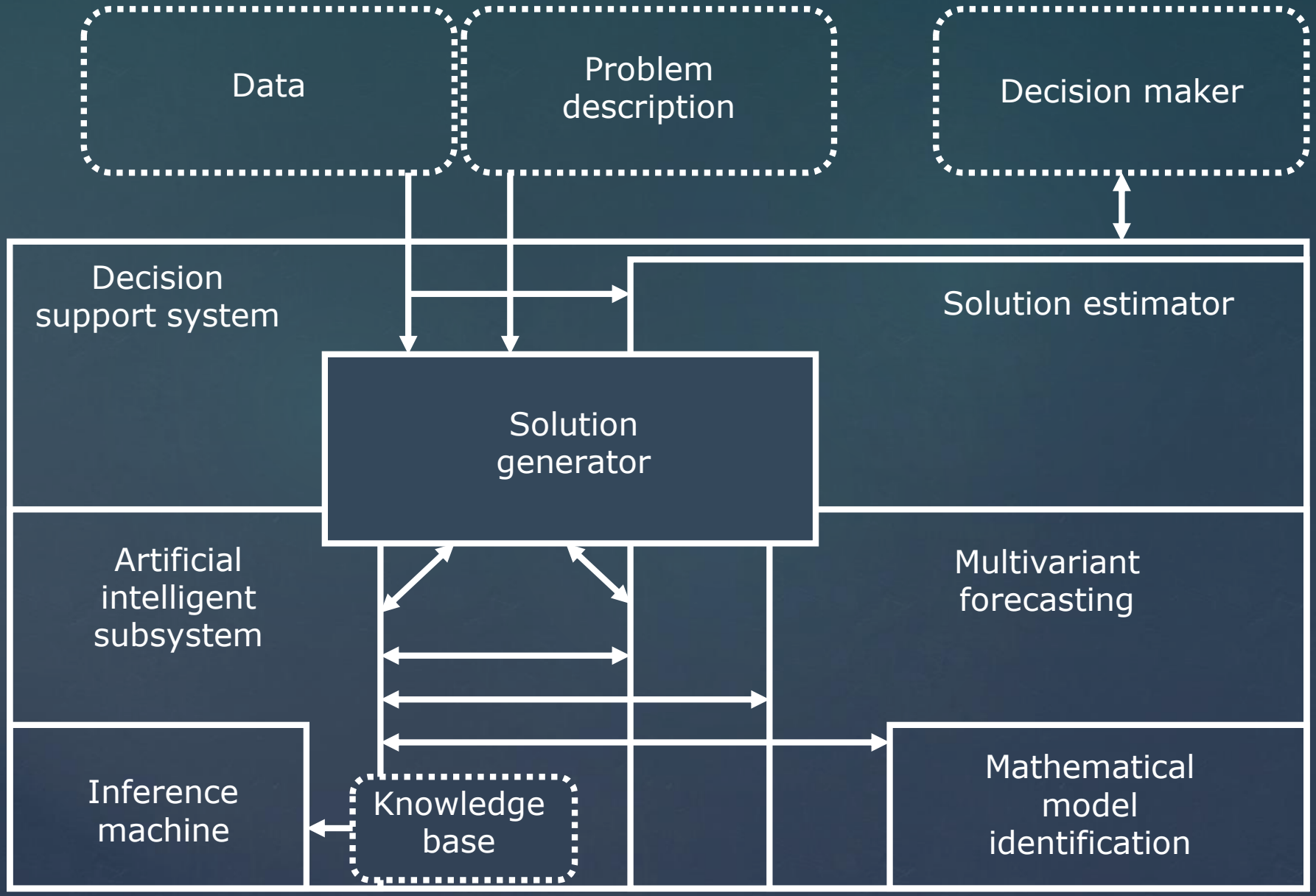
Resulted map



For example, calculations were carried out for a period of 50 years, taking into account the preservation of the current volumes of logging, fires and other adverse factors. The simulation results are shown on the map of the Irkutsk region.

The difference between the forest area for all categories of age at the end and the beginning of the simulation interval was taken as a value. Lighter shades correspond to negative values relative to the initial values, it is a decrease, darker shades is positive values, i.e. their area increases.

Decision support system architecture



Thanks for your attention!