Designing Sustainable Landscapes: Local and Regional Vulnerability

A project of the University of Massachusetts Landscape Ecology Lab

Principals:

- Kevin McGarigal, Professor
- Brad Compton, Research Associate
- Ethan Plunkett, Research Associate
- Bill DeLuca, Research Associate
- Joanna Grand, Research Associate

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McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2017. Designing sustainable landscapes: local and regional vulnerability. Report to the North Atlantic Conservation Cooperative, US Fish and Wildlife Service, Northeast Region.

General description

Local and HUC6 regional vulnerability 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). T These 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).

These two vulnerability products represent the vulnerability of high-valued places to future development, but differ in whether they reflect potential impacts of development on connectivity independent of any designated terrestrial cores (local vulnerability) or dependent on the designated cores (HUC6 regional vulnerability).

Local vulnerability measures the vulnerability of a cell to the loss of high local conductance caused by future development (**Fig. 1**); it is a function of the cell's current local conductance (i.e., magnitude of predicted ecological flow through a cell) and integrated future probability of development (see probability of development document, McGarigal et al 2017). Local vulnerability identifies places that currently have high local conductance but that are at high risk of development in the future. Cells with relatively low local conductance have low vulnerability regardless of risk of development, since local connectivity will not be degraded much if they get developed. On the other hand, cells with relatively high local conductance will have high vulnerability if they suffer high risk of development, since local connectivity will be seriously degraded if they get developed.

HUC6 Regional vulnerability measures the vulnerability of an irreplaceable cell (i.e., a cell in which a high proportion of the flow paths between two adjoining cores go through that cell) with high regional conductance to the loss of its connectivity value caused by future development (**Fig. 2**); it is a function of the cell's estimated regional conductance (see conductance document, McGarigal et al 2017) and regional irreplaceability, both of which are based on the HUC6 terrestrial cores (see terrestrial core area network document, McGarigal et al 2017), and the integrated future probability of development (see probability of development document, McGarigal et al 2017). Cells with relatively low regional conductance and/or irreplaceability have low vulnerability regardless of their risk of development, since regional connectivity will not be degraded too much if they get developed. On the other hand, cells with relatively high regional conductance that are irreplaceable will have high vulnerability if they suffer high risk of development, since regional connectivity will be seriously degraded if they get developed.

Use and interpretation of these layers

Local and regional vulnerability layers provide seamless and continuous indices of local conductance independent of any designated cores (local vulnerability) or between the designated HUC6 terrestrial cores (regional vulnerability), respectively. These products are primarily useful in the context of landscape conservation design to identify places that confer a relatively high degree of connectivity that are vulnerable to future development,

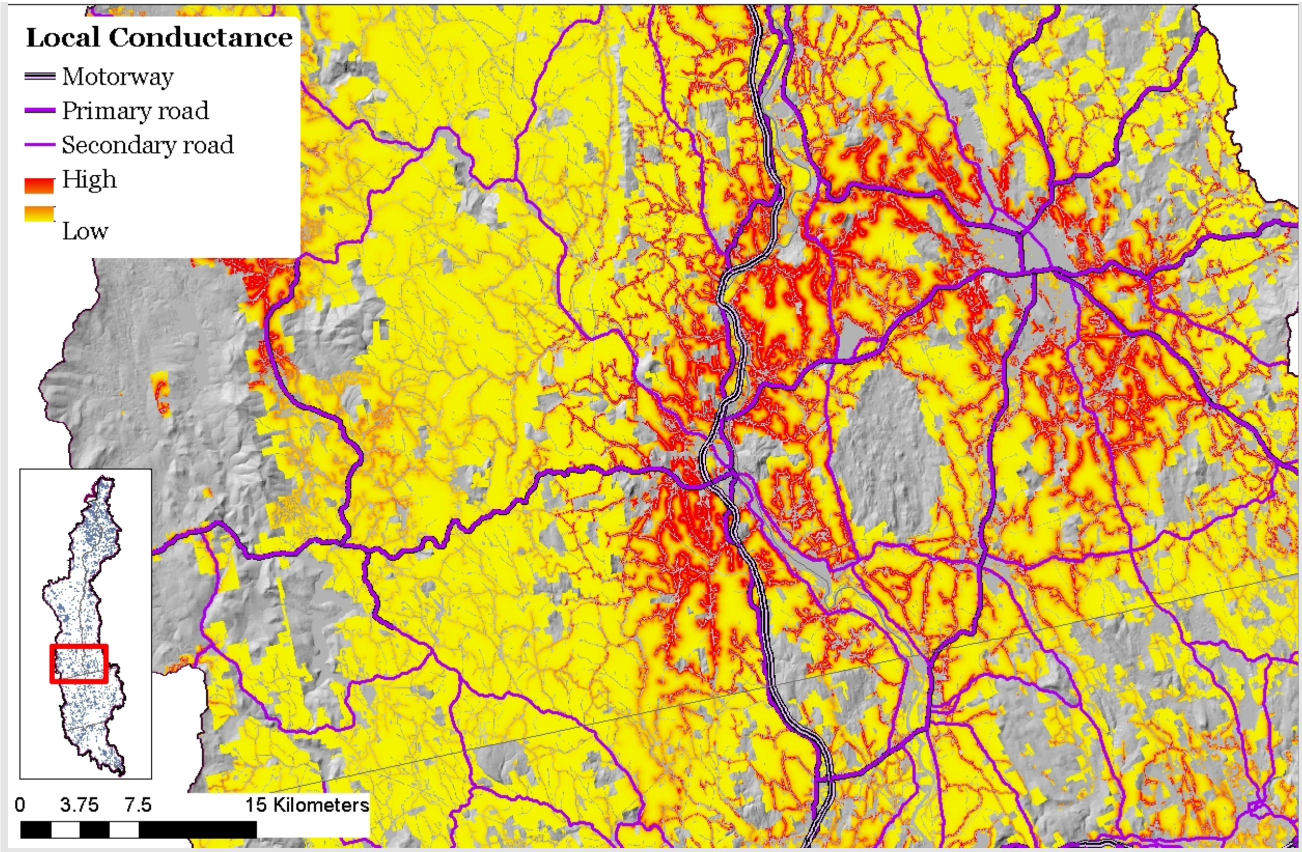

Figure 1. Illustration of the local vulnerability metric. The areas shown in red depict relatively high local vulnerability to future development, whereas the areas shown in yellow depict relatively low local vulnerability to future development; areas already developed or secured from development are transparent; major roads are depicted by class.

which could represent priorities for land protection. The use of these products should be guided by the following considerations:

- It is important to acknowledge that the local and regional vulnerability layers 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 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.

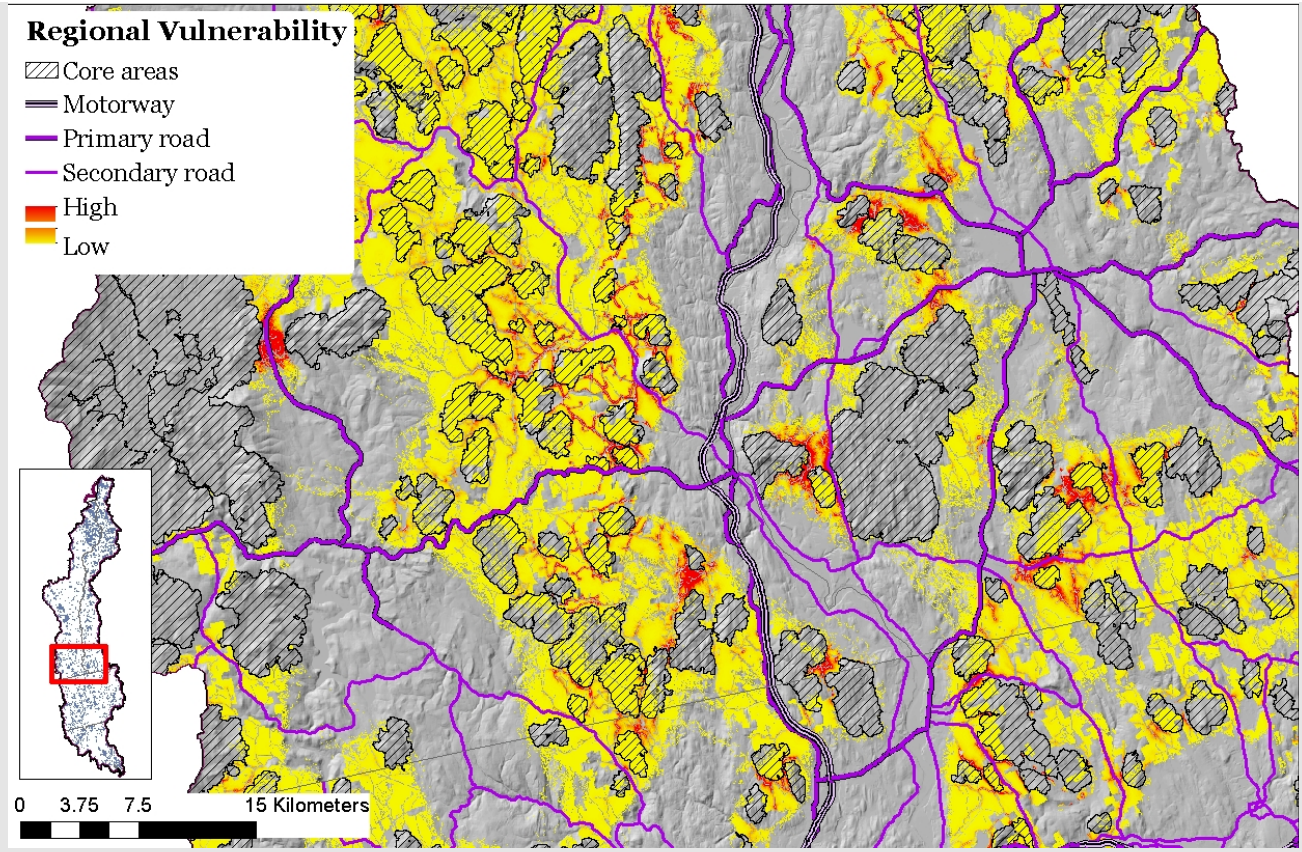

Figure 2. Illustration of the HUC6 regional vulnerability metric, shown here for a designated core area network and a small portion of the Connecticut River watershed. Vulnerability is shown here as a gradient from low (yellow) to red (high) and represents the relative probability of cells with high regional conductance that are irreplaceable being developed in the future; major roads are depicted by class.

- It is important to recognize the relative nature of these two vulnerability measures. Both measures are derived from metrics that have a relative interpretation, such as the integrated probability of development (see probability of development document, McGarigal et al 2017). A value of 0 can be interpreted as a cell that has no predicted vulnerability to future development, either because it has no predicted conductance through it or because the future probability of development is zero. Otherwise, non-zero values reflect increasing vulnerability of cells with relatively high conductance to future development. The absolute value of these measures has no particular meaning, thus values are mainly useful in a relative sense for comparative purposes. Moreover, the two vulnerability measures are scaled differently and thus the absolute values cannot be compared between products.

- Regional vulnerability is computed for every cell, regardless of whether it is between designated terrestrial cores or within them, but interpreting the values within the cores is problematic and should be avoided. Conversely, local vulnerability is computed for every cell independent of whether it is inside or outside of a designated core, and thus it can be used independently of designated core areas. However, these

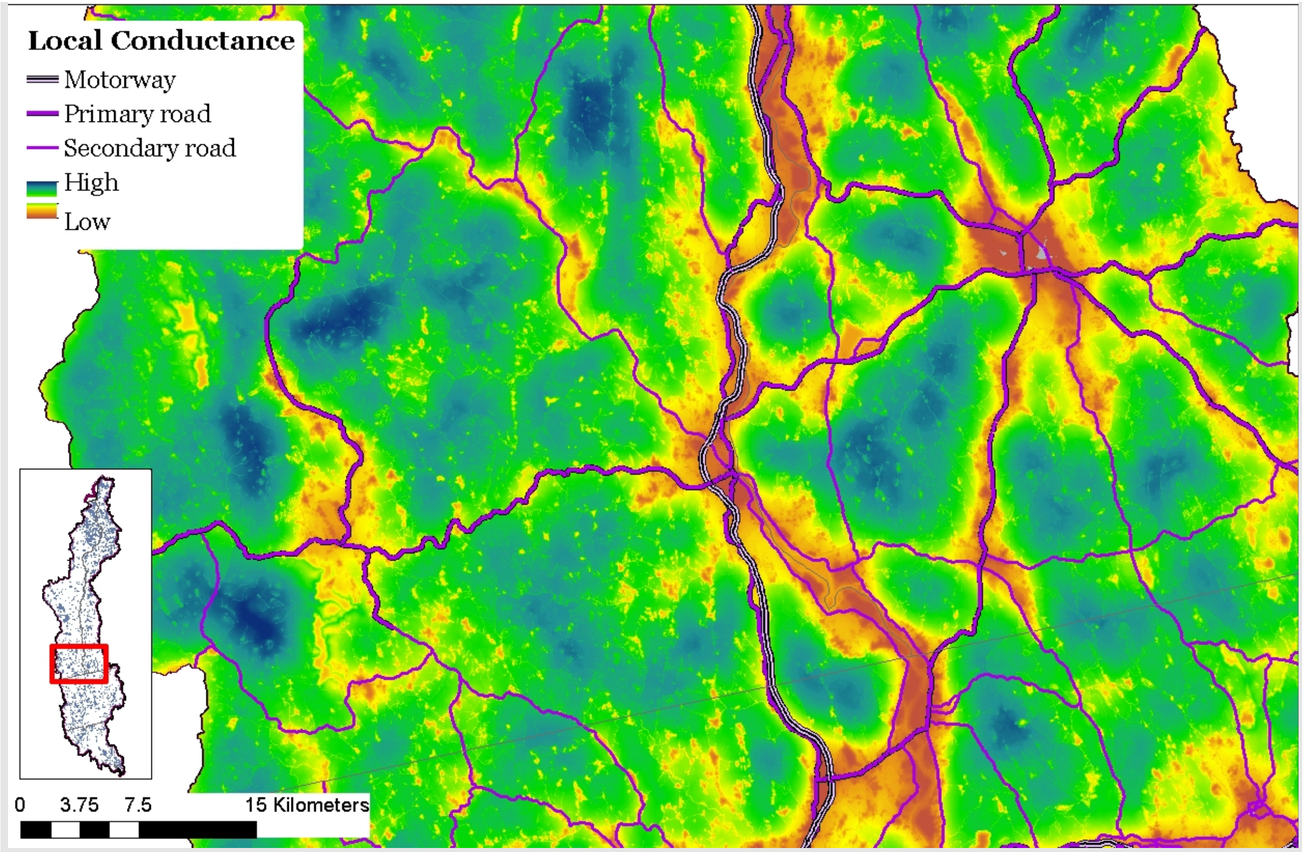

Figure 3. Illustration of the local conductance metric. The areas shown in blue depict relatively high local conductance, whereas the areas shown in red depict relatively low local conductance; major roads are depicted by class.

two measures can be used together in a complementary fashion by combining local conductance within cores and regional conductance between cores.

Derivation of these layers

1. Local vulnerability

Local vulnerability is computed as the product of local conductance (see conductance document, McGarigal et al 2017) and the integrated probability of development (see probability of development document, McGarigal et al 2017). Briefly, this measure is computed as follows:

1. First, we compute the local conductance index (**Fig. 3**), which measures the total potential amount of movement of plants and animals (ecological flow) through a cell from neighboring cells as a function of the ecological similarity between the focal cell and neighboring cells at the scale of one to a few kilometers. The conductance of a focal cell is affected by the amount of development and ecological similarity of its neighborhood (within one to a few kilometers) as well as the resistance of the focal cell itself (i.e., its ecological dissimilarity to neighboring cells). Conductance increases as the proportion of the neighborhood that is undeveloped increases, as the ecological

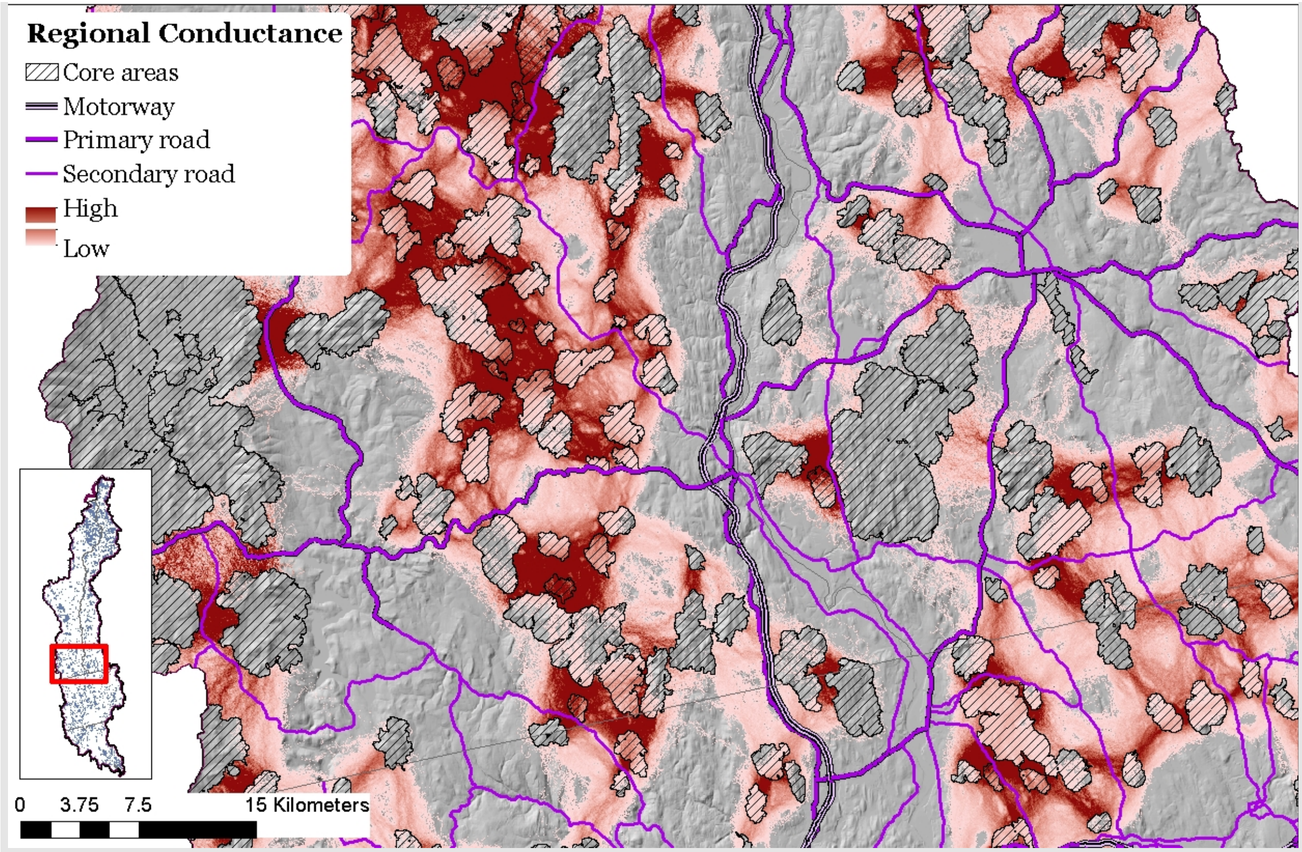

Figure 4. Illustration of the HUC6 regional conductance metric, shown here for a designated core area network and a small portion of the Connecticut River watershed. Conductance is given by the intensity of red and depicts areas of relatively high predicted ecological flows between designated core areas; major roads are depicted by class.

similarity among neighboring cells increases, and as the ecological similarity between the focal cell and its neighbors increases. For example, a forested cell surrounded by forested cells would have high conductance, whereas a forest cell surrounded by aquatic and wetland cells would have lower conductance, and a forested cell surrounded by development would have the least conductance.

2. Next, we compute the integrated probability of development index based on a custom urban growth model that accounts for the type (low intensity, medium intensity and high intensity), amount and spatial pattern of development. This index represents the probability of development occurring sometime between 2010 and 2080 at the 30 m cell level. The projected amount of development in an area is downscaled from county level forecasts based on a U.S. Forest Service 2010 Resources Planning Act (RPA) assessment. The type and pattern of development is based on models of historical development and is influenced by factors such as geophysical conditions (e.g., slope, proximity to open water), existing secured lands, and proximity to roads and urban centers.

3. Lastly, we compute the local vulnerability index (**Fig. 1**) as the product of the local conductance index and integrated probability of development index.

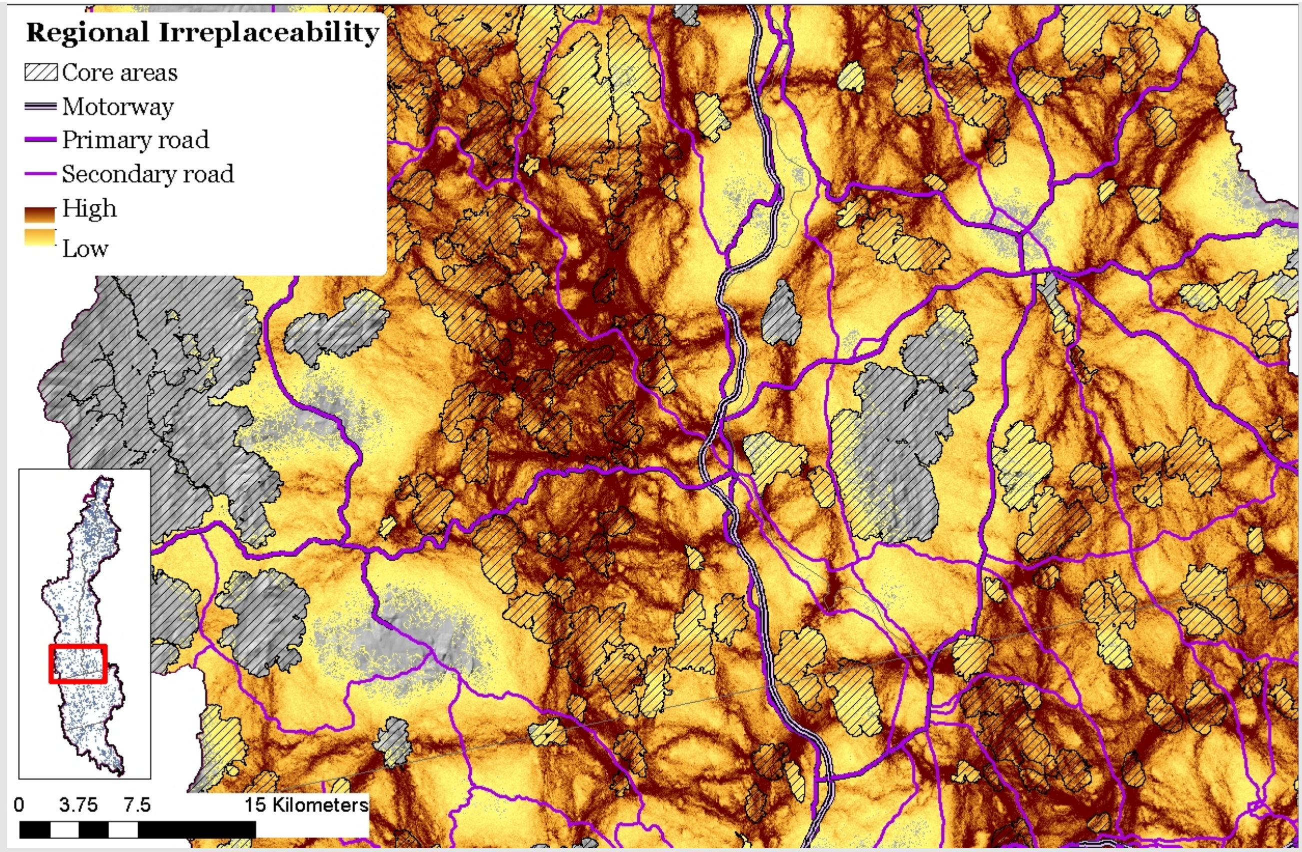

Figure 5. Illustration of the regional irreplaceability metric, shown here for a designated core area network and a small portion of the Connecticut River watershed. Irreplaceability is given by the intensity of brown and depicts the proportion of random low-cost paths between designated core areas that traverse each cell; major roads are depicted by class.

As defined above, local vulnerability is greatest where there is high local conductance; i.e., in ecologically similar areas with minimal current development, but that have relatively high probability of development. Thus, places with high vulnerability tend to occur in the least developed areas within the urban sprawl zone – outside the urban centers that already have low local conductance but close enough to the urban centers to have high probability of development in the future.

2. HUC6 Regional Vulnerability

HUC6 regional vulnerability is computed as the product of HUC6 regional conductance (see conductance document, McGarigal et al 2017), regional irreplaceability (see connectivity document, McGarigal et al 2017), and the integrated probability of development (see probability of development document, McGarigal et al 2017). Briefly, this measure is computed as follows:

1. First, we compute the HUC6 regional conductance index (**Fig. 4**), which measures the total amount of ecological flow through a cell from nearby designated HUC6 terrestrial cores (see terrestrial core area network document, McGarigal et al 2017) and is a

function of the size and proximity of the cores and the resistance of the focal cell and the intervening landscape between the focal cell and the nearby cores.

2. Next, we compute the HUC6 regional irreplaceability index (**Fig. 5**), which measures the concentration of ecological flow between nearby designated HUC6 terrestrial cores going through a cell. Irreplaceability does not indicate whether a cell is irreplaceable or not in an absolute sense, since there are almost always alternative pathways between cores. Rather, it is a function of the proportion of the random low-cost paths between two cores that go through each cell independent of the size and proximity (up to a limit) of the cores; a cell that accounts for a large proportion of the paths is relatively irreplaceable. Whereas regional conductance reflects how much flow is likely to occur through a cell (i.e., its ecological importance in promoting connectivity), which is strongly influenced by the size and proximity of nearby cores as well as the resistance of the intervening landscape, regional irreplaceability measures the proportion of the flow paths between cores that go through a cell regardless of the size and proximity (up to a limit) of nearby cores. Thus, regional irreplaceability reflects the relative importance of a cell to flow if it were to occur, but does not reflect how much flow is likely to occur or be lost if that cell were developed. Cells within a relatively wide "corridor" between two cores will have low irreplaceability because there are a lot of alternative paths between the cores. Conversely, a cell that is a "pinchpoint" of low resistance between two cores will have high irreplaceability because most of the paths are likely to go through that cell.
3. Next, we compute the integrated probability of development index, as described above.
4. Lastly, we compute the HUC6 regional vulnerability index (**Fig. 2**) as the product of the regional conductance index, regional irreplaceability index, and integrated probability of development index.

Thus, as any one of the components goes to zero, then the product goes to zero, and the product is only large when all three components are large. Consequently, regional vulnerability is greatest where there is high regional conductance and irreplaceability; i.e., in narrow "corridors" of ecologically similar areas with minimal current development between large nearby nodes (core areas), and where there is also relatively high probability of development in the future.

GIS metadata

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

- **Local vulnerability geoTIFF raster** (30 m cells) -- with cell value ranges from 0 (no vulnerability; e.g., secured land, water, already developed) to a theoretical maximum of 1 (but the maximum observed value is typically quite small).
- **HUC6 regional vulnerability geoTIFF raster** (30 m cells) -- with cell value ranges from 0 (no vulnerability; e.g., secured land, water, already developed) 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/