

Connectivity Analysis Software for Estimating Linkage Priority

A User Guide for the Linkage Priority Tool of the Linkage Mapper Toolbox

Version 2.0—Updated March 2018

John A. Gallo¹ and Randal Greene²¹Conservation Biology Institute

²Feaver's Lane

Software Requirements and Licensing

Linkage Priority tool requires **ArcGIS 10** with the Spatial Analyst extension (we have tested with versions up to 10.6). More details can be found on the Linkage Mapper website, where our code is hosted: <http://www.circuitscape.org/linkagemapper>.

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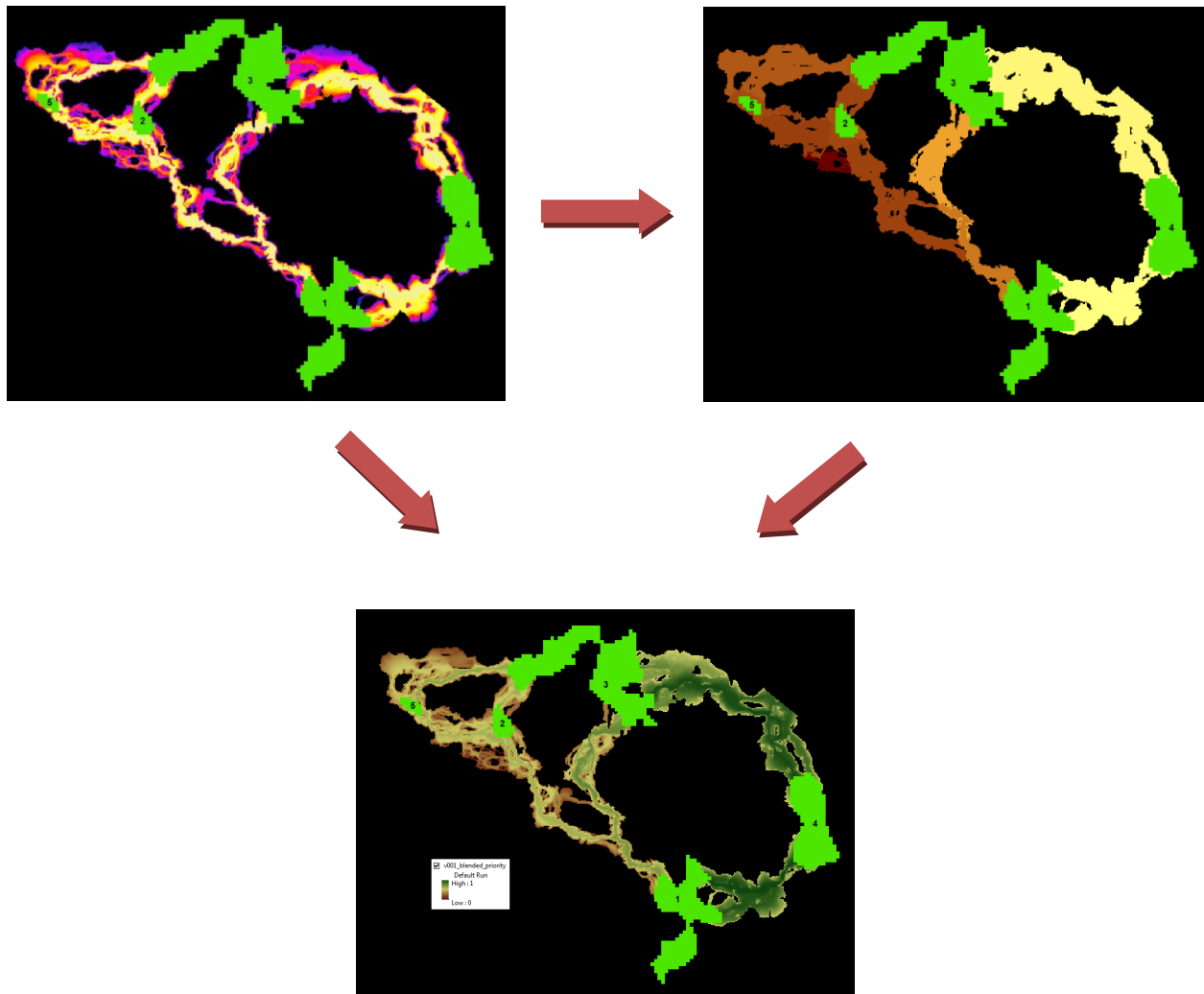


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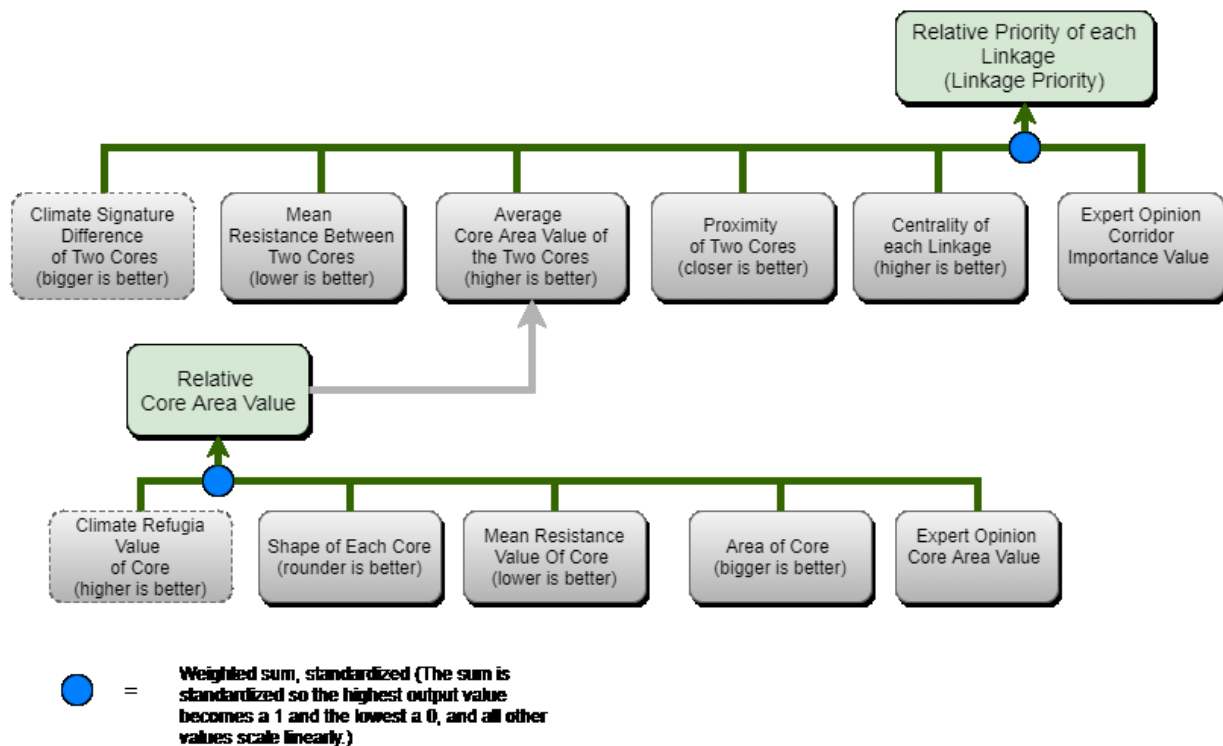
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1 Introduction

Linkage Priority (LP) is an ArcGIS tool that helps quantify the relative conservation priority of each linkage in a landscape.

LP is run after linkages are created using the Linkage Pathways (LM) tool of the Linkage Mapper Toolbox (McRae and Kavanagh 2011). (The implementation of this original Linkage Mapper tool is hereafter symbolized as “LM” in this version of the User Guide).

The Linkage Priority Tool is based on weighted combinations among many factors (see below Figure). The lower set of factors on the diagram estimate the relative priority of the two cores at either end of a linkage. These factors include the shape, mean resistance value, size, and expert opinion. An assumption is then made that a linkage which connects two really important core areas is a higher conservation priority than one that connects two marginal core areas. The Tool calculates this relative value for every linkage. This output is combined with the other higher level factors (top row) that relate directly to linkage priority, including the permeability of each linkage (i.e., the mean resistance values along the least cost path), the proximity, the centrality (i.e. how central the linkage is to the entire network), and an expert opinion option. The expert opinion option is implemented via a table of each linkage as a row, and a relative value of each linkage based on expert opinion, or other factors, such as demographic analyses.



Users can also include climate-wise decision-making, giving higher priority to linkages that span a climate gradient, facilitating species range shifts over decades and centuries. This criterion, on the top row of the diagram, is optional. Users can also include climate in determine relative core area value, by giving higher value to cores with higher amount of climate refugia. This criterion, on the bottom row of the diagram, is also optional.

See the section “Using Linkage Priority” for more details.

Prototype applications of various beta versions of the Linkage Priority Tool have been performed in six regions (Sierra Nevada mountains, Sonoma County, Santa Barbara County, West Mojave, Sacramento Valley, and Modoc Plateau), with outputs available on databasin.org and reports and publications in preparation. In the last three of these studies, climate was considered in three ways in determining priority: (1) quantifying which linkages best facilitated long-term species range shifts, (2) which core areas provided refuge from climate change, and (3) which core areas contained more climate micro-refugia for withstanding climate change.

2 Acknowledgements

Dr. Gallo developed an original Linkage Priority Tool with funding from a South Africa National Research Foundation post-doctoral research grant (#47264) through Nelson Mandela Metropolitan University. In 2014 he approached Brad McRae with the idea of embedding this Linkage Priority Tool into Linkage Mapper and Brad was very gracious, and encouraging. To implement this, a fundamental change in the algorithm was needed. This coding was implemented by Randal Greene. The result here is a change of the original algorithm to allow this merge.

Alas, Brad has since passed away, stricken by cancer. “Everyone who knew Brad was impressed with his intelligence, thoughtfulness, integrity, honesty, and his steadfast commitment to what he cared about: his family, friends and conserving the natural world.”¹ We couldn’t agree more. He asked Dr. Gallo to carry the Linkage Mapper project forward and we are honored to do so with some support from Conservation Biology Institute, and hopefully much support from the Linkage Mapper community. Rest his soul.

We would like to thank the additional organizations that have funded this work: Sonoma County Agricultural Preservation and Open Space District, The Wilderness Society, and Conservation Biology Institute.

Thanks also to Darren Kavanagh, Annie Prisbrey, Nik Stevenson-Molner and Tim Sheehan for their advice and their participation in the release of LP.

3 Installation

Download Linkage Mapper v2.0 or greater from <http://www.circuitscape.org/linkagemapper> and follow the installation instructions of the Linkage Pathways User Guide. You can test your installation by running the tutorial at the end of this document.












4 Using Linkage Priority

The key factors of LP’s multi-criteria analysis are summarized in the introduction.

The weights for these, and the associated parameters, are accessed through the graphical user interface (GUI).

LP is run after understanding and running LM, and optionally after Centrality Mapper instead. Open LP from the Linkage Mapper Toolkit.




¹ from Joe Fargione, Brad McRae's supervisor

- [-]  Linkage Mapper Toolkit
 - [-]  Linkage Pathways Tool
 -  Build Network and Map Linkages
 - [-]  Additional Tools
 -  Barrier Mapper
 -  Centrality Mapper
 -  Climate Linkage Mapper
 -  Linkage Priority
 -  Pinchpoint Mapper
 - [+]  Multi-tool Combinations (Alpha)
 - [+]  Utilities


The following tool dialog should appear:

Linkage Priority




Model Inputs

- Project Directory 
- Core Area Feature Class 
- Core Area Field Name
- Resistance Raster 

Core Area Value (CAV) Options

- Other Core Area Value Raster (optional) 
- Resistance Weight in CAV Calculation
- Size Weight in CAV Calculation
- Area/Perimeter Weight in CAV Calculation
- Expert Core Area Value Weight in CAV Calculation
- Current Flow Centrality Weight in CAV Calculation
- Other Core Area Value Weight in CAV Calculation



Corridor Specific Priority (CSP) Options

- Core Pairs Table (optional) 
- From Core Field (optional)
- To Core Field (optional)
- Expert Corridor Importance Value Field (optional)
- Current Climate Envelope Raster (optional) 
- Future Climate Envelope Raster (optional) 
- ☐ Higher Climate Envelope Values are Cooler
- Closeness Weight in CSP Calculation
- Permeability Weight in CSP Calculation
- Core Area Value Weight in CSP Calculation
- Expert Corridor Importance Value Weight in CSP Calculation
- Climate Envelope Difference Weight in CSP Calculation
- Proportion of Top CSP Values to Keep

Blended Priority Options

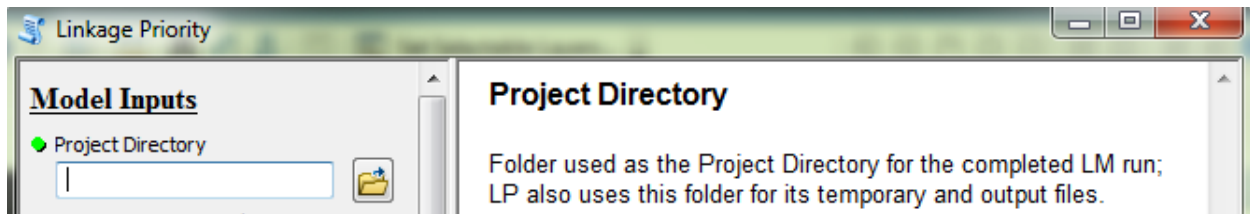
- Truncated Corridors Weight in Blended Priority Calculation
- Linkage Priority Weight in Blended Priority Calculation

Additional Options

- Output for ModelBuilder Precondition (optional) 
- Custom Settings File (optional) 

OK Cancel Environments... Show Help >>

Descriptions for the required and optional tool parameters follow. They are also available in the tool dialog by selecting a parameter and clicking Show Help >>, for example:



For additional details, please see the Geoprocessing Overview and Other Usage Notes sections later in this document.

4.1 Required Inputs

- *Project Directory*: folder used as the Project Directory for the completed LM run; LP also uses this folder for its temporary and output files
- *Core Area Feature Class*: core habitat area polygons, used as the Core Area Feature Class for the completed LM run
- *Core Area Field Name*: field in the Core Area Feature Class containing a unique identifier for each core, used as the Core Area Field Name for the completed LM run
- *Resistance Raster*: cost raster, used as the Resistance Raster for the completed LM run

4.2 Core Area Value (CAV) Options

- *Other Core Area Value (OCAV) Raster*: optional raster whose values within each core will be averaged to create the OCAV for that core
- Weighted sum weights (should sum to 1) to be used in the calculation of the CAV attribute:
 - *Resistance Weight*: decimal value between 0 and 1 to be multiplied by the normalized mean resistance for the core
 - *Size Weight*: decimal value between 0 and 1 to be multiplied by the normalized size of the core
 - *Area/Perimeter Weight*: decimal value between 0 and 1 to be multiplied by the normalized area/perimeter ratio of the core
 - *Expert Core Area Value (ECAV) Weight*: decimal value between 0 and 1 to be applied to the normalized optional ecav field, for storing an expert assessment of the relative value of each core; see sections 6.2 and 6.4 below for additional details
 - *Current Flow Centrality (CFC) Weight*: decimal value between 0 and 1 to be applied to the normalized CF_Central field, which is optionally calculated by Centrality Mapper after running LM but before running LP; see section 6.2 below for additional details
 - *Other Core Area Value (OCAV) Weight*: decimal value between 0 and 1 to be applied to the normalized ocav field, which is calculated from the optional OCAV raster; see section 6.2 below for additional details

4.3 Corridor Specific Priority (CSP) Options

- *Core Pairs Table*: optional table, feature class or raster attribute table containing an Expert Corridor Importance Value (ECIV) field that stores an expert assessment of the relative value of each corridor
- *From Core Field*: field in the Core Pairs Table that stores the unique identifier for one of the cores in the pair

- *To Core Field*: field in the Core Pairs Table that stores the unique identifier for the other core in the pair
- *Expert Corridor Importance Value Field*: field in the Core Pairs table that stores the expert assessment of the corridors
- *Current Climate Envelope Raster*: optional raster used to calculate the current climate envelope for each core, which feeds into the climate envelope difference calculation for the two cores at the end of each corridor; see section 6.2 below for additional details
- *Future Climate Envelope Raster*: optional raster used to calculate the future climate envelope for each core, which feeds into the climate envelope difference calculation for the two cores at the end of each corridor; see section 6.2 below for additional details
- *Higher Climate Envelope Values are Cooler*: normally, higher climate envelope values indicate warmer/drier; check this option to indicate that higher climate envelope values are cooler/wetter
- CSP weighted sum weights (should sum to 1) used to create a CSP raster for each corridor:
 - *Closeness Weight*: decimal value between 0 and 1 to be multiplied by the normalized distance between the two cores of the corridor
 - *Permeability Weight*: decimal value between 0 and 1 to be multiplied by the normalized permeability (inverse of the average resistance) of the corridor
 - *Core Area Value Weight*: decimal value between 0 and 1 to be multiplied by the normalized average CAV of the two cores of the corridor
 - *Expert Corridor Importance Value Weight*: decimal value between 0 and 1 to be multiplied by the normalized ECIV of the corridor
 - *Climate Envelope Difference Weight*: decimal value between 0 and 1 to be multiplied by the normalized climate envelope difference between the two cores of the corridor
- *Proportion of Top CSP Values to Keep*: decimal value between 0 and 1 that is used to clip the size of each corridor before they are combined into the project_CPV and project_linkage_priority output rasters

4.4 Blended Priority Options

- Blended Priority weighted sum weights (should sum to 1) used to create the project_blended_priority output raster:
 - *Truncated Corridors Weight*: weight to be multiplied by the project_NORMTRUNC output raster
 - *Linkage Priority Weight*: weight to be multiplied by the project_linkage_priority raster

4.5 Additional Options

- *Output for ModelBuilder Precondition*: optional output copy of the input cores, which can be used in ModelBuilder workflows to indicate that LP has finished processing
- *Custom Settings File*: optional .py file to be used in place of lp_settings.py, which facilitates keeping all the settings needed to reproduce a scenario run

4.6 Advanced Settings in lp_settings.py

The following settings will not normally need to be changed, and can only be changed by editing lp_settings.py. The one of special note is in bold:

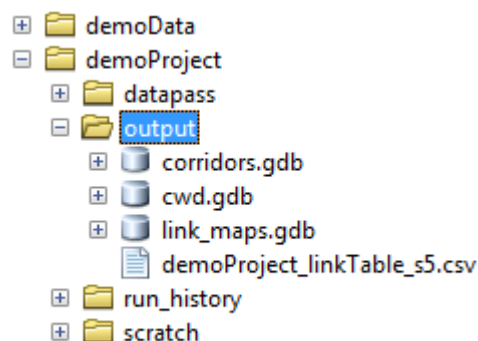
- RELPERMNORMETH (number): relative permeability normalization method (use 0 for score range normalization; any other value for maximum value normalization)

- RELCLOSENORMETH (number): relative closeness value normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- CALCLP (Boolean): calculate linkage priority
- NORMCORRNORMETH (number): normalized corridor normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- RESNORMETH (number): resistance normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- SIZENORMETH (number): size normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- APNORMETH (number): area/perimeter ratio normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- ECAVNORMETH (number): ecav normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- CFCNORMETH (number): cfc normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- **MINCPV (number): minimum corridor priority value (use 0 to keep all). Best to examine CPV values from a previous run in setting a non-zero value.**
- NORMALIZERCI (Boolean): normalize RCI
- TRUNCNORMETH (number): truncated raster normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- CALCBP (Boolean): calculate blended priority (requires CALCLP above to also be True)
- NORMALIZELP (Boolean): normalize Linkage Priority
- NORMALIZEBP (Boolean): normalize Blended Priority
- KEEPINTERMEDIATE (Boolean): keep intermediate outputs for troubleshooting purposes
- MAXCSPWEIGHT (Boolean): relative max CSP value weight in CPV calculation
- MEANCSPWEIGHT (Boolean): relative mean CSP value weight in CPV calculation

5 Geoprocessing Overview

The following algorithm details are not required for using LP. If, however, you would like to understand the algorithm further, a high-level overview is provided here (additional details are available in the Linkage Priority Developer Documentation).

- Check that LM in the same Project Directory successfully finished Steps 3 and 5, and terminate if issues
- Make preliminary calculations for each corridor
 - Calculate Permeability
 - Calculate Relative Closeness



demoProject_LCPs				
	cwd_to_Eff_Resist_Ratio	Raw_Perm	Rel_Perm	Rel_Close
▶	-1	0.132773	0	1
	-1	0.584323	0.734004	0.568521
	-1	0.516648	0.623997	0
	-1	0.747961	1	0.884988
	-1	0.7165	0.94886	0.660342

- Invert and normalize
(set KEEPINTERMEDIATE = True in lp_settings.py to see these datasets)

[-]	datapass
[+]	adj
[+]	cwd
[-]	nlcc
[+]	mos10
[-]	nlc
[-]	inv_norm
[+]	1_11
[+]	1_13
[+]	7_13
[+]	7_8
[+]	7_9
[+]	8_11
[+]	8_9
[+]	9_11
[+]	9_13

- Calculate Core Area Value (CAV) and its components for each core
 - Check weights and warn if issues

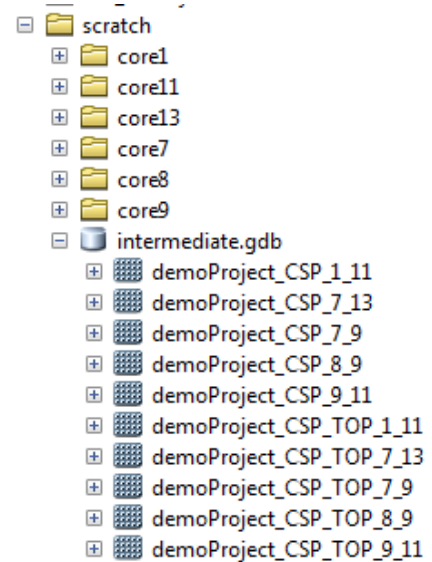
Resistance Weight in CAV Calculation	0.33
Size Weight in CAV Calculation	0.33
Area/Perimeter Weight in CAV Calculation	0.34
Expert Core Area Value Weight in CAV Calculation	0
Current Flow Centrality Weight in CAV Calculation	0
Other Core Area Value Weight in CAV Calculation	0

- Add and calculate attributes in the input Core Area Feature Class

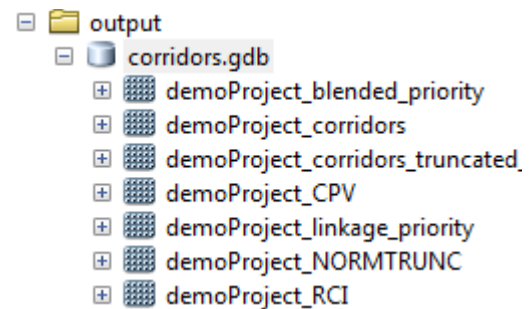
Cores										
	core_ID	mean_res	norm_res	area	norm_size	perimeter	ap_ratio	norm_ratio	cav	norm
▶	1	4.250301	0.986931	99737396.3079	0.169169	39670.891195	2514.120387	0.502201	0.481134	0.33
	7	4.461851	0.984475	307397448.098	0.521391	74365.863378	4133.582724	0.825693	0.888917	0.88
	8	12.290479	0.893586	513040166.78	0.87019	108232.308724	4740.175765	0.946861	0.971064	0.97
	9	3.124618	1	339987924.353	0.576669	73789.908601	4607.512474	0.920361	0.658489	0.57
	11	9.472708	0.9263	341809693.939	0.579759	82785.662154	4128.851362	0.824748	0.233081	0.57
	13	86.134374	0.036276	589572360.609	1	117768.463499	5006.19897	1	0.644335	0.57

- [Optional] Calculate climate envelope attributes for each core
- Complete calculations for each corridor
 - [Optional] Add and calculate attributes of the Core Pairs table

- Calculate corridor specific priority (CSP) raster for each corridor
(set KEEPINTERMEDIATE = True in lp_settings.py to see these datasets)



- Create overall result rasters
 - Combine CSP_TOP rasters using Max and Mean to create overall Corridor Priority Value (project_CPV) raster
 - Clip project_CPV to the MINCPV and normalize to create relative corridor importance (project_RCI) raster
 - Clip project_RCI to extent of truncated raster to create project_linkage_priority raster
 - Invert and normalize truncated raster to create project_NORMTRUNC raster
 - Calculate overall project_blended_priority raster



6 Other Usage Notes

6.1 Upgrading

For those upgrading to version 2.0.0 from earlier versions of LM, please consider the following:

- If you want your old projects to automatically use the new LM and LP, install the toolbox in the same location as the previous version.
- Due to the addition of new LM parameters in the LM tool dialog, running LM from geoprocessing results history will result in “ERROR 000820 The parameters need repair”. To overcome this issue, run LM from the toolbox, not from the geoprocessing history.
- ModelBuilder models that use LM will need to be edited, re-validated and saved.

6.2 Enhancing Analyses Using Optional Settings

LP’s optional settings can be used in a variety of ways. Some suggestions are provided here:

- Climate change analyses can be incorporated into linkage prioritization in at least two ways:
 - By providing an Other Core Area Value raster, such as a refugia dataset, that reflects the relative importance of different areas of the landscape in providing resilience to climate change.

- This will impact the Core Area Value, which is a component of Corridor Priority Value.
 - See the Linkage Priority Tutorial below for an example.
- By providing Current, and optionally Future, Climate Envelope datasets, which allow a Climate Envelope Difference to be calculated for each corridor.
 - See the Linkage Priority Tutorial below for an example.
- Expert input can be incorporated in at least two ways:
 - By adding an Expert Core Area Value field (must be name “ecav”) to the Cores polygon input dataset. This will impact the Core Area Value, which is a component of Corridor Priority Value.
 - By providing a table of core pairs, with an Expert Corridor Importance Value (ECIV) field (can be any name). ECIV is an optional component of Corridor Priority Value.
- Centrality is a measure of how important a link or core area is for keeping the overall network connected. If run, Centrality Mapper will create a field in the Cores polygon dataset called CF_Central. Providing a Current Flow Centrality Weight will normalize CF_Central and include it in the Core Area Value calculation.

6.3 Fine Tuning

This section details how to minimize the “carryover effect” of this Linkage Priority algorithm. This effect is most apparent when there is a really high priority linkage emanating from a core area, and also a low priority linkage from the same core area in a different direction. The high values of the high priority linkage carryover to the back side of the core area, essentially providing a small buffer. This buffer around the core then becomes a portion of the low priority linkage. The buffer of high value ends abruptly into the lower value of the top priority linkage, showing a counter intuitive result for this small portion of the landscape. LP outputs are commonly overlaid with LM outputs to get the “blended priority” output, so this effect is reduced.

Having the LP and LM linkage extents match (or LP being smaller) minimizes this effect even more. (The width of the linkages from LP are different than those from LM.) The width of LP linkages are affected most dominantly by the setting “Proportion of Top CSP Values to Keep” (PropKeep). A deliberate way to set this value so the outputs best match those from LM is as follows:

- Run an initial run of LM and LP.
- Label the cores layer in ArcMap with a Core ID# and then add the following layers
 - The LM output: \outputs\corridors.gdb\(\projectname)_corridors_truncated_at_(X
 - a “CSP” layer: \scratch\intermediate.gdb\(\projectname)_CSP_(Core#A)_(Core#B).
 - The KeepIntermediate parameter in the lm_Settings.py file must = True for these files to be available.
 - It is useful to add one where the “carryover effect” is most apparent on the LP output (see footnote).
- Adjust the Min/Max color ramp of the “CSP” layer (using the Properties/symbology tab) with a few trial and error tests until it aligns sufficiently with the LM output.
 - Hint: Min value will likely be very near the Max value.
 - See “if you want to understand the algorithm more” below for an alternate way of approaching this task.

- Once this point is reached, the new PropCSP value for the next run can be calculated using this formula: $(\text{max-newmin})/(\text{max-oldmin})$; where newmin is the new min value that yields the desired output and oldmin is the original min value.
- Apply this result as the PropCSP value for the next model run.

Advanced nuances to the above:

- It is best to NOT use the Bounding Circles Buffer Distance of LM when using LP. Using this makes increased variance in the widths of the linkages resulting from Proportion of Top CSP Values to Keep. Two cores that are small and close together will have a much smaller range of values than large/far cores.
- Extent of analysis also affects this relationship between LM linkage width and LP linkage width. If calibrating the model with test runs, it is best to use the entire extent, but just use 4 or so cores, rather than using a sub-region for calibration.
- Now that LP exists, some of the techniques in LM for eliminating linkages are not as necessary, and could be left unused. LM provides the following options for limiting the number of linkages mapped: Maximum Cost-Weighted Corridor Distance and Maximum Euclidean Corridor Distance. LP users may want to consider relaxing or eliminating these constraints in order to allow long, but high quality linkages to still be mapped. The long linkages that do not make ecological sense will get a very low RCI value. (These can be removed using MinCPV value in LP). More importantly, the ones that do make sense will still be mapped. A tradeoff is that not using these options will increase LM's runtime.
- Due to rounding errors, it may be that all the above works better with resistance surfaces that have a high range of values, such a 1-1000, but that still needs to be confirmed.

If you want to understand the algorithm a bit more:

- Scale $\backslash(\text{projectname})_CSP_(\text{Core\#A})_(\text{Core\#B})$ using a Min/Max color ramp (using the symbology tab) to the same ratio as Proportion of Top CSP Values to Keep (PropCSP) in run that created it.
 - This can be done using the formula $\text{max}-[(\text{max}-\text{min})*\text{PropCSP}]$, using the max and min values of the raster.
 - Manually apply this value as the new min value in the symbology tab
 - This should match the output for this linkage on the corridors.gdb\(\text{projectname})_linkage_priority raster.
 - As well as the intermediate.gdb\(\text{projectname})_CSP_TOP_(\text{Core\#A})_(\text{Core\#B})

6.4 Other Suggestions and Troubleshooting

- When creating a field to store expert values for ECIV for each corridor, project_LCPs is not a good place to do this because it gets overwritten on every run of the LM tools. One option is to make a copy of this feature class in another location and use it.
- If you encounter an error along the lines of “ERROR 010423: project_RCI.RASTER.1(Band_1) does not have valid statistics as required by the operation” when calculating overall linkage priority, it could be that the setting used for Proportion of

Top CSP Values to Keep resulted in an empty Corridor Specific Priority for one or more corridors, and therefore an empty RCI raster. Try a larger value for the Proportion of Top CSP Values to Keep setting.

- If you move the project directory structure and files to another location after LM has been run (not advised), please note that:
 - LM must be re-run before LP can be run, because the LM environment has been picked up from the run history and contains the old path.
 - You cannot re-run the LM family of tools from the geoprocessing history because the location of the tools will have changed.

6.5 Other Applications

LP came about primarily to facilitate embedding of linkage analysis in iterative geoprocessing routines such as Land Advisor models (Aplet et al. 2016, Gallo et al. In Prep). Land Advisor evaluates a landscape for conservation priorities, uses a greedy heuristic to assume the highest priority area is conserved, and then repeats the process to identify the second-highest priority area. Embedding LM/LP allows Land Advisor to extend its scope from prioritization of core protected areas to include prioritization of corridors among them.

Of course, LP can also be used in standalone corridor identification projects that require prioritization of conservation action among potential corridor areas. Doing such an analysis draws from a rich field of theory and practice. Perhaps the best repository of such information is <https://conservationcorridor.org/library/> and the best practical guide for getting up to speed on the practice of resistance-surface based connectivity modeling is by Wade et al. (2015).

7 Support

Please join the Linkage Mapper User Group to get updates, report bugs, and suggest enhancements (<https://groups.google.com/forum/#!forum/linkage-mapper>).

We also encourage contributions to the LM project by ArcGIS/Python developers. This could include enhancements and fixes to existing tools, and development of new tools for the LM toolbox. We encourage new tools to follow the protocols in Linkage Priority and Climate Linkage Mapper, which are currently the two newest tools in the LM toolbox. Please see the LP Developer Documentation for details on the source code repository.

8 Key Acronyms

- CAV = Core Area Value
- CFC = Current Flow Centrality
- CPV = Corridor Priority Value
- CSP = Corridor Specific Priority
- CW = Cost Weighted
- CWD = Cost Weighted Distance
- ECAV = Expert Core Area Value
- ECIV = Expert Corridor Importance Value
- LCP = Least Cost Path

- LP = Linkage Priority
- LM = Linkage Mapper
- OCAV = Other Core Area Value
- RCI = Relative Corridor Importance

9 Select References

Aplet, G, P. McKinley, and J. Gallo. 2016. Keynote Presentation: Spreading Conservation Risk with a Portfolio of Strategies Natural Areas Association. Sacramento, CA Oct. [[video](#)]

Gallo, J., G. Aplet, F. Davis, R. Greene, M. Lombard, J. Thomson and P. Leonard. In Prep. A new framework of spatial allocation modeling for multiple objectives that emphasizes transparency and includes climate-wise connectivity.

McRae BH, Kavanagh DM. 2011. Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle, WA. Available from <http://www.circuitscape.org/linkagemapper>.

Wade, Alisa A. McKelvey, Kevin S. Schwartz, Michael K. 2015. Resistance-surface-based wildlife conservation connectivity modeling: Summary of efforts in the United States and guide for practitioners. General Technical Report RMRS-GTR-333. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. Available from http://www.fs.fed.us/rm/pubs/rmrs_gtr333.pdf.

10 Linkage Priority Tutorial

10.1 Run with Default Parameters

- Open “LP Demo Arc10.mxd”
- Use the Catalog Window to make a subfolder within demoProject, called v001
- Open and run the **Build Network and Map Linkages** tool in “Linkage Pathways Tool” toolset.
 - Optionally, you can run **Climate Linkage Mapper** in the “Additional Tools” toolset instead.
- Use the default settings, with v001 as the Project Directory.
- If you don’t have an ArcGIS Advanced/ArcInfo license, you will also need to select modoc_distances_cores.txt (provided in the demoProject folder) as the Core Area Distances Text File.
 - (See LM user guide for info on how to create such a file)

Build Network and Map Linkages

Model Inputs

Project Directory

Core Area Feature Class

Core Area Field Name

Resistance Raster

Process Steps

☒ Step 1 - Identify Adjacent Core Areas

☒ Step 2 - Construct a Network of Core Areas

Network Adjacency Method

Core Area Distances Text File. Leave blank to generate (ArcInfo license only)

☒ Step 3 - Calculate Cost-Weighted Distances and Least Cost Paths

☒ Drop Corridors that Intersect Core Areas

☐ Step 4 - Prune Network Using Options Below (optional)

Option A - Maximum Number of Connected Nearest Neighbors

Option B - Nearest Neighbor Measurement Unit

☒ Option C - Connect Neighboring Constellations

☒ Step 5 - Calculate, Normalize and Mosaic Corridors

Additional Options

Bounding Circles Buffer Distance (optional)

Maximum Cost-Weighted Corridor Distance (optional)

Maximum Euclidean Corridor Distance (optional)

Output for ModelBuilder Precondition (optional)

☒ Truncate Corridors

Cost-Weighted Distance Threshold to Use in Truncating Corridors

Custom Settings File (optional)

Project Directory

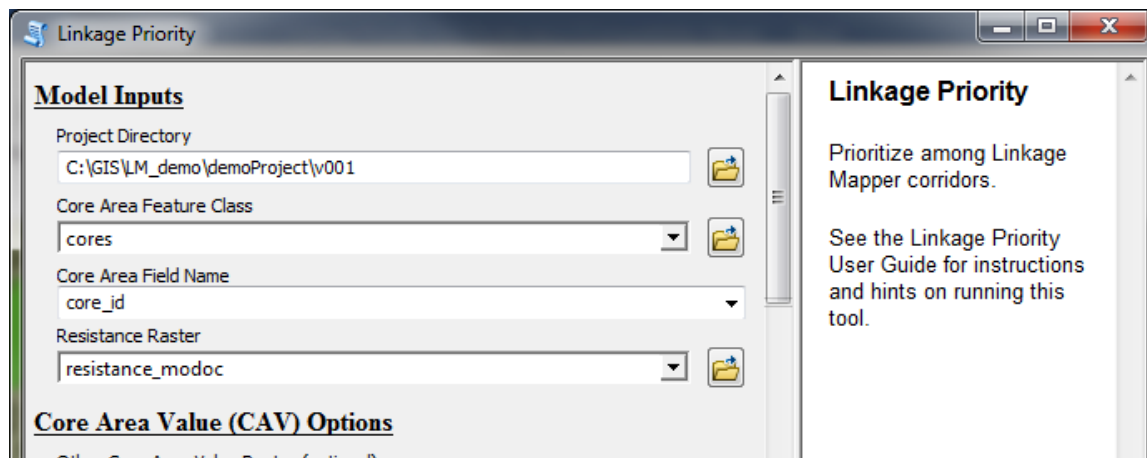
Project directory. A different directory should be used for each unique project/scenario.

NOTE: You can re-load finished or canceled run settings using the Results tab in ArcMap.

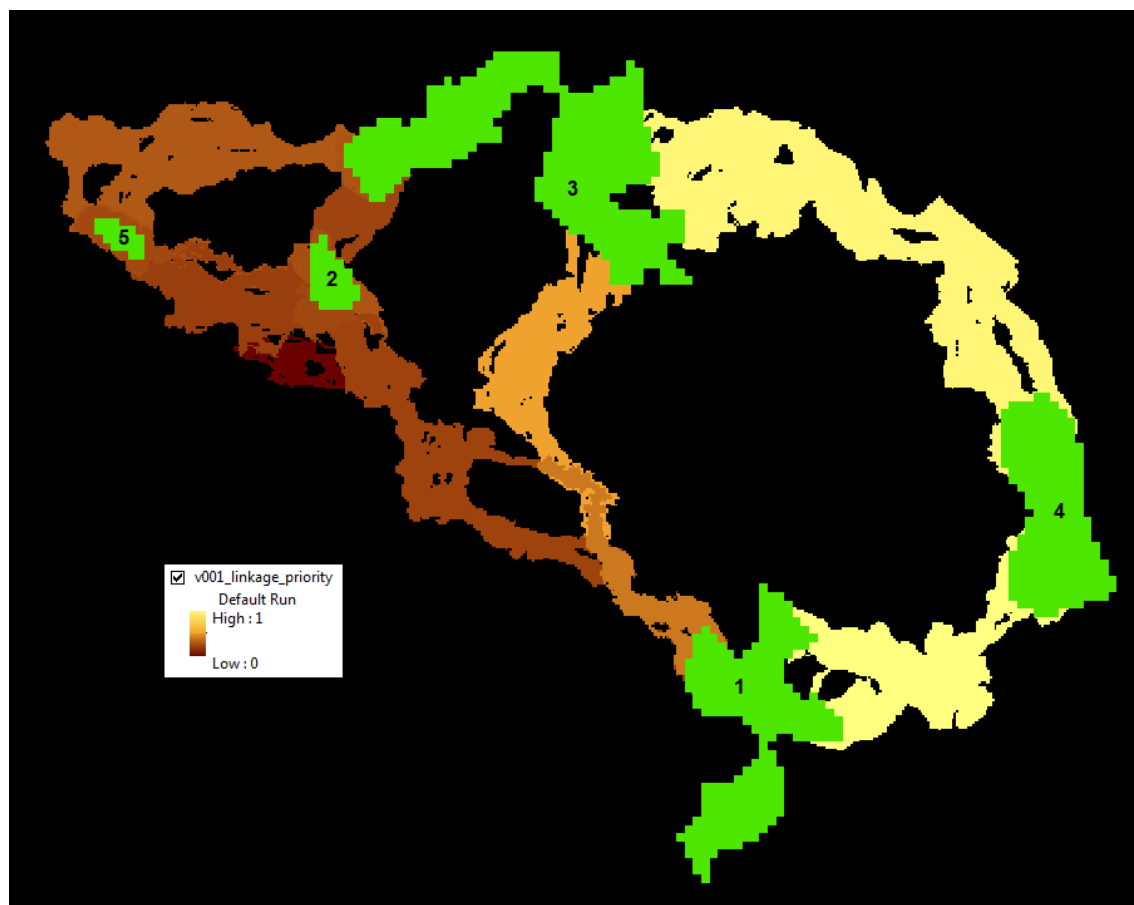
OK Cancel Environments... << Hide Help Tool Help

- Click **OK** to run the tool.

- Then, open the **Linkage Priority** tool in the Additional Tools toolset, point to the same inputs, and use the default settings:



- Click **OK** to run the tool.
- After completion, add the dataset `demoProject\v001\output\corridors.gdb\v001_linkage_priority` to your map, and symbolize it with a Minimum-Maximum stretch. The output is referred to as the “Default Run” and should look something like the following:



(Note, sometimes the low value is not exactly 0 due to a rounding error.)

LP also combines the linkage priority with the truncated cost output from the Build Network and Map Linkages tool in an evenly weighted sum, and calls it v001_blended_priority layer:



Note, you can change the weight in the Blended Priority Options:

Blended Priority Options

Truncated Corridors Weight in Blended Priority Calculation

0.5

Linkage Priority Weight in Blended Priority Calculation


0.5

10.2 Add Climate Refugia

In addition to the default considerations for Core Area Value, LP has an option to consider an additional raster input. This **Other Core Area Value** is averaged for each core area. It can be used for example, to give higher priority to corridors where the connected cores constitute important refugia areas. A dataset has been provided to demonstrate this capability, as follows:

- If you do not want to overwrite then make a new folder called v002 and run **Build Network and Map Linkages** tool again.
- Open the **Linkage Priority** tool. Provide the standard Model Inputs as above.
- Scroll down to the **Core Area Value (CAV) Options** and enter the following settings:

Core Area Value (CAV) Options

Other Core Area Value Raster (optional)	
climate_refugia_modoc	
Resistance Weight in CAV Calculation	0.1
Size Weight in CAV Calculation	0.1
Area/Perimeter Weight in CAV Calculation	0.1
Expert Core Area Value Weight in CAV Calculation	0
Current Flow Centrality Weight in CAV Calculation	0
Other Core Area Value Weight in CAV Calculation	0.7

Other Core Area Value Raster: select climate_refugia_modoc

This dataset has higher values for areas of more stable climate and more topographic heterogeneity (from <https://databasin.org/datasets/d58de1a0b08443fea53c25b70804866c>) and is pre-loaded into the LP Demo .mxd. You can take a moment to examine the layer, and predict how it will change the results.

Resistance Weight in CAV Calculation: 0.1

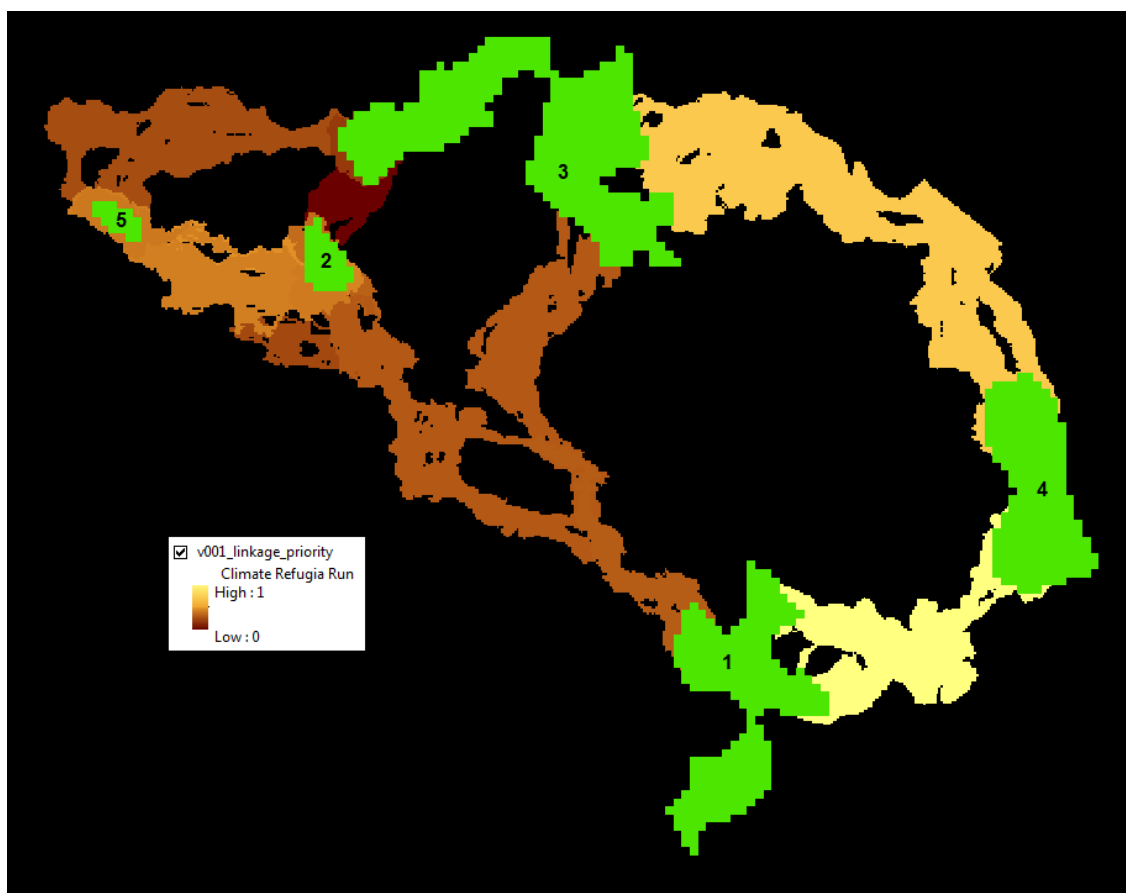
Size Weight in CAV Calculation: 0.1

Area/Perimeter Weight in CAV Calculation: 0.1

Other Core Area Value Weight in CAV Calculation: 0.7

Note that much higher priority is given to the Other Core Area Value than to the other factors for illustration purposes.

- Leave all other settings at their defaults.
- Click **OK** to run the tool.
- Add the dataset demoProject\output\corridors.gdb\demoProject_linkage_priority to your map, and symbolize it with a Minimum-Maximum stretch. The output should look something like the following:






Note how the relative importance of linkages 2-5 and 1-4 are now higher. This is because cores 4,1, and 5 have more micro-refugia, and hence a higher average refugia score, than the other cores.

10.3 Add Climate Signature

Another one of LP's **optional features** for prioritizing corridors is **climate signature**. Two datasets have been provided to demonstrate this capability in the demo project, as follows:

- Open the **Linkage Priority** tool. Provide the standard Model Inputs as in Default Run, which means undoing the changes made for the Climate Refugia Run.
- Scroll down to the Corridor Specific Priority (CSP) Options and enter the following settings:

Corridor Specific Priority (CSP) Options

Core Pairs Table (optional)	<input type="text"/>	
From Core Field (optional)	<input type="text"/>	
To Core Field (optional)	<input type="text"/>	
Expert Corridor Importance Value Field (optional)	<input type="text"/>	
Current Climate Envelope Raster (optional)	<input type="text" value="climate_signature_current"/>	
Future Climate Envelope Raster (optional)	<input type="text"/>	
<input type="checkbox"/> Higher Climate Envelope Values are Cooler		
Closeness Weight in CSP Calculation	<input type="text" value="0.1"/>	0.1
Permeability Weight in CSP Calculation	<input type="text" value="0.1"/>	0.1
Core Area Value Weight in CSP Calculation	<input type="text" value="0.1"/>	0.1
Expert Corridor Importance Value Weight in CSP Calculation	<input type="text" value="0"/>	0
Climate Envelope Difference Weight in CSP Calculation	<input type="text" value="0.7"/>	0.7

Current Climate Envelope Raster: select climate_signature_current

This dataset is the observed Climatic Water Deficit, where higher values are hotter/drier (from <https://databasin.org/datasets/dbd45814e4db43dea4472c3a3ccacd9b>).

Closeness Weight in CSP Calculation: 0.1

Permeability Weight in CSP Calculation: 0.1

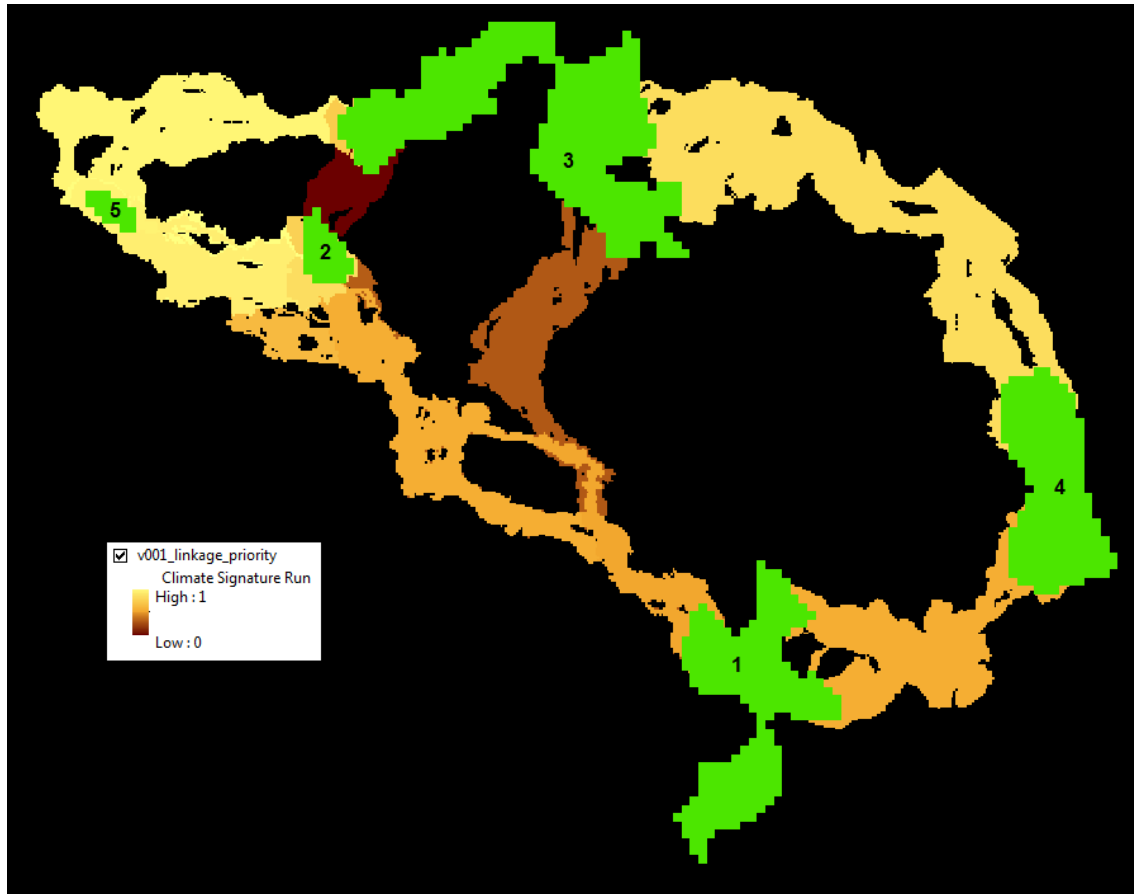
Core Area Value Weight in CSP Calculation: 0.1

Climate Envelope Difference Weight in CSP Calculation: 0.7

Note that much higher priority is given to the Climate Envelope Difference than to the other factors. Climate envelope difference gives higher priority to corridors where the difference in climate envelope (i.e. climate signature) between the cores is high. This simulates cores where individuals of a species are able to move to “higher ground” and more suitable climate, over the decades.

- Leave all other settings at their defaults. Take a moment to look at the “climate_signature_current” layer in the table of contents. Note which core areas have a lower value (cooler and wetter).
- Click **OK** to run the tool.

- Add the dataset demoProject\output\corridors.gdb\demoProject_linkage_priority to your map, and symbolize it with a Minimum-Maximum stretch. The output should look something like the following:



Compared to the earlier results, including climate envelopes in the prioritization increases the relative priority of the corridors 2-5, 3-5 and 3-4, as all of these link a core with high climatic water deficit (hotter/drier) to one with lower CWD.

Note that a `climate_signature_future` layer has also been provided, and you are encouraged to run the climate signature scenario again with both the current and future layers, which will calculate the climate envelope difference of core pairs between the current situation and the future estimate.

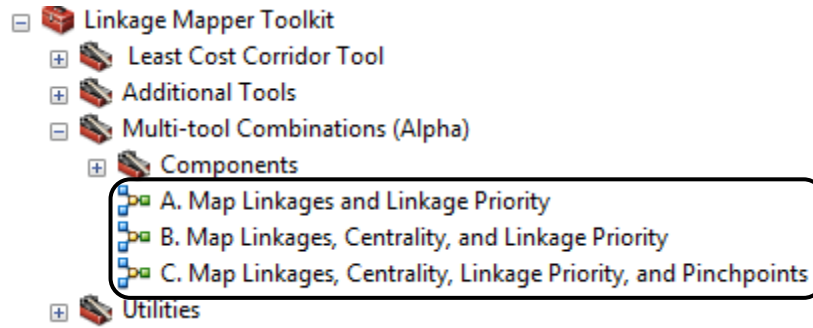
Please refer to sections 4.3, 4.4 and 4.5 above for other optional inputs to corridor prioritization.

11 Advanced Linkage Priority Tutorial

11.1 Shortcut for Multiple Runs

In most projects it is useful to run multiple iterations of the model to explore different parameters, and values, and to compare their outputs. So far, each iteration has been overwriting outputs in the `v001` folder. The following discusses how to make and store multiple runs, and how to run both **Build Network and Map Linkages** as well as **Linkage Priority** tools at the same time, which is especially useful for huge landscapes, and running both overnight. at the same time.

Click “Edit” on one of these tools:



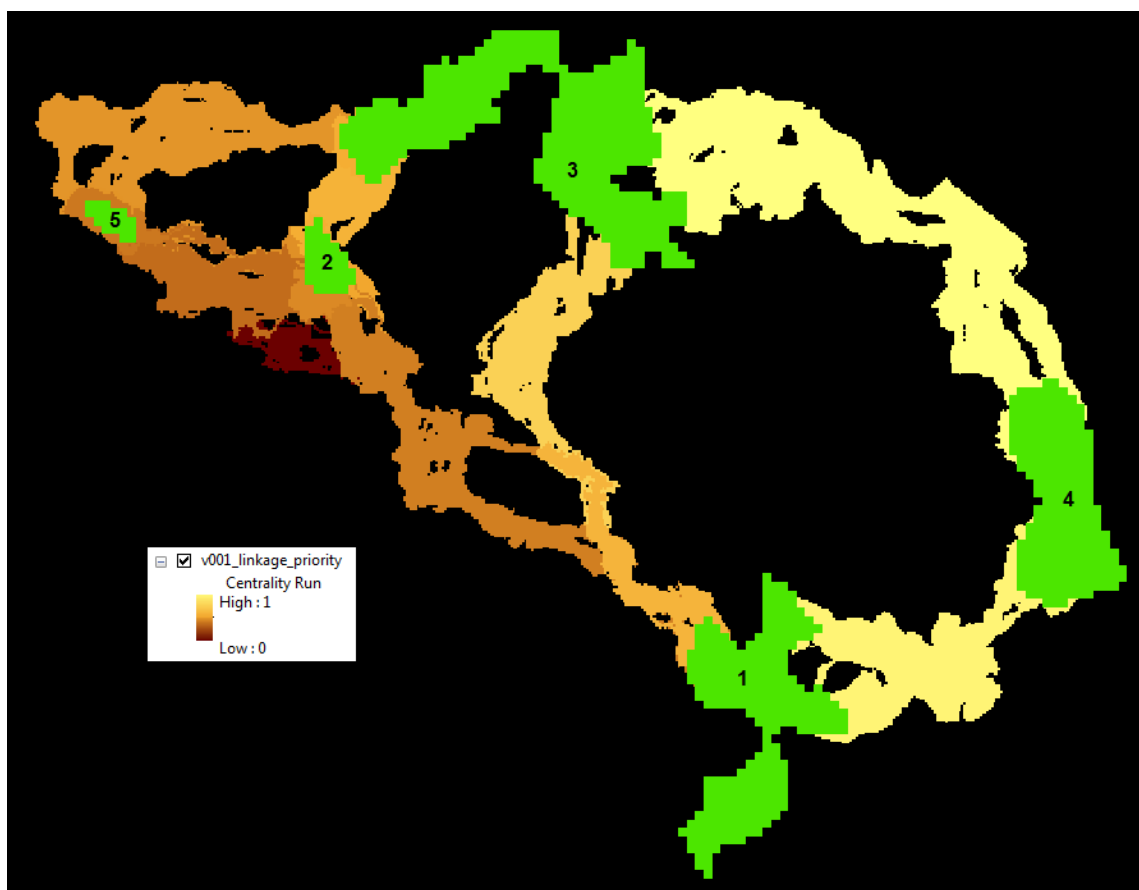
Change the “Project Directory” value to a new name. Run as much of the model as you can (the first step). Then validate the model. Then edit any parameter values as necessary. Save, and run the entire model.

11.2 Add Centrality

Another one of LP’s **optional features** for prioritizing corridors is **core centrality**. This incorporates the outputs of Centrality Mapper as an input. See the Centrality Mapper user guide for more information on that tool. To use it here, run Centrality Mapper tool after running Build Network and Map Linkages, using the same Project Directory. Then, when using Linkage Priority, give Current Flow Centrality Weight in CAV Calculation a non-zero value, such as the following (remember, “best practice” is that all weights add to 1, so note that the Current Flow Centrality Weight has been adjusted):

Resistance Weight in CAV Calculation	0.1
Size Weight in CAV Calculation	0.1
Area/Perimeter Weight in CAV Calculation	0.1
Expert Core Area Value Weight in CAV Calculation	0
Current Flow Centrality Weight in CAV Calculation	0.7
Other Core Area Value Weight in CAV Calculation	0

The result should look like the following:



Note that Cores 2 and 3 are more central than Cores 1, 4 and 5. Hence, linkages that involve these cores have a higher relative priority than they did on the initial run with default parameters. Note, the Centrality Mapper Tool iterates through all core pairs. Pinchpoint Mapper was written after Centrality Mapper, and gives an “all-to-one” option which is faster on large landscapes and very similar in output.

11.3 Inspect Core Area Value Component Calculations

The components of core area value (see Geoprocessing Overview above) are all calculated in the input Core Area Feature Class attribute table, as follows:

core_id	mean_res	norm_res	area	norm_size	perimeter	ap_ratio	norm_ratio	cav	norm_cav
1	59.243835	0.82172	284846014.7	0.612849	153970.514522	1850.003656	0.684152	0.838353	0.704098
2	69.693207	0.728271	35970005.50	0.07739	29988.992004	1199.440298	0.443567	0.739202	0.331133
3	111.818739	0.351541	464790017.1	1	209965.788112	2213.646429	0.818631	0.917017	1
4	39.308835	1	237912008.7	0.51187	87982.546481	2704.081869	1	0.761446	0.414807
5	41.75524	0.978122	18978005.07	0.040831	21989.85156	863.034706	0.31916	0.651172	0

core_id	clim_env	nclim_env	fut_clim	nfut_clim	ocav	nocav	ecav	necav	CF_Central	ncfc
1	0.705774	0.68298	<Null>	<Null>	0.470491	0.707121	0	0	5.933104	0.894973
2	0.845077	1	<Null>	<Null>	0.113216	0	0	0	5.817546	0.877542
3	0.819734	0.942326	<Null>	<Null>	0.125309	0.023934	0	0	6.629368	1
4	0.516559	0.252368	<Null>	<Null>	0.618469	1	0	0	4.832424	0.728942
5	0.405666	0	<Null>	<Null>	0.395187	0.558079	0	0	4.899675	0.739086

Note that the Expert Core Area Value (ecav) can be specified by editing this table. All other values will be overwritten on each run of LM/LP.