Matrix Applications to Landscape Ecology

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Overview

State of knowledge

Maintaining metapopulations is a common theme in the literature of matrix applications. According to metapopulation theory, some subpopulations within patches of habitat will go extinct. These patches will then be recolonized by individuals from other subpopulations. Many articles discuss the influence of dispersal and its associated energy costs and increased mortality risks as a limiting factor to recolonization. Without recolonization events, metapopulations cannot persist. Managers of metapopulations are beginning to realize the need to increase knowledge of matrix factors that influence dispersal such as heterogeneity, permeability and the variation with which different species utilize the matrix.

Opdam et al. (2003) discussed the state of our knowledge of matrix theory and its applications to management practices. Additionally, they developed a strategy for utilizing matrix concepts that can be carried out while knowledge of a landscape’s ecosystem is still rudimentary. They based their method on the idea that the spatial structure of the matrix affects the dispersal of individuals to patches in the suitable habitat network. Opdam et al. claimed that the persistence of species is dependent on the cohesion of the habitat, not simply on habitat abundance. They described their methodology for creating a multi-species cohesion index with which to analyze a landscape pattern. Such an index is an astonishing tool for managers. The end result is a straightforward map, a key component of a management plan dealing with stakeholders who may not have an interest in learning all of the science behind the statistical output of an index. An essential element of Opdam et al.’s idea is the ability to create a cohesion index with limited knowledge that is flexible enough to incorporate information acquired in the future. In order to create successful management strategies, Opdam et al., along with many other authors, realize the need for the development of our knowledge of the many concepts of a matrix.
Concepts

To keep applications of matrix theory unconfounded due to oversimplifying, managers must take into consideration many matrix concepts. Rodewald (2003) discussed how matrix effects have several implications for the management and acquisition of conservation areas. She stated that most forests in North America are surrounded by agricultural or urban land. She goes on to say that traditionally, landscape ecologists have considered the amount of habitat to be the necessary measure of ecosystem health; however, many studies have shown that the surrounding matrix has greater effect on wildlife than does the suitable habitat patch size. To effectively manage landscapes, managers need to understand key matrix concepts such as heterogeneity, permeability and species-specific effects.

Gone are the days of island biogeography theory. Management plans are advancing beyond binary approaches that simplify landscapes into habitat and non-habitat. Today matrix heterogeneity is realized to be a factor in the functioning of an ecosystem. In Rickett’s (2001) study of butterfly resistance to movement through a matrix of varied compositions, he discovered that matrix heterogeneity was an important factor in determining movement abilities of butterflies through the matrix. Managers can learn from Ricketts study that altering land use practices in the surrounding matrix may be more feasible than creating habitat corridors. Furthermore, Wethered and Lawes (2005) discussed the need for a heterogeneous mix of matrix where plantations occur. Their study found that otherwise, habitat tolerant species tended to be selected for. A heterogeneous matrix can lessen the detrimental effects a homogeneous matrix could pose to species. Managers must keep in mind the value of increasing matrix heterogeneity as it both decreases the risk of mortality and increases the utilization of this previously considered area of ‘non-habitat.’

Matrix permeability is another major factor in the ability of a metapopulation to persist. Rather than form a barrier to movement, Antongiovanni and Metzger (2005) recommended increasing the permeability of the matrix to lessen the effects of forest fragmentation on birds. In addition, Jonsen et al. (2001) discovered that two closely related species of beetles used in biocontrol of weeds have very different abilities to
move through various compositions of matrix. In weed biocontrol strategies, Jonsen et al. suggest it is important to tailor practices by considering the structure of the landscape into which each species of beetles is to be released. Without a permeable matrix, recolonization of patches will not be able to take place where subpopulations go extinct.

Our world is composed of a multitude of species as a result of the many habitats promoting speciation. Each species has developed its own niche that must be managed if the species is to persist. While it may be a daunting task to create a management plan for multiple species, matrix studies have pointed again and again to the necessity to do so. Joly et al. (2001) sited the ability of mice to move through an increasingly fragmented agricultural landscape while newts cannot because they do not possess the same abilities to navigate to suitable habitat due to their apparent lack of a cognitive map. As previously mentioned, Jonsen et al.’s (2001) closely related beetle species had completely different abilities to move through the landscape. Wethered and Lawes (2005) discovered in areas of small suitable patches formed by a matrix of plantations, more species occurred than in a matrix of grassland. These species, however, seemed to be composed of generalist species. In larger patch sizes, Wethered and Lawes found species of greater sensitivity to plantation fragmentation were able to persist. In the deforested Amazon, Antongiovanni and Metzger (2005) discovered that some species of birds could utilize the matrix, and thus, they persisted while others did not. To confuse matters even more, Manning et al (2004) studied the superb parrot and found that nature reserves are not likely to protect the parrot because they actually live in the agricultural matrix. The superb parrot depends on old trees with hollows in fields for their nest sites. Conserving habitat for multiple species is a continual dilemma for managers. It is hopeless to strategize for all species present in a landscape. Suggestions such as Opdam et al.’s (2003) cohesion index begin to get at a solution to managing for multiple species.

**Advances in environmental monitoring and management**

Applications of matrix theory to environmental monitoring and management have been slow to evolve largely because of the complexity involved. Matrix heterogeneity, permeability and multiple species use, however, are factors that cannot be ignored. Management practices must be appropriate for a mosaic of landscape patterns.
comprising a matrix habitat and cannot simply lump the matrix into one classification of 'non-habitat.' Because the entire landscape is utilized by many organisms, oversimplifying areas into habitat/non-habitat can result in poor management strategies. Managers must realize that matrix heterogeneity and permeability are necessary components of their strategies for maintaining metapopulations. Ricketts (2001) suggests it may be more feasible to reduce the effective isolation of fragmented habitats by altering management practices in the surrounding matrix than to connect the fragments through corridors. Wethered and Lawes (2005) also encourage the creation of a heterogeneous matrix rather than simply planting pine trees around a plantation because binary approaches of creating a uniform matrix tend to select for habitat-tolerant species. Antongiovanni and Metzger (2005) reason forestry practices could apply techniques that do not favor a particular type of second-growth vegetation that bird species have trouble utilizing. Adopting such techniques would lessen the decline of species that are highly and moderately sensitive to fragmentation. The most successful management practices and monitoring plans will often be those that take into consideration all of the concepts of the surrounding matrix. A matrix can be hospitable to species movement or it can act as a barrier. Altering a matrix to make it hospitable is a management strategy that needs to be accomplished in order for biologically diverse populations to persist.

Annotated Bibliography


In their study of the influence of the matrix habitat on birds, Antongiovanni and Metzger touch on many important aspects of the matrix. Their results have important implications for the maintenance of forest regeneration in the Amazon Basin. They separated bird species into groups of high, moderate and low sensitivity to fragmentation. Because some species could use matrix habitat, they persisted. The authors also measured re-colonization rates between matrix types of two secondary vegetation growth types. Species were better able to utilize Cecropia spp. dominated secondary vegetation than Vismia spp. dominated vegetation. Unfortunately, slash and burn techniques tend to favor the establishment of Vismia spp. The authors make several suggestions for management using knowledge they gained in the use of matrix theory. Using techniques that favor Cecropia spp. could be a compromise for the expansion of agricultural frontiers while maintaining species of moderate and low fragmentation sensitivity. Antongiovanni and Metzger also suggest that more mature matrices can offer a barrier
edge effect, essentially increasing the effective interior of fragments. Additionally, increasing the permeability of the matrix may lessen the effects of forest fragmentation.


Fisher et al. give a good overview of older matrix theory and discuss the need to move on from such simplified and erroneous ideas. They discuss the concept of habitat contours as a tool for modeling spatially heterogeneous habitat. They discuss the need for such a model as landscape models are often biased toward an anthropogenic perspective of the world. Oversimplifying ecological complexity can have undesired consequences for conservation. This occurs in the original concept of a 'matrix' where a matrix was viewed as a hostile environment or was evaluated in a binary manner- an area being either habitat or non-habitat. Models must consider species-specific differences in response to a given landscape. Fisher et al. apply the concept of habitat contours to the conservation of greater gliders in Australia. They are able to create prediction maps of the likelihood of occurrence of the greater glider in an area designated for wood production.


This is a great paper for understanding matrix applications because the concepts are straightforward. I also appreciated the discussion of the matrix in light of metapopulations. Joly et al. compared the abundance of newts in sites with varying amount of cultivated ground. They found the width of the uncultivated sector linking the pond to the forest was a good predictor of abundance. Newt presence was also related to the number of ponds within a 50-ha radius. This result links the idea of a functioning metapopulation dependent on the ponds. Because newts respond to chemical cues and travel between forest and pond habitats in a straight line, it is important to conserve as much uncultivated matrix habitat as possible. In prior years, pastures served as the matrix habitat. Now, however, pastures are being replaced by crop land. Species such as mice that have been shown to have a cognitive map will benefit from corridors, however, such a cognitive map has not been shown to exist in newts, thus a better management practice (vs. corridors) is to conserve as much uncultivated land as possible.


Jonsen et al.’s study is an excellent example of how matrix concepts can be applied to weed biocontrol. Jonsen et al. studied the effect of matrix habitat on variation in movement ability by insects in order to apply their findings to both metapopulation dynamics and weed biocontrol species. They tagged and released two species of beetles (Aphthona nigriscutis and Aphthona lacertosa) commonly used to control the invasive weed, leafy spurge. They used generalized linear models to compare the effects of matrix habitat types (grass vs. shrub), species on observed immigration probabilities. A. nigriscutis had a much higher immigration probability when moving through a shrub dominated matrix, whereas A. lacertosa immigrated similarly through both habitats but overall, significantly lower than A. nigriscutis. Jonsen et al. suggest
applying their findings to release strategies for weed biocontrol by tailoring practices according to the structure of the landscape into which beetle releases are planned. It is also important to note that closely related species can have significantly different movement abilities.


An important concept of this paper is that the matrix should not be considered as hostile but as agricultural, and therefore it is not completely devoid of the ability to support species. The results of this study were used to assess the conservation management implications of maintaining a tree hollow-dependent bird species in the agricultural matrix. Manning et al. found that the superb parrot may not be effectively protected by nature reserves because many actually live in the agricultural matrix, across the entire landscape. Manning et al. suggest patches of trees (of varying age classes, all with the potential to have hollows) be embedded in the agricultural matrix. A heavy point of this paper is the requirement for long term conservation planning. The trees used as habitat by the superb parrot take over a hundred years to mature and even longer for hollows to develop.


Opdam et al. discuss the effect of the spatial pattern of suitable habitat on the persistence of metapopulations. It is the spatial structure of the matrix that affects the dispersal of organisms to patches in the habitat network. Opdam et al. develop a concept for considering the effects on biodiversity of the entire landscape rather than just the habitat area. Their concept is meant for applying conservation measures based on something with predictive power for multiple species. The output is a map that can be used by stakeholders. The overall concept is to analyze a landscape pattern for each separate species and then integrate the results into a multi species index. I like how this paper discusses the use of landscape cohesion in agricultural and urban development. They talk about how habitat patches in these areas are low in abundance and distinct. Species persistence is really dependent on the cohesion of the habitat and not simply on habitat abundance.


This paper discusses landscape fragmentation and the applications of matrix theory to metapopulation persistence of Iberian lynx. Revilla et al. site a need to incorporate a behavioral component of matrix use into models of interpatch connectivity. The authors express concern over the use of individual-based spatially explicit models because 1. it is difficult to obtain information on the actual behavior of individuals moving in the matrix during interpatch long-distance dispersal events and 2. movement properties depend on spatial and temporal scale and change depending on life history traits makes suspicious the use of movement rules obtained at local scales to predict parameter at a population scale. The paper gives good support to the idea that a patch centered approach is unrealistic.

Ricketts recognized that terrestrial habitats are often surrounded by a complex mosaic of other land cover types. Ricketts conducted a mark-recapture study of a butterfly community inhabiting meadows and measured the resistance of matrix habitats, conifer forest and willow thicket, to movement between meadow patches. He found that effects differed even among closely related taxa. An excellent admission by Ricketts is that his resistance estimates should only be taken into consideration in applications of movement of individuals within local landscapes. Larger-scale movements are likely triggered by different behavioral cues. Ricketts claims it may be more feasible to reduce the effective isolation of fragments by altering management practices in the surrounding matrix than to reconnect them with restored corridors. As with other articles, Ricketts admits the general effects of the matrix on interpatch movement is difficult to predict, as even closely related species have significantly different responses.


This paper is a comprehensible discussion of matrix theory with several ideas about the application of matrix theory. Rodewald addresses the characteristics of the landscape matrix. Of particular importance to applications of matrix theory, Rodewald discusses how matrix effects have several implications for the management and acquisition of conservation areas. She states that most forests in North America are surrounded by agricultural or urban land and that affects of adjacent land uses on wildlife need to be seriously considered. For example, many studies have shown that the surrounding matrix has a greater effect on wildlife than does the effect of suitable patch size. She also talks about managers needing to prioritize land acquisitions and conservation by targeting areas that have the greatest potential to provide quality habitat for wildlife and to do so, they need to take the surrounding matrix into consideration. Rodewald also recommends, where possible, low development or buffer zones should be established to help the success of a habitat reserve.


This paper was all too theoretical. Russel et al. used a model that cannot be applied at all to the natural world. There are many good points made about the effects of the intervening landscape on behavioral decisions affecting movements between patches. Perceived risk is a big component of their model. Some species cannot perceive risk while others can and this will affect the population especially in an area dominated by patches of hostile human land use areas. Inner-patch heterogeneity is also an important concept for some species that can utilize non-ideal areas such as those created by humans.

The authors explore the relationships between forest history (absence/presence past logging) and the occurrence of particular fungal species thought to be indicators of ecological continuity of dead wood in a forest stand. Sverdrup-Tygeson and Lindenmayer define ecological continuity as an ecological attribute that is maintained within an area over time. They found that the presence of the fungi in a stand was dependent on the conditions in the surrounding matrix over a time-scale of more than 200 years. Thus, using P. nigrolimitatus as an indicator species of continuity can be misleading if used at the stand level. Knowledge of forest history on a broader scale is necessary. You get the feeling the authors were dissatisfied with their results. At any rate, the take home message is that the surrounding area can strongly influence the incidence and abundance of species.


I really enjoyed this paper for its discussion of many matrix concepts and for its application potential. Wethered and Lawes compare compositions of 61 species of birds in areas embedded in either a grassland matrix or a plantation matrix. They find that in forest patches <50 ha embedded in a plantation matrix are more species rich than in grassland matrix. However, when forest patches are>50 ha, species are more rich within a grassland matrix. Species-area relationships exist in the grassland matrix but do not in the plantation matrix. Instead, the plantation matrix assemblage seems to be composed primarily of generalist species. To avoid this insularisation effect on plantations, large forest patches need to be conserved in a natural matrix. The best management practice would be to keep plantations away from large forest patches and increase the number of small patches. Increasing small patches increases the likelihood of colonization after extinction. Where plantations do occur, the matrix should be a heterogenous mix, rather than surrounding plantations with a single species such as pine. This reduces the potential of selecting for habitat-tolerant species.