Models for spatial processes: patches and grids

There are two basic approaches to dealing with space: treat it in a continuous manner or treat it in a discrete manner. The continuous approach leads to partial differential equations, the discrete approach leads to models on grids, or patches. Note that GIS packages treat space as either discrete (the approach of raster based packages in which the maps are viewed as 2-d lattices with each grid within the lattice being a pixel on the computer screen) or continuous (vector based approaches in which elements are described by vectors which outline them in space, which of course has an inherent discrete limitation given by the machine's screen, so is ultimately discrete as well). The numerical solution of PDE's is ultimately discrete as well - there is some kind of spatial gridding going on in their solution, though it may be adaptive (e.g. modifying the level of resolution in a region based upon the dynamics there).

Spatial effects on populations:

There is a very large literature dealing with methods to characterize spatial patterning, and to tease apart the relationship between local abundances and underlying environmental or habitat factors. These mainly fall within the area of multivariate statistics although there is an active area called spatial statistics. Very simple methods here (such as the mean/variance ratio) aid in analyzing whether a particular measured population tends to be more clumped than random (where random refers to a Spatial Poisson process, such that the number of individuals within a particular subregion has a distribution with is Poisson with parameter being linear in the area of the region), or more uniform (evenly dispersed) than random.

Here a Poisson distribution with parameter λ give the probability of finding k individuals within a region of area A as

$$\frac{e^{-\lambda A}\lambda^k}{k!}$$

which has the property that both the mean and variance are equal to λA. So if the population is very clumped, the variance of the number of individuals in spatial samples (think of taking lots of small quadrats and counting the number of individuals within them) is very high and thus the mean/variance ratio < 1 while if the population is very uniformly distributed in space, the variance between samples will be low and the mean/variance ratio > 1. There are lots of other statistics for spatial point processes though. Another entire approach to spatial patterning is involves analyzing population clines, meaning changes in population along some environmental gradient.

Spatial effects may be grouped into effects external to the population of interest and internal effects. Internal effects would include spatial patterning due to intraspecific competitive interactions, leading to territory formation and well as shading and nutrient limitation effects in plants, allelopathy, pheromone release, and any type of behavioral interactions which lead to differential spatial use by certain individuials within a population relative to others (e.g. dominant individuals excluding subdominants from prime feeding locations). There is a large literature on territory formation and size, with little of this dealing in any explicit way with space - much of the objective is to determine when territoriality might most readily arise.

Much of the literature on spatial patterning deals with how underlying environmental factors affect population structure.

These include patch views of the world (the island case is one example of this, as well as the case of a refuge from predation), and cases in which there is an underlying continuous change in environmental factoirs with some spatial dimension (e.g. elevation). Some of the motivation in the latter dealt with understanding how spatial pattern may arise in circumstances which appear to be spatially uniform. The classic example of this is the formation of planktonic patches in the open ocean (discussed by Kierstad and Slobodkin). More recently, much of landscape ecology analyzes spatial variation and how it relates to population structuring. There are also many approaches to analysis of dispersal patterns and the pattern of spread of a population from an initial focus (such as release of an alien species, a small founder population, or spread of a pathogen).

Types of models:

1. No explicit spatial representation - a population model with an immigration/emmigration term.

2. Patch occupancy models - a metapopulation approach in which the state variables represent the fraction of patches occupied and unoccupied - sort of a statistical mechanics of patches, in which no explicit concern is taken with exactly where one patch is relative to another.

3. Explicit patch models - metapopulation models in which the population is characterized by some state variables (such as population size, age structure, etc.) within each of a collection of patches, there is movement between patches, and the dynamics of the state variables are followed for each patch explicitly. Here, the spatial relationship between patches may be considered explicitly (e.g. patch 1 is 2 km from patch 2 and 3 km from patch 3, etc.), or may be implicit, so that there is some exchange between patches sending propagules into a "bath" with which all

patches exchange individuals.

One special case of this are cellular automata models, which typically have a fixed regular grid of patches (rectangular or hexagonal), a limited state space for the local condition within a grid (occupied, or not, in the simplest case), and an explicit set of rules for how one the state in one location changes depending upon the condition at the present time and the condition of neighbors.

4. Continuous space models - the environment is viewed as continuous with population density varying across it - typically leading to partial differential equation models framed as reaction-diffusion (reaction refering to local growth and diffusion refering to dispersal between nearby locations) along with advection terms (e.g. wind driven movement).

5. Individual-based approaches - population is viewed as made up of individuals moving around on a spatially-explicit landscape with rules dependent upon local conditions. This can be thought of as an extremely complex cellular automata, since it is framed within a discrete spatial grid structure, but the difference in part is that it may not be local effects that matter at all. One example would be birds which can move great distances in search of food, causing state changes the next time step at grid cells far away from the current grid they occupy.