On the role of interactions in stabilizing complex ecosystems

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Abstract

The relationship between ecological interactions and the stability of natural systems has become a key study field in community ecology. Still, emerging publications about the way that interactions affect stability and the underlying process driving such relationship denote a lack of consensus even in the most fundamental aspects (Ives and Carpenter, 2007; McCann, 2000). In the past, theoretical analysis of large simulated networks carried out by May (1971) proved that ecological communities of many interacting species were unstable (Gardner and Ashby, 1970). This finding conflicted with previous theories based on the observation of less fluctuations (MacArthur, 1955) and greater resistance to invasions (Elton, 2020) at increasing richness, what had been attributed to a dampening of the predator-prey intrinsic cycles.

The role of connectance (number of interactions per species) and interaction strength is now mostly agreed upon the scientific community. Both variables are known to reduce the overall system stability when the other remains constant. Hence, reducing the mean strength is needed when augmenting connectance in order to keep complex systems stable (McCann, 2000)".

On the other hand, how different types of interactions affect complexity is still being debated. In some cases, mutualistic and competitive interactions are proved to be destabilizing (Allesina and Tang, 2012) while in some other cases a mixture of competitive, mutualistic and antagonistic interactions is found to provide the best complexity-stability relationship (Mougi and Kondoh, 2014). An in-depth examination of inconsistent results presented by multiple authors (Allesina and Tang, 2012; Grilli et al., 2017; Mougi and Kondoh, 2014; Okuyama and Holland, 2008; Qian and Akçay, 2020; Rohr et al., 2014; Rozdilsky and Stone, 2001) reveals severe differences in their methodology.

One of the main sources of variability within methodologies is the approach taken to assess stability of simulated models. The concept of stability can have many different definitions that will vary depending on the type of inherent dynamics exhibited by a system and the perturbations it experiences (Ives and Carpenter, 2007). This is evident when considering specific systems with different dynamics. For instance, in a predator-prey system governed by a

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non-point attractor stability can be assessed either by measuring the amplitude of the oscillations or by how non-chaotic the attractor is. However, in a system composed by alternative stable states stability can be defined by the number of stable states or the ease with which systems can switch between states. Following May (1971) steps we assessed stability as the rate at which a systems returns to a local equilibrium after a perturbation, through the interpretation of the Jacobian matrix and its eigenvalues.

Another crucial aspect to understand such variability relies on the model construction and the way it is tweaked to assess the role of the studied variable. For instance, Mougi and Kondoh (2014) found the greatest stability at intermediate mutualistic interactions contrary to the previous consensus stablished by Allesina and Tang (2012). A brief methodology comparison reveals that in the former work mutualistic interactions were added to an empty interaction matrix whereas the latter added the interactions to a hybrid matrix.

Here we review more recent works on complexity-stability positive relations and asses the role of interactions in maintaining this contradiction through a numerical simulation. We focus on analysing how the number of interactions, the interaction strength and the proportion of interaction types affects local stability. To do so, random populations were simulated using a standard deterministic interaction model. The role of each of the three aspects concerning interactions in the model (connectance, weight and proportion of each interaction type) was individually assessed through multiple permutations of random communities.

Our results were consistent with May (1971), showing a decreasing probability of local stability at higher connectance values and stronger interaction strength. Interestingly, resilience showed a positive trend with both variables. Regarding interaction type proportions, we found a strong destabilizing effect of mutualism and the opposite trend for competence, a pattern that differs from Mougi and Kondoh (2014) and points in the same direction as Allesina and Tang (2012). Yet again, a slight modification of the methodology leaded to substantially different results.

Due to our findings and bibliographical research, we suspect that the reason for debate is the multifaceted nature of the stability concept as it has (or has not) been conceived. Different types of stability describe different properties of an ecosystem, resulting in different stability-complexity relationships(Ives and Carpenter, 2007). When considering how interaction richness affects local stability, we conclude that the strength and structure of the network used to study this relationship plays a major role (Qian and Akçay, 2020). This provides a new approach to assess the complexity-stability debate in the future: analysing how different structured networks affect this relationship.

Lastly, even though we value analytical and numerical approaches to further the understanding of such complex concepts, mainly due to the ease of experimentation they provide, we question the use of such arbitrary models to obtain a unique and valid answer for all systems, particularly in this case, where it is difficult to justify the existence of truly destabilizing properties in real ecosystems. Consequently, the construction of realistic models reproducing real world data is crucial for elucidating relevant process.

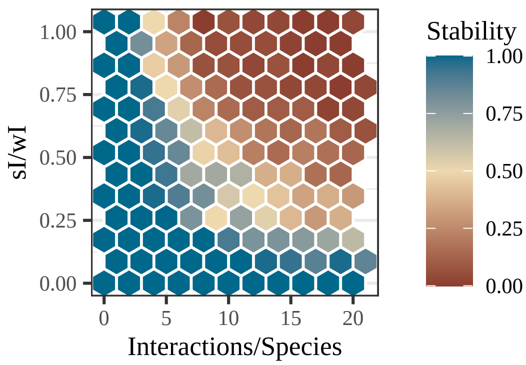

Figure 1: Probability of stability at different connectance and interaction weight proportions (sI= Strong interaction,wI = weak interaction). nSp=20 and all interaction types are equal.

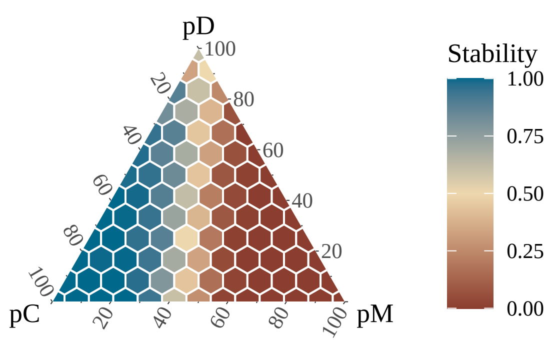

Figure 2: Probability of stability at different interaction type proportions (mutualistic: pM, competence: pC, predation: pD). nSp=20, connectance = 10 and interacion weight is evenly distributed between 0.05 and 0.2.

Having these lasts thoughts into consideration, we believe that a shift towards more specific questions using lower scale models that are parametrized with real data, may be more beneficial to understand the fundamental process concerning stability and complexity.

Figures 1 and 2 represent two of the most representative results of this work.

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