Designing Sustainable Landscapes:
Local and Regional Conductance

A project of the University of Massachusetts Landscape Ecology Lab

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General description

Local and HUC6 regional conductance are two of the principal Designing Sustainable Landscapes (DSL) landscape conservation design (LCD) products, which are best understood in the context of the full LCD process described in detail in the technical document on landscape design (McGarigal et al 2017). These particular products were initially developed for the Connecticut River watershed as part of the Connect the Connecticut project (www.connecttheconnecticut.org) — a collaborative partnership under the auspices of the North Atlantic Landscape Conservation Cooperative (NALCC), and subsequently developed for the entire Northeast region as part of the Nature's Network project (www.naturesnetwork.org).

Local conductance is a measure of the total amount of ecological flow through a cell from neighboring cells as a function of the ecological similarity between the focal cell and the neighboring cells (**Fig. 1**). Local conductance differs slightly from the local connectedness metric (one of the resiliency metrics that is incorporated into the composite *Index of Ecological Integrity*, or *IEI*) in that conductance measures how much flow there is to and through a cell from neighboring cells independent of the ecological similarity of the focal cell to its neighbors, whereas connectedness measures how much flow there is to the focal cell from ecologically similar neighboring cells. Thus, the local conductance of a focal cell is determined in a sense by the average resistance of its neighborhood across all the ecological settings, whereas the local connectedness of a focal cell is determined largely by the ecological similarity of its neighborhood. However, in practice these two measures tend to be highly correlated. Conceptually, these two metrics have different interpretations and uses. Local connectedness is a measure of ecological isolation; it confers resiliency to a site in the short-term, since being connected to similar ecological settings should promote recovery of the constituent organisms following a local disturbance. Local conductance, on the other hand, is a measure of importance in promoting ecological flows across the local landscape, regardless of whether the cell itself is highly connected to an ecologically similar neighborhood. Thus, a cell can have high conductance and low connectedness, at least theoretically, although this tends not to happen too often in real landscapes. Lastly, local conductance does not depend on the designation of core areas like the regional conductance index below; thus, it can be used independently from any designated core area network.

HUC6 regional conductance is a measure of the total potential amount of movement of plants and animals (ecological flow) through a cell from nearby designated HUC6 terrestrial core areas at the scale of a few to ten kilometers (**Fig. 2**). Importantly, this metric is contingent upon the a prior designation of terrestrial core areas, and thus is it only meaningful when referenced to those designated terrestrial cores. Regional conductance increases with the size and proximity of nearby cores, because larger cores produce larger numbers of plants and animals and the probability of an individual getting to any particular location decreases with distance from the source. Regional conductance also reflects the resistance of the focal cell and intervening cells between the nearby cores based on their ecological dissimilarity to the cells in the nearby cores. For example, a forest cell between largely forested cores would have higher regional conductance than if it were lake.

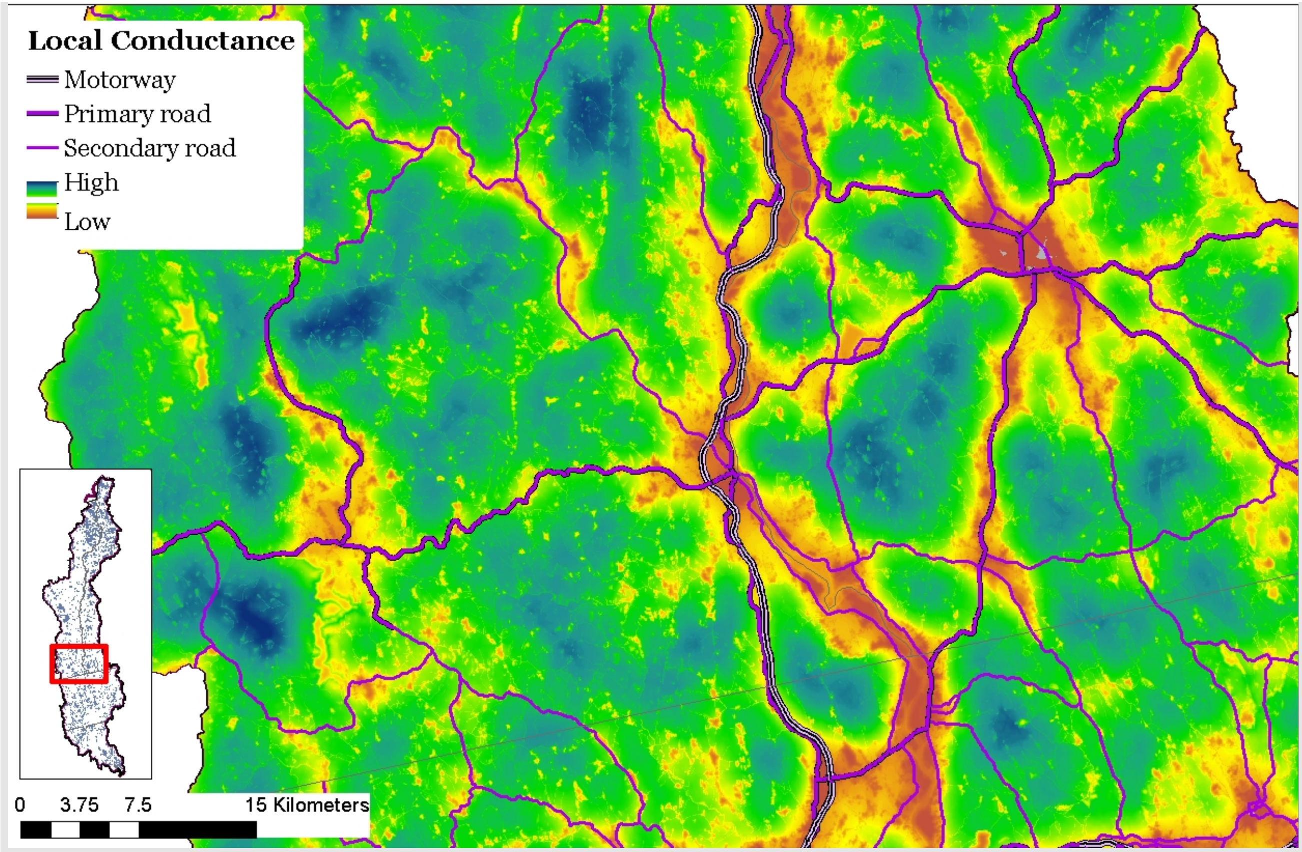

Figure 1. Illustration of the local conductance metric. The areas shown in blue depict relatively high local conductance, whereas the areas shown in red depict relatively low local conductance; major roads are depicted by class.

HUC6 regional conductance is based on the HUC6 terrestrial cores (see terrestrial core area network document, McGarigal et al 2017) and provides a continuous surface of conductance values between cores. The "connectors" in the HUC6 terrestrial core-connector network are a discrete (binary) representation of conductance and are generally positioned along routes between cores having the greatest regional conductance.

Use and interpretation of these layers

Local and regional conductance both provide a seamless and continuous index of conductance or ecological flow through a cell; the former is completely independent of designated cores, the latter is specific to the designated terrestrial cores. These products are primarily useful in the context of landscape conservation design to identify places that confer connectivity independent of or between the terrestrial cores and thereby contribute to the ecological connectivity of the entire region. The use of these products should be guided by the following considerations:

- It is important to acknowledge that both local and regional conductance were derived from a model, and thus subject to the limitations of any model due to incomplete and imperfect data, and a limited understanding of the phenomenon being represented. In particular, the GIS data upon which these products were built are imperfect; they

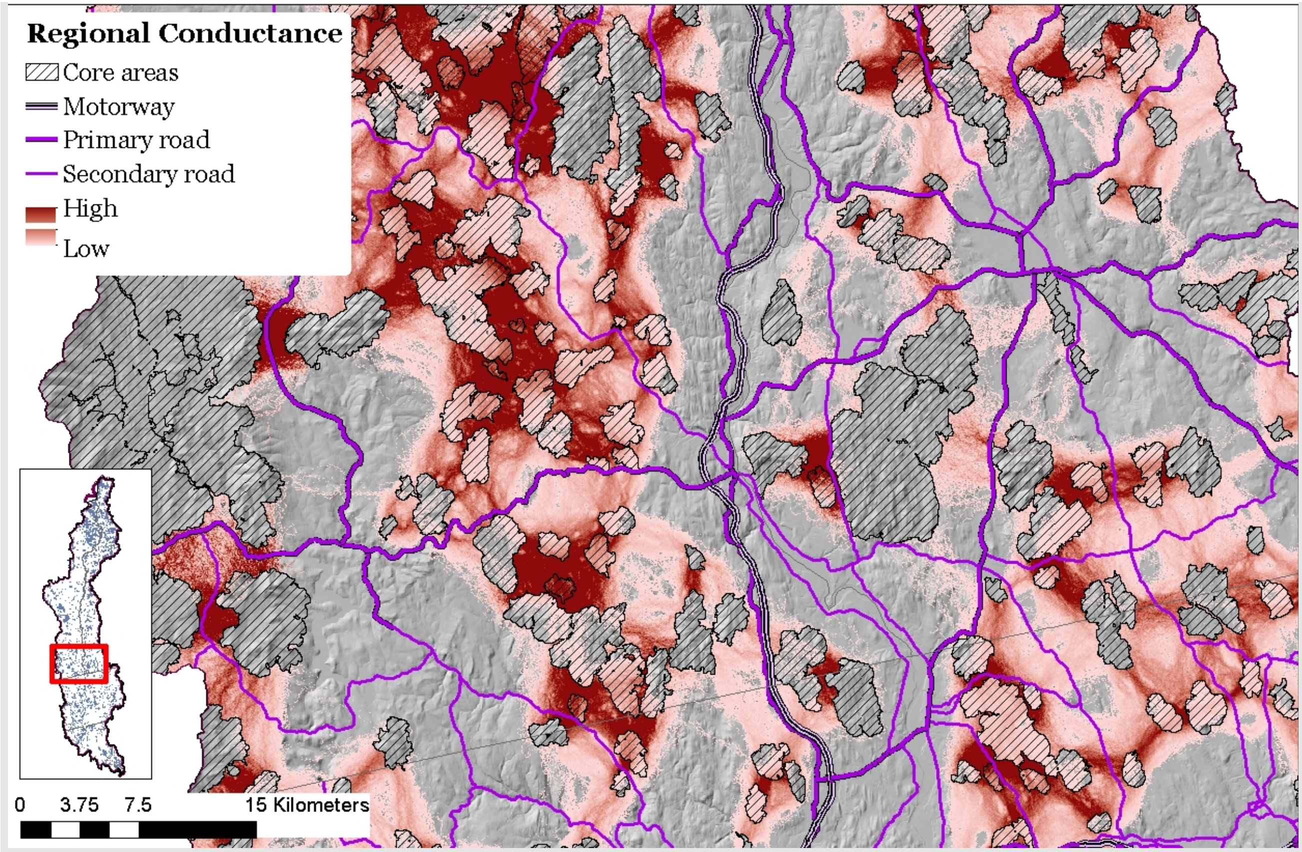

Figure 2. Illustration of the regional conductance metric, shown here for a designated core area network and a small portion of the Connecticut River watershed. Conductance is given by the intensity of red and depicts areas of relatively high predicted ecological flows between designated core areas; major roads are depicted by class.

contain errors of both omission and commission. Consequently, there will be places where the model gets it wrong, not necessarily because the model itself is wrong, but rather because the input data are wrong. Thus, these products should be used and interpreted with caution and an appreciation for the limits of the available data and models. However, getting it wrong in some places should not undermine the utility of the product as a whole. As long as the model gets it right most of the time, it still should have great utility. Moreover, the model should lead to new insights that might at first seem counter-intuitive or inconsistent with limited observations. This is so because the model is able to integrate a large amount of data over broad spatial scales in a consistent manner and thus provide a perspective not easily obtained via direct and limited observation.

- It is important to recognize the relative nature of both the local and regional conductance metrics. A value of 0 can be interpreted as a cell that has no predicted ecological flow going through it, either because it is itself developed, surrounded by development, or too far from the nearest core areas. Conversely, a value of 1 represents the theoretical maximum, but it is almost never achieved, and with regional conductance the maximum observed value is typically quite small. Thus, the absolute value has no particular meaning with either of these metrics, therefore the values are mainly useful in a relative sense for comparative purposes. For example, it is impossible to say how much absolute flow of organisms might occur through a cell with a value of 0.2, but we can say that it has twice the likelihood of conducting ecological flows than a cell of 0.1.

- Local and regional conductance are generic measures of ecological flow; i.e., they are based on the ecological similarity of the focal cell to the ecosystems in the neighboring cells (local conductance) and in adjoining terrestrial cores (regional conductance), in which ecological similarity is based on a variety of ecological settings variables representing biophysical attributes of the cell. Thus, these metrics don't necessarily reflect connectivity for any single species.

- Regional conductance is computed for every cell, regardless of whether it is between cores or within cores, but the index is most useful for assessing the conductance of cells between the designated cores. Cells within cores can get a conductance value because the random low-cost paths can pass through these cells between the originating cell in the "from-core" and the terminating cell in the "to-core"; however, there is a strong bias towards cells near the periphery of the cores since the paths terminate at the first cell of the corresponding ecosystem encountered in the "to-core". In addition, some paths flow completely through a core between two other nearby cores. Thus, some of the conductance attributed to cells within cores is attributed to their role in facilitating flows between other cores. For these reasons, interpreting the conductance values for cells within the cores is problematic and thus should be avoided

- These products are used in combination with the probability of development layer (see probability of development document, McGarigal et al 2017) to identify places that confer greater connectivity that are especially vulnerable to future development either independent of core areas or between designated terrestrial core areas (see vulnerability document, McGarigal et al 2017), which could represent priorities for land protection.

- Local and regional conductance can and do have non-zero values for developed cells. This is the result of the necessity of traversing developed areas, for example, when moving between cores embedded in a developed landscape. However, generally local and regional conductance are strongly negatively correlated with development. The inclusion of non-zero conductance in such developed areas should not be interpreted as indicating their intrinsic ecological value, but rather that they represent places through which organisms may be forced to move due to the lack of better options. These developed areas with high local or regional conductance (see vulnerability document, McGarigal et al 2017) could be considered high priorities for restoration or sustainable urban redevelopment.

Derivation of these layers

1. Local conductance

Local conductance is computed as the overlap at the focal cell of *resistant* Gaussian kernels derived for every neighboring undeveloped cell (see technical documentation on integrity, McGarigal et al 2017, for a detailed description), briefly as follows:

1. For each undeveloped focal cell, build a resistant Gaussian kernel (2 km bandwidth, extending out to a maximum distance of 4 km) for all neighboring cells;
2. divide by the maximum value in step 2 for a nonresistant (i.e., resistance = 1 everywhere) and homogeneous ecologically similar neighborhood,
3. cumulatively sum the resulting kernel at each neighboring cell; and let this be the local conductance index.

In step 1 above, the resistance between the focal cell and each neighboring cell is based on weighted Euclidean distance in multivariate ecological setting space, as described in detail in the integrity document.

As defined above, local conductance is influenced strongly by how much undeveloped land there is within the local neighborhood of a focal cell, since a resistant kernel is built for each neighboring undeveloped cell but not for developed cells. The ecological similarity of the neighborhood also influences the value of the metric. All other things being equal, an ecologically similar neighborhood will produce larger kernels and increase the conductance through the focal cell, but the degree of ecological similarity of the neighborhood generally has much less impact on local conductance than the amount of development. In addition, since the amount of development and the ecological similarity of the neighborhood influence both local conductance and local connectedness, these two metrics differ only subtly and in most cases a cell with high connectedness will also have high conductance. However, there are situations in which a cell can have high conductance but low connectedness. Specifically, if a focal cell is surrounded by undeveloped but ecologically very dissimilar settings, the conductance could be relatively high because there is still a lot of unimpeded flow getting to the focal cell, but the connectedness of the focal cell itself could be very low because of its low ecological similarity to the neighboring cells. However, a focal cell surrounded by homogeneous identical ecological conditions would have both a connectedness and conductance score of 1 and, for example, a focal cell surrounded by a sea of development would have both a connectedness and conductance score of 0. Note that a road or developed cell will have undefined connectedness, but may have a value for conductance, representing flow across the road or developed area.

2. HUC6 Regional conductance

We assessed the regional conductance between each pair of HUC6 terrestrial cores using a new approach, random low-cost paths. It would be straightforward to connect one or more points in each core to one or more points in each neighboring core with a least-cost path; however, there are a number of drawbacks to using least-cost paths. They typically select unrealistically narrow corridors (e.g., one cell wide—something that would be unlikely to be used by most migrating or dispersing animals). As a result, least-cost paths are very sensitive to small GIS errors. They also ignore the number of alternatives, failing to distinguish between situations where there is a single path and situations where there are many alternatives. There are significant limits, therefore, to how usefully one can assess landscape connectivity with least-cost paths.

Our approach is to add some random variation to least-cost paths, making them sub-optimal and variable. We believe this approach, which we call random low-cost paths, more realistically represents the way animals move through the landscape, and more completely and robustly describes the connectivity between two areas. Random low-cost paths have three parameters: one that determines how random they are (ranging from deterministic least-cost paths to random walks), and two momentum parameters that determine the grain of randomness. For this project, we selected parameters that gave “reasonable” paths, as there is no direct biological interpretation of these parameters.

Regional conductance is derived from random low cost paths as follows:

1. for each pair of HUC6 terrestrial cores within a designated threshold distance (e.g., 20 km), select a fixed number of random points (e.g., 1,000) within each core (the “from-core”). These random points are stratified by the representation of each macrogroup of ecological communities within the from-core;

2. construct a *random low-cost path* from each of these points to the first point in the same macrogroup encountered in each neighboring core (the “to-core”). If a macrogroup in the from-core doesn’t exist in the to-core, that path is dropped. Ultimately, paths are built in both directions between each pair of cores. For each focal macrogroup (based on cells in the from-core), random low-cost paths are built on a resistant landscape based on cells in that macrogroup in the to-core. This is done by following a resistant kernel built on a number of points in the to-core “uphill” from the from-core. The result is a set of up to, for example, 2,000 random low-cost paths between each nearby (less than the designated threshold distance between core centroids) pair of cores in the landscape, stratified by macrogroup. Note, stratification by macrogroup insures that connections are made between similar cells, such that it is likely that an animal moving from one core to another would find habitat at its destination. Paths between each pair of points honor the landscape resistance for the macrogroup in the focal cell—thus, a path from a ridgetop cell will favor dry, steep ridgetops, whereas a path from a wetland will favor wetlands and low, wet areas;

3. measure the functional length of each path (i.e., *path length*) by adding the landscape resistance (based on each starting point in the from-core) along the path’s length. This gives path functional distance, which integrates the distance travelled by the path in meters with the resistance of the intervening landscape given each cell’s ecological distance from the starting cell to each cell along the path. The minimum resistance value is 1.0, so a 1 km long path through cells in an identical setting as the starting cell would have a functional distance of 1,000;

4. convert path functional distance to *path probability of connectivity* using a Gaussian density function based on a bandwidth (standard deviation) representing dispersal ability. As this is a coarse-filter assessment, we are not focusing on individual species; thus, ideally we would use a series of bandwidths (e.g., 2 km, 5 km, and 10 km, with a maximum spread of 2 times the bandwidth) to represent a range of dispersal abilities.

However, to minimize the complexity of the results we report only the results of the 10 km bandwidth. Note, the Gaussian function represents a non-linear decay with distance, such that the probability of connectivity declines slowly at first with increasing functional distance and then declines rapidly as the functional distance increases further, and eventually declines to zero. Any path with a functional distance greater than 2 times the bandwidth is dropped; and

5. multiply path probability of connectivity by the mean value of the two cores, where the value of each core is computed as the sum of the core area selection index (as described in the landscape conservation design document), assign this value to each cell in the path, sum across all paths in the landscape, and let this be the regional conductance index. Note, the sum of the core area selection index is simply a more meaningful indicator of core size that takes into account not only the size of the core but also its quality as represented by the selection index.

As defined above, the regional conductance index is influenced by three major factors. First, the resistance of the focal cell itself, which is a function of its ecological similarity to the cells in the nearby cores, and the resistance of the intervening landscape between the nearby cores affects the magnitude of conductance; the greater the resistance of the focal cell and intervening landscape between the cores, the lower the probability of connectivity of the paths through the focal cell, and thus the lower the regional conductance. Second, the proximity of the nearby cores affects conductance, since the probability of connectivity decreases according to a Gaussian function of the functional distance between cores, and cores beyond a functional distance of 2 times the bandwidth are considered functionally disconnected. Third, the size and quality of the nearby cores affects conductance, since the path probability of connectivity is weighted by the size and quality of the two cores connected by the path. Thus, cells with higher values are functionally closer to larger cores and indicate a greater probability that animals will pass through these cells.

GIS metadata

Conductance includes two separate data products that can be found at McGarigal et al (2017):

- **Local conductance geoTIFF raster** (30 m cells) -- with cell value ranges from 0 (no conductance) to a theoretical maximum of 1 (but the maximum observed value is typically not observed).
- **HUC6 regional conductance geoTIFF raster** (30 m cells) -- with cell value ranges from near 0 (no conductance) to a theoretical maximum of 1 (but the maximum observed value is typically quite small).

Literature Cited

McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2017. Designing sustainable landscapes products, including technical documentation and data products. https://scholarworks.umass.edu/designing_sustainable_landscapes/