*Ninth Workshop Dynamical Systems Applied
to Biology and Natural Sciences DSABNS 2018
Turin, Italy, February 7-9, 2018*

VEGETATION TURING PATTERNS: FROM PDE TO HYBRID MODELLING

Francesco Giannino[1]*, Fabrizio Cartenì[1] and Christian E. Vincenot[2]

[1]Department of Agricultural Sciences,
University of Naples Federico II, Napoli, Italy

[2]Department of Social Informatics, Kyoto University, Kyoto, Japan

giannino@unina.it (*corresponding author),
fabrizio.carteni@unina.it, vincenot@bre.soc.i.kyoto-u.ac.jp

Spatial patterns and self-organization of plants has been a subject of great interest because the underlying mechanisms have been diverse and hard to simulate, raising different explanatory hypotheses. Moreover, in mathematical terms, reaction-diffusion systems which give rise to Turing instabilities have been used to model emergence of vegetation patterns under different environmental conditions [1,2]. Finally, hybrid modelling is the integration of different modelling approaches with the new paradigm emerging from the integration of differential equations (ODE and/or PDE) into individual-based models (IBM), two antithetical yet complementary views of systems.

Here we present different modelling approaches to study the emergence of vegetation patterns : from partial differential equation to hybrid models relying on the System Dynamics (SD) and Individual Based (IB) hybrid modelling approach [3].

First, we built a continuous model (PDE) to simulate the dynamic balance between plant biomass, water, and toxic compounds and we found the regions of the models parameter space that give rise to stable spatial Turing patterns [2]. Moreover in [4], plants with their individual characteristics (i.e. algorithmic life cycle based on metabolic processes with relevant state variables such as age or biomass) were naturally integrated inside of IB individuals. Likewise, the hydrology of soil parcels was simulated using a PDE system. SD-IB hybrid modelling made it possible to couple submodels computed in continuous time with other submodels taking decisions in discrete time. This technical capability increased the accuracy of the mathematical model by representing processes more naturally. Metabolism and local water dynamics are obviously biological and physical processes that happen continuously. On the other hand, the plants life cycle and seed dispersal include temporally punctual phenomena that should be modeled in discrete time. We studied the model behavior in relation to plant-specific parameters (seed dispersal distance and

 ISBN: 978-989-98750-4-3

reproductive age) and climatic inputs (precipitation intensity and seasonality). The importance of the representation of individual biological dispersal is thereby also evaluated through a comparison with previous reaction-diffusion models.

In a second undertaking [5], a derived model was capable of reproducing many patterns visible in nature. Simulations also made it possible to deduce some characteristics of plant populations subject to self-organization and spatial patterning. Divergences between the hybrid and the continuous diffusion model were noticeable in most of the simulation results, thus stressing the usefulness of fostering hybrid modelling approaches to overcome technical limitations and improve mathematical model accuracy [6].

References

[1] F. Cartenì, A. Marasco, G. Bonanomi, S. Mazzoleni, M. Rietkerk, F. Giannino (2012). *Negative plant soil feedback explaining ring formation in clonal plants*, Journal of Theoretical Biology, 313, 153–161.

[2] A. Marasco, A. Iuorio, F. Cartenì, G. Bonanomi, D. M. Tartakovsky, S. Mazzoleni, F. Giannino (2014). *Vegetation Pattern Formation Due to Interactions Between Water Availability and Toxicity in Plant-Soil Feedback*. Bulletin of Mathematical Biology, 76, 2866–2883.

[3] Vincenot C.E., Giannino F., Rietkerk M., Moriya K., Mazzoleni S. (2011). *Theoretical considerations on the combined use of System Dynamics and individual-based modeling in ecology*, Ecological Modelling, 222, 210–218.

[4] Vincenot Christian E., CartenìFabrizio, Mazzoleni Stefano, RietkerkMax, Giannino Francesco (2016). *Spatial Self-Organization of Vegetation Subject to Climatic Stress-Insights from a System Dynamics-Individual-Based Hybrid Model*, Frontiers in Plant Science, 7, fpls.2016.00636.

[5] Vincenot, Christian E., Cartenì, Fabrizio, Bonanomi, Giuliano, Mazzoleni, Stefano, Giannino, Francesco (2017). *Plant-soil negative feedback explains vegetation dynamics and patterns at multiple scales*, Oikos, 126, 1319–1328.

[6] Vincenot C.E., Mazzoleni S., Parrott L. (2017). *Hybrid Solutions for the Modeling of Complex Environmental Systems*, Frontiers Media SA. ISBN: 978-2-88945-055-8

ISBN: 978-989-98750-4-3