Software notes

Ecography 35: 388–392, 2012
doi: 10.1111/j.1600-0587.2012.07168.x

Subject Editor: Thiago Rangel. Accepted 7 February 2012

LORACS: JAVA software for modeling landscape connectivity and matrix permeability

Naiara Pinto, Timothy H. Keitt and Michael Wainright

N. Pinto (npinto@umd.edu), Dept of Geographical Sciences, Univ. of Maryland, 2181 LeFrak Hall, College Park, MD 20742, USA. – T. H. Keitt and M. Wainright, Integrative Biology, Univ. of Texas at Austin, 1 Univ. Station, A6700, Austin, TX 78712, USA. MW also at: MetaVR, Inc, 19 Prospect Hill Ave no. 2, Somerville, MA 02143, USA.

GIS tools and remote sensing products have opened the possibility to model the impacts of matrix permeability on a broad range of ecological phenomena. LORACS (Landscape ORganization and Connectivity Survey) is JAVA software containing a GUI interface and an API for easy extensibility. The user inputs maps with the relative costs to move within each pixel and the location of source and target patches. The software outputs Multiple Shortest Paths and Conditional Minimum Transit Cost maps. One key feature is the derivation of uncertainty estimates around path length, cost, and spatial distribution. We use data from the Brazilian Atlantic Forest to illustrate how LORACS can be used to translate assumptions about habitat quality into landscape connectivity patterns.

Land cover change is the main cause of extinction in terrestrial habitats (Millennium Ecosystem Assessment 2005), raising the need for a theoretical framework to model the impacts of habitat fragmentation on natural populations. One central question refers to the ability of individuals to disperse in the landscape matrix between habitat patches. Here, we present a new software package (LORACS: Landscape Organization And Connectivity Survey) that integrates GIS maps of land use/land cover and habitat preferences to predict dispersal routes across the landscape matrix. Matrix permeability has been shown to impact animal dispersal with consequences for abundance (Ricketts 2001), genetic structure (McRae and Beier 2007, Braunisch et al. 2010), and diversity patterns (Lees and Peres 2009).

The availability of GIS tools and remote sensing products has allowed the application of least-cost paths (Adriaensen et al. 2003) to model animal movement in heterogeneous landscapes. This is implemented by representing study sites as a graph (Urban and Keitt 2001) and applying search algorithms (Dijkstra 1959) to identify optimum routes between two points. The least-cost path between two nodes *s* and *t* is defined as a unique set of nodes such that the sum of edge weights is minimized. Biologically, if edge weights correlate with relative movement costs (by capturing predation risk, foraging quality, or energy expenditure), the least-cost path comprises the collection of stepping stones most likely to be used by surviving individuals moving between *s* and *t* (Pinto and Keitt 2009).

Calibrating least-cost path models requires quantifying their sensitivity to assumptions about habitat preferences (‘subjective translation problem’, Beier et al. 2008) and land cover classification (or land cover change). Ultimately, model predictions also need to be validated with field data. However, the least-cost path algorithm in its original form does not lend itself to addressing these issues. Since only a single path is output, the researcher gets no uncertainty estimates associated with the paths’ cumulative cost or spatial distribution. Here, we tackled this problem by modifying Dijkstra’s breath-first search algorithm (Cormen et al. 2001) to model multiple potential movement routes using the same basic assumptions of least-cost path models (Pinto and Keitt 2009). Our modified algorithm produces two maps: Multiple Shortest Paths (MSPs) and Cumulative Minimum Transit Cost (CMTC) maps. MSPs are obtained by making edge placement a probabilistic function that generates multiple realizations of the least-cost path. The CMTC for a given pixel *p* between two nodes *s* and *t* is defined as the cost-weighted distance to move from *s* to *t*, conditional on the route forming the shortest passage between *s* and *t* while passing through *p* (Pinto and Keitt 2009). CMTC maps have been employed to model potential dispersal corridors (Majka et al. 2007). Both algorithms have been implemented in LORACS, as described below.

LORACS is free, platform-independent JAVA software. The source code as well as executable binaries are distributed under the GNU license and downloadable from the website <http://purl.oclc.org/loracs>. The package includes a GUI interface (Fig. 1A), a documentation file, sample input files, and a complete API allowing for easy extension of the functions. User input is in the form of two simple ascii

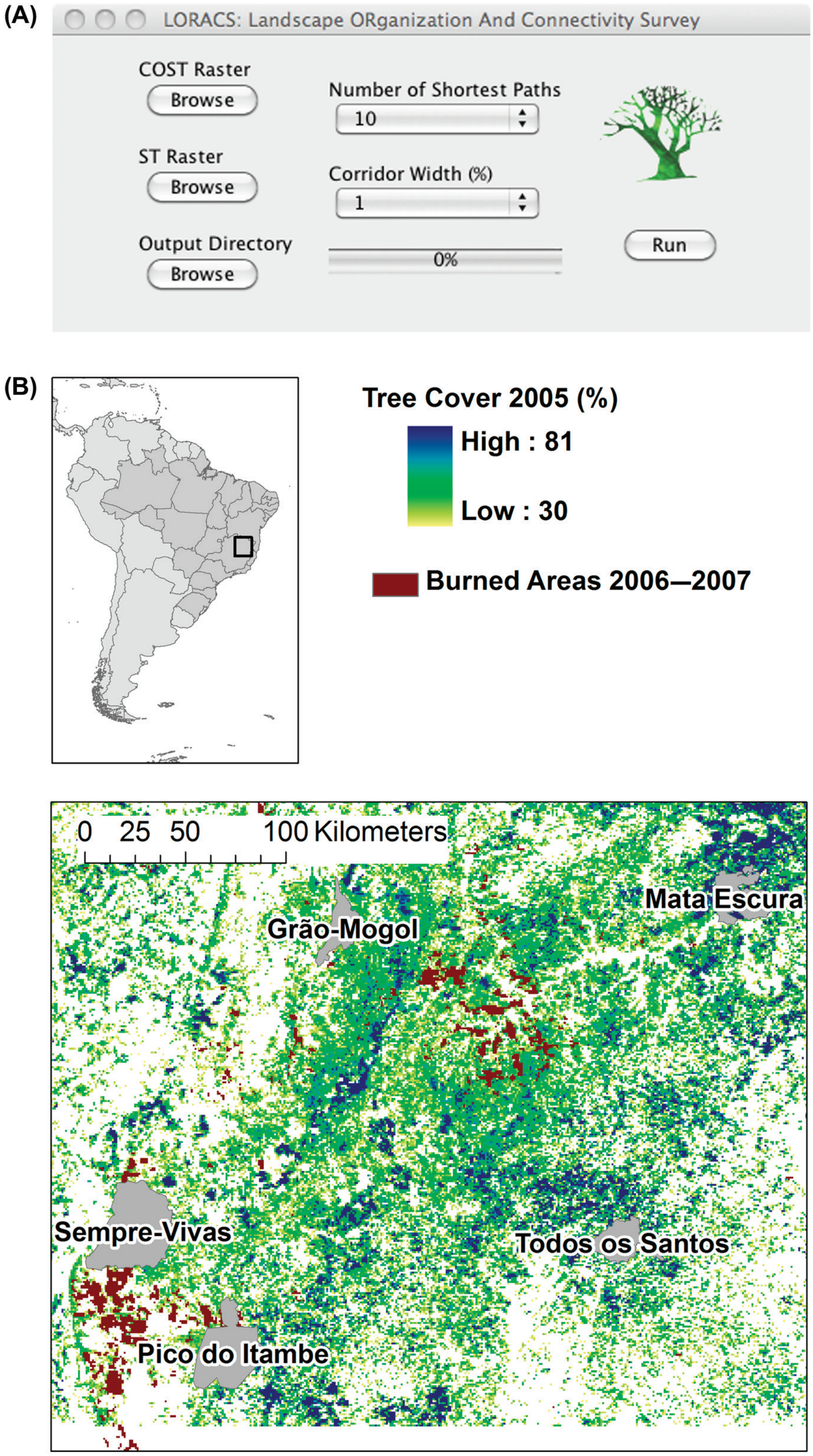

Figure 1. A screen shot of the LORACS GUI interface (A) and example of a cost grid built for a forested site in SE Brazil (B). In our example, we assumed the pre-fire relative cost for each pixel to be (100 – % tree cover). In the post-fire scenario, the % tree cover in burned areas is assumed to be reduced to zero.

rasters: 1) a cost raster where the value at each pixel represents the relative cost to cross it in any direction; and 2) an st raster with the same dimension and resolution of the cost raster and marking the location of the source and target patches between which connectivity patterns are modeled. After selecting the input rasters, the next step is to choose the number of shortest paths (1–1000) and the percent corridor width (1–100) to be calculated.

LORACS outputs two ascii rasters ('CMTC.asc' and 'MSPs.asc') with the same dimension and resolution of the input cost raster. The program also prints a comma-delimited file ('stats.csv') containing the cumulative cost and the total length of each shortest path. Path length is output in the same distance unit input by the user, that is, the attribute 'cell size' in the header of the ascii file. To demonstrate the software, we use LORACS to model movement between pairs of conservation units in the Brazilian Atlantic Forest. We show how the distribution of cumulative costs associated with MSPs can be used to statistically compare matrix permeability before and after a fire event. The spatial uncertainty of predicted movement routes is examined as follows: 1) the CMTC map depicts a cost surface as opposed to a single path; 2) the MSPs map shows the number of times each pixel is selected as part of the least-cost path, thus revealing potential dispersal bottlenecks. Last, 3) the stats.csv file has the cumulative cost and length for each MSP path. Collectively, these represent an empirical distribution of least-cost paths that can be used to statistically compare landscape connectivity under different assumptions about matrix composition, habitat quality, and distribution.

We identified conservation units in Northern Minas Gerais (Fig. 1B) based on the World Database on Protected Areas (UNEP-WCMC 2009). The pre-fire cost raster for year 2005 was built to approximate the habitat preferences of a forest specialist: each pixel value was calculated as 100 minus percent tree cover (MODIS VCF, Hansen et al. 2006). Fires occurring during the 2006–2007 fire season were mapped using the MODIS Burned Areas product (Justice et al. 2002). The post-fire cost raster was built by assigning a value of 100 to all pixels identified as burned. We modeled the connectivity between two pairs of conservation units: Itambe-Sempre Vivas and Itambe-Mata Escura. For each *st* pair, we ran LORACS with the pre-fire and the post-fire cost rasters. We chose to obtain 100 MSPs and 20% corridor width.

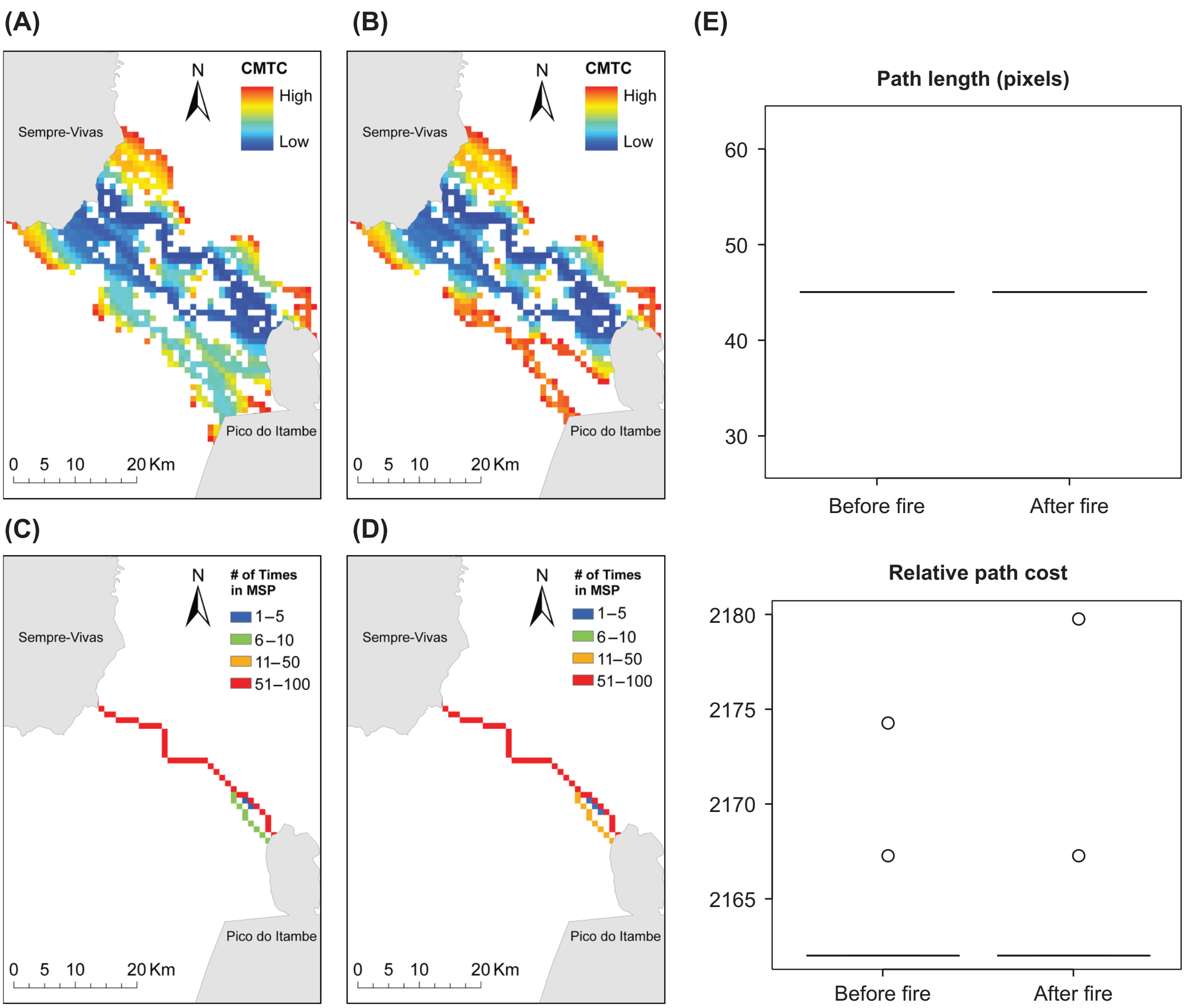

Figure 2. Connectivity analyses for Pico do Itambe-Sempre Vivas: CMTC before (A) and after (B) fire, MSPs before (C) and after (D) fire, and (E) distribution of the modeled path length/cost.

The resulting maps were displayed in ArcGIS (ESRI, CA, USA). The CMTC maps for the pair Itambe-Sempre Vivas show potential corridors with high trasversability (= low CMTC values, shown in blue) in the center (Fig. 2A, B). The post-fire corridor (Fig. 2B) covers 12% fewer pixels because the burned area in the south increases the CMTC cost beyond the 20% threshold. The CMTC maps for the pair Itambe-Mata Escura illustrates how the route of least resistance can depart from a straight line (Fig. 3A, B). The post-fire corridor (Fig. 3B) covers 8% fewer pixels than the pre-fire corridor.

MSP maps for Itambe-Sempre vivas show two possible dispersal routes next to Itambe that merge into a single bottleneck in blue (Fig. 2C, D). The list of 100 values of path cost/length output by LORACS represents an empirical distribution of least-cost paths. The pre-fire and post-fire scenarios were compared with a t-test in R (R Development Core Team 2012) for each pair of conservation units. Forest fires led to significant differences in path cumulative cost and length for the pair Itambe-Mata Escura ($p < 0.05$; Fig. 3E) but not for Itambe-Sempre Vivas ($p > 0.05$; Fig. 2E).

Least-cost paths are widely applied in conservation initiatives (Larkin et al. 2004), but evaluating their usefulness as estimates of animal movement remains a challenge. Next, we list a few scenarios where LORACS could be used to address this issue.

Calibration/validation of dispersal models

Model calibration/validation initiatives must determine how connectivity estimates emerge from assumptions about species' cognitive abilities, habitat preferences, thematic resolution of land cover maps, and temporal scale. These issues can be investigated with LORACS, to the extent that the user can represent alternative scenarios with different cost rasters. For example, when studying an herbivore, least-cost paths can be generated with DEMs and vegetation cover maps to compare the dispersal routes that emerge from terrain features vs. distribution of food sources. LORACS outputs the distribution of path lengths and costs which can be used to make a statistical comparison between routes.

Delineation of movement bottlenecks

MSP maps predict the location of dispersal bottlenecks (e.g. larger values on Fig. 2B, C and 3B, C). These are sites that should either be monitored as part of the calibration/

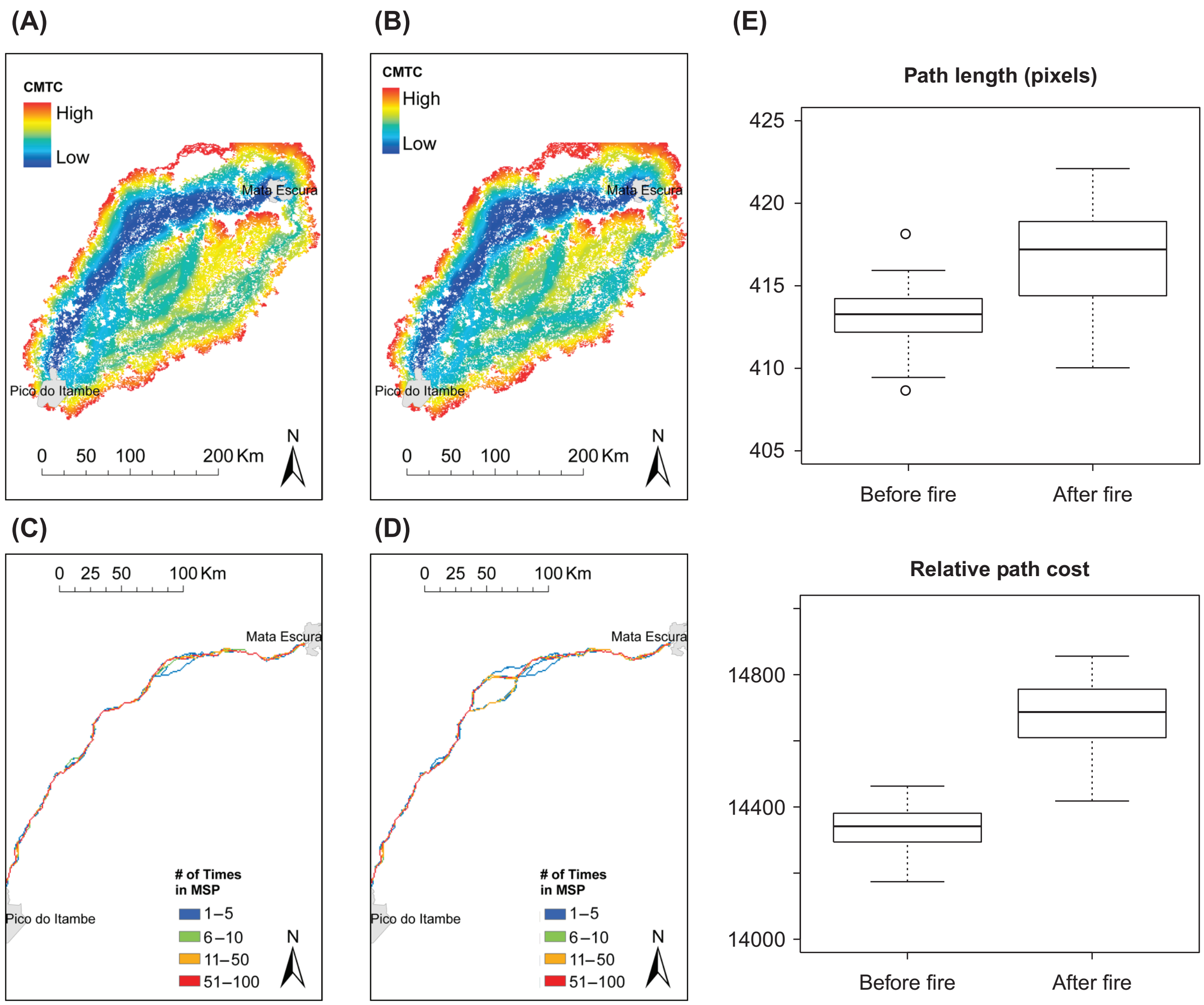

Figure 3. Connectivity analyses for Pico do Itambe-Mata Escura: CMTC before (A) and after (B) fire, MSPs before (C) and after (D) fire, and (E) distribution of the modeled path length/cost.

validation procedure, or prioritized for protection once the dispersal model is validated.

Comparison with movement data

MSP and CMTC maps show connectivity estimates that attain continuous values and can be statistically compared against movement data (Driezen et al. 2007) from census counts or camera traps.

In conclusion, LORACS provides an opportunity for biologists to test graph theoretical models with a GUI interface and without the need for commercial GIS software.

To cite LORACS or acknowledge its use, cite this Software note as follows, substituting the version of the application that you used for 'version 0':

Pinto, N., Keitt, T. H. and Wainright, M. 2012. LORACS: JAVA software for modeling landscape connectivity and matrix permeability. – Ecography 35: 388–392 (ver. 5).

Acknowledgements – The authors would like to thank Tania Pena-Baca, Katherine Behrman, Jesse Lasky, and Betsy Reardon for comments on the manuscript.

References

Adriaensen, F. et al. 2003. The application of "least-cost" modeling as a functional landscape model. – Landscape Urban Plan. 64: 233–247.

Beier, P. et al. 2008. Forks in the road: choices in procedures for designing wildland linkages. – Conserv. Biol. 22: 836–851.

Braunisch, V. et al. 2010. Modelling functional landscape connectivity from genetic population structure: a new spatially explicit approach. – Mol. Ecol. 19: 3664–3678.

Cormen, T. H. et al. 2001. Introduction to Algorithms. – MIT Press, USA.

Dijkstra, E. W. 1959. A note on two problems in connexion with graphs. – Numerische Math. 1: 269–271.

Driezen, K. et al. 2007. Evaluating least-cost model predictions with empirical dispersal data: a case-study using radiotracking data of hedgehogs (*Erinaceus europeus*). – Ecol. Model. 209: 314–322.

Hansen, M. et al. 2006. Vegetation Continuous Fields MOD44B, 2001 Percent Tree Cover, Collection 4. – Univ. of Maryland, College Park, MD, 2001.

Justice, C. et al. 2002. The MODIS fire products. – Remote Sens. Environ. 83: 244–262.

Larkin, J. L. et al. 2004. Landscape linkages and conservation planning for the black bear in west-central Florida. – Anim. Conserv. 7: 23–34.

Lees, A. C. and Peres, C. A. 2009. Gap-crossing movements predict occupancy in Amazonian forest fragments. – Oikos 118: 280–290.

Majka, D. et al. 2007. CorridorDesigner: ArcGIS tools for designing and evaluating corridors. – <http://corridordesign.org>.

McRae, B. H. and Beier, P. 2007. Circuit theory predicts gene flow in plant and animal populations. – Proc. Natl Acad. Sci. USA 104: 19885–19890.

Millennium Ecosystem Assessment 2005. Ecosystems and human well-being: biodiversity synthesis. Chapter 3. – World Resources Inst., Washington, DC.

Pinto, N. and Keitt, T. H. 2009. Beyond the least-cost path: evaluating corridor redundancy using a graph-theoretic approach. – Landscape Ecol. 24: 253–266.

Ricketts, T. H. 2001. The matrix matters: effective isolation in fragmented landscapes. – Am. Nat. 158: 87–99.

UNEP-WCMC 2009. Data structure of the World Database on Protected Areas (WDPA) Annual Release 2009, New WDPA Schema. – Web-download version – February 2009, <www.wdpa.org/>.

Urban, D. L. and Keitt, T. H. 2001. Landscape connectivity: a graph-theoretic perspective. – Ecology 82: 1205–1218.