# Connectivity in a real fragmented landscape: distance vs movement model based approaches

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**Abstract**: Graph theory derived models and measures are increasingly being used to quantify landscape connectivity in order to contribute to conservation biology and management. This is particularly relevant in the case of real landscapes in which local actions may have crucial consequences for maintaining biodiversity on large scale. A number of graphs were compared sharing an identical node weight definition and whose link weights representing functional patch-connectivity, were derived from conceptually different approaches. Habitat suitability was taken into account. Calculated patch-connectivity was compared between all the graphs and these differences, evaluated by a set of indices describing network properties at the element structure level, were investigated.

**Keywords**: fragmentation, habitat suitability, matrix permeability, maximum entropy, graph theory, connectivity.

## 1. Introduction

Since the 1960's, the issue of species persistence in fragmented landscapes is crucial in both conservation biology and landscape ecology. Amongst other approaches, graph theory derived models and measures (Urban *et al.* 2009) are increasingly being used to quantify landscape functional connectivity in order to contribute to species and habitat conservation and management. Such tools have the potential to account for habitat availability, dispersal ability, species habitat requirements and dispersal route quality. These aspects are crucial to the conceptualisation and measurement of a landscape' permeability to the movement of organisms and thus to actually measure functional connectivity, as opposed to structural connectivity. However, landscape graph indices and models - as well as other techniques taking into account a heterogeneous landscape matrix - with desirable properties, may become too computation intensive for real large landscapes. The aim of this paper is to investigate the trade offs between a switch from binary landscape perspective to one embodying ecological continuity for a large real landscape.

## 2. Materials and Methods

The study area (EU NUT3 ITF45 Lecce, 275,716) is characterized by a very low forest share (1.4%) and a very high degree of fragmentation which challenge metapopulation dynamics (Hanski; 1991). One such dynamic is the dispersal of fleshy fruit broadleaved in pine plantations, likely to be mediated by bird species, among which the focal species was selected and described in terms of both breeding habitat and dispersal distance (5000 and 2500 m, 90-percentile). The habitat for the focal species was defined on two spatial data sets: 1) a 2008 land use vector map (1:5000 nominal scale) with potential breeding habitat (semi-natural woodland and plantations), and 2) a grid map (resolution 50 m) with probabilities of species-geographic distribution as a proxy to habitat suitability. These probabilities were obtained by applying an Environmental Niche Model (MaxEnt, Phillips and Dudík, 2008). The model was run using presence data (128 points) from a sub-regional ornithological monitoring program (La Gioia and Scebba, 2009). Several environmental predictor variables (i.e., land use, climate, landform, density of water elements and semi-natural vegetation), Linear Quadratic Hinge feature and a regularisation parameter equal to 3.0 , to compensate for potential overfitting, were considered in the model specification. The habitat system was cast in terms of graph theory, as a graph $G$, consisting of $n$ nodes connected by $m$ links. A node here is a functional unit: a patch with a local population, obtained from the clustering of nearby fragments likely to exchange individuals, within 250 m, which also served to greatly reduce the number of units, while preserving the exact habitat area. Patch population size is expressed as potential number of breeding pairs (reproductive units, RU) for which focal species is proposed as a measure of node weight ($w_i$). RU is determined by the area of suitable habitat and quality of the area. This is obtained by combining the definition of breeding habitat (vector format), with the MaxEnt derived definition of quality (raster format). Four graphs, two for each dispersal distance, were generated with identical nodes and node weights but different links. These were calculated either from Euclidean distance ($D$) assuming a negative-exponential relationship or with a simplification of the original GRIDWALK stochastic grid-based movement model . Distance-based links are symmetrical, as opposed to movement model based asymmetrical ones. The graph analysis was made as follows. Firstly, the weights of all links and the distance-based values ($p_d$) vs movement-based ones ($p_m$) were compared. Secondly, a set of published index, were based on the *PC* index routinely used for landscape conservation planning and change monitoring applications (Saura and Rubio 2010). These indices were compared at element level (Rayfield *et al.* 2011) by means of the measure of the individual patch's importance (*dPC*), and its breakdown into *dPC*(intra, flux, connector). The performance of a simplified, less computationally intensive, version of such indices was tested. In particular, *PCDP* and *DE* indices were considered. In PCDP index, the direct probabilities $p_{ij}$,weighted by source and target node, are used instead of maximum product probabilities $p^*_{ij}$ . The *DE* index (dispersal efficiency index),sums the values of all the fluxes in the graph. . In itsspecification a flux is defined as source node weight multiplied by link weight ($w_i \times p_{ij}$) and represents a relative measure of the number of dispersers expected to be exchanged between patches. For both indices we can define individual patch contributions, *dPCDP* and *dDE* as well. The map output similarities were evaluated by a fuzzy numerical approach (Hagen-Zanker *et al.*, 2006, http://www.risks.nl/mck/), an extension to the numerical maps of Fuzzy Kappa method, generally used for comparing categorical maps in order to account for fuzziness of locations and category. The comparison result is represented by a third map, indicating for each location the level of agreement in a range from 0 (non identical) to 1 (identical) between cells and by the similarity statistics evaluated as average of a combined one-way similarity over the whole map. An exponential decay function (2.5 km -5 km) was used for evaluating the similarities between maps in order account for the function used to evaluate the connectivity.

## 3. Results

The set of the statistical analysis on the model performance provided among MaxEnt model output information indicate a good model performance. As expected MaxEnt assigned different probabilities of distribution values to different patches ($\mu$= 0.490, $\sigma$=0.184), and particularly to woodlands ($\mu$= 0.672, $\sigma$=0.220) and plantation ($\mu$= 0.553, $\sigma$=0.167) patches even though they belong to the same habitat type (i.e. suitable breeding habitat) for the focal species. This is because the model refers each focal habitat spatial element to its surrounding context conditions as defined by the niche factors fed into the model. Comparing distance-based with movement-based connectivity, we see little similarity. Differences were expected as the distance-based model ignores several factors that are known to affect the probability of encountering a patch, and that are taken into account in the movement-based values. A $\chi^2$ test suggests complete independence between the variables. The distance-based values for the size of the target node (Moilanen and Nieminen 2002) were weighted by raising them to power of ½ in order to improve the correlation with the movement based ones. In general, the values of the distance-based approach are larger, providing a more optimistic view of connectivity. However, the impact of matrix heterogeneity is low: comparison of $p_d$ with $p_m$ values for a homogeneous matrix does not lead to a smaller $\chi^2$ statistic. When directly comparing $p_m$ for heterogeneous and homogeneous matrix the $\chi^2$ values are very small, amounting to 0.0615 and 0.0867 for 2500 and 5000 m dispersal distance, respectively. For both the shorter and the longer dispersal distances considered (2500 m and 5000 m), the pairwise comparison shows a certain similarity between the *dPC* and *dPCDP* maps, as indicated by the values of similarity statistic which respectively assumes the values of 0.643 and 0.573. The similarity is weaker between *dPC* and *dDE* (0,410 and 0,480 respectively for the two distances). Indices *dPC_flux* and *dDE,* proxies for route specific fluxes, do not appear to be associated at neither distances (0.366 and 0.023).

## 4. Concluding remarks

It seems to be clear that by incorporating habitat quality (MaxEnt output) in the node weight, the resulting patch population carrying capacities were reduced in comparison to an approach based on the distribution of habitat only. However, the map defining matrix permeability, appeared to be relatively uniform at the local scale (50 m). As a consequence, we observed relatively little impact of matrix heterogeneity on connectivity, with $p_m$ being relatively similar in homogeneous and heterogeneous landscapes. In this case, the value of working with a structured landscape matrix instead of assuming a homogeneous matrix seems somewhat limited. This, far from contradicting the evidence that the matrix really does matter (Fisher *et al.*, 2008), indicates that the methods (including scale) we apply to estimate and express spatial heterogeneity, also matter. Distance and movement-based connectivity were very different but could be made more similar by correcting $p_d$ with target patch size raised to ½. The extent to which correction is possible and it is however limited, as the real factor influencing accessibility (encounter rate) is the physical size of the patch accounting for shape as well, for which node weight (in *RU*) is just a weak approximation. In addition, there are several other factors determining accessibility in a movement-based approach, including 'shadowing' effects between patches, that are hard to correct for (but see . Likewise, it would be hard to correct for matrix heterogeneity. However, an interesting option appeared applying the movement model for a binary landscape. In this case, no assessment of landscape heterogeneity is needed, but still we implicitly deal with the impact of patch size and shape, and shadowing effects on patch connectivity. The large differences in underlying connectivity values ($p_d$ versus $p_m$) do not translate into very different values of indices on the level of the nodes (*dPC* and *dPCDP*), the connected area metrics. We found a very high correlation between the index based on maximum product paths *dPC* and a comparable but simpler index based on direct probabilities *dPCDP*. Our results suggest that the latter may be used to substitute the first when dealing with large networks (>10^3 nodes and/or >10^5 links), reducing computation time from days to minutes. However, a more thorough analysis of the behaviour of *dPCDP* compared to that of *dPC* is required, to ensure that essential properties of *dPC* are preserved in the approximation.

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