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POPULATION MODELS ON CONTINUOUS-VALUED HETEROGENEOUS LANDSCAPES

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Introduction

We study models of single-species populations on landscapes where environmental quality varies depending on location. Spatial population models of this type can be used to study the spread of invasive species, as well as the effects of habitat loss and fragmentation on native populations. Previous population models with varying habitat quality typically employed a dichotomized scheme, with habitat being either suitable or uninhabitable by the species of interest (Hiebeler 2000). For our project, however, the quality of sites on the lattice follow a continuous uniform distribution of values between zero and one (zero being uninhabitable and one being perfect), where the quality of a site affects the reproductive rate of the organism, their mortality rate, or both. We study the effects of various parameters of interest in the model, such as the amount of variability in the habitat quality among sites on the landscape, and to what extent quality affects fecundity and mortality rates. We also explore the effects of the spatial structure in habitat quality across the landscape, comparing cases where quality is highly clustered (neighboring sites share similar habitat quality) and unclustered (neighboring sites have opposing habitat qualities). A spatial clustering parameter is used to characterize the structure of landscapes, as well as to generate artificial landscapes with the desired properties for use in simulations.

The Model

Our model is a patch-occupancy model with K sites, each site with quality q_i $(i = 1, \dots, K)$, where q_i is a continuous value between 0 and 1, and occupancy primarily denoted by a green marker (see simulation examples below). Habitat quality is kept fixed. Organisms on an occupied site with quality q_i reproduce according to the function $f(\varphi) = \varphi * q_i$, where $\varphi = 2$ is a fixed fecundity rate, and die (causing the site to become empty) according to the function given by $g(\mu) = 1 - 0.9 * q_i$, where $\mu = 0.5$ is a fixed mortality rate. Whether or not fecundity or mortality rates are affected by habitat quality are specified. In the case that they are not, mortality and fecundity rates remain fixed for the entire simulation.

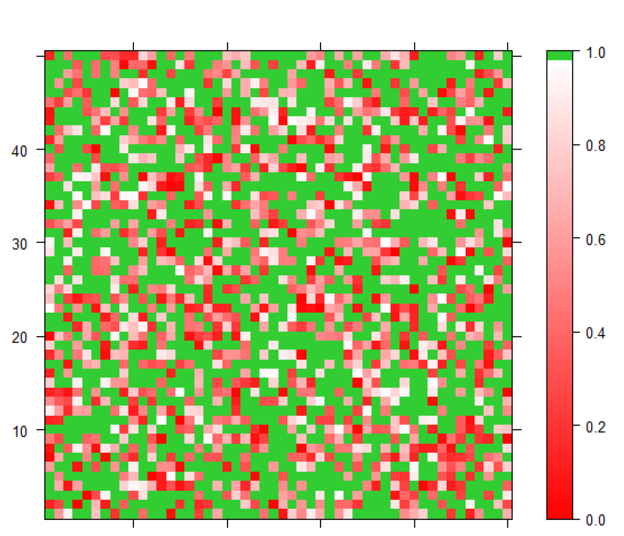

Fig. 5 Simulation with global dispersal ($\alpha = 1$).

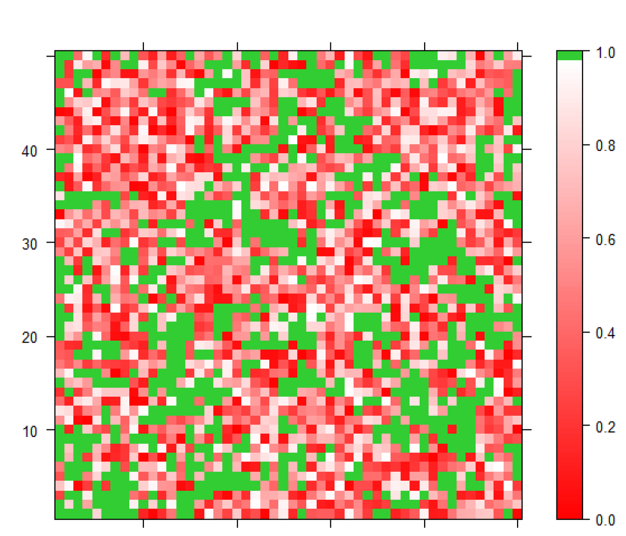

Fig. 6 Simulation with local dispersal ($\alpha = 0$).

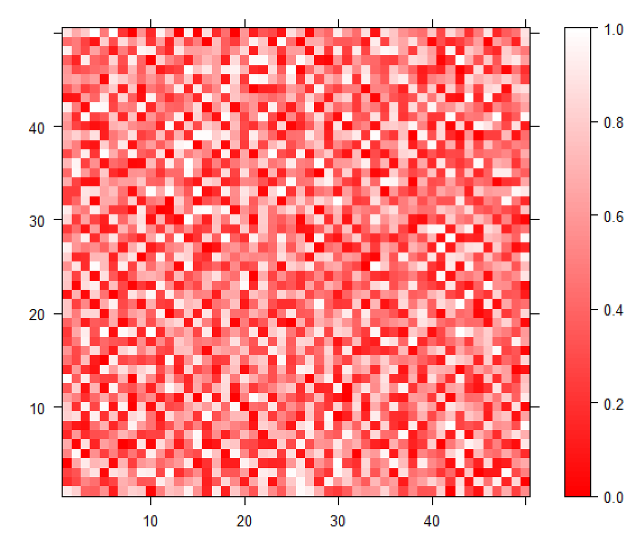

Fig. 1 Clustered spatial lattice with $\rho = -0.2$.

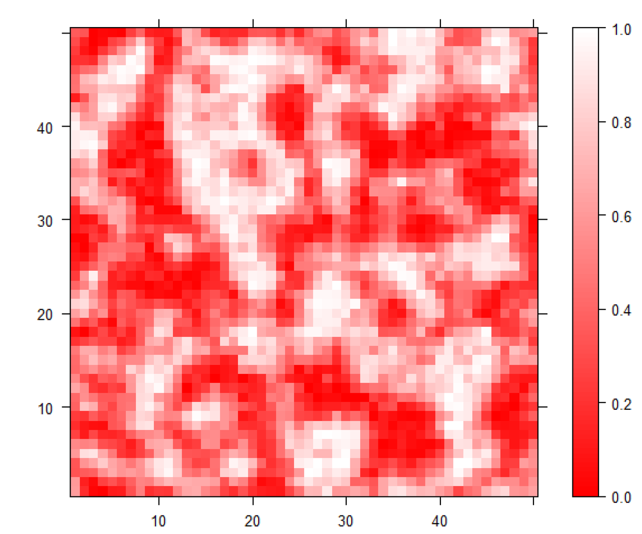

Fig. 2 Clustered spatial lattice with $\rho = 0.8$.

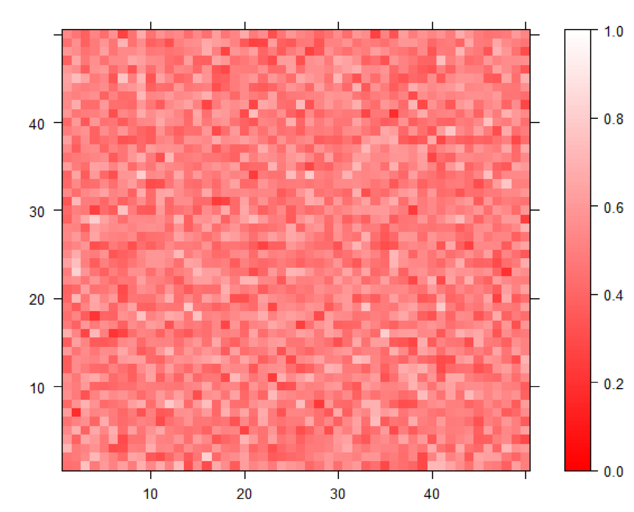

Fig. 3 Spatial lattice with standard deviation sigma = 0.1.

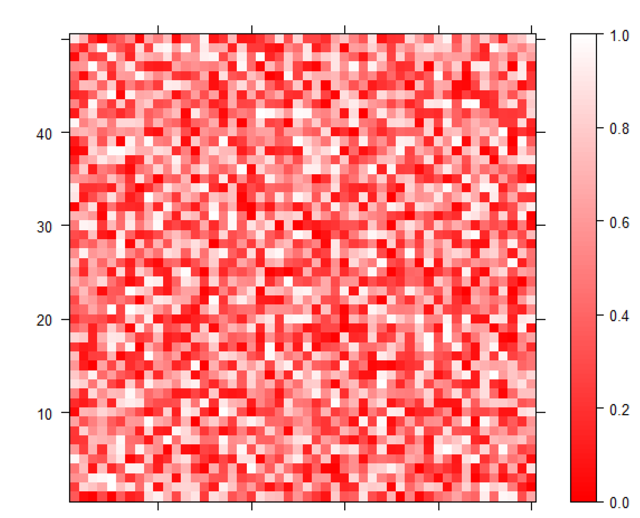

Fig. 4 Spatial lattice with standard deviation sigma = 1.

The occurrence of events follow continuous Poisson processes, i.e. events with rate λ occur with frequency $1/\lambda$. Organisms on the lattice can have either global ($\alpha = 1$) or local ($\alpha = 0$) dispersal (see Figures 5 and 6, respectively). For the former, an unoccupied site in the lattice is chosen at random for the offspring to inhabit, whereas for the latter, offspring are sent to an unoccupied cardinal neighbor of the parent organism.

While the average habitat quality of the lattice is kept fixed at 0.5, the standard deviation σ is varied at times to generate environments of both uniform and dynamic quality (see Figures 3 and 4). Environmental clustering is also varied according to a spatial clustering constant ρ. More negative values of ρ correspond to greater affinities for sites of opposing qualities (a "checkerboard" effect), while more positive values yield clustering of habitat sites with similar qualities (creating "islands" of similar habitat).

Results

Population models were investigated for various values of σ (the standard deviation of habitat quality), ρ (spatial clustering), and α (either global or local dispersal). In total, nine simulations were run with different parameter inputs. Parameter sweeps #1-4 varied σ with different values of α and explored how habitat quality-dependent fecundity and mortality rates affect such measurements as final population density, final population clustering, average occupied habitat quality. Parameter sweeps #5-8 had fixed habitat quality variance, dynamic values of ρ (spatial clustering), and differing configurations of offspring dispersal and site quality-dependent rates with the same aforementioned measurements.

Most simulations displayed little dependence on habitat variance and clustering. Parameter sweep #2, however, tested local dispersal of organisms with habitat quality affecting fecundity rates. The results are displayed in Figures 7 and 8. For larger variance in habitat quality, population density decreased by 8% - four times the amount typical of all other simulations. For this simulation, $\rho = 0$ so there was no spatial clustering of sites. Final population density decreased even though the average occupied habitat remained relatively constant, and even increased by a small proportion of 2%.

Conclusion

For increasing variance in the habitat quality, the population becomes "trapped" in regions characterized by good habitat quality. The organisms locally disperse offspring to neighboring regions which suffer from poorer quality and thus do not reproduce before death. Therefore, population density decreases as the offspring die off and the parent organisms inhabiting preferential regions persist (see Figures 7 and 8). It would seem that the presence of higher quality sites in the lattice allows the population to inhabit lower quality sites, but this in turn negatively effects population density as organisms occupying lower quality sites do so at the cost of any reproduction. Greater variance in habitat quality is thus not necessarily suitable for organisms whose fecundity rates are affected by habitat quality.

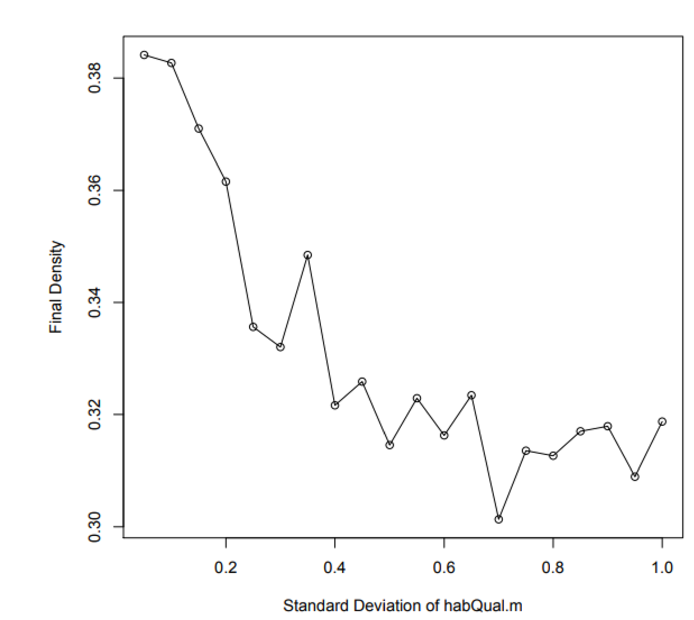

Fig. 7 Final density v. σ of habitat quality for Parameter Sweep #2.

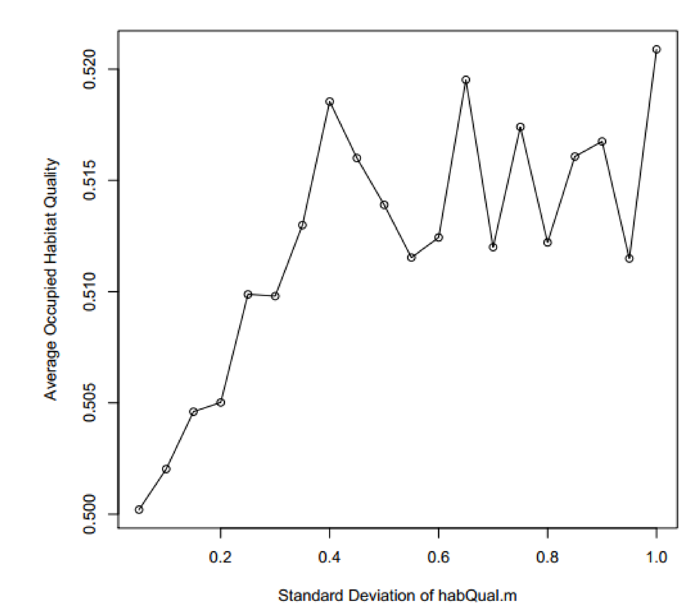

Fig. 8 Average occupied habitat quality v. σ of habitat quality for Parameter Sweep #2.

Acknowledgements

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