A statistical-mechanistic approach to ecology and coral reefs

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Abstract

Statistical and mechanistic models are not mutually exclusive, but complementary. While statistical models allow for very broad hypotheses testing, they do not implement causality. On the other hand, mechanistic models allow for very specific hypothesis testing. We propose a framework for the study of ecological systems that combines statistical learning with mechanistic models for dynamical ecological systems.

Introduction

Methods

Assume that we take m samples of a coral reef and find n taxons. Assume that these samples have been taken in a short timescale such that two approximations hold: 1. The system behaves stably, that is, no transient dynamics will occur if there are no external changes in the energy budget of the ecosystem. 2. There are no major evolutionary changes in the system.

We build matrix M assuming that samples are sorted by the time they were collected:

$$M = \begin{pmatrix} M_{11} & \cdots & M_{1m} \\ \vdots & \ddots & \vdots \\ M_{n1} & \cdots & M_{nm} \end{pmatrix} \tag{1}$$

where M_{ij} represents the abundance (or rank) of taxon i in the sample j. Each row of M thus represents the dynamics of i over time. Column j represents a snapshot of the coral reef (or any other ecosystem) at a given time (t=t_j). Suppose we build a matrix X that represents the correlations between taxa (matrix rows):

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{pmatrix} \tag{2}$$

where X_{lk} represents the dynamic correlations of taxa l and k. That is, how related their dynamics were over time. If $X_{lk} = 1$, taxon i and k are positively correlated, meaning that they have mantained their rank or abundance more or less constant through time. This would indicate an assembly relation between them. If $X_{lk} = -1$ there is a predatory relation between i and k. Finally, if X_{lk} 0 there is no relation between i and k. Matrix X is essentially an adjacency matrix where X_{lk} represents the type of interactions between taxa l and k (nodes). There are two types of links: positive and negative. Nodes have weights. The weights are the average rank of each taxa or the rank in the last sample. This network is a snapshot of the dynamics of the ecosystem over time.

The network is complemented by the rank curves of each taxa. That way, if taxa l and k are correlated, that does not tell us much in "absolute numbers": are both ranks very low or very high all the time on average? do ranks increase or decrease at the same rate? While the first case would not suggest any mechanistic relations between l and k, the second one could be indicative of mutualism or

$$M = \begin{pmatrix} 0 & + & 0 & - \\ + & Mutualism & Commensalism & Predation \\ 0 & Commensalism & No \quad interaction & Amensalism \\ - & Predation & Amensalism & Competition \end{pmatrix} \tag{3}$$