COMPUTER SIMULATIONS ON CELLULAR AUTOMATA MODELS OF METAPOPULATIONS IN CONSERVATION BIOLOGY

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HU ISSN 1418-7108: HEJ Manuscript no.: ENV-011125-A

Abstract

Metapopulations are sets of local populations of isolated patches connected via migration of individuals. They are realistic models of populations living in patchy environment and hence they can be used to predict the changes of such systems in relatively large time scales. Cellular automata are effective modelling tools for describing metapopulations. In this paper, we apply computer simulations on cellular automata models of metapopulation to investigate two problems of conservation. Habitat destruction can dramatically alter the outcome of the competition between a weedy and a resident species. Invasive species cause considerable problems worldwide. Our simulations show that it is impossible to get rid of them only by elimination.

1 Introduction

Metapopulation biology is a young field of ecology that studies habitat-systems called metapopulations [1]. Thanks to the applications in different fields of population ecology, landscape ecology and conservation biology, metapopulation biology improving fast and has become a new discipline in itself.

As a result of human activity for transforming the environment, natural life is restricted to quite narrow patches. A lot of species live in habitat patches connected by migrating individuals. One of the most relevant problems in conservation and regional planning is how to make balance between the human needs (sometimes demands) for occupying area and the demand of preserving the natural communities.

Habitat destruction can cause essential and sometimes fatal changes in natural communities. For example, even only one new petrol station can destroy a live metapopulation with large equilibrium patch occupancy and high total abundance [1]. Habitat destruction helps *non–indigenous* species to invade intact habitats. On the other hand, it can mean unsolvable problem for the native species to spread. When a non-indigenous species enters a metapopulation, it can increase its abundance so high that it changes the properties of the habitat patches that prevents the recolonisation of the resident species. Invasive species can cause even worse economical losses. According to David Primentel et al. „Invading non-indigenous species in the United States cause major environmental damages and losses adding up to more than $138 billion per year” [2]. The problem is not confined to the New World, it is also present in Europe. There is no good solution. Eradication is expensive, dangerous and many times practically impossible as in cases of plants [3].

In this paper, we consider mathematical models and present the results of our computer simulations to investigate the questions how the competition against invader is effected by habitat destruction and if it is possible to eradicate non-indigenous species by clearing patches.

2 The Models

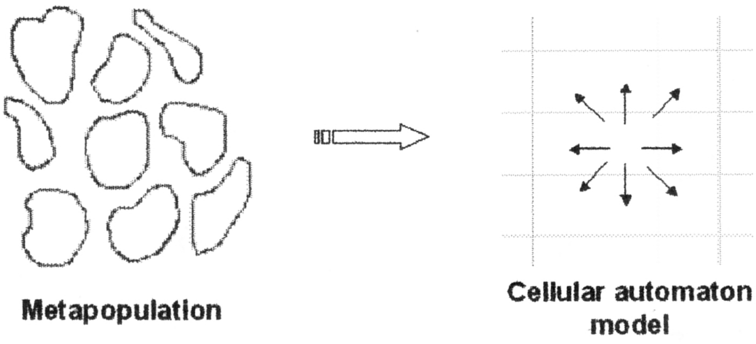
In general, a metapopulation is a set of local populations inhabiting isolated patches of resources, which are connected by migrating individuals. The local populations of patches are generally considered individuals. To describe the behaviour of a metapopulation, first we have to give the variation and the connection of the patches in space and time, i.e., the variation of the topology of the life–space. In the simplest cases, the position, shape and size of the patches are considered to be constant. Then, we need to give a transition function or updating rule that defines the development of the local populations of the patches. It can depend on time, the local properties and the inter–patch effects such as migration, colonisation and the interactions between the different species.

Cellular automata provide realistic, effective and reliable models of the spatiotemporal dynamics of metapopulations [4]. Consider a lattice of cells in the space with a given neighbourhood (topology). A simple case is a lattice of squares on the plane, where each square has eight neighbours according to Figure 1. The squares correspond to the patches of the metapopulation. The state of the cells at a given moment is described by the composition of species occupying the corresponding patch. The transition function gives the next state of the cells (the time scale is discrete). It can depend on the time and the current state of the local and the neighbouring cells. Next, we deal with a cellular automaton for the phenomenon of *habitat destruction*, and then consider the case of invasive species.

2.1 Habitat destruction

Habitat destruction means that there are empty patches in the metapopulation and no species are able to colonise them. The relative frequency of destroyed patches is called the degree of destruction. To study the global behaviour of habitat destruction Nee & May [5] developed a model of ordinary differential equations that describes the global behaviour in the time (global proportion of the species) of the system. Since the change of the local properties, e.g. the behaviour of the patches is also significant, we built a cellular automaton model, which allows studying both the local and global space–time development of the system. We note that for the global properties our cellular automaton and the differential equations of Nee and May give equivalent results. In our model, there are two competing species. If one of them is a

Figure 1: Building a cellular model of a real metapopulation



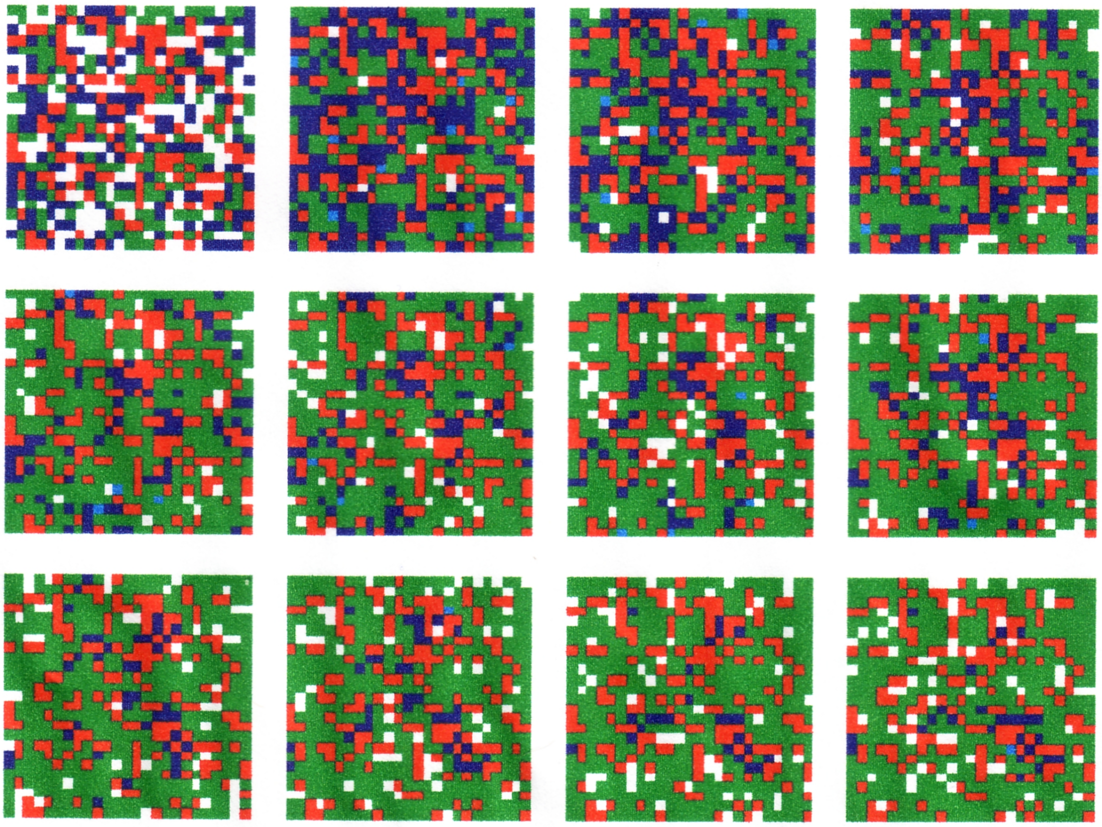
competitive superior to the other and later it becomes more dispersive (weed), then they can live together in a metapopulation. For the simplicity, we assume that the transition function does not depend on the time and the spatial position of the cells. Only the superior competitor can overcolonise those patches, which are occupied by the other species. A cell cannot be occupied by more than one species. When both species colonise the same patch, the superior wins within one time–step. The characteristic properties of each species are the probabilities of colonisation and the survival after local stochastic environmental catastrophes. Hence the cellular automaton model contains two parameters for each species. Colonisation rate (c_i) is the probability of colonisation of given empty patch by species #i, if it has a neighbour occupied also by #i. Extinction rate (e_i) is the probability at which the given patch occupied by #i becomes empty at the next step.

For the simplicity, we assume that the superior competitor can overcolonise the patches occupied by the weedy species as if they were empty patches. After overcolonisation the weed dies out of that patch. We summarize the updating rule in the following table:

State of the patch	Species #1	Species #2 (weed)
Destructed	unable to colonise	unable to colonise
Occupied by #1	dies out with prob. e_1	unable to colonise
Occupied by #2	colonise with prob. c_1	dies out with prob. e_2
Empty	colonise with prob. c_1	colonise with prob. c_2
Occupied by both	remains	dies out

Figure 2. shows the development of this metapopulation model provided by our packages in Mathematica (Wolfram Research). For the technical details, see [4][6][7].

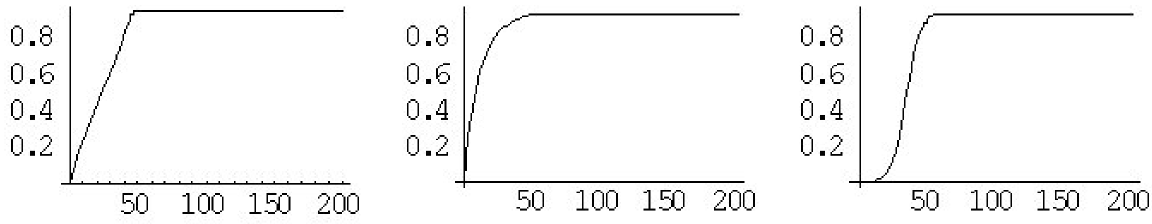
Figure 2: The states of the metapopulation at every 20th steps from the initial to the 220th step. Colouring of patches: green - species #1, blue - weedy patches, red - destructed habitats, white - empty patch. ($c_1 = 0.01$, $e_1 = 0.01$, $c_2 = 0.25$, $e_2 = 0.01$)



2.2 Invasive species

To simulate the varying attitude of the invasive species, let the updating rule of the cellular automaton explicitly depend on the time. Initially, when the alien species is rare, the situation seems to be good, it is not weeded out, and it is even propagated. But later, the alien becomes common and begins to disturb important species. Then propagation has to turn into eradication. Such a control of the invasive species appears in our model as decreasing colonisation and increasing extinction rate function $e(t)$. We investigated the behaviour of the system at different the constant colonisation rates (no artificial migration at early time-steps) and with linearly, exponentially and logistically saturating extinction functions (see Figure 3). The maximal efficiency of elimination, i.e., the maximum of $e(t)$, is smaller than 1 in each case.

Figure 3: Linear, exponential and logistic extinction rates. The maximum efficiency of eradication is 0.95 in all cases.



3 Results

Our simulations show that habitat destruction helps the spreading of weedy species in a wide range of parameter values. Destruction increases the proportion of the patches occupied by the weeds. They can survive higher destruction as we can also see in the nature and other models [5][6].

We can also conclude that invasive species can be eradicated if and only if its colonisation rate is low enough. Hence, there is no hope to eradicate non–indigenous species from the metapopulation by just eliminating most of the individuals even through hundreds of years. But it keeps the invasive process under control and reduces the equilibrium occupancy. This result is essentially independent of the function used to describe the growing elimination probability.

4 Discussion

Due to human and other reasons the original equilibrium of the natural life have dramatically changed. Weedy species can easily overcolonise the territories occupied so far by valuable ones, and there are more and more destructed regions, deserts. Our simulations confirmed that really good solutions are to decrease the colonisation ability of weeds, increase the propagation of native species, reduce habitat destruction and maintain better conditions for natural species. But until they all will be possible, huge human efforts and billions of money are needed year by year on all over the World to control invasive species.

Figure 4: Proportion of patches occupied by species #1 (green) and the weed (blue) the degree of destruction (red line) as a function of time–steps at different maximal colonisation and extinction rates ($c_1 = 0.1$, $e_1 = 0.2$, $c_2 = 0.6$, $e_1 = 0.1$)

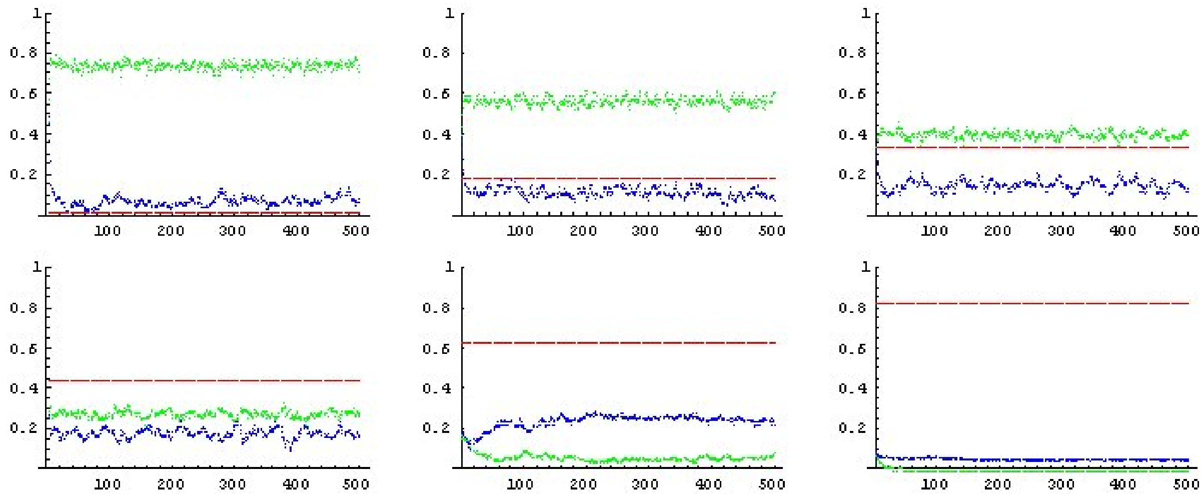
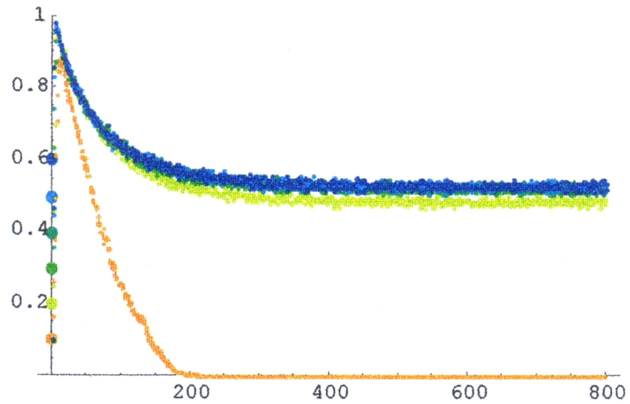


Figure 5: Change of the fraction of occupied patches in time, using exponential extinction and different colonisation rates. Colouring is as in Figure 4.



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