MODELING OF LAND COVER CHANGES ON ALTERNATIVE SCENARIOS

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ABSTRACT

The modeling of changes in landscape cover is a task that helps to predict the development of the territory, which may be useful, for example, in planning infrastructure development (Singh et al. 2015). In practice it is also useful to consider other development scenarios of the study area. In this paper we consider the task of handling the simulation by alternative scenarios using cellular automata and Markov chains. Approach to the preparation of initial data for modeling by an alternative scenario is proposed, the conditions for the correctness of the modification are considered, and a modification algorithm is proposed that allows maintaining correctness when partial modification conditions are met. The approach is tested on the problem of land cover changes forecasting of Portugal territory in the framework of the project LANDYN.

1 INTRODUCTION

With the development of the computers capabilities and availability of different thematic data for multi-temporal analysis, different approaches to predicting changes in landscape cover are developing. The most widespread approaches to build predictive thematic maps are deterministic and stochastic (O'Sullivan and Torrens 2000, Cabral and Zamyatin 2011). The main advantages of deterministic approaches are the high reproducibility and efficiency of obtaining the calculation result. Successful examples of the deterministic models application are given in studies (Xu et al. 2013; Menzel et al. 2013), which contain the modeling and analysis of future development scenarios of interest areas. Considering the fact that processes of change in landscape have a significant stochastic component, the use of the known deterministic methods of extrapolation and prediction does not always yield a satisfactory result. Therefore, a stochastic approach based on the use of the Markov chain apparatus is widely applied and has positively proved itself in solving problems of modeling the behavior of various complex systems, including spatial modeling of changes in the land cover (Arsanjani, Kainz and Mousivand 2011; Cabral and Zamyatin 2009; Chen et al. 2013; Gong et al. 2015; Iacovo and Levinson 2012; Muller and Middleton 1994; Moghadam and Helbich 2013; Turner 1987; Yang et al. 2012).

Modeling changes in the land cover implies finding the predicted map at the time *t3* in the future based on the revealed trends of changes in two maps at times *t1* and *t2*. The simulation allows obtaining the result that gives an idea of the case study area change in the preservation trends of the previous period of time. If there are some reasons to believe that the trend will change or it is necessary to consider other predictive maps with changing trends, it makes sense to simulate by alternative scenarios (Coppedge, Engle and Fuhlendorf 2007; Zamyatin, Afanasyev and Cabral 2015).

Under the alternative scenario we will understand the process of land cover simulation in which the obtained forecast map will be significantly and predictably different from the forecast maps obtained in the regular way, that is, with the assumption of maintaining current trends of changes. Under a significant change we will understand a change that could only occur as a consequence of the stochastic nature of the process. By predictability we will understand the condition of deliberate information about the share of which landscape class (L.C.) in the final image should decrease, and which - increase.

2   DESCRIPTION OF THE SIMULATION ALGORITHM

Stochastic models are often based on the cellular automata (CA) apparatus and Markov chains.
Input data of such algorithm are thematic maps $\mathbf{I}^{t1}$ and $\mathbf{I}^{t2}$ at time points *t1* and *t2* which considered as two matrices. Each element of such matrix contain number of landscape class $i^{t1} \in [0; N]$, $i^{t2} \in [0; N]$, *N* – is the number of land cover types Zero value corresponding to background. Output data is $\mathbf{I}^{t3}$ – forecast map for time point *t3* in future.

The algorithm uses several matrixes, described below. Size of all matrixes is *N*. Each element of actual transition matrix $\mathbf{M}_a = [m_{ij}^a]$ contains amount on of elements switched from class ω_i to the class ω_j on the time interval $\Delta t1 \in [t1;t2]$. Construction of such matrix is rather obvious task $\mathbf{M}_a = f_a(\mathbf{I}^{t1}, \mathbf{I}^{t2})$.
Matrix of transition probability, or stochastic matrix $\mathbf{P} = [p_{ij}]$ contain probability estimation of matrix $\mathbf{I}^{t2}$ elements transition from class ω_i to the class ω_j. This matrix is also easy to construct on the base of $\mathbf{M}_a - \mathbf{P} = f_p(\mathbf{M}_a)$. Matrix of expected transitions $\mathbf{M}_{exp} = [m_{ij}^{exp}]$ has the same meaning that $\mathbf{M}_a$, but corresponding to time interval $\Delta t2 \in [t2;t3]$. The matrix $\mathbf{M}_{exp}$ is calculated according to the following algorithm:

Step 1. Transpose $\mathbf{M}_a$ and obtain $\mathbf{M}_a^T$.

Step 2. Obtain the vector $\mathbf{S} = [s_1, s_2 \dots s_N]^T$, such that $s_i = \sum_{j=1}^N (m_{ij}^a)^T$, s_i – is the number of image elements expected to move to the class ω_i.

Step 3. Obtain $\mathbf{M}_{exp} = [m_{ij}^{exp}] = [s_i \times p_{ij}]$.

The idea of the simulation in the implementation of transitions between classes of the image It2, defined in the matrix M$_{exp}$ with probabilities defined by the matrix P. It is worth noting that in practice for the calculation of transition probabilities are also taken into account the location of a specific element of the image It2 and, possibly, some additional data like suitability maps, which determine additional probabilities of the appearance of land cover class in the specific element.

3   SIMULATION SCENARIOS

3.1   The ways of modifying

To implement an alternative modeling scenario, it is necessary to make changes to the original data or the modeling procedure. Tendencies of the changes, within the simulation will be performed, are determined by the matrices $\mathbf{M}_{exp}$, $\mathbf{P}$ and some additional data, like suitability maps. Changes can be made in both matrices (Coppedge, Engle and Fuhlendorf 2007) or in suitability maps (Tong et al. 2012). However in the matrix $\mathbf{M}_{exp}$, the numbers of all transformations are specified and by its parameters are easy to

determine all differences of alternative scenarios from the standard. Also new matrix **P** can be obtained from $\mathbf{M}_{exp}$.

3.2 The procedure of the expected transitions matrix modification

3.2.1 Statement of the problem

There is a matrix of expected transitions $\mathbf{M}_{exp}$, of size $N{\times}N$, where N – is the number of classes of land cover. It is required to find matrix $\mathbf{M}'_{exp}$, modified according to some conditions, within the framework of a concrete alternative modeling scenario. The result of simulation by alternative scenario is map $\mathbf{I}'^{t3}$.

$$\mathbf{M}_{exp} = \begin{pmatrix} m_{11}^{exp} & \cdots & m_{1N}^{exp} \\ \vdots & \ddots & \vdots \\ m_{N1}^{exp} & \cdots & m_{NN}^{exp} \end{pmatrix}$$

The other initial data in this task are parameters of the modification. The parameters of the modification can be specified depending on the needs of the researcher and stakeholders. The simplest option is to set the relative change in the class areas in the forecast map, relative to the main scenario. This condition is specified with the vector of the general change **G**.

$$\mathbf{G} = \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g_N \end{bmatrix} g_i \in [0, \infty), g_i = \frac{S_{\omega_i}^{\mathbf{I}'^{t3}}}{S_{\omega_i}^{\mathbf{I}^{t3}}}, i = 1..N$$

Where $S_{\omega_i}^{\mathbf{I}^{t3}}$ – sum of elements with class ω_i in map $\mathbf{I}^{t3}$, and $S_{\omega_i}^{\mathbf{I}'^{t3}}$ - sum of elements with class ω_i in map $\mathbf{I}'^{t3}$.

Modification of matrix $\mathbf{M}_{exp}$ can be performed in that way:

$$\mathbf{M}'_{exp} = \{m_{ij}^{exp'} = m_{ij}^{exp} \cdot g_j\}$$

So definition of **G** can be given in another way:

$$g_j = \sum_{i=1}^{N} m_{ij}^{exp'} / \sum_{i=1}^{N} m_{ij}^{exp}, j = 1 \dots N$$

In a more complicated approach, a matrix of local coefficients **L**, which determines the coefficients to correct $\mathbf{M}_{exp}$ modification is also defined. Such matrix determines specific elements of $\mathbf{M}_{exp}$ that can be modified, as well as the increasing and decreasing coefficients.

$$\mathbf{L} = \begin{pmatrix} l_{11} & \cdots & l_{1N} \\ \vdots & \ddots & \vdots \\ l_{N1} & \cdots & l_{NN} \end{pmatrix} l_{ij} \in \{0; \infty\},$$

In the special case $l_{ij} \in \{0; 1\}$ matrix **L** determines only the permissions or the prohibition on changing the individual elements of the matrix $\mathbf{M}_{exp}$. In case of all $l_{ij} = 1$ the task reduces to the first case, in which only vector **G** is defined. If matrix **L** is defined it is impossible to modify the matrix $\mathbf{M}_{exp}$ by multiplication each element to the corresponding element of the vector **G**, so we need to define corrected vector $\mathbf{G}^c$ from the following expressions:

$$\left(l_{ij} > 0 \to \sum_{i=1}^{N} m_{ij}^{exp} \cdot l_{ij} \cdot g_j^c\right) + \left(l_{ij} = 0 \to \sum_{i=1}^{N} m_{ij}^{exp}\right) = g_j \cdot \sum_{i=1}^{N} m_{ij}^{exp} , j = 1..N$$

$$g_j^c = \frac{g_j \cdot \sum_{i=1}^{N} m_{ij}^{exp} - (l_{ij}=0 \to \sum_{i=1}^{N} m_{ij}^{exp})}{\sum_{i=1}^{N} m_{ij}^{exp} \cdot l_{ij}}, j = 1..N \tag{1}$$

Modification of matrix $\mathbf{M}_{exp}$ with defined matrixes $\mathbf{G}$ and $\mathbf{L}$ can be performed in that way:

$$\mathbf{M}'_{exp} = \{m_{ij}^{exp\prime} = \begin{cases} m_{ij}^{exp} \cdot l_{ij} \cdot g_j^c, & if \ l_{ij} > 0 \\ m_{ij}^{exp}, & if \ (l_{ij} = 0 \end{cases} \}$$

3.3 Feasibility of modification

Despite of simplicity of matrix $\mathbf{M}_{exp}$ modification procedure, the result matrix $\mathbf{M}'_{exp}$ must satisfy the condition:

$$\sum_{j=1}^{N} m_{ij}^{exp\prime} = \sum_{j=1}^{N} m_{ij}^{exp}, i = 1 \dots N \tag{2}$$

Condition (2) follows from the fact that the sums of rows of the matrix $\mathbf{M}_{exp}$ reflect the number of elements of the corresponding classes on the initial map for modeling ($\mathbf{I}^{t2}$), and the sum of every row should not be changed because it is contrary to the meaning of this matrix. Also this condition reflects the fact that modifications of the matrix may not change the total sum of the matrix $\mathbf{M}_{exp}$ elements, which reflects the total area of the territory. The change in the total sum of matrix elements contradicts its meaning.

It will be useful to determine the conditions that allow us to verify the feasibility of the modification in advance. If only vector $\mathbf{G}$ is specified then the conditions of modification correctness can be written as follows:

$$\sum_{j=1}^{N}\left(g_j \cdot m_{ij}^{exp} - m_{ij}^{exp}\right) = 0, i = 1..N \tag{3}$$

$$\sum_{j=1}^{N}\left(g_j \cdot \sum_{i=1}^{N} m_{ij}^{exp}\right) = \sum_j^{N} \sum_i^{N} m_{ij}^{exp} \tag{4}$$

Condition (3) follows from conditions (2) and reflects the necessary to preserve the rows sums of the matrix. Condition (4) reflects necessary to preserve total elements sum of matrix $\mathbf{M}_{exp}$.

If the matrix $\mathbf{L}$ also defined, then condition (4) is also applicable, but condition (3) needs to be modified according to expression (1).

$$\sum_{j=1}^{N}\left(l_{ij} > 0 \to g_j^c \cdot l_{ij} \cdot m_{ij}^{exp} - m_{ij}^{exp}\right) = 0, i = 1..N$$

4 MODIFICATION ALGHORITHM

4.1 General approach

In practice, it is rather difficult to choose $\mathbf{G}$ and $\mathbf{L}$ which will ensure the fulfillment of the transformation conditions and at the same time preserve the correctness of the matrix $\mathbf{M}_{exp}$ therefore, it is suggested to consider the algorithm for modifying the $\mathbf{M}_{exp}$ matrix which have priority of saving correctness. The algorithm below reduces the corresponding elements of the matrix $\mathbf{M}_{exp}$ and then increases determined elements, but only to the extent that save correctness. Thus, the matrix $\mathbf{M}'_{exp}$ match conditions:

$$\sum_{i=1}^{N} m_{ij}^{exp\prime} = g_j \cdot \sum_{i=1}^{N} m_{ij}^{exp} , j = 1 \dots N, g_j < 1$$

$$\sum_{i=1}^{N} m_{ij}^{exp'} > \sum_{i=1}^{N} m_{ij}^{exp}, j = 1 \ldots N, g_j > 1$$

Thus, this algorithm ensures the fulfilment of the conditions of specific classes reduction, but does not guarantee the fulfillment of the increasing terms.

4.2   Algorithm 1. Global conditions only

Step 1. Correct values of matrix $\mathbf{M}_{exp}$ to change sums of columns that we need to reduce.

$$m_{ij}^{exp'} = g_j \cdot m_{ij}^{exp}, \text{ if } g_j < 1, j = 1..N, i = 1..N$$

Step 2. Correct values of matrix $\mathbf{M}'_{exp}$ to recover sums of rows.

If the sum in the row has changed, then find out which elements needs to be increased. Calculate the values to increase as matrix of local differences ($\mathbf{D}_l$). Calculate correction coefficient (c_i). Correct matrix of local differences ($\mathbf{D}'_l$) and add to matrix $\mathbf{M}'_{exp}$.

$$d_i = \sum_{j=1}^{N} m_{ij}^{exp} - \sum_{j=1}^{N} m_{ij}^{exp'}, \ i = 1 \ldots N, d_i\text{- change of raw } i \text{ sum.}$$

$$d_{l_{ij}} = g_j \cdot m_{ij}^{exp'} - m_{ij}^{exp'}, \text{if } g_j > 1, i = 1 \ldots N, j = 1..N$$

$$c_i = \frac{d_i}{\sum_{j=1}^{N} d_{l_{ij}}}, i = 1 \ldots N$$

$$d'_{l_{ij}} = d_{l_{ij}} \cdot c_i, i = 1..N, j = 1..N$$

$$m_{ij}^{exp'} = m_{ij}^{exp'} + d'_{l_{ij}}, i = 1..N, j = 1..N$$

4.3   Algorithm 2. Global and local conditions

In this algorithm, in addition to the vector $\mathbf{G}$, we will consider also the matrix $\mathbf{L}$. Thus, the condition for $\mathbf{M}'_{exp}$ will look like

$$\sum_{i=1}^{N} m_{ij}^{exp'} = (l_{ij} > 0 \rightarrow \sum_{i=1}^{N} m_{ij}^{exp} \cdot l_{ij} \cdot g_j^c) + (l_{ij} = 0 \rightarrow \sum_{i=1}^{N} m_{ij}^{exp}), \ j = 1 \ldots N, g_j < 1$$

$$\sum_{i=1}^{N} m_{ij}^{exp'} \geq \sum_{i=1}^{N} m_{ij}^{exp}, j = 1 \ldots N, g_j > 1$$

Step 1. Correct values of matrix $\mathbf{M}_{exp}$ to change sums of columns that we need to reduce. In this case, consider the matrix $\mathbf{L}$ and corrected values of g_j^c.

$$m_{ij}^{exp'} = \begin{cases} m_{ij}^{exp} \cdot l_{ij} \cdot g_j^c, \ if \ l_{ij} > 0, \ g_j < 1 \\ m_{ij}^{exp}, \ if \ l_{ij} = 0 \end{cases}, \text{if } j = 1..N, i = 1..N$$

Step 2. Correct values of matrix $\mathbf{M}'_{exp}$ to recover sums of rows.

Calculate the values to increase as matrix of local differences ($\mathbf{D}_l$). Calculate correction coefficient (c_i). Correct matrix of local differences ($\mathbf{D}'_l$) and add to matrix $\mathbf{M}'_{exp}$.

$$d_i = \sum_{j=1}^{N} m_{ij}^{exp} - \sum_{j=1}^{N} m_{ij}^{exp'}, \; i = 1 \ldots N$$

$$d_{l_{ij}} = (g_j^c \cdot m_{ij}^{exp'} - m_{ij}^{exp'}) \cdot l_{ij}, \text{ if } g_j^c > 1, l_{ij} > 0, i = 1 \ldots N, j = 1 .. N$$

$$c_i = d_i / \sum_{j=1}^{N} d_{l_{ij}}$$

$$d'_{l_{ij}} = d_{l_{ij}} \cdot c_i \cdot l_{ij}, l_{ij} > 0, i = 1 .. N, j = 1 .. N$$

$$m_{ij}^{exp'} = m_{ij}^{exp'} + d'_{l_{ij}}, i = 1 .. N, j = 1 .. N$$

5   CASE STUDY

Here is an example of the above described approach application to solve the problem of predicting changes in landscape cover of Portugal territory, implemented in the framework of the international research project LANDYN with the support of the Portuguese science Foundation. The main objectives of the project LANDYN were the following:

1) Creation of a scientific and methodological basis for the study of land cover changes in the country.
2) Determination and study of the main factors influencing land cover changes.
3) Creation of predictive conditional (alternative) scenarios of land cover changes using spatial models.
4) Investigation of energy needs and emission and absorption of greenhouse gases.

The research project continues the analysis of land cover changes in continental Portugal and regions which began in the 1980s as part of the European Union project NUTS (Nomenclature of Territorial Units for Statistics) and supported by the General Directorate of Planning in Portugal (Direção-Geral do Território, DGT).

We used thematic maps of the Portugal territory for 1990 and 2006 years. The area of interest includes the Lisbon Metropolitan Area. The sample dataset in ESRI shapefile format was converted to TIFF raster format with a 100 m spatial resolution and then imported into the IDRISI Selva software. The land cover class structure of the study area is represented by 15 land cover classes.

Table 1: Case study area land cover classes.

	Land cover class	Proportion for 2006, %
1	Urban fabric	15.9
2	Industrial, commercial and transport units	4.8
3	Mine, dump and construction sites	1.0
4	Artificial, non-agricultural vegetated areas	0.5
5	Arable land	10.1
6	Permanent crops	4.7
7	Pastures	1.6
8	Heterogeneous agricultural areas	26.5
9	Forests	16.5
10	Shrub and/or herbaceous vegetation associations	10.5
11	Open spaces with little or no vegetation	0.1
12	Inland wetlands	0.0

13	Coastal wetlands	1.6
14	Continental waters	0.4
15	Marine waters	5.8
		100

Table 2: Matrix of expected transitions ($\mathbf{M}_{exp}$).

L.C.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	46906	851	72	41	1	0	0	1	48	6	0	0	0	0	0
2	724	13746	0	3	0	0	0	0	0	0	0	0	0	0	0
3	1295	402	953	46	2	1	0	20	35	207	0	0	0	0	0
4	50	1128	0	439	0	0	0	0	0	0	0	0	0	0	0
5	4137	1776	292	57	21284	541	123	1173	325	782	0	0	0	57	0
6	465	351	77	2	1615	11066	82	310	41	70	0	0	0	1	0
7	152	104	13	2	2886	19	1545	52	16	99	0	0	12	2	0
8	13312	3188	661	71	1520	1318	6	57360	536	1499	0	0	0	1	0
9	2583	2309	776	20	2427	566	56	2324	28227	10410	42	0	0	11	0
10	3734	2708	1021	81	817	327	64	601	6174	16217	2	0	0	1	0
11	12	59	29	0	1	1	0	1	16	153	177	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	55	0	0	0
13	22	170	0	48	0	0	0	0	0	0	0	0	4561	0	40
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1238	0
15	3	222	0	1	0	0	0	0	0	0	0	0	374	0	16898

The stochastic model used to model further changes is based on the mathematical Markov chain model, so that it is advisable to verify that the simulated processes are Markovian. The value of the criterion χ^2 obtained for the transition probability matrix $\mathbf{P}$ by the Chapman–Kolmogorov equation is 3,177. For a significance level of 0.95 with 15 degrees of freedom $\chi^2 = 7,261 > 3,177$. Hence, the hypothesis that the process of land cover changes in the study area is Markovian is valid.

Vectors and matrices that determine global and local conditions give alternative modeling scenarios. The degree of change is determined semantically with the legend (Table 3). For example, consider one of the alternative scenarios.

Table 3: The original data legend.

Legend	The value
+++	Very strong increase
++	Strong increase
+	Moderate increase
0	Persistence
-	Moderate decrease
-	Strong decrease
---	Very strong decrease

$$\mathbf{G}'^{\mathrm{T}} = [+, ++, -, +, --, +, 0, -, 0, ++, 0, 0, 0, +, +]$$

$$\mathbf{L'} = \begin{bmatrix}
0 & 0 & - & + & - & 0 & 0 & - & 0 & + & 0 & 0 & 0 & 0 & + \\
0 & 0 & - & 0 & - & 0 & 0 & - & 0 & + & 0 & 0 & 0 & + & + \\
0 & 0 & - & 0 & - & 0 & 0 & - & 0 & + & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
++ & ++ & - & 0 & - & + & 0 & - & 0 & 0 & 0 & 0 & 0 & + & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
+ & + & - & + & - & + & 0 & - & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & + & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Table 4: The numerical value of changes.

Legend	The numerical value
+++	1.15
++	1.10
+	1.05
0	0
-	0.95
--	0.90
---	0.85

To perform the transformations we need numerical values of the matrices **G** and **L**. Calculation of specific numerical values is a serious complex task for the expert and deserves separate consideration. In our case, for simplicity, we will take the values of change as 5%, 10% and 15% (Table 4).

Check for correctness the conditions of modification. Let's check condition (4).

$$\sum_{j}^{N}\sum_{i}^{N} m_{ij} = 301557$$
$$\sum_{j=1}^{N}\left(g_j \cdot \sum_{i=1}^{N} m_{ij}\right) = 306169$$

As we can see, results are not equal and condition (4) is not fulfilled, so modification of $\mathbf{M}_{exp}$ cannot be fully implemented.

Let's apply the considered algorithm and carry out simulation with original and modified conditions. At the Figure1 we can see the results of modeling by main and alternative scenarios. They are difficult to compare visually, so let's present a difference map showing the growth areas of the corresponding classes. Because of applying the modification algorithm, we obtain a new matrix of expected transitions. Below (Table 5) is the statistic of the modified matrix. The number of elements of the landscape class, intended to decrease according to the vector **G**, decreased by the required value. The number of elements of the landscape class, intended to increase according to the vector **G**, increased by a value less than a defined one, as expected. Whole sum of elements has not changed.

a   b   c

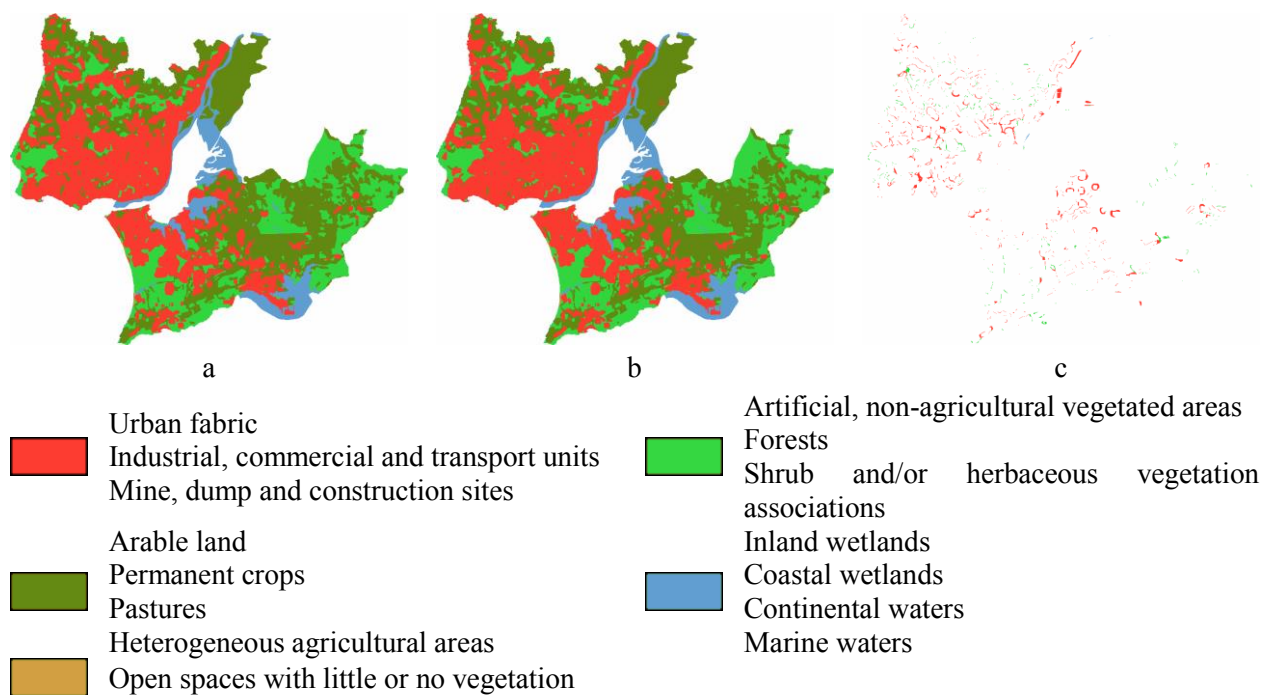|			
🟥	Urban fabric Industrial, commercial and transport units Mine, dump and construction sites	🟩	Artificial, non-agricultural vegetated areas Forests Shrub and/or herbaceous vegetation associations
🟫	Arable land Permanent crops Pastures Heterogeneous agricultural areas	🟦	Inland wetlands Coastal wetlands Continental waters Marine waters
🟧	Open spaces with little or no vegetation		

Figure1: Forecast map by main scenario (a), alternative scenario (b) and difference map (c).

Table 5: Statistic of modified matrix of expected transitions.

L.C.	The number of elements in the predictive map	The changed number of elements in the predictive map	The difference	The difference in proportions	G
1	73395	76145	2750	1,04	1,05
2	27014	28938	1924	1,07	1,10
3	3894	3696	-198	0,95	0,95
4	811	830	19	1,02	1,05
5	30553	27493	-3060	0,90	0,90
6	13839	14258	419	1,03	1,05
7	1876	1876	0	1,00	1,00
8	61842	58749	-3093	0,95	0,95
9	35418	35418	0	1,00	1,00
10	29443	30672	1229	1,04	1,10
11	221	221	0	1,00	1,00
12	55	55	0	1,00	1,00
13	4947	4947	0	1,00	1,00
14	1311	1321	10	1,01	1,05
15	16938	16938	0	1,00	1,05
All	301557	301557	0	1	-

6   CONCLUSIONS

Considering alternative simulation scenarios can be useful for a comprehensive study of the territory development. Alternative scenario can be implemented by making changes in matrix of expected transitions. When you make changes you need to remember about preserving the correctness of the matrix. The conditions of maintaining the correctness of expected transitions matrix may contradict the parameters of its change, so the selection of such parameters is a difficult task. As an approach to the modification of expected transitions matrix an algorithm that prioritizes a reduction of the specified classes is proposed. This approach allows estimating how the representation of classes in the forecast map will change in advance, before modeling, in contrast to the similar approaches. The presented algorithm saves correctness of expected transitions matrix, even with incorrectly specified initial conditions. The proposed algorithm is tested on a real task of Portugal territory modelling. However, it can be easily adapted to any territory of application.

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