Final Report
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Sabbatical dates: September 2012 - January 2013

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January 15, 2013

Research

1. My main goal was to develop statistical approaches to the study of community dynamics in the presence of large numbers of species. In previous work, I used semi-parametric methods to build up a picture of community dynamics aggregated into a small number of categories. The basic idea was to predict the composition of a community one time unit into the future, given its current composition, using information on the future compositions of communities with similar current composition. We applied this idea to data on changes in coral reef composition from a large number of reefs, where composition was grouped into three broad categories. The semi-parametric approach allowed us to avoid assuming a particular form for the relationship between current and future composition. We used numerical integration to study the long-term behaviour of the model.

   I originally planned to extend this to large numbers of species by replacing the semi-parametric model with a linear model for the effects of community composition and environmental variables on changes in community composition (after an appropriate transformation). The semi-parametric approach relied on having large numbers of observations with similar current composition, which is very unlikely in a high-dimensional space. In contrast, the linear modelling approach makes the assumption that the effects of current composition on changes on composition can be described by a simple statistical model with constant parameters. To deal with the large number of parameters, I proposed treating them as random effects. To avoid having to do numerical integration over a large number of dimensions, I planned to reduce the dimension of the fitted model for changes in composition using non-negative matrix factorization, before integrating to study its long-term dynamics.

   Between planning this work and arriving at NIMBioS, several ideas led me to change the approach. First, unlike the semi-parametric model, it is straightforward to study the long-term behaviour of the linear model analytically. This formed the basis for the short-term visit project described below. We found that for the coral reef data we had previously studied using the semi-parametric approach, a linear model also performed well, and made it easy to include the long-term effects of changes in environmental variables. We studied these effects analytically, using derivatives of the stationary probability distribution of the model.

   Second, non-negative matrix factorization seemed like the best dimension reduction technique in the initial proposal, because the aim was to describe a high-dimensional probability density function, which must be everywhere non-negative. On the other hand, if we work with a transformation that maps changes in community composition into an unbounded real space, the covariance matrix of those changes can be summarized in few dimensions using much more familiar singular value decomposition.

Thinking about the geometry of the space of changes in composition led me to consider what initially seemed like a simple problem: the appropriate measurement of the rate at which a community is changing (in other words, the rate of succession). I worked for much of my visit on decomposing the vector representing changes in composition into two components, representing the "size" and "shape" of change. I showed that the "size" component is closely related to popular measures of biodiversity change such as the World Wildlife Fund's Living Planet Index. On the other hand, the "shape" component captures an entirely different aspect of change, the extent to which populations of different species differ in their rates of change. I showed that this gives a measure of the rate of succession that is consistent with basic principles of population biology. In particular, it is constant if every species is growing at a constant proportional rate, a property that existing measures of the rate of succession do not have.

Now that I have a more solid understanding of the geometry of changes in community composition, I intend to return to the problem of dimension reduction. The decomposition into "size" and "shape" discussed above is in some sense a two-dimensional approximation to a change in community composition, which has a simple biological meaning. On the other hand, the sense in which singular value decomposition is an optimal low-dimensional approximation to a high-dimensional matrix is well known. Given the analytical results about long-term behaviour of linear models for changes in composition, it should be fairly easy to establish whether singular value decomposition also leads to an optimal low-dimensional model for community dynamics, in the sense of having minimum error in the long-term. I hope to determine whether this is the case, and whether the first two dimensions of this approximation are close to the "size" and "shape" components of change in some empirical examples.

2. I also spent some time finishing a manuscript on density-structured population models, in collaboration with Professor Rob Freckleton (University of Sheffield, UK), Professor Michael Burrows (Scottish Association for Marine Sciences, UK), Dr Nova Mieszkowska (Marine Biological Association, UK), and Gregg Milligan (University of Liverpool, UK). Density-structured population models are models in which a population is treated as being structured into discrete density classes, with transitions between classes representing changes in population density. This is a simple way to incorporate both density dependence and stochasticity into empirically-based population models. We applied this idea to survey data in which density classes for two species of marine mollusc were recorded over approximately a decade at hundreds of sites around the UK coastline. Recording density classes rather than precise abundance estimates made it possible to visit large numbers of sites, but had so far limited the extent to which information about population dynamics could be obtained from the data. We showed that density-structured models allowed us to obtain estimates of population persistence times and uncertainty about future dynamics that were consistent with what is known about the life histories of these species.

Participation

1. Short-term visit. I worked with Dr John Bruno (Department of Biology, University of North Carolina, Chapel Hill) and Jennifer Cooper (University of Liverpool, UK) on compositional dynamics of coral reefs in a changing environment (2-6 October 2012). The project was based on Jennifer Cooper's undergraduate research. Having all the participants in the same place for a few days allowed us to identify the scientific questions most relevant to an ecological audience, download and process data, do some mathematical analysis of the model, and plan the paper that will result. We have continued to work together via email and Skype. I have written all the necessary code, the methods section of the manuscript, and all the figures for the results section. Jennifer Cooper also presented this work at the British Ecological Society Annual Meeting, December 2012, Birmingham, UK.

2. Seminars. As well as the NIMBioS seminars, I regularly attended the Ecology seminars, seminars in the Department of Mathematics (particularly in analysis, applied mathematics, and the junior colloquium). My own research was not very closely related to any of the working groups, but I did have some productive informal interaction with the Food Web Dynamics group.

Other activities

1. While at NIMBioS, I reviewed four grant applications for the British Ecological Society, and started on reviewing a set of 14 grant applications for the Finnish Academy of Sciences. Although this is not research, it is an important service, which I would not have found the time for during my normal working schedule, and is likely to improve my own grant writing.

2. While at NIMBioS, I took the Applications of Probability exam, the final requirement for a Diploma in Statistics (and part of a degree in mathematics and statistics) from the Open University, UK (passed with distinction).

3. While at NIMBioS, I read Hilbert and Cohn-Vossen's Geometry and the Imagination, and Einstein's Relativity: the Special and the General Theory. Although neither has much apparent connection to ecology, the geometric ideas they contain have suggested some new approaches to the time scales of ecosystem dynamics that I hope to pursue in future. Having the time to think about these more distant ideas may turn out to be the biggest long-term benefit of my sabbatical.

Publications

1. I submitted a manuscript on "Measuring the rate of succession using the growth space of a community" to American Naturalist in January 2013.

2. A manuscript resulting from the short-term visit of John Bruno and Jennifer Cooper is in preparation, and will be submitted to Ecology in 2013.

3. A manuscript resulting from work on density-structured models is at the final draft stage, and will be submitted to Journal of Animal Ecology in early 2013.