Meta-community multitrophic dispersal dynamics

Abstract

[1]

Author Summary

1 Introduction

Understanding the structure and dynamics of ecological networks has become critical for understanding the persistence and stability of ecosystems [2]. Robustness studies based on the simulation of sequential extinction of species have reveal led aspects about the response of ecosystems to ecological disturbances at species level [1]. Such structural analyses are relatively fast and easy but their utility in capturing important information about functions and processes is often questioned [3], especially when considered the variability of the effects of ecological disturbances among individuals of the same species. Dynamical models in contrast provide essential information especially if one needs to understand changes in abundances, with the structure of the food web being almost constant [3].

2 Results

Steady State

Space of Parameters

Metabolic Theory of Ecology

3 Discussion

4 Materials and Methods

4.1 Dispersal dynamics

Here we describe the dynamics of predation and migration in explicit landscapes. There can be several species at each trophic level and there are several spatially distinct sites. The trophic levels are resources (R), consumers (H), and predators (P), thus, we have three distinct metacommunities of resource, consumers, and predators/parasitoids. To model spatio-temporal changes in the abundance of these sites, we need to define dispersal and trophic interaction rules together with population dynamics. We consider two models of dispersal between sites. Model 1 assumes that dispersal between any two sites occurs only between the neighboors and it is density-independent in the sense that dispersal probabilities are a function of species abundance of the leaving site. Model 1 also assumes that resources, consumers and predators move independently of each other. This means individuals are not aware of the state of each site before the disperse (i.e., the number of prey or predators in each site). Dispersal to the neighboors is also occuring in the model 2, but now individuals have information of each site and they disperse with higher probabilities to the sites that have a low number of predators and a high number of resources available.

4.1.1 Model 1: Dispersal dynamics in non-informed landscapes

Our first model assumes an individual that emigrates moves with probability proportional to the carrying capacity of the receiving site. Thus, individual movement is independent of the state of each receiving site and they do not know the number of resources or predators before the emigration. This leads to the dispersal rate of species k_ϕ in metacommunity ϕ from site j to site i (where ϕ stands either for the basal (R), intermediate (I), or top predator metacommunity (P))

$$m_{ij}^{k_\phi} = \mathcal{K}_\phi^i m_\phi c_{ij} \mathcal{M}_\phi, \tag{1}$$

where $\mathcal{K}_\phi^i$, m_ϕ, c_{ij}, and $\mathcal{M}_\phi$ are the carrying capacity of the receiving site i of metacommunity ϕ, the background emigration rate of metacommunity ϕ, the probability to move from site j to site i (c_{ij} = 1 if there is a link between site i and site j and 0 otherwise), and the mobility probability that is 1 in the non-informed model because individuals move regardless the state of resource availability and number of predators in the receiving site.

Given the dispersal rate, the number of individuals of species k in metacommunity ϕ that move from site j to site i is

$$N_{ij}^{k_\phi} = m_{ij}^{k_\phi} N_j^{k_\phi}, \tag{2}$$

where $N_j^{k_\phi}$ is the abundance of species k in site j.

4.1.2 Model 2: Predator-prey ratio dispesal dynamics in informed landscapes

Our second model assumes the dispersal rates are density-dependent and an individual that emigrates has a preference that is a function of the state of each site. The state of each site is driven by the number of resources available and the number of predators in each site. Thus, the migration probability of a species k_ϕ in metacommunity ϕ from site j to site i is defined as the difference between the number of individuals of species that are prey and species that are predators of species k_ϕ in site i. This leads to the dispersal rate of species k_ϕ in metacommunity ϕ from site j to site i

where... is the ... between site i and j and m_ϕ is the metacommunity-specific background dispersal rate (we need here a figure with the landscape considered and we also need to simplify the flow chart and explain this model). The migration of a species k_ϕ from site j to a neighborhood site i occurs only if $m_j^k(t) > m_i^k(t)$. The number of individuals of species k that move from i to j must respect the threshold imposed by the carrying capacity of the target patch ($cc_j^k(t)$) and is defined as seen below:

4.1.3 Model 3: Density-dependent predator-prey ratio in informed and niche-driven landscapes

4.2 Demographic dynamics

In the previous section we have described the dispersal dynamics. Here we describe the birth and death probabilities associated with each model...

4.2.1 Model 1: Density-independent and non-informed dispersal dynamics

At each time (specify the MC rate) we leave all the individuals of each site i to be choosen by a *Multinomial Distribution* [4]. The chosen individual k can have three different behaviors:

1. it can die for natural reasons;
2. it can eat one individual among its prey;
3. if k have eaten an individual among its prey, so it can give an offspring.

If k individual is not a predator (if it is a basal species) the model assumes it has infinity food suply and the only possible behaviors are 1. and 2.. For each MC time-step mc, this simulation is repeated for all individuals of each patch of the landscape. The births will occur only if there is free space in the patch i, that means, if the number of individuals alive at i is lower than its carrying capacity (cc). For each time t in which one individual of species k gives an offspring in a patch i, its number of individuals in this patch will be increased by 1; for each time t in which one individual of species k dies naturally or by predation in a patch i, its number of individuals will be decreased by 1. In Figure 1 we show a fluxogram that summarizes the running of the predation dynamic of the model.

EQUATION NOT TRANSFORMED!

- **Birth Probability**

$$Bp\left(k\right) = \left[1-\rho\left(k\right)\right] \times \left[\sum_{b\in H(k)} \rho\left(b\right)\left(1-\sum_{c\in P(b)} \rho\left(c\right)\right)\right] \times \left[1-\sum_{c\in P(k)} \rho\left(c\right)\right]$$

Where: Availability of Resources of Basal Species is 1.0

EQUATION NOT TRANSFORMED!

- **Death Probability**

$$Dp\left(k\right) = \left[\rho\left(k\right)\right] \times \left[\sum_{b\in H(k)} \left(1-\rho\left(b\right)\right)\left(\sum_{c\in P(b)} \rho\left(c\right)\right)\right] \times \left[1-\sum_{c\in P(k)} \rho\left(c\right)\right]$$

Where: Death Probability of Basal Species is 1.0

EQUATION NOT TRANSFORMED!

- **Natural Death Probability**

$$NDp\left(k\right) = \left[\rho\left(k\right)\right] \times \left[\sum_{b\in H(k)} \left(1-\rho\left(b\right)\right)\left(\sum_{c\in P(b)} \rho\left(c\right)\right)\right] \times \left[1-\sum_{c\in P(k)} \rho\left(c\right)\right]$$

EQUATION NOT TRANSFORMED!

- **Carrying Capacity (for each species in each site)**

$$CC\left(k\right) = \left[\sum_{b \in H(k)} \frac{(\rho(b))}{\left(\sum_{c \in P(b)} \rho(c)\right)}\right]$$

4.2.2 Model 2: Density-dependent predator-prey ratio dispersal dynamics

At each time (specify the MC rate) we leave all the individuals of each site i to be choosen by a *Multinomial Distribution* [4]. The chosen individual k can have three different behaviors:

1. it can die for natural reasons;
2. it can eat one individual among its prey;
3. if k have eaten an individual among its prey, so it can give an offspring.

If k individual is not a predator (if it is a basal species) the model assumes it has infinity food suply and the only possible behaviors are 1. and 2.. For each MC time-step mc, this simulation is repeated for all individuals of each patch of the landscape. The births will occur only if there is free space in the patch i, that means, if the number of individuals alive at i is lower than its carrying capacity (cc). For each time t in which one individual of species k gives an offspring in a patch i, its number of individuals in this patch will be increased by 1; for each time t in which one individual of species k dies naturally or by predation in a patch i, its number of individuals will be decreased by 1. In Figure 1 we show a fluxogram that summarizes the running of the predation dynamic of the model.

EQUATION NOT TRANSFORMED!

- **Birth Probability**

$$Bp\left(k\right) = \left[1 - \rho\left(k\right)\right] \times \left[\sum_{b \in H(k)} \rho\left(b\right) \left(1 - \sum_{c \in P(b)} \rho\left(c\right)\right)\right]$$
$$\times \left[1 - \sum_{c \in P(k)} \rho\left(c\right)\right]$$

Where: Availability of Resources of Basal Species is 1.0
EQUATION NOT TRANSFORMED!

- **Death Probability**

$$Dp\left(k\right) = \left[\rho\left(k\right)\right] \times \left[\sum_{b \in H(k)} \left(1 - \rho\left(b\right)\right) \left(\sum_{c \in P(b)} \rho\left(c\right)\right)\right]$$
$$\times \left[1 - \sum_{c \in P(k)} \rho\left(c\right)\right]$$

Where: Death Probability of Basal Species is 1.0
EQUATION NOT TRANSFORMED!

- **Natural Death Probability**

$$NDp\left(k\right)=\left[\rho\left(k\right)\right]\times\left[\sum_{b\in H(k)}\left(1-\rho\left(b\right)\right)\left(\sum_{c\in P(b)}\rho\left(c\right)\right)\right]$$
$$\times\left[1-\sum_{c\in P(k)}\rho\left(c\right)\right]$$

EQUATION NOT TRANSFORMED!

- **Carrying Capacity (for each species in each site)**

$$CC\left(k\right)=\left[\sum_{b\in H(k)}\frac{\left(\rho(b)\right)}{\left(\sum_{c\in P(b)}\rho(c)\right)}\right]$$

4.3 Spatial landscapes

We consider several spatial configurations. We start with a 2-dimensional toroidal lattice where individuals only move to the nearest 4-neighborhoods.

4.4 Multi-trophic metacommunity dynamics

Here, we describe the equations that combine dispersal, trophic and population dynamics across multiple sites and trophic levels in a broad geographic region. We track demography and species abundances in each site by considering at each time step birth-death events across all the sites.

EQUATION NOT TRANSFORMED!

$$\left\{\left[1-NDp\left(k\right)\right]\left[\sum_{b\in H(k)}\rho\left(b\right)Dp\left(b\right)\right]\left[Bp\left(k\right)\right]-\left[\sum_{c\in P(k)}\rho\left(c\right)\left(1-NDp\left(c\right)\right)\frac{\rho\left(k\right)}{\sum_{d\in H(c)}\rho\left(d\right)}Dp\left(k\right)\right]-\left[NDp\left(k\right)\right]\right\} \tag{3}$$

where ... describes the probability to choose...

4.5 Spatial patterns of ecological and spatial networks

4.5.1 Simulations

We use a Monte Carlo (MC) approach to simulate the dispersal and predation dynamics. Sites are represented as nodes of a geographical neighborhood network and the connectivity of those sites are represented as edges of this network (refs). Trophic relationships among species within each site are represented by a directed network in which each node represents a species and each directed link represents a trophic relationship between a pair of species.

Define background emigration rate and the values explored Define carrying capacity used, equal or different across sites.

Acknowledgments

References

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Figures

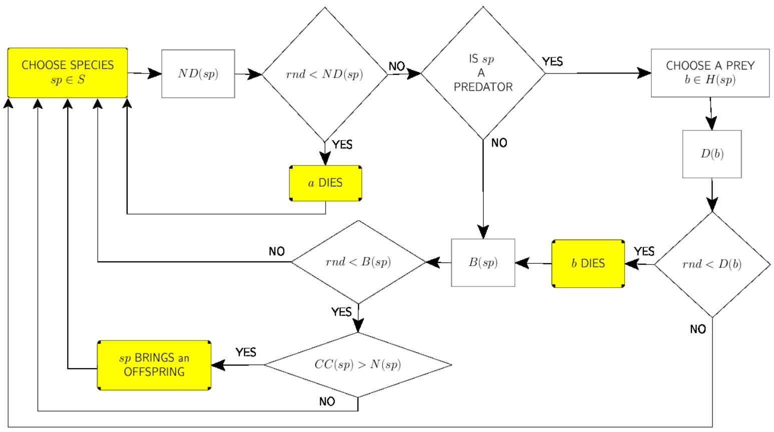

Figure 1. Fluxogram. Fluxogram of the model.

Tables