Proposal for Shipley-Skinner Reserve – Riverside County Endowment

Modelling the effects of space on community stability in Western Riverside County

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Research Aims

I propose to use an allometric food web model to describe the effects of spatial structure on the dynamics of communities in Western Riverside County, including the Shipley-Skinner reserve. Modelling the dynamics of communities can significantly improve our ability to conserve them as it reveals information about their stability, specifically their intrinsic variability and ability to recover from disturbance (Ives et al. 2007), which cannot be found from commonly-used presence-absence modelling (Keith et al. 2008, Swab et al. 2012). Describing the effects of space on stability is crucial, both because space has been increasingly shown to play a significant role in maintaining diversity (Holyoak et al. 2005, Leibold et al. 2004) and because advancing human development and fragmentation alter the spatial structure of natural communities (Chen et al. 2010, Crooks and Sanjayan 2006, Fahrig 2003). Specific to Riverside, the Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP) plans to significantly alter the spatial configuration and connectivity of communities through land acquisition (http://www.wrc-rca.org/library.asp), the effects of which on communities should be understood.

The proposed modelling is accessible to general theoretical methods but also empirically motivated and defensible. I will conduct modelling in two parts: (**1**) I will use randomly generated communities and spatial structures to generate general predictions for the effects of space on stability and (**2**) I will use available data on the spatial structure and community composition of the land conserved under the Western Riverside County MSHCP to parameterize a model to generate management recommendations. The goal of this approach is to supplement the data available for Western Riverside County with standard theoretical modelling to produce informative descriptions and recommendations applicable even in the absence of highly resolved multi-species data, a significant limiting factor for community-level conservation.

Background and Rationale

Current methods for conservation modelling generally lack description of the effects of species interactions at the community level, focusing instead on the relationship between individual organisms and the physical environment (Araujo and Luoto 2007, Elith and Leathwick 2009, Ferrier and Guisan 2006). I plan to address this limitation by modelling community dynamics using a generalization of Yodzis and Innes (1992)'s allometric consumer-resource model. Formulation of this model was focused on plausible parameters based on "energetic reasoning and allometric empiricism," with values such as body size and respiration rate that can be easily extracted from readily-available ecological data sets. The model has been successfully parameterized to reproduce the dynamics of whole communities from empirical data (Berlow et al. 2009, Brose et al 2006, Otto et al. 2007). Its increasing use represents an important opportunity for conservation applications which I aim to exploit.

As previously stated, modelling dynamics allows for prediction of the dynamics and therefore stability of organisms within communities. This includes description of a community's ability to recover from disturbance, critical for maintaining long-term viability in nature, and its intrinsic variability, an important determinant of extinction risk (Ives et al. 2007). Additionally, modelling the dynamics of the whole community grants important insight into the effects of community interactions on individual species' abilities to persist. Of particular concern in this proposal is the maintenance of spatial mechanisms of coexistence, which rely on dispersal between communities to alter community dynamics and allow persistence of species which are excluded otherwise (Holyoak et al. 2005, Leibold et al. 2004). Determining which organisms rely upon these mechanisms and the effect of changing spatial structure on them is critical for reducing extinctions.

These spatial mechanisms of coexistence rely on both dispersal of individuals between communities and the maintenance of asynchronous population dynamics between communities (Koelle and Vandermeer 2005, Gouhier et al. 2010). This is because spatial mechanisms rely on some degree of independence between communities, for example species which go extinct in one will not simultaneously go extinct in another. When fluctuations in communities are synchronized, this is no longer true, and extinctions or low abundances in one patch cannot be buffered by recolonization from another. Therefore asynchrony is a crucial component of coexistence for species dependent upon spatial mechanisms. Unfortunately, dispersal tends to synchronize communities, leading to a necessary balance between dispersal rate and asynchrony: when dispersal is too high or too low, the diversity maintained by spatial mechanisms is lost. Determining where the line is for maintaining the benefits of space when increasing connectivity and therefore dispersal between communities, as planned by the MSHCP, is an important goal of my proposed work.

Additionally, the tendency for dispersal to synchronize communities can be buffered by the effects of spatial structure, independent of dispersal rate or degree of connectivity. Recent work (Holland and Hastings 2008) including modelling and experimental studies for my thesis (forthcoming) describe the variation in tendency toward asynchrony in community dynamics as a function of other spatial properties independent of connectivity (Arenas et al 2010, Yeakel et al. 2014). Including consideration of these spatial properties into planning for MSHCP land acquisition and other land use change in Western Riverside County (Chen et al. 2010) represents a valuable opportunity for prioritizing and improving management efforts.

Research Plan

I will use an allometric consumer-resource model originally developed by Yodzis and Innes (1992) generalized for *i* species and *p* communities:

(Resource)

$$\frac{dB_{i,p}}{dt} = B_{i,p}a_{r,i}M_i^{-.25}\left(1 - \frac{B_{i,p}}{K_{i,p}}\right) - \sum_{j=1}\frac{a_{x,j}y_jM_j^{-.25}\omega_{j,i}B_{i,p}B_{j,p}}{e_{j,i}\left(B_0^h + \sum_{k=1}\omega_{j,k}B_{k,i}^h\right)} + m_i\sum_{r=1}A_{r,p}B_{r,p}$$

(Consumer)

$$\frac{dB_{i,p}}{dt} = B_{i,p}a_{x,i}M_i^{-.25}y_i\frac{\sum_{j=1}\omega_{i,j}B_{j,p}^h}{B_0^h + \sum_{j=1}\omega_{i,j}B_{j,p}^h} - \sum_{j=1}\frac{a_{x,j}y_jM_j^{-.25}\omega_{j,i}B_{i,p}B_{j,p}}{e_{j,i}\left(B_0^h + \sum_{k=1}\omega_{j,k}B_{k,i}^h\right)} - B_{i,p}a_{x,i}M_i^{-.25} + m_i\sum_{r=1}A_{r,p}B_{r,p}$$

Where B is a population's biomass, M its average body mass, m its species-specific dispersal rate, ω the community interaction matrix, and A the adjacency matrix describing connectivity among communities. For resource species, a_r is its mass-specific growth rate and K its carrying capacity. For consumer species, a_x is its mass-specific metabolic rate, y its maximum consumption rate relative to metabolic rate, e its assimilation rate for a specific prey. B_0 is the half-saturation coefficient and h the shape parameter which together define the functional response of consumers.

In similar models communities are commonly described by an i (number of species) by i interaction matrix, where entry $[i,j]$ describes the direct effect of species i feeding on species j (and 0 denotes no feeding). This information is critical to the functioning of most models, but challenging to generate from field data (Berlow et al. 2004). In this model, the usual community interaction matrix is broken into the parameters a_x (mass-specific metabolic rate), y (metabolic-specific consumption rate), e (assimilation efficiency), and M (body mass), which collectively describe the total strength of an organism's effect on the all species it feeds on based on physiology, and ω, an i by i matrix describing only presence/absence of feeding interactions and preference. Each row $[i,.]$ in ω describes the diet of species i and sums to 1, with each entry describing how the organism's total effect (from a_x*M*y/e) is apportioned among the species it consumes, or feeding preference. When preference is equal among species, each entry $[i,j]$ is equal to 1/(number of species i's prey). This allows crucial information on the quantitative interaction strengths to be derived from more easily obtained qualitative food web data.

Spatial structure is described by the p (number of communities) by p matrix A, where each entry $[p,q]$ describes existence of a dispersal connection between communities p and q. The magnitude of $[p,q]$ corresponds to the relative distance between patches. The diagonal $[p,p]$ represents individuals lost due to emigration, a negative value such that each row/column sums to 0 to balance the individuals sent from each patch to those received by its neighbors. Directional biases in dispersal exist when $[p,q]$ does not equal $[q,p]$. While describing space in this way assumes discrete communities, it is otherwise very flexible and can approximate real spatial patterns well.

As stated, modelling will be conducted in two parts:

(1) <u>Random communities</u>

The qualitative interaction structure (ω) of random, ecologically relevant communities will be generated using the niche model (Williams and Martinez 2000), which assigns species a niche value (corresponding to their trophic level), a feeding 'radius' (corresponding to generality). Combined, these generate a realistic range of niche values each species feeds from, reproducing many of the critical properties observed in real food webs. This structure will be combined with a range of ecologically relevant values of a_r, a_x, y, e, and M (Brose et al. 2006, Yodzis and Innes 1992) to generate realistic random communities. Spatial structure (A), or the ability to disperse between communities, will be set by generating networks using the Erdös-Rényi model, standard for generating random networks (Erdös and Rényi 1960).

Generation of both community and spatial structure requires inputs of size and connectance/connectivity (the overall likelihood of a connection between any two species/communities, or non-zero entry in each matrix), which will be varied systematically as the basic descriptor of structure. Additionally, the resulting community and dispersal structure will be described with a range of metrics from food web, information, and graph theory, including interaction diversity and complexity (Bersier et al. 2002, Ulanowicz 2009), clustering,

topological path length (Arenas et al. 2010), and synchronizability (Yeakel et al. 2014). 'Treatments' of community/spatial structure will be crossed, with each random community subjected to each spatial structure to avoid mixing effects.

I will then simulate dynamics on these communities and measure synchrony (correlation of population dynamics across communities), variability (coefficient of variation of population abundances), and persistence (percentage of total species with non-zero abundances) at equilibrium, as well as resilience (time to equilibrium from randomly generated initial conditions, simulating disturbance) (Ives et al. 2007). I will use comparisons between these measurements of stability and characteristics of community and dispersal structure to determine which spatial features are most effective at preventing synchronization and promoting stability, as well as to control for any secondary effects. From this I hope to provide management recommendations regarding the most important spatial features to be included in reserve design.

In a similar fashion I will compare species characteristics (e.g. trophic level, generality) with their extinction risk under synchrony and asynchrony to find predictors of species' sensitivity to spatial coexistence mechanisms. By predicting the response of species, particularly those of conservation concern, to spatial changes, I hope to improve recommendations for management.

(2) Western Riverside County communities

To make recommendations based specifically on the species and lands conserved under the MSHCP, I will first review available species data to parameterize the model. Most parameters can be approximated from commonly available information: average body size (M), metabolic type, e.g. endotherm, ectotherm, or invertebrate (a_x, y), or trophic position (e) (Brose et al. 2006, Yodzis and Innes 1992). As discussed, model parameterization is also robust to limited feeding information. Where this data is not available, a range of approximate values will be used to determine the sensitivity of results to unknown parameters and estimate a distribution of outcomes. Spatial parameters (K, A) and groupings of community 'patches' will be estimated from available landscape data, with a range of dispersal structures (A) considered based on the land acquisition goals of the MSHCP (http://www.wrc-rca.org/library.asp) and changing land use in Western Riverside County (Chen et al. 2010).

Using the same simulation framework as with random community simulations, I will model the stability of communities in Western Riverside County, focusing specifically on species and areas of conservation concern such as the Shipley-Skinner Reserve. By modelling the stability of these communities with different spatial structures corresponding to changing land use, I hope to prioritize areas to be acquired based on their value for community stability, test whether spatial coexistence mechanisms will be maintained, and identify any dynamically important areas threatened by advancing urbanization. Furthermore, I hope to identify any species prone to extinction or communities vulnerable to disturbance resulting from species interactions, particularly those not identified by current modelling practices.

From this data I hope to offer a description of the stability of communities in the region particularly by providing priorities for land acquisition and protection, and by identifying species/communities of concern based on their stability properties.

Conclusion

Fundamentally, my goal is to utilize an empirically grounded theoretical approach to offer additional insight into the dynamics of conserved communities, thereby refining the focus and improving the efficacy of management efforts. The primary value of this approach compared to other approaches to modelling from data is the ability to simulate dynamics and understand the effects of community interactions, an important force in determining the persistence of species and ultimately shaping diversity. I focus primarily on the effects of space, as both an important determinant of dynamics and a feature heavily influenced by human activity. Thank you for your time and consideration.

Budget

49% GSR for Fall 2015 to conduct research:

Gross Salary BC11: $5715.36
GSHP: $1125.00
PFR: $4064.00
BC20 benefits: $47.44

GSR Total – $10,951.80

Mathematica site license for modelling - $84.90
ArcGIS license for handling spatial data - $93.00

Travel for collaboration/visiting sites (approx. 400 miles at .56/mi) - $224.00

Total - $11353.70

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