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Response to Rothley. 2005. “Finding and Filling the "Cracks" In Resistance Surfaces for Least-cost Modeling”

A Note on Creating Robust Resistance Surfaces for Computing Functional Landscape Connectivity

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Key Words: *cost-weighted surfaces; functional connectivity; GIS methods*

INTRODUCTION

Increasingly, conservation scientists are using geographical information systems (GIS) and, in particular, cost-weighted methods to compute metrics of landscape connectivity. Rothley (2005) raised an important technical issue that scientists need to be aware of when using these methods. Cost-weighted methods are used to compute the connectivity of a surface, a raster, by specifying the cost of traveling across a landscape using a surface of cost-weights. This surface is often called the friction or resistance surface (Knaapen et al. 1992) or its inverse, the permeability surface (Singleton et al. 2002). In GIS literature, this general method has been typically called cost-weighted distance and least-cost path analysis (Eastman 1989, Berry 1993, Douglas 1994, reviewed in Theobald 2005*b*).

Rothley (2005) recently extended the work by Adriaensen et al. (2003), who identified “cracks” in the cost-weighted distance surface that might allow a least-cost path to artificially pass through a “barrier” or a high-cost landscape feature such as a lake or a highway. A least-cost path is a line of cells a single cell wide that is commonly used as an estimate of interpatch distance. Two key sentences from Rothley’s (2005) article describe the problem well: “Cracks result when narrow land features that are costly, i.e., those that are risky or speed-inhibiting from the point of view of a moving organism, such as roads or train tracks, are represented in raster form ... For least-cost models to be reliable and credible, however, the validity of input data must be demonstrated. Least-cost modelers must also exercise extreme caution when using any GIS-based analysis of this kind.”

I agree with Rothley and others that these cracks are potentially problematic for landscape connectivity analyses, and I join them in cautioning conservation scientists to create valid models when generating spatial data inputs to cost-weighted analyses. However, I disagree as to the cause and the ubiquity of these cracks. I also provide a few additional procedures that will eliminate potential problems resulting from the misspecification of resistance surfaces and minimize possible additional artifacts arising from any correction processes. This note is intended to continue the important discussion about developing useful methods for computing functional landscape connectivity.

DEFINING AND FINDING “CRACKS”

Generally, connectivity analyses involve two steps. First, resistance values are specified for different land features to generate a cost-weighted raster. Second, the cost-weighted raster is used by cost-weighted algorithms to estimate least-cost distances across a surface. “Barriers” or “hard-to-cross” features have a high resistance value or cost, whereas features and cover types that provide protection or offer minimal resistance have low resistance values. Often these landscape features are represented spatially in geographical information systems (GIS) as feature-based or vector data structure lines that represent real-world objects such

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Table 1. A simple algorithm to test for possible “cracks” when converting linear features to raster format in ArcGIS (Environmental Systems Research Institute, Redlands, California, USA).

1. Convert polylines to raster R	Spatial analyst → features to raster → R
2. Convert all cells to a single value	[t1] = con ([R] >= 0, 1)
3. Count the number of orthogonal neighbors	[t2] = con ([t1] == 1, focalsum([t1], CIRCLE, 1))
4. Find contiguous cells via four neighbors	[t3] = regiongroup ([R], #, FOUR)
5. Find diagonal neighbors that are in different clusters	[t4] = focalvariety ([t3], RECTANGLE, 3, 3)
6. Cracks equal 1, 0 not cracks	C = con ([t4] >= 2, AND [t2] <= 2, 1, 0)

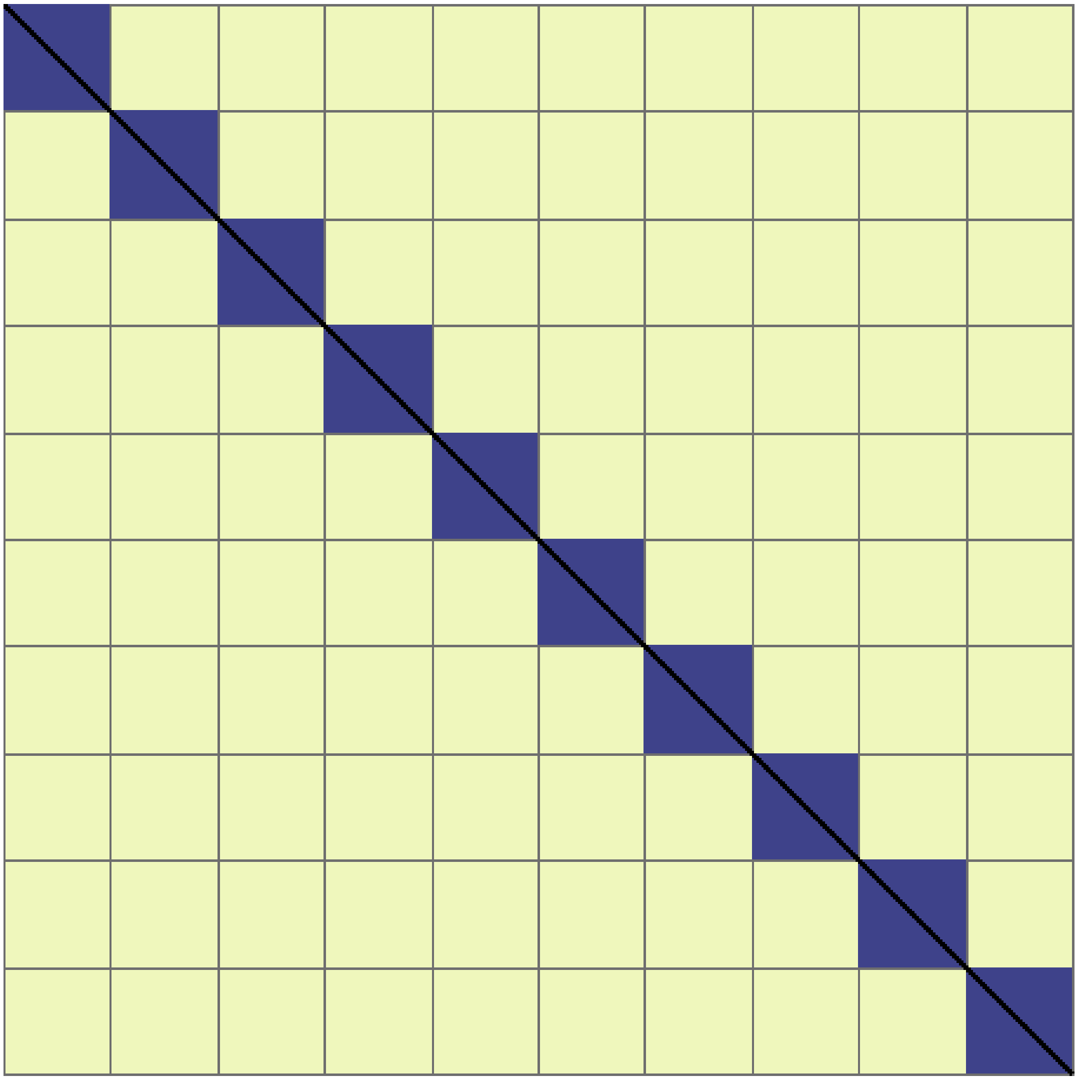
as highways, train tracks, rivers, etc., or as polygons that represent lakes, wide rivers, mountain ranges, etc. These features need to be converted to raster-based representation because cost-weighted methods in GIS are implemented by using graph-theory methods placed in a grid of cells embedded in a raster data structure. That is, the center of each cell is represented by a node, and nodes are connected to adjacent cells. Typically, eight diagonal and orthogonal neighbors are connected. Cracks can occur when relatively high-cost neighbors are only diagonal neighbors with no orthogonal neighbors, so that a relatively low-cost pathway can be found that passes through the high-cost feature (Fig. 1; Rothley 2005).

To understand how likely or to what extent these “cracks” may appear in a cost-weighted surface, one must understand the original data structure used to store features of different resistances, whether a point, line, polygon, or raster, and the algorithm used to convert the data to a raster data structure. The most problematic feature types are linear or polyline data. This is because landscape features that cause significant barriers or impediments, such as highways, railways, and rivers, are represented by lines and because different feature-to-raster conversion algorithms can cause different results. One type of conversion algorithm, often called “ideal line,” finds the cells that best represent a line by, most often, using a decision rule based on the distance of the line from the center of a cell. It results in one and often more locations along the line being represented only by diagonal neighbors whenever the orientation is not lined up with the grid, i.e., not 0&#176 nor 90°, and thus can cause a “crack.” Another type of algorithm, often used for antialiasing, results in a line that is represented by both orthogonal and diagonal neighbors that computer scientists refer to as “the jaggies.”

In addition to Rothley’s (1995) algorithm, a simple test can be used to determine whether the conversion of a line feature to raster format resulted in “cracks” (Table 1). How likely are “cracks” to creep into GIS-based analyses of landscape connectivity? This depends mostly on the conversion algorithm used by a particular GIS. For ArcGIS (Environmental Systems Research Institute, Redlands, California, USA), the situation represented by Fig. 1 occurs only in rare situations in which the line crosses directly, topologically, over the intersection of four cells. This can occur when the line is oriented precisely at 45° and aligns perfectly to cross the center and corners of the grid. It can also occur for straight-line segments with other orientations as well (Figs. 2 and 3). Otherwise, any interior portion of a grid cell that is barely touched by the line is converted to raster format (Fig. 4). In effect, this creates a line represented by diagonal and orthogonal neighbors. As a quick case study, I tested a raster layer created in ArcGIS v9 of major roads for the State of Colorado with 30 m resolution, 22,480 columns by 19,160 rows, and I found no “cracks” (Fig. 5). GIS that use an ideal line algorithm for conversion, such as IDRISI by Clark Labs (Worcester, Massachusetts, USA), create raster representations in which diagonal-only neighbors are very common for lines that are not orthogonal.

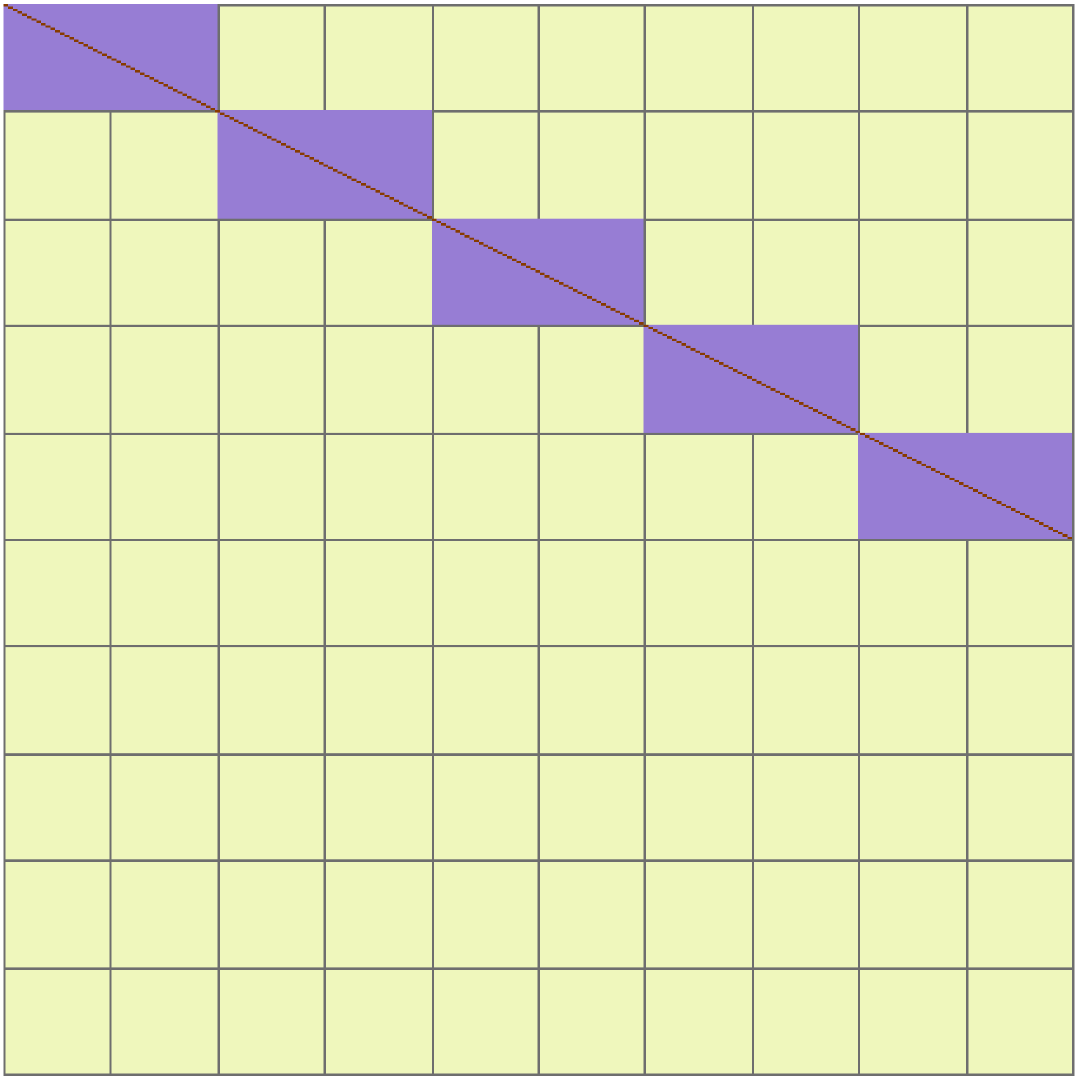
Unwanted discontinuities or “cracks” can also occur

Fig. 1. A line converted to raster format using ArcGIS v9 (Environmental Systems Research Institute, Toronto, Ontario, Canada). The line is represented by two points that fall precisely on the corners of the top left and bottom right cells.



when polygons are converted to raster format, as identified by Adriaensen et al. (2003) and Rothley (2005). They commonly occur at the narrows of polygons in which the cell center does not fall within the polygon, using the center method. The dominant cell conversion method can also cause discontinuities in polygon conversion (Theobald 2000, 2005*a*). Theoretically, the cell size, or resolution, should be no larger than half of the narrowest polygon feature. Nevertheless, practical trade-offs often force the cell size to be larger to minimize the file size of the cost-weight surface. Moreover, cost-weighted algorithms are computationally intensive, and relatively coarse resolutions are often

Fig. 2. A line converted to raster format using ArcGIS v9 (Environmental Systems Research Institute, Toronto, Ontario, Canada). The line is represented by two points snapped to grid corners so that the line crosses other grid corners every couple of cells.

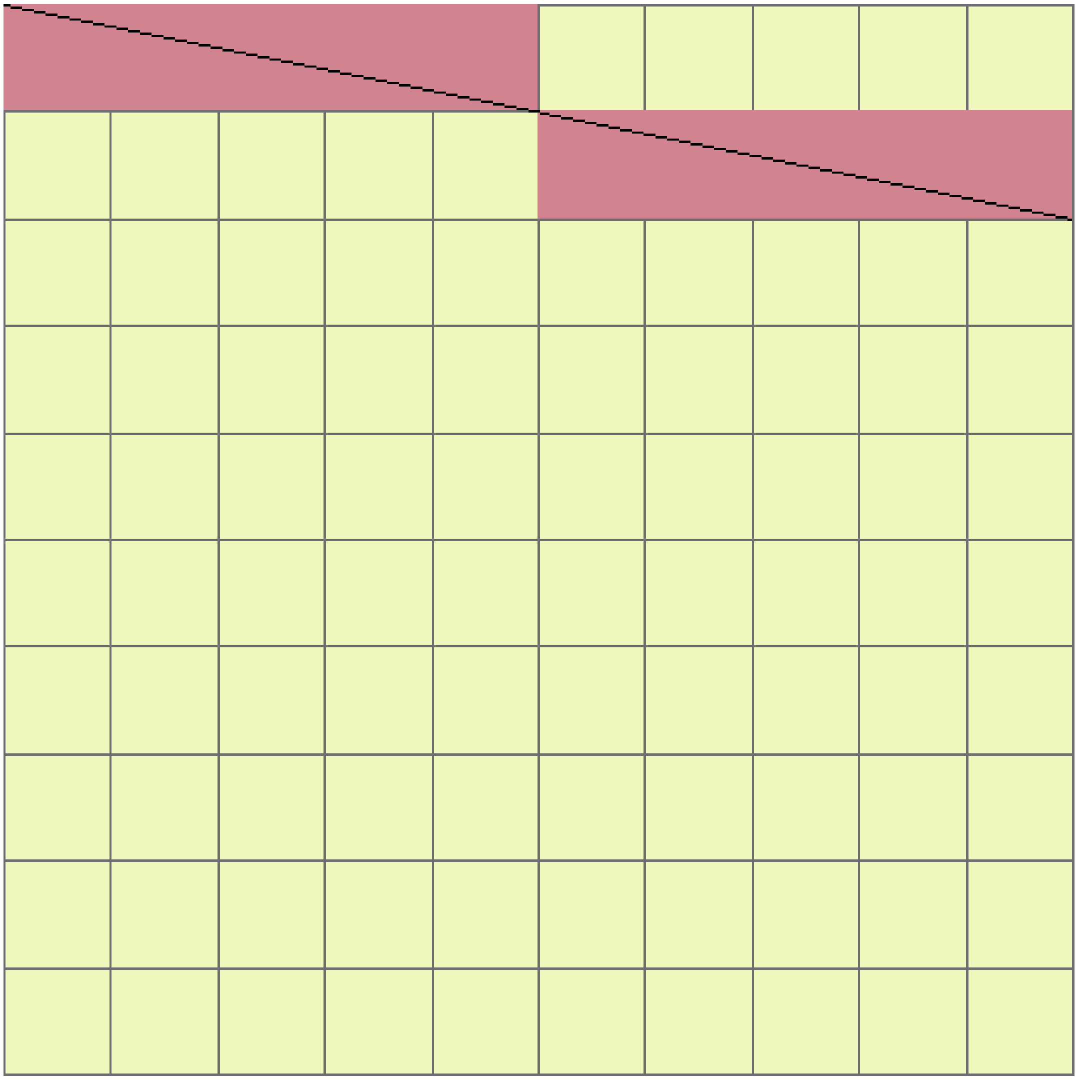


needed simply to "get the job done."

MITIGATING "CRACKS"

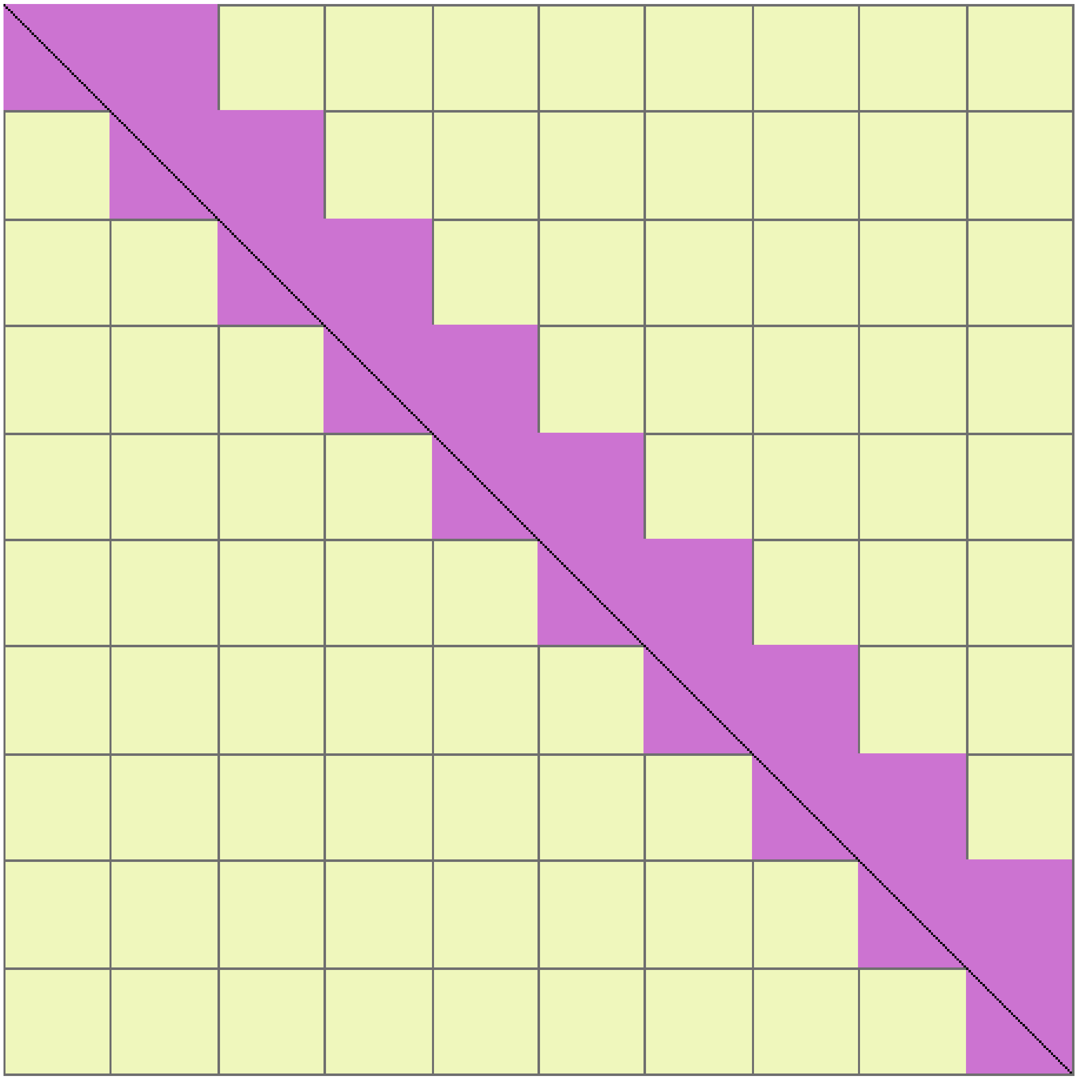
A couple of options are available for generating robust cost-weight surfaces that will mitigate possible cracks. Although buffering features in all directions (Adriaensen et al. 2003) or on a single side (Rothley 2005) can be used, this can introduce

Fig. 3. A line converted to raster format using ArcGIS v9 (Environmental Systems Research Institute, Toronto, Ontario, Canada). The line is represented by two points snapped to grid corners so that the line crosses one other grid corner.



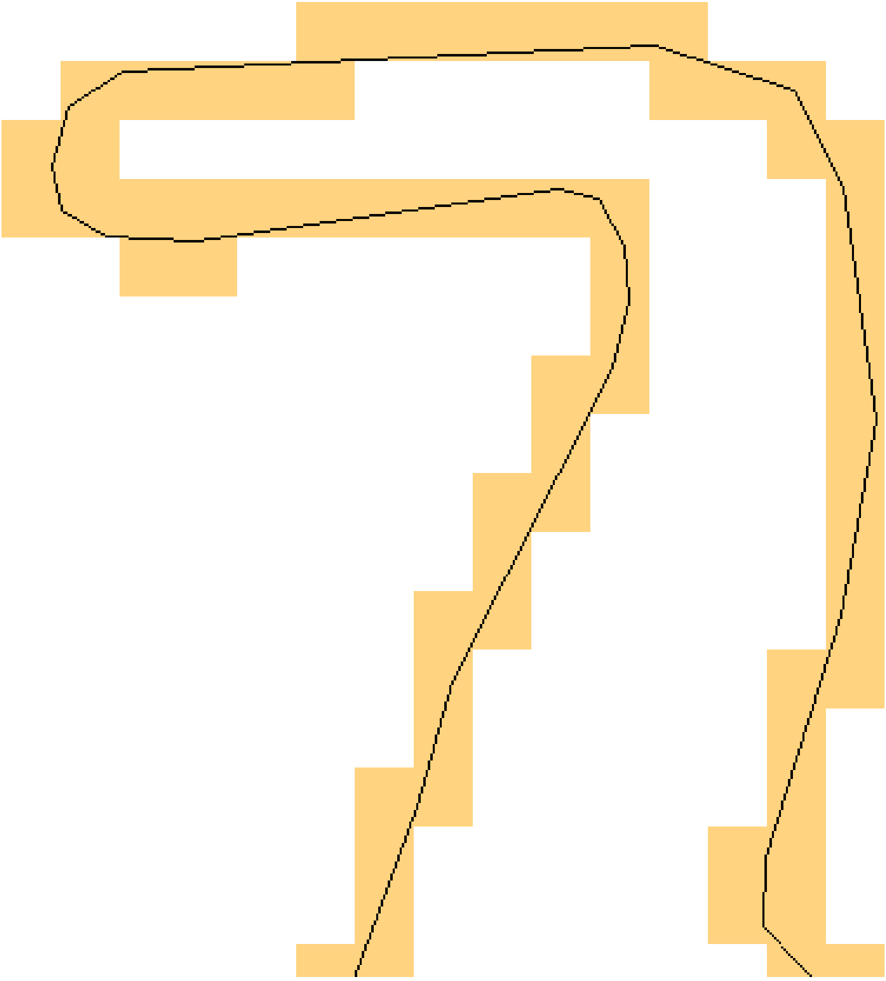
additional artifacts by "thickening" the line and adding high costs to the surface. Another method is to aggregate data from finer to coarser resolutions, not by resampling but by using mean values to generate robust cost-weight surfaces. For example, land-cover data are often provided in 30 m resolution, as they are for the National Land Cover Data of the U.S. Geological Survey and the U.S. Environmental Protection Agency, or converted from polygon data. Often roads and railways are "burned in" so that the land-cover value of any cell that touches a linear feature is coded appropriately. These land-cover and road data are reclassified so that a cost-weight or resistance value is specified

Fig. 4. A line converted to raster format using ArcGIS v9 (Environmental Systems Research Institute, Toronto, Ontario, Canada) and similar to the line illustrated in Fig. 1. In this case, however, the bottom right coordinate is moved by 0.0000001% of the width of a grid cell to prevent the line from precisely crossing the grid corners.



for each cell based on its type. A second step is to aggregate these cost-weights to a coarser resolution by replacing a group of cells (e.g., 2 x 2, 3 x 3, 4 x 4, etc.) by its mean cost value. This aggregation process creates a coarse-resolution, cost-weight surface that is much more robust, minimizes possible cracks, generates no additional buffer artifacts, and allows reasonable computation time of least-cost paths and cost-weighted distances.

Fig. 5. A close-up view of road line work converted to raster format. Note that the interior of any grid cell that is touched by a line is used to represent the line.



CONCLUSION

I fully support the caution that cost-weighted methods need to be used carefully and encourage the additional use and development of these methods to compute functional landscape connectivity. Methods that estimate functional connectivity based on least-cost paths are sensitive to possible "cracks." However, an awareness of the problems surrounding feature-to-raster conversion methods and resolution issues should allow researchers to produce robust resistant surfaces. Any input into cost-weighted methods should also be tested for "cracks."

Alternative approaches to computing connectivity using the least-cost path alone are emerging. Examining the full distribution of cost-distance values, and not just the minimum value or least-cost path, allows a more robust and potentially more biologically meaningful measure. For example, Theobald (2005*b*) describes a method for computing functional connectivity between patches based on the value at a given percentile, such as the 5th percentile, the 10th percentile, etc.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol10/iss2/resp1/responses/

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