Tomoyuki Obuchi
Department of Computational Intelligence and Systems Science, Tokyo Institute of Technology
e-mail: obuchi@sp.dis.titech.ac.jp

Yoshiyuki Kabashima
Department of Computational Intelligence and Systems Science, Tokyo Institute of Technology
e-mail: kaba@dis.titech.ac.jp

Kei Tokita
Department of Complex Systems Science, Graduate School of Information Science, Nagoya University
e-mail: tokita@is.nagoya-u.ac.jp

Degree of interactions essentially change relative species abundance

In community ecology, the relation between diversity, stability and species abundance patterns (SAP) has been discussed as one of the "unanswered questions in ecology in the last century" [1]. In special, theoretical understanding of SAP for a system in a single trophic level has been greatly progressed in the last decade, based on Hubbell's neutral theory [2, 3]. Meanwhile, for more complex systems occurring on multiple trophic levels and including non-neutral species with various types of interspecies interactions among them, a pioneering work by May [4], which triggered a controversial debate between the diversity and stability [5], has demonstrated efficacy of a linear analysis and the theory of random matrices. Beyond the linear model, statistical mechanics have been employed for analyzing nonlinear models and have provided global and quantitative information for diversity, stability and SAP [6, 7, 8, 9, 10]. While we have clarified relationships among the strength of the intraspecific competition, asymmetry of interspecies interactions and SAP for a system with fully-connected interactions [9], we present that sparse interactions essentially change SAP and it reveals multiple peaks which have been observed in several experimental data [11, 12, 13] but was not demonstrated theoretically. Sparseness of the interspecies interactions, moreover, gives novel non-monotonic dependence of diversity on the ratio of mutualistic interactions, suggesting that the mutualism is not a simple factor for species coexistence in a system with sparse interactions. Since the present theory is based on the general replicator dynamics [14], the theoretical prediction can be verified not only in ecology but also in population genetics, game theory, chemical reaction networks, gene regulatory networks and evolution of grammer, etc., and the significance of sparse and mutualistic interactions may give a broad impact on those areas.

References

[1] May, R.M., 1999. Unanswered questions in ecology. *Phil. Trans. R. Soc. London*, **B 264**: 1951-1959.
[2] Hubbell, S.P., 2001. *The Unified Neutral Theory of Biodiversity and Biogeography.* Princeton University Press.
[3] Etienne, R.S. and Alonso, D., 2007. Neutral community theory: how stochasticity and dispersal limitation can explain species coexistence. *J. Stat. Phys.*, **128**: 485-510.
[4] May, R.M., 1972. Will a large complex system be stable? *Nature*, **238**: 413-414.
[5] McCann, K.S., 2000. The diversity-stability debate. *Nature*, **405**:228-233.
[6] Tokita, K., 2004. Species abundance patterns in complex evolutionary dynamics. *Phys. Rev. Lett.*, **93**: 178102.
[7] Galla, T., 2006. Random replicators with asymmetric couplings, *J. Phys. A: Math. Gen.*, **39**: 3853-3869.
[8] Yoshino, Y., Galla, T. and Tokita, K., 2007. Statistical mechanics and stability of a model eco-system. *J. Stat. Mech.*: P09003.
[9] Yoshino, Y., Galla, T. and Tokita, K., 2008. Rank abundance relations in evolutionary dynamics of random replicators. *Phys. Rev. E*, **78**: 031924.
[10] Tokita, K., 2015. Analytical theory of species abundance distributions of a random community model. *Popul. Ecol.*, **57**: 53-62.
[11] Magurran, A.E. and Henderson, P.A., 2003. Explaining the exces of rare species in natural species abundance distributions. *Nature*, **422**: 714-716.
[12] Gray, J. S., Bjørgesæter, A. and Ugland, K. I., 2005. The impact of rare species on natural assemblages. *J. Anim. Ecol.* **74**:1131-1139.
[13] Dornelas, M. and Sean, R., 2008. Connolly Multiple modes in a coral species abundance distribution, *Ecol. Lett.* **11**: 1008-1016.
[14] Hofbauer, J. and Sigmund, K., 1988. *The Theory of Evolution and Dynamical Systems.* Cambirdge University Press.