Pattern recognition and simulation in ecology

Article · December 2015

3 authors:

Xiaozhuo Han
GuangDong University of Technology
19 PUBLICATIONS   **126** CITATIONS

SEE PROFILE

Meng Gao
Lanzhou University
193 PUBLICATIONS   **1,308** CITATIONS

SEE PROFILE

Cang Hui
Stellenbosch University
251 PUBLICATIONS   **2,445** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project   The social-ecological impacts of invasive species View project

Project   MPDE'17: Global Change in Ecology - Cape Town/04-08/Sep/2017 View project

Article

Pattern recognition and simulation in ecology

Xiaozhuo Han[1], **Meng Gao**[2], **Cang Hui**[3,4]

[1]School of Applied Mathematics, Guangdong University of Technology, No.161, Yinglong Road, Tianhe District, Guangzhou 510520, China

[2]Key Laboratory of Coastal Environmental Processes and Ecological Remediation, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, 264003, China

[3]Center for Invasion Biology, Department of Mathematical Sciences, University of Stellenbosch, Matieland 7602, South Africa

[4]Mathematical and Physical Biosciences, African Institute for Mathematical Sciences, Muizenberg 7945, South Africa

E-mail: hanxzh@gdut.edu.cn

Abstract

In ecology, the patterns usually refer to all kinds of nonrandom spatial and temporal structures of ecosystems driving by multiple ecological processes. Pattern recognition is an important step to reveal the complicated relationship between ecological patterns and processes. To review and present some advances about ecological modeling, patterns recognition, and computer simulation, an international workshop on Mathematical & Numerical Ecology with the theme "Pattern recognition and simulation in ecology" was held in in October 2014 in Guangzhou, China, and the International Society of Computational Ecology was the co-sponsor. Eight peer-reviewed papers those were originally presented at this workshop covering three themes: patterns in phylogeny, patterns in communities and ecosystems, and spatial pattern analysis are included in this special issue.

1 Introduction

Understanding ecological patterns and their underlying mechanisms is central to ecology. Driven by multiple ecological processes, an ecological system usually exhibits spatial or temporal structures that are significantly different from those generated of a random process (Legendre and Fortin, 1989; Grim et al., 1996; Hui et al., 2010). These nonrandom spatial and temporal structures are defined as ecological patterns that contain information on the mechanisms behind their emergence(Grimm et al., 2005).The importance of ecological patterns has already been realized by ecologists since 1940s (Watt, 1947; Hutchinson, 1953; Southwood, 1980). Nowadays, the concept of nonrandom patterns are dissipating across all domains of ecology, ranging from

population (Watt, 1947) to community (Anderson and Kikkawa, 1984; Hubbell, 2001), from landscape (Wiens, 1999; Roura-Pascual et al., 2010) to global scales (Roura-Pascual et al., 2011).

Pattern recognition tries to extract information from ecological patterns and is the first step for inferring ecological processes from patterns (e.g., Boyero et al., 2015).Since the scope of ecological pattern is extensively broad, there is no universal methodology in describing these patterns. In general, depicting ecological patterns using a simple metric or statistical distribution is a preferred way, such as the branching diagram used in phylogenetic analysis, species abundance distribution in a community, spatial-correlation of species distributions (Hui, 2009; Gao, 2014), network architectures of complex ecosystems (Zhang et al., 2011; Minoarivelo et al., 2014; Nuwagaba et al., 2015), and various biodiversity indictors. Unfortunately, the relationship between ecological pattern and process is neither one-to-one nor linear (e.g. Hui and McGeoch, 2014): a single ecological process can produce different context-dependent ecological patterns, and similar ecological patterns can also be driven by different ecological processes (Brown et al., 2011).

To further understand how ecological mechanisms and processes work, computer simulations are commonly used for addressing questions that cannot be solely answered by controlled experiments or observations. Especially, with the rapid advance of computational power during the past few decades, it is possible now to simulate more complicated ecological systems with explicit details, implementing individual level interactions and spatial structures. With intensive simulations, the relationships between biological processes, the environment, and ecological patterns across different scales can be revealed. Computer based ecological models can further predict the future of evolution (Zhang et al., 2013; Landi et al., 2015). Developing, optimizing, and applying computer simulations for ecological modeling have become the central task for computational ecology (Zhang, 2012). To this end, pattern recognition is a key procedure for evaluating ecological simulations, as the congruence between the simulated and observed patterns is the main criterion for model performance evaluation.

2 Editorial Viewpoint

In this special issue, we present eight peer-reviewed papers that are written under the banner of the theme on *Pattern recognition and simulation in ecology*. These papers were originally presented at the *International Workshop on Mathematical & Numerical Ecology*, held in October 2014 in Guangzhou, China. As ecological patterns cover such a wide range, we only selected a few papers that were hotly discussed during the workshop. These papers can be grouped into three themes:1) patterns in phylogeny; 2) patterns in communities and ecosystems; and 3) on spatial pattern analysis.

Minoarivelo et al. (2015) reviewed the recent progress made in statistical phylogenetics. The trends and pitfalls of the commonly used methods, such as the parsimony-based approach, maximum likelihood based method, and the Bayesian inference approach. They speculate that the computational and statistical advances in the phylogenetic analysis will continue to escalate in the future. Nuwagaba and Hui (2015) reviewed three metrics of ecological networks: species degree distribution, compartmentalization, and nestedness. They fitted the node degree distributions of 61 empirical antagonistic networks to five different parametric models and tested the observed levels of compartmentalization and nestedness against null model expectations.

Ochiaga and Hui (2015) focused their attention on species abundance distribution, which describes the relative abundances of species in a community and is considered as one of the most important metrics in community ecology. Four major parametric forms (log series, negative binomial, lognormal and geometric distributions) and three mechanistic models (maximum entropy theory of ecology, neutral theory and the theory of proportionate effect) were reviewed. Lu et al. (2015) investigated species spatial distribution using spatial point patterns. A Gamma-Poisson model representing an inhomogeneous Poisson process was presented.

The probability distribution model was then used to fit the spatial distribution of both simulated and empirical data. An alternative method, the particle swarm algorithm, for parameter estimation was proposed.

Han et al. (2015) used a spatially-explicit individual-based cellular automaton to investigate the effect of niche construction on the spatial-temporal dynamics of spatially structured populations. They found that niche construction can influence the dynamics, the competition and diversity of metapopulations in a profound way. Zhang and Gao (2015) simulated a probabilistic automaton model on regular grids to investigate the effect of spatial structure on evolutionary dynamics of different strategies. To elucidate the mechanisms for the evolution of cooperation, evolutionary game theory was used to solve the so-called social dilemmas problem. Both computer simulation and mathematical analyses showed that the evolution of cooperation could be promoted in spatially-structured populations.

The remaining two papers reviewed the progress made in the spatial modeling of ecological and epidemiological dynamics. Ramanantoanina and Hui (2015) reviewed the modeling of population spread when dispersal is driven by habitat fragmentations, density-dependent predation and mixed propagules. Su and Wang (2015) reviewed the modeling of eco-epidemiological systems from both non-spatial and spatial perspectives. The effects of spatial structures in determining the success or failure of disease invasion in a spatially structured population was also discussed.

Real ecosystems are way more complicated than what we can imagine. Quantifying observed ecological patterns and linking them to the underlying mechanisms are probably the first step for unveiling the mystery of nature. The complex relationship between ecological patterns and processes poses a real challenge for inferring mechanisms driving ecological systems. Advances in computation and the availability of high quality data have made it possible to elucidate candidate mechanisms for complicated ecological patterns in many systems (Beaumont, 2010; Ulrich and Gotelli, 2013). Sophisticated computer and mathematical models are destined to make more important contributions to the future ecology.

References

Anderson DJ, Kikkawa J. 1984. Community Ecology: Pattern and Process. Blackwell Scientific Publications, London, UK

Beaumont MA. 2010. Approximate Bayesian Computation in Evolution and Ecology.Annual Review of Ecology and Systematics, 41: 379-405

Boyero L, Pearson RG, Swan CM, Hui C,AlbariñoRJ, Arunachalam M, Callisto M, Chará J, Chará-Serna AM, Chauvet E, Cornejo A, Dudgeon D, Encalada A, Ferreira V, Gessner MO, Gonçalves Jr JF, Graça MAS, Helson JE, Mathooko JM, McKie BG, Moretti MS, Yule CM. 2015. Latitudinal gradient of nestedness and its potential drivers in stream detritivores. Ecography (in press) DOI: 10.1111/ecog.00982

Brown C, Law R, Illian JB, Burslem DFRP. 2011. Linking ecological processes with spatial and non-spatial patterns in plant communities. Journal of Ecology, 99(6): 1402-1414

Gao M. 2013. Detecting spatial aggregation from distance sampling: a probability distribution model of nearest neighbor distance. Ecological Research, 28: 397-405

Grimm V, Frank K, Jeltsch F, Brandl R, Uchmański J, Wissel C. 1996. Pattern-oriented modelling in population ecology. Science of The Total Environment. 183(1-2): 151-166

Grimm V, Revilla E, Berger U, Jeltsch F, Mooij WM, Railsback S,Thulke HH, Weiner J, Wiegand T, DeAngelis DL. 2005. Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. Science. 310: 987-991

Han X, Huang Y, Hui C. 2015. Spatial distributions of niche-constructing populations. Computational Ecology and Software, 5(4): 286-298

Hubbell SP. 2001. The Unified Neutral Theory of Biodiversity and Biogeography (1st edn). Princeton University Press, Princeton, NJ, USA

Hui C, McGeoch MA. 2014. Zeta diversity as a concept and metric that unifies incidence-based biodiversity patterns. American Naturalist, 184: 684-694

Hui C. 2009. On the scaling pattern of species spatial distribution and association. Journal of Theoretical Biology, 261: 481-487

Hui C, Veldtman R, McGeoch MA. 2010. Measures, perceptions and scaling patterns of aggregated species distributions. Ecography, 33: 95-102

Hutchinson GE. 1953. The Concept of Pattern in Ecology. Proceedings of the Academy of Natural Sciences of Philadelphia, 105: 1-12

Landi P, Hui C, Dieckmann U. 2015.Fisheries-induced disruptive selection. Journal of Theoretical Biology, 365: 204-216

Legendre P, Fortin MJ. 1989. Spatial pattern and ecological analysis. Plant Ecology, 80(2): 107-138

Lu F, Mo DY, Gao M. 2015. Particle swarm optimization algorithm for parameter estimation in Gamma-Poisson distribution model of k-tree distance. Computational Ecology and Software, 5(4): 276-285

McGill BJ, Etienne RS, Gray JS, Alonso D, Anderson MJ, Benecha HK, et al. 2007. Species abundance distributions: moving beyond single prediction theories to integration within an ecological framework. Ecology Letters, 10, 995-1015

Minoarivelo HO, Hui C, Terblanche JS, Kosakovsky Pond SL,Scheffler K. 2014.Detecting phylogenetic signal in mutualistic interaction networks using a Markov process model. Oikos, 123: 1250-1260

Minoarivelo HO, Diedericks G, Hui C. 2015. An introduction to phylogenetic analyses and modelling in ecology. Computational Ecology and Software, 5(4): 328-339

Nuwagaba S, Zhang F, Hui C. 2015. A hybrid behavioural rule of adaptation and drift explains the emergent architecture of antagonistic networks. Proceedings of the Royal Society B: Biological Sciences, 282: 20150320

Nuwagaba S, Hui C. 2015. The architecture of antagonistic networks: node degree distribution, compartmentalization and nestedness. Computational Ecology and Software, 5(4): 317-327

Ochiaga EO, Hui C. 2015. Forms and genesis of species abundance distributions. Computational Ecology and Software, 5(4): 340-353

Ramanantoanina A, Hui C. 2015. Modelling spread with context-based dispersal strategies. Computational Ecology and Software, 5(4): 354-366

Roura-Pascual N, Hui C, Ikeda T, Leday G, Richardson DM, Carpintero S, Espadaler X, Gómez C, Guénard B, Hartley S, Krushelnycky P, Lester PJ, McGeoch MA, Menke SB, Pedersen JS, Pitt JP, Reyes J, Sanders NJ, Suarez AV, Touyama Y, Ward D, Ward PS, Worner SP. 2011.The relative roles of climate suitability and anthropogenic influence in determining the pattern of spread in a global invader. Proceedings of the National Academy of Sciences of the United States of America, 108: 220-225

Roura-Pascual N, Krug RM, Richardson DM, Hui C. 2010. Spatially-explicit sensitivity analysis for conservation management: exploring the influence of decision in invasion alien plant management. Diversity and Distributions, 16: 426-438

Southwood TRE. Ecology: A mixture of pattern and probabilism. Synthese, 43(1): 111-122

Su M, Wang H. 2015. Modeling at the interface of ecology and epidemiology. Computational Ecology and Software, 5(4): 367-379

Ulrich W, Gotelli NJ. 2013. Pattern detection in null model analysis. Oikos, 122: 2-18

Watt AS, 1947. Pattern and process in the plant community. Journal of Ecology, 35(1-2): 1-22

Wiens JA. 1999. Landscape ecology: the science and the action. Landscape Ecology, 14: 103

Zhang WJ. 2012. Computational Ecology: Graphs, Networks and Agent-based Modeling. World Scientific, Singapore

Zhang F, Hui C, Pauw A. 2013. Adaptive divergence in Darwin's race: how coevolution can generate trait diversity in a pollination system. Evolution, 67: 548-560

Zhang F, Hui C, Terblanche JS. 2011. An interaction switch predicts the nested architecture of mutualistic networks. Ecology Letters, 14: 797-803

Zhang H, Gao M. 2015. Effect of spatial structure on the evolution of cooperation based on game models. Computational Ecology and Software, 5(4): 299-316