Individual based model of plant communities

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Abstract. Simulation modelling is an important aspect of research in ecological and environmental subjects. Such model can guide the research process, integrate the knowledge coming from a variety of studies, permit the testing of hypothesis, and enable predictions to be made. A model of Mediterranean plants growing as stand alone on communities is proposed. In this paper a vegetation model (Individual Based Plant Communities - IBCM), developed in the *Simile* modelling environment, is proposed which is able to simulate the growth of several plant species in mixed communities under different environmental conditions is presented

1 Introduction

In the past, population models were represented by few variables, such as the number of trees in a plant community, or amount of carbon in the ecosystem. This approach was not able to assess the interactions between individual organisms, thus the possibility of investigation of competition processes was limited. Traditional programming languages (e.g. Fortran, C++ or Basic) have been used to implement such models, but recently new approaches (system dynamic and object oriented languages) have been proposed [5]. These new system supply flexible tools and user friendly environments able to represent complex variables and processes interactions [12]. Based on these new available technology, arising interest on individual-based models of ecological population is found in scientific literature [3]. Many software tools on system dynamic paradigm, e.g. Stella, Simulink, PowerSim, Model Maker, are now available (see [2] for review. Recently, a new modelling system, Simile, characterised by high flexibility and modularity, has been developed by the University of Edinburgh. This system is very powerful to handle the modelling of complex ecological systems such as plant communities [10]. In this paper a vegetation model (Individual Based Plant Communities - IBCM) able to simulate the growth of several plant species growing in mixed communities under different environmental conditions is presented. In the model plant individuals interact by mutual shading and by affecting the water content on the same soil volume.

2 The modelling issues

Different models have been developed by using the Simile modelling environment, a software distributed by Simulistc Ltd (www.simulistics.com). The software allows to specify a model structure by a graphical representation of the system; i. e. compartments and flows, with related influences by different types of variables. A model is compiled automatically by the software, either in Tcl or C++ code, and can be run on PC under Windows and Linux systems. In Simile, models can be structured by assemblage of different sub-models which can also be nested one into each other. Moreover, any model can be replicated by creation of multiple instances which transform all model elements (compartments, flows, variables) into vectors [10].

2.1 IPM - Individual Plant Model

The Individual Plant Model (IPM) is a generic model to simulate biomass growth of plant-systems. It calculates the biomass of three plant parts: leaves, stem-trunk, roots. The IPM is divided in to five different sub-models:

1. The *Photosynthesis* model calculates the amount of photosynthate (PN) produced by a plant. PN is driven by light and is calculated as the response of leaves to photosynthetic photon flux density (PPFD), hourly averages of incident irradiance. The resulting values is corrected by two reduction coefficients related to temperature and leaf water potential respectively. The functions relating PN to PPFD, temperature and water potential are species specific, and the equation is [8]
$$PN = a + b * c^{PPFD}, \tag{1}$$
where the parameters a, b, c are functions of species.
2. The *Maintenance* sub-model calculates the carbon requirement for respiration of all plants parts. The respiration requirement are estimated by the living biomass of different plant structures multiplied by some coefficient related to species and temperature. A similar approach is followed in the GOTILWA model [7]. The maintenance coefficient are mathematically expressed as
$$k * 2^{\frac{temperature-25}{10}}, \tag{2}$$
where k is a species parameters and the exponent of 2 reflects the effects of temperature changes with an optimal reference term of 25 C.
3. The *Partitioning* of biomass in plants is a complex process which depends on both internal and external factors [1] [6]. In the model development, the following premises have been considered: partitioning between plant parts changes with age; plants do allocate differently above and below ground in order to compensate limiting environmental factors (e.g. limiting light and water conditions induce increased allocation to leaves and

roots respectively); partitioning behaviour changes in reaction to disturbances (cut, fire, root predation and turn-over) in order to facilitate the recovery of removed structures. The model presented here solved the above mentioned problems by relating the allocation behaviour to the internal status of plants instead of considering external growth conditions [9].

4. The *Growth* sub-model divides the net photosynthesis PN in maintenance respiration and vegetation growth. The remaining amount increases the reserve pool. A surplus in the reserve compartment produces an essudation flow out from the roots. The growth of above and below structures is function of species parameters and is affected by limiting growth factors (temperature and water potential).
5. The *Plant Soil Water Relation* sub-model calculates the soil water content and the amount of water transpired by the plants. The soil is divided into layers defined by different size and soil characteristics (depth and radius, organic matter, bulk density, and texture). Plants remove water from different soil layers according to their relative root biomass and activity. Water flows into layers are: infiltration by rain, in-drainage from above layer, out-drainage to below layer, evaporation (only for surface layer), transpiration (water removed by plants). Soil water retention curves are evaluated by pedotransfer [13] laws which are function of θ (water volume fraction) and ψ (water potential in bars). Potential transpiration can be estimated by Penman-Monteith equation [4] and leaf area index values to evaluate the potential transpiration [11]. The actual transpiration is calculated by partitioning the potential value according to θ, temperature and root biomass in each layer. The model removes water from different layers taking into account the root distribution along the soil profile.

2.2 IBCM - Individual Based Communities Model

The IBCM is generated by the assemblage of IPMs. This is done by assigning spatial coordinates to the different individuals. The model calculates the amount of shading for every plants in the community, i.e. the reduction of incident light due to shade by neighbours. In the model, each plant is defined by its x, y position, radius of crown and height. The model uses a "conditional submodel", i.e. a calculation tool that verifies IF condition is accomplished before executing calculation. The conditions are:

- the height of tree i (target tree for shade calculation) is less than height of tree j (neighbour tree).
- distance between i and j is less the sum of crown radii (Ri+Rj)of the considered plants. After verification of these conditions the model estimates a shade index as function of distance, size, and species. The figures 1 and 2 represents the application of the IBCM in two different communities, characterised by changing cover levels

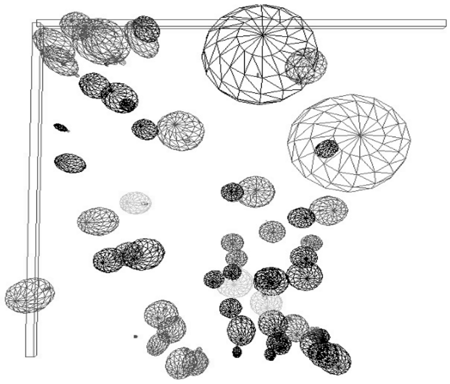

Fig. 1. IBCM and low cover

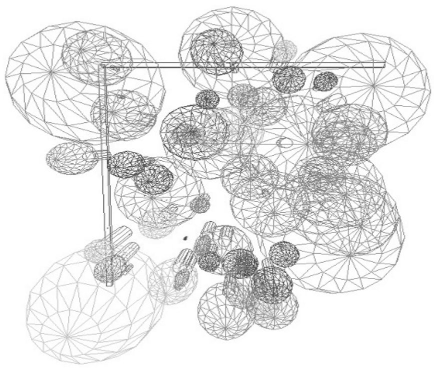

Fig. 2. IBCM and hight cover

3 Plant community 3D visualization

A TCL/TK code was written to interface the Individual based model of plant communities to VRML (Virtual Reality Modelling Language). A helper tool in Tcl/Tk of SIMILE was implemented to read the value of the IBCM model output to produce a ASCII file for VRML 2.0, used to generate the image of the community. Each tree is represented as an ellipsoid on the top of a cylinder whose size are respectively proportioned to crop and to the trunck, moreover each species is characterised by different colour. Therefore, the input of this viewer tool are: the (x,y) coordinates, species type, height of plant and the tree axes of the crown.

The VRML file has also a "clock" to simulate the growth of the communities according to the IBCM results. Figure 2 shows a screen image of an IBCM, in 3 different positions.

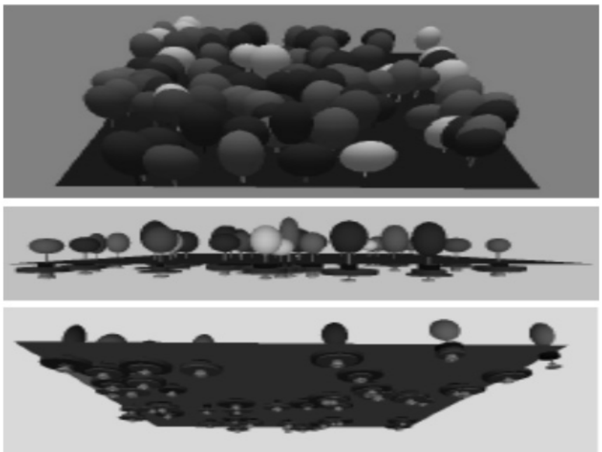

Fig. 3. 3D visualization in VRML of a plant community: above top view, central lateral view, bottom underground view.

4 Results and discussion

The present version of IBCM allows the user to compare the functioning of different plant communities with a high level of structural and functional details on above ground vegetation. In fact, it is possible to simulate the development and physiological behaviour of individual plants as effected by environmental conditions. Figure 3 shows the growth of individuals of different plant species.

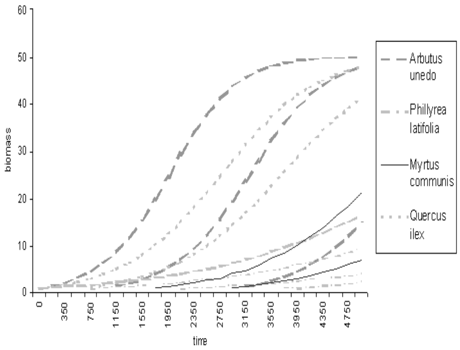

Fig. 4. Output curves of IBCM for 4 species

The IBCM seem a powerful and versatile spatially explicit vegetation model. In the figure 4 it is possible see the IBCM curves in a communites with four differnt species (Arbutus unedo, Phillyrea latifolia, Phillyrea latifolia and Quercus ilex). The Simile modelling environmental showed a high capability to implement ecological knowledge into a simulation model. Further applications will deal with increasing details on the plant shape representation and higher resolution of soil spatial variability. The model and further details can be found at http://www.ecoap.unina.it.

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