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Χρησιμοποιώντας μοντέλα προσομοίωσης οικοσυστημάτων για τη διδασκαλία της «ελαστικής» φύσης

Georgios Ampatzidis, Marida Ergazaki

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Using ecosystem simulation models to teach about the 'resilient nature'

Χρησιμοποιώντας μοντέλα προσομοίωσης οικοσυστημάτων για τη διδασκαλία της «ελαστικής» φύσης

Georgios Ampatzidis Adjunct lecturer Helleni Open University ampatzidis.georgios@ac.eap.gr	**Marida Ergazaki** Associate Professor University of Patras ergazaki@upatras.gr

Abstract

This paper is concerned with the NetLogo models we developed in order to simulate possible trajectories of disturbed/protected ecosystems according to findings of current ecological research. The four models we present here were integrated in a learning environment aimed at supporting non-biology major students in (a) substituting the idea of the 'balanced nature' with the currently valid idea of the 'resilient nature' and thus constructing an up-to-date understanding on ecosystems' function, and (b) using this understanding to advance systems thinking skills. Each model has two versions concerning two different trajectories of the ecosystem with specific initial conditions or features of the recovery plan. In our case studies, students explored in triads the ecosystem models with the aid of worksheets, which required predictions about the ecosystem's behaviour before using the model and explanations afterwards. Half of students' triads explored the 1st version of each model while the other half explored the 2nd one. At the end of each session, the two different trajectories simulated by each model were discussed with the whole class to enhance the emergence of the idea of contingency. Our results about the effectiveness of the final version of the learning environment were promising and are reported elsewhere.

Keywords: *Ecosystems' models, model-based learning, resilient nature, balanced nature, ecology teaching and learning*

Περίληψη

Το παρόν άρθρο αφορά την ανάπτυξη μοντέλων NetLogo τα οποία προσομοιώνουν την πορεία οικοσυστημάτων που διαταράσσονται ή προστατεύονται και βασίζονται σε ευρήματα της σύγχρονης οικολογικής έρευνας. Τα τέσσερα μοντέλα που παρουσιάζονται ενσωματώθηκαν σε ένα μαθησιακό περιβάλλον που στοχεύει να υποστηρίξει μη βιολόγους φοιτητές (α) στην αντικατάστασή της ιδέας της «φύσης σε ισορροπία» από τη σύγχρονη ιδέα της «ελαστικής» φύσης, και (β) στην αξιοποίηση αυτής της αντίληψης για την ενίσχυση «δεξιοτήτων συστημικής σκέψης». Κάθε μοντέλο έχει δύο εκδοχές που προσομοιώνουν δύο διαφορετικές εκδοχές της πορείας του οικοσυστήματος ανάλογα με συγκεκριμένες αρχικές συνθήκες ή δράσεις στην προσπάθεια επαναφοράς. Στις μελέτες περίπτωσης που πραγματοποιήσαμε, οι φοιτητές σε τριάδες διερεύνησαν τα μοντέλα με τη βοήθεια φύλλων εργασίας, που τους ζητούσαν να κάνουν προβλέψεις για την πορεία του υπό μελέτη οικοσυστήματος και έπειτα να τις ελέγξουν «τρέχοντας» το μοντέλο. Οι μισές τριάδες των φοιτητών ασχολήθηκαν με την 1η εκδοχή κάθε μοντέλου και οι άλλες μισές με τη 2η. Στο τέλος κάθε μαθήματος, οι δύο διαφορετικές εκδοχές της πορείας του οικοσυστήματος που προσομοίωνε κάθε μοντέλο γίνονταν θέμα συζήτησης όλης της τάξης ώστε να αναδειχθεί η ιδέα της ενδεχομενικότητας. Τα αποτελέσματα της λειτουργίας της τελευταίας εκδοχής του μαθησιακού περιβάλλοντος είναι ενθαρρυντικά και δημοσιεύονται σε άλλα άρθρα μας.

Λέξεις-κλειδιά: *Μοντέλα προσομοίωσης οικοσυστημάτων, μάθηση με βάση μοντέλα, ελαστική φύση, φύση σε ισορροπία, διδασκαλία και μάθηση οικολογίας*

Introduction

Current views on ecosystems describe them as complex and dynamic (Ladle & Gillson, 2009). According to the idea of the 'resilient nature', ecosystems may exist in more than one alternative stable states and they may transit between them rather abruptly when specific tipping points are reached (Scheffer, 2009). The reversion of these transitions may show 'hysteresis', meaning that shifting back from stable state B to stable state A – if possible – may happen at a different tipping point than the original shift from stable state A to stable state B did (Scheffer, 2009). Thus, nature is considered constantly changing in both time and space in non-linear, contingent ways (Gunderson, Allen, & Holling, 2010; Holling, 1973).

The 'resilient nature' idea opposes the scientifically criticized 'balanced nature' idea, which appears to be prevalent in public opinion (Ladle & Gillson, 2009), school science (Jelinski, 2005; Westra, 2008) and students' reasoning about ecosystems' responses to human-driven disturbance or protection (Ergazaki & Ampatzidis, 2012). It has been argued that the 'balanced nature' idea, which implies a predetermined order and stability assured by the will of a divine power or nature itself (Cooper, 2001; Cuddington, 2001), may hinder conceptual understanding, since it opposes what is considered to be an up-to-date understanding of nature's function. It may also interfere with environmental awareness; in fact, by implying that ecosystems have an overestimated ability to restore their initial state whenever disturbed, the 'balanced nature' idea may undermine the significance of not disturbing them (Gunderson et al., 2010; Westra, 2008).

Considering how important it is to help young people abandon the idea of the 'balanced nature', we decided to design a learning environment that introduces the idea of the 'resilient nature' instead. Since this idea may also offer an appropriate context for advancing systems thinking skills (Boersma, Waarlo, & Klaassen, 2011; Richmond, 2004), the objectives were to support non-biology major students in (a) challenging the idea of the 'balanced nature' and constructing an up-to-date understanding of ecosystems' function through the idea of the 'resilient nature', and (b) using this understanding to advance context-free ideas such as interdependence and reciprocality, which have to do with systems thinking skills.

Moreover, we decided to have ecosystem simulation models integrated in our learning environment. So, we used NetLogo in order to develop four models that simulate possible trajectories of ecosystems that have been studied in current ecological research. Using computer-supported models would give students the chance to visualize dynamic processes that take place at time-scales that are not really accessible by them (Rutten, van Joolingen, & van der Veen, 2012), and promote inquiry-based learning through meaningful interactions with peers and tools (Ergazaki & Zogza, 2008).

Our learning environment was implemented and tested in several research cycles of a developmental research. The results about its effectiveness with regard to students' ecological understanding and systems thinking skills have been discussed elsewhere (e.g. Ampatzidis & Ergazaki, 2017; Ampatzidis & Ergazaki, 2016; Ampatzidis & Ergazaki, 2014). Here we focus just on the four simulation models we developed for the purpose of this study.

Overview of the learning environment

The learning environment aims to highlight the contingent behaviour of ecosystems through the basic assumptions of the 'resilient nature' idea. The learning objectives (LOs) have to do with understanding these assumptions (LO1-LO4), and with using them to (a) challenge the notion of balance as an inherent feature of nature, and (b) move to the notion of contingency ($LO_{-contingency}$) (Table 1).

Learning Objectives	
LO1	Ecosystems may have multiple alternative states
LO2	Each state is self-organized through feedbacks changing at tipping points
LO3	Shifts between alternative states may be irreversible or reversible based on initial state or handlings
LO4	Reversing the factor that caused the shift, does not necessarily bring the ecosystem to its prior state
$LO_{-contingency}$	Natural systems show a contingent and not pre-determined behaviour ('resilient nature' vs 'balanced nature')

Table 1. Learning Objectives (LO).

Students were actively introduced to the target assumptions of the 'resilient nature' idea in five, 2-hour sessions of an optional ecology course. In sessions 1-4, they explored 'NetLogo' models (in short 'NM'), with the aid of worksheets that required predictions about the ecosystem's behaviour before using the model and explanations afterwards. The four models we developed for the study simulated terrestrial or aquatic ecosystems which were either protected or disturbed by humans, and were based on findings of current ecological research. Each model had two different versions, showing two different trajectories of the ecosystem depending on initial conditions (NM1, NM2, NM4) or on certain human actions in the recovery plan (NM3). Half of the students' triads explored the 1st version of each model while the other half explored the 2nd one. At the end of each session, the two different trajectories that were simulated by each model were discussed with the whole class.
The interface of the models included the following: (a) a series of boxes showing population size and the level of key abiotic factors (e.g. nutrients) whether applicable, (b) a simulation window showing the individuals of the different populations in different shapes and colors, and (c) a graph window showing changes regarding population size and levels of abiotic factors with time and thus providing students with a graphical representation of the trajectory of the ecosystem they were exploring.
In the 5th session, students were engaged in reasoning about ecosystems' behaviour using landscape models made from plasticine cardboard and hands-on activities concerning systems thinking.

The NetLogo Models in detail

NM1-Forest

NM1-Forest simulates a forest with two plant populations (bushes and spruces) and three animal populations (rabbits, budworms, passerines) connected with the following trophic relations:

- Budworms live on the spruces and feed on their leaves.
- Passerines feed on budworms that they find on the spruces.
- Rabbits feed on the leaves of the bushes.

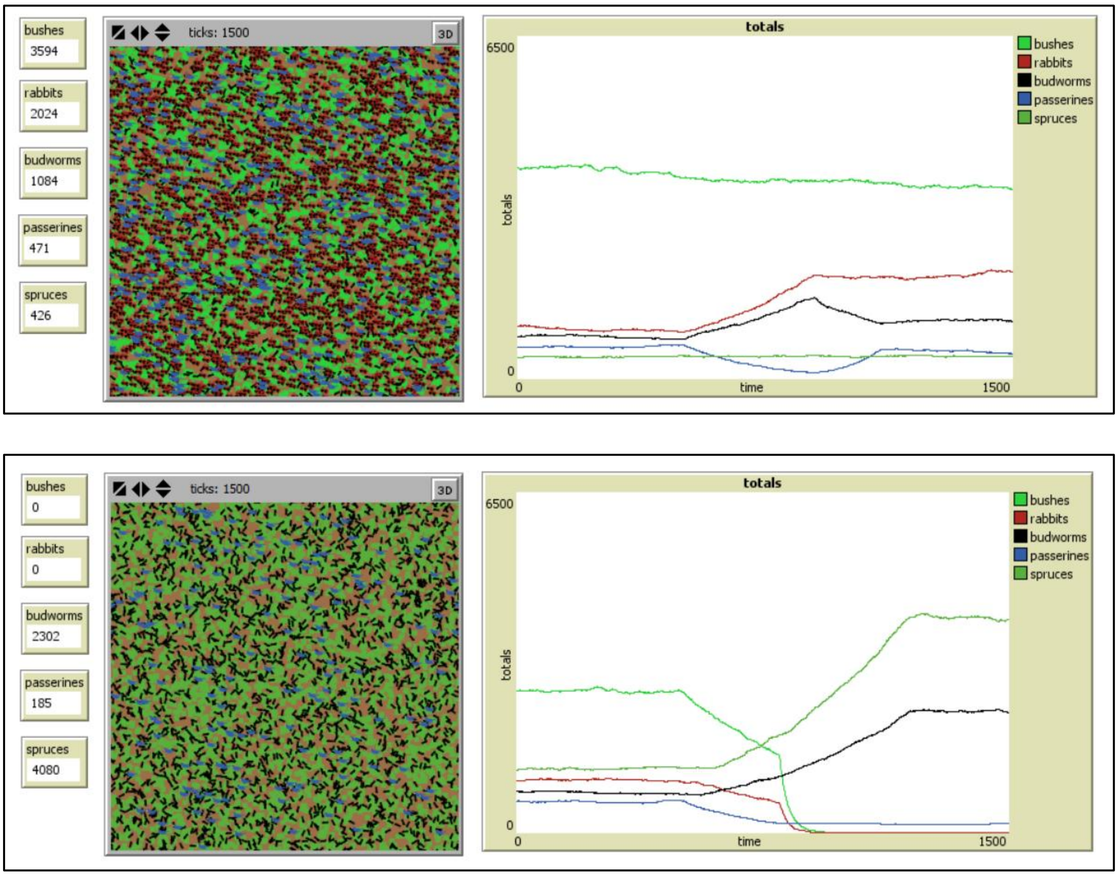

Figure 1. The two-version NM1-Forest model: version 1 at the top, version 2 at the bottom.

The forest is going through a maturation process which results in changes of the size of the forest populations. Within the 1st version of the model, the ecosystem remains at the same stable state, while within the 2nd version the bushes and rabbits disappear and the ecosystem shifts to another stable state. The design of NM1-Forest was informed by the research of Gunderson et al. (2010) regarding a forest ecosystem in Canada. Their study concerns the abrupt increase of numbers of budworms who parasitize spruces. When their population increases over a threshold, they are able to destroy large parts of forest. It is suggested that the possible time when such an increase may happen depends on the age of the trees and the size of their predators' populations (Gunderson et al., 2010). NM1-Forest focuses on LO1, LO2 and LO

contingency·

NM2-Lake

NM2-Lake simulates a lake with two plant populations (phytoplankton and lakebed plants) and three animal populations (zooplankton, fish-a, fish-b) connected with the following trophic relations:

- Zooplankton feed on phytoplankton.
- Fish-a feed on zooplankton.
- Fish-b feed on lakebed plants.

Extra nutrients are introduced in the lake which results in changes of the size of the lake populations. Within the 1st version of the model, the ecosystem remains at the same stable state, while within the 2nd version all populations except phytoplankton die out and the ecosystem shifts to another stable state.

The design of NM2-Lake was informed by the research of Scheffer (2009) regarding a lake ecosystem in Netherlands. His study concerns a eutrophic lake where the large size of the population of phytoplankton impedes the growth of lakebed plants, since little sunlight reaches the bottom of the lake. It is suggested that the effort to decrease the nutrients in the water has certain difficulties, because the absence of lakebed plants leads to anoxic conditions at the lakebed, which facilitate the release of nutrients (phosphorus) from it to the lake's water. Moreover, the search for food by fish near the lakebed makes the growth of lakebed plants even more difficult (Scheffer, 2009). NM2-Lake focuses on LO1-4 and $LO_{\text{-contingency}}$.

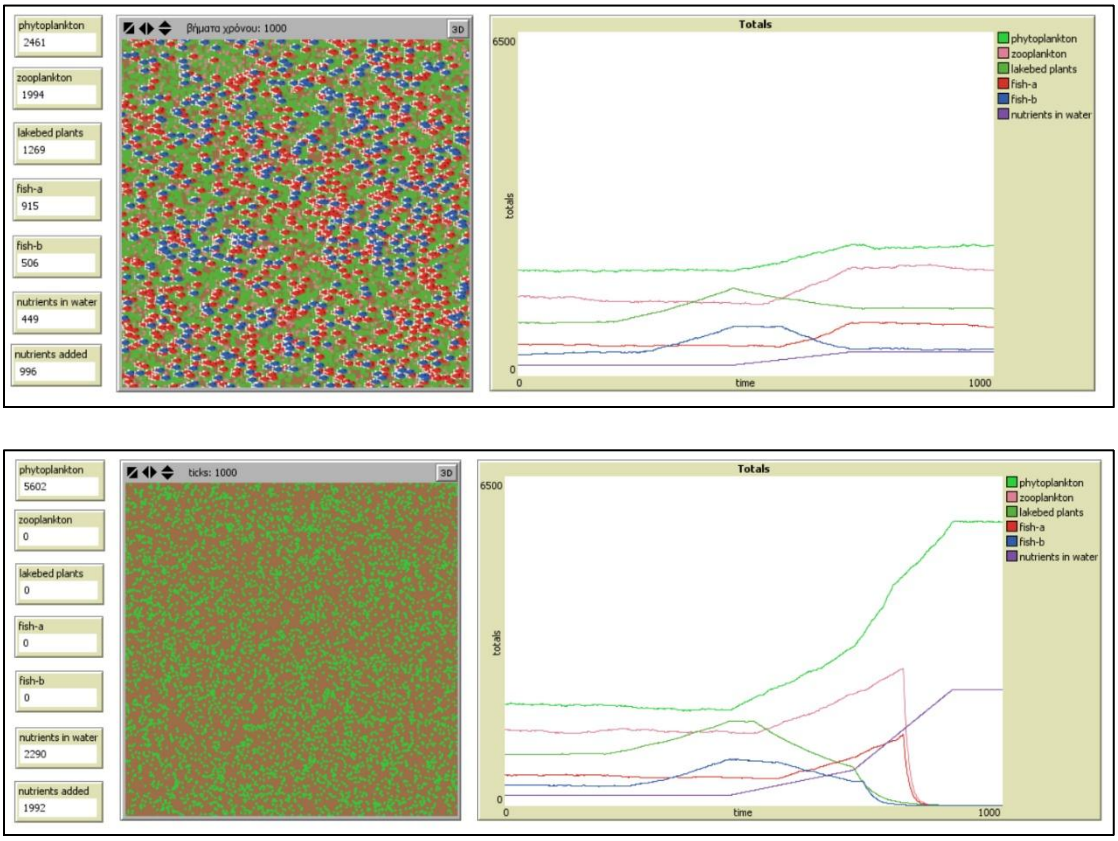

Figure 2. The two-version NM2-Lake model: version 1 at the top, version 2 at the bottom.

NM3-Lake / recovery plan

NM3-Lake simulates a lake with two plant populations (surface plants and lakebed plants) and two animal populations (fish-a, fish-b) connected with the following trophic relations:

- Fish-a feed on surface plants.
- Fish-b feed on lakebed plants.

Extra nutrients are introduced in the lake which results in changes of the size of the lake populations. Subsequently, a recovery plan is implemented, which includes removing nutrients and adding the populations that died out along with other corrective actions. Within the 1st version of the model, the lake shifts back to its previous stable state, while within the 2nd version this shift is not possible.

The design of NM3-Lake was informed by the research of Scheffer (2009) regarding the eutrophic lake we already mentioned, but in the phase of a recovery attempt. According to his findings, the removal of a big number of fish from the lake limits the side-effects from their food-search near the lakebed and gives the lakebed plants a chance to grow. This growth may result in the increase of the oxygen level in the water, stopping the release of nutrients (phosphorus) from the bottom of the lake (Scheffer, 2009). NM3-Lake focuses on LO1-4 and LO$_{\text{-contingency}}$.

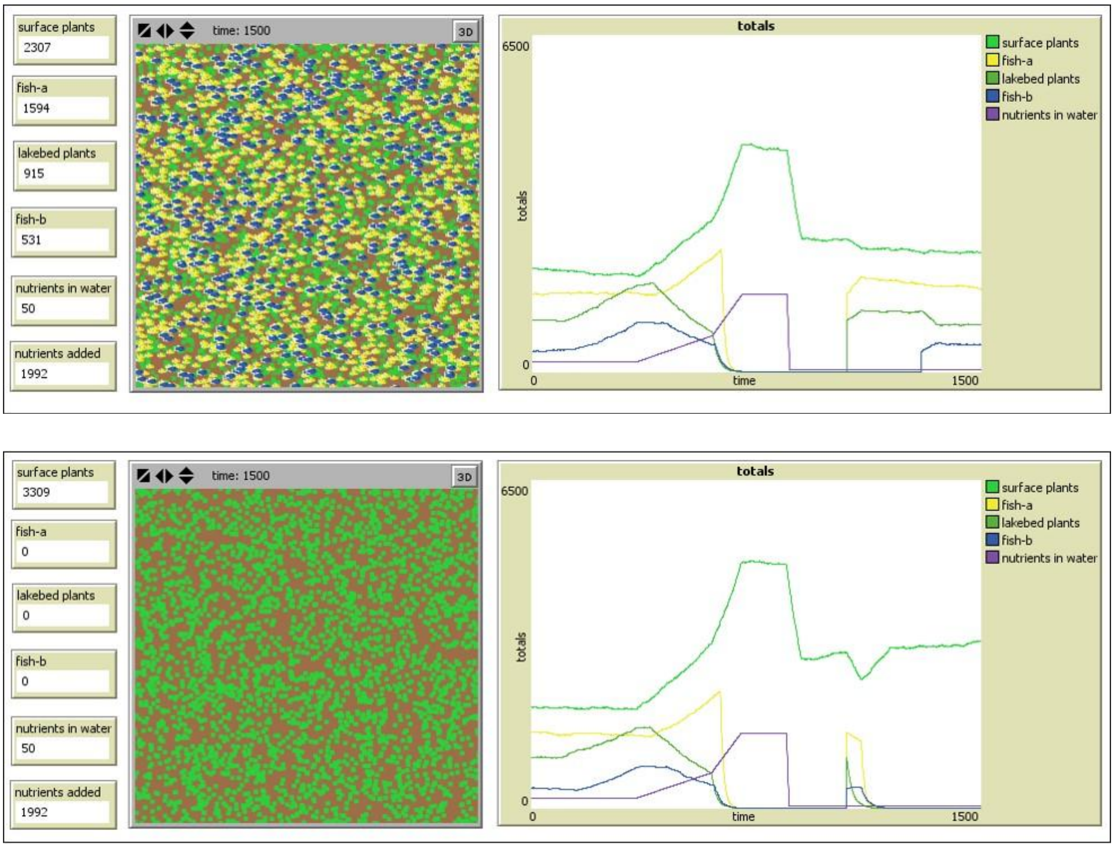

Figure 3. The two-version NM3-Lake / recovery plan model: version 1 at the top, version 2 at the bottom.

NM4-Meadow

NM4-Meadow simulates a meadow with two plant populations (plants-a and plants-b) and three animal populations (bugs, grasshoppers, spiders) connected with the following trophic relations:

- Bugs feed on plants-a.
- Grasshoppers feed on plants-b.
- Spiders feed on grasshoppers.

At some point all the spiders are removed from the meadow for a certain period of time and they are re-introduced later. This results in changes of the size of the meadow populations. Within the 1st version of the model, the meadow shifts back to its previous stable state (i.e. the one before the spider removal), while within the 2nd version this shift is not possible.

The design of NM4-Meadow was informed by the research of Schmitz (2010) regarding a meadow ecosystem in USA. His study concerns the trophic relations among two certain plant populations, a grasshopper population which feed on the plants and a spider population which are predators of the grasshoppers. It is suggested that when a spider population is present in the meadow, the grasshoppers feed on a specific plant population, while when the spider population is removed they change their food preference and feed on another plant population. Thus, spiders control indirectly the size of the plant populations in the meadow by affecting the food preference of the grasshoppers (Schmitz, 2010). NM4-Meadow focuses on LO1-4 and $LO_{\text{-contingency}}$.

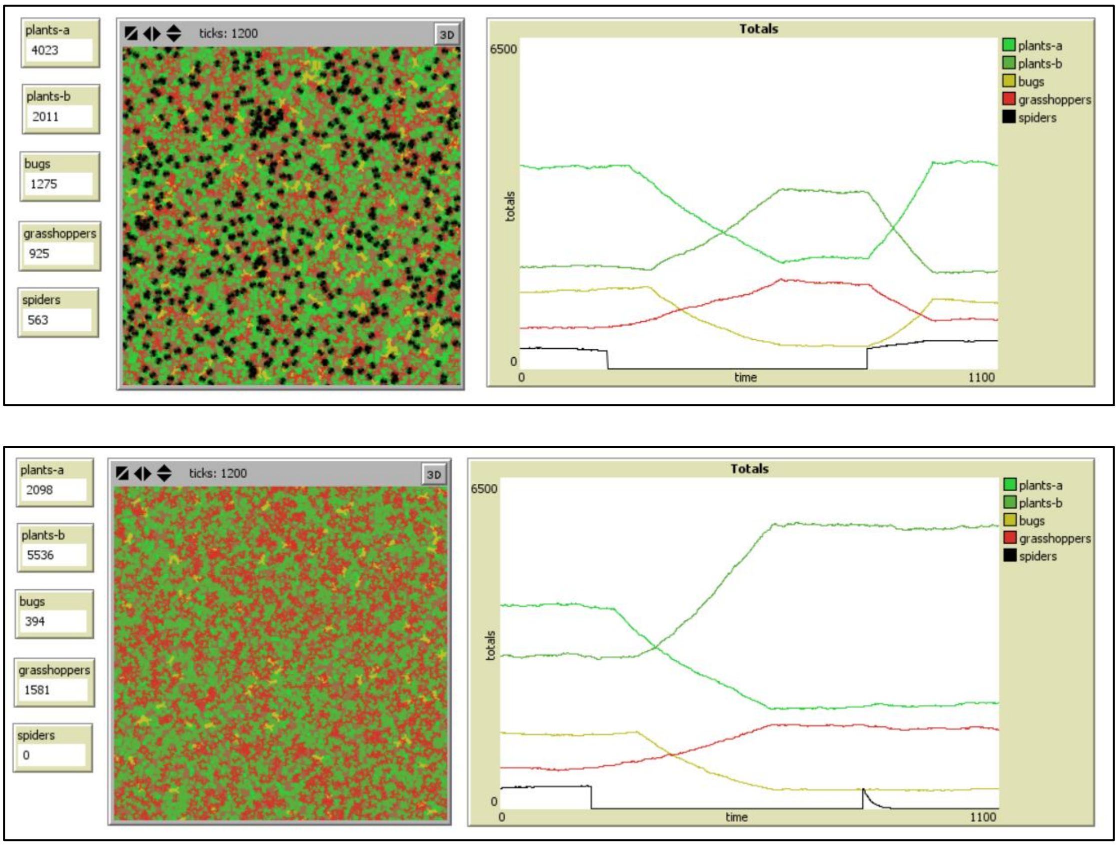

Figure 4. The two-version NM4-Meadow model: version 1 at the top, version 2 at the bottom.

Theoretical output

The theoretical output that derives from the use of two-version models when introducing contingency will be thoroughly presented in a paper we are currently preparing (Ampatzidis & Ergazaki, in preparation), and it seems to be rather promising. In summary, it can be conceptualized as a 'Bifurcated Domino Path' ('BDP') with several 'forks' and 'meeting points'. At each 'fork', some peer-groups explore one version of the target phenomenon and some others explore an alternative one, while at each 'meeting point' they all share their different conclusions in order to realize the underlying contingency. It is possible that the computer-supported 'BDP' can contribute to the teaching and learning of different biological phenomena underlied by contingency as well. Testing this possibility seems quite interesting.

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