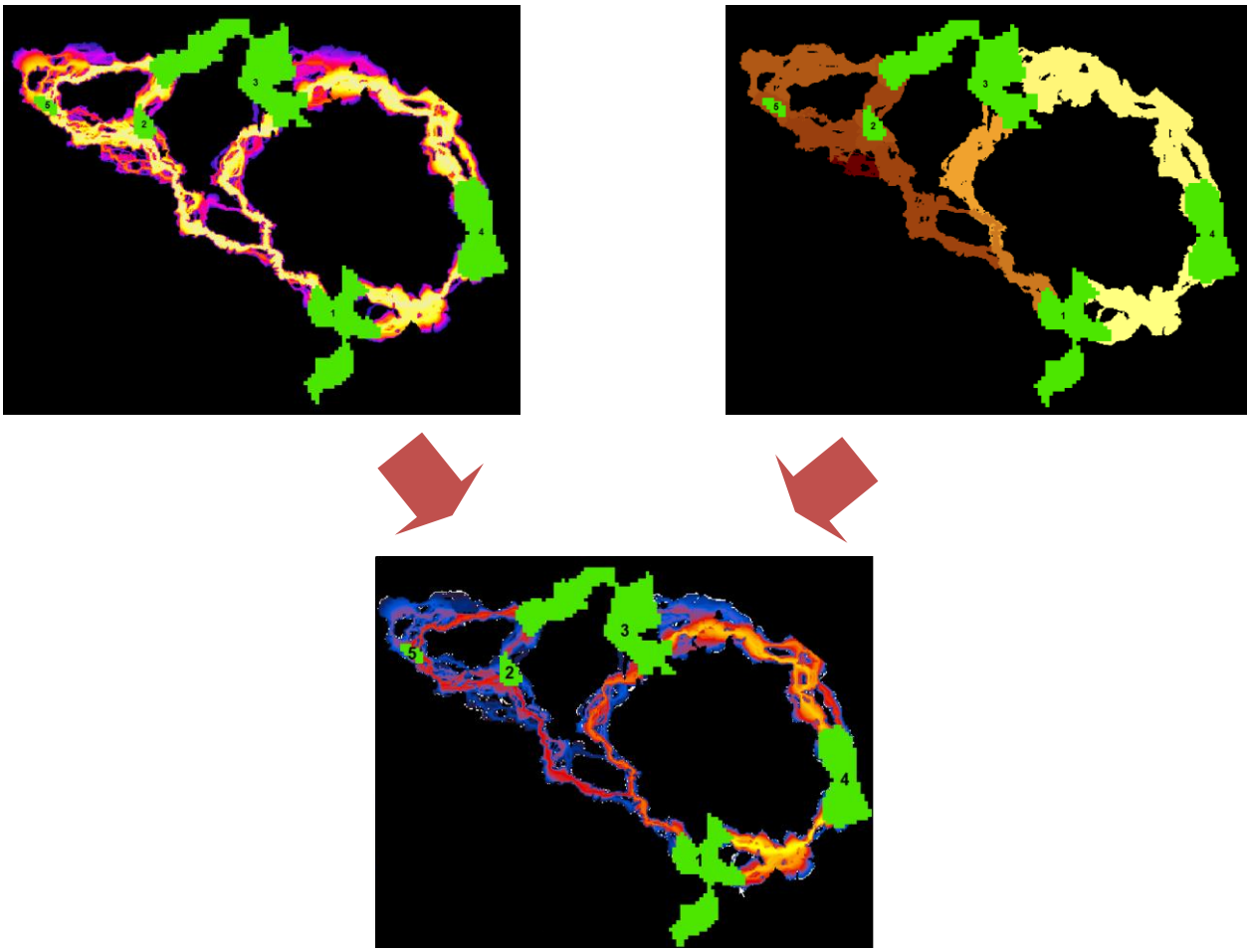
Connectivity Analysis Software for Estimating Linkage Priority



Linkage Mapper Toolbox:
Linkage Priority User Guide and Tutorial

Version 3.0—Updated July 2021

Want a quick start?
Run tutorial in section 9.1
and refer to section 1.1

Software Requirements and Licensing

Linkage Priority requires **ArcGIS Desktop** (10.3 or greater) or **ArcGIS Pro,** with the **ArcGIS Spatial Analyst** extension. This software is provided free of charge and is licensed under a GNU General Public License.

Preferred Citation[1]

Gallo, J. A., & R. Greene. 2018. Connectivity Analysis Software for Estimating Linkage Priority. Conservation Biology Institute, OR https://doi.org/10.6084/m9.figshare.5673715

[1] This is evolving software with evolving authorship, but we have been advised to keep the original preferred citation for tracking purposes. John Gallo designed the changes from v2.0 to v3.0, and Darren Kavanagh wrote most of the new code.

Table of Contents

1 Introduction 4
1.1 Tool Overview 4
1.2 Climate-wise Considerations (optional to run) 5
1.3 Example Applications 5
2 Acknowledgements 5
3 Installation 6
4 Using Linkage Priority 6
4.1 Required Inputs 6
4.2 Core Area Value (CAV) Options 7
4.3 Corridor Specific Priority (CSP) Options 7
4.4 Blended Priority Options 10
4.5 Additional Options 10
4.6 Advanced Settings in lp_settings.py 10
5 Other Usage Notes 11
5.1 Upgrading 11
5.2 Enhancing Analyses Using Optional Settings 11
5.3 Other Suggestions and Troubleshooting 11
5.4 Other Applications 12
6 Community 12
7 Key Acronyms 12
8 Select References 13
9 Linkage Priority Tutorial 14
9.1 Run Linkage Pathways, then Linkage Priority Tool with Defaults 14
9.2 Add Other Core Area Value (e.g. Climate Refugia) 18
9.3 Using Climate Signature to Prioritize Climate Analogs 20
9.4 Combine the above sections into a single model run. 23
10 Advanced Linkage Priority Tutorial 24
10.1 Shortcut for Multiple Runs 24
10.2 Add Centrality 25
10.3 Inspect Core Area Value Component Calculations 27
10.4 Export Corridor Importance Value 27

1 Introduction

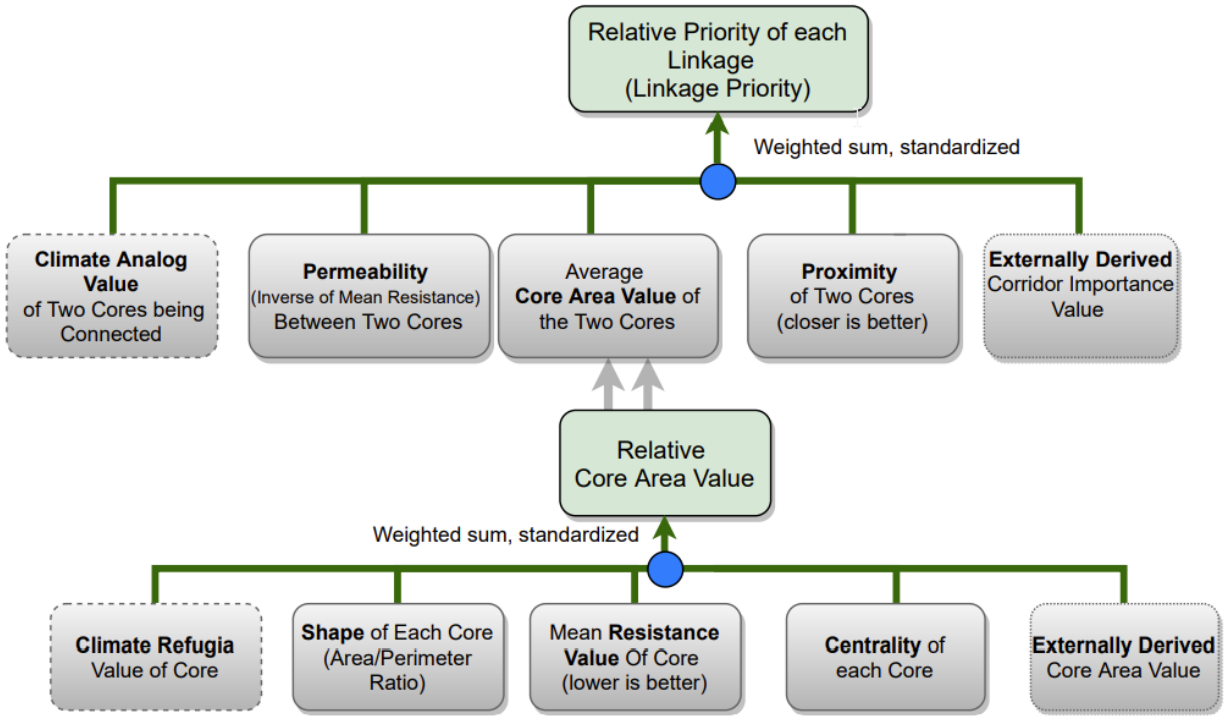
Linkage Priority (LP) is an ArcGIS tool that helps quantify the relative conservation priority of each linkage in a landscape.

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).

1.1 Tool Overview

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.

Figure: Diagram of all the optional criteria that can be used in determining the relative priority of each linkage



1.2 Climate-wise Considerations (optional to run)

There are many climate considerations that can be incorporated in habitat connectivity modeling and mapping. Two have previously been pursued in isolation from each other, and yield quite different recommendations for linkage priority. However, we maintain that they are two extremes of the same continuum, and have updated this tool (in v3.0 compared to v2.0) so the user can model for one, or the other, or an appropriate blend between both (which we recommend). The first consideration is "range shift connectivity", and gives higher priority for linkages that connect core areas that will become too hot/dry in the future with cores that are much cooler/wetter, allowing species to "move to higher ground" (Keeley et al. 2018). Meanwhile, "climate analog connectivity" gives higher priority to linkages with the destination core having the same predicted climate at a future time (e.g. 2050), as the climate in the source core at the current time (e.g. Littlefield et al. 2017). Each approach is better than nothing, but each has its opposing questionable assumptions. In addition to being able to model for a balance between these assumptions, we also added "preferred climate" as a factor in defining linkage priority. If this parameter is used, then linkages that end in a core area that is predicted to be near the preferred climate are given higher priority than linkages that lead to core areas predicted to be much hotter/drier than the preferred climate. More details are provided in the "white paper / specifications document", the conference presentation video, and conference slides (Gallo, 2019a,b,c). 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 9.3 "Using Linkage Priority/Add Climate Signature" for more details.

1.3 Example Applications

Prototype applications of various beta versions of the Linkage Priority Tool have been performed in seven regions (Sierra Nevada mountains, Sonoma County, Santa Barbara County, West Mojave, Sacramento Valley, and Modoc Plateau), with outputs available on a databasin.org Gallery and reports (Spencer et al. 2019; Gallo et al. 2019a, Gallo et al. 2019b). Climate was considered in several of these in determining priority in several ways: (1) quantifying which linkages best facilitated long-term species range shifts, (2) which core areas had more stable climate over time and hence provided refuge from climate change, and (3) which core areas contained more climate micro-refugia for withstanding climate change.

2 Acknowledgements

The first iteration of the Linkage Priority Tool was developed thanks to funding from a South Africa National Research Foundation post-doctoral research grant (#47264) through Nelson Mandela Metropolitan University. We would like to thank the additional organizations that have funded this work in various co-production applications: Sonoma County Agricultural Preservation and Open Space District, The Wilderness Society, California Department of Fish in Game via Dr. Megan Jennings, Charlotte Martin Foundation, and Conservation Biology Institute.

Thanks also to Darren Kavanagh, Annie Prisbrey, Nik Stevenson-Molner, Tim Sheehan, Nathaniel Mills, and Justin Brice for their advice and their participation in the updates and/or releases of LP.

In caring memory of Brad McRae, the founding developer of Linkage Mapper toolbox. "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."[2]

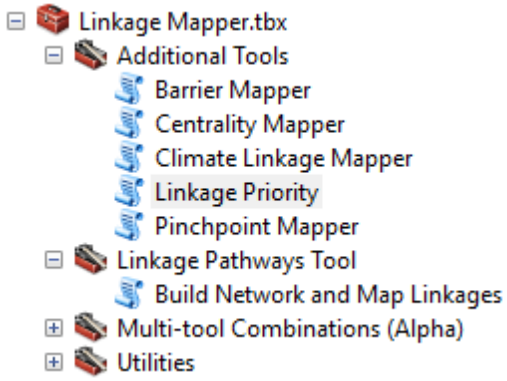
3 Installation

Download Linkage Mapper v3.0 or greater from https://circuitscape.org/linkagemapper and first 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.

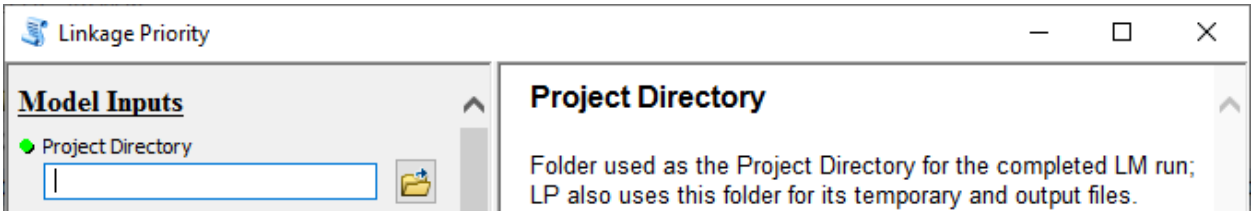
4 Using Linkage Priority

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

The weights for these, and the associated parameters, are accessed through the ArcGIS toolbox tool. LP is run after understanding and running LM, and optionally after Centrality Mapper. Open LP from the Linkage Mapper toolbox.



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 section 5 Other Usage Notes 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.

[2] from Joe Fargione, Brad McRae's supervisor

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. `(Default value: 0.33)`
    - *Size Weight*: Decimal value between 0 and 1 to be multiplied by the normalized size of the core.`(Default value: 0.33)`
    - *Area/Perimeter Weight*: Decimal value between 0 and 1 to be multiplied by the normalized area/perimeter ratio of the core. `(Default value: 0.34)`
    - *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 5.2 and 5.4 below for additional details. `(Default value: 0)`
    - *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 5.2 below for additional details. `(Default value: 0)`
    - *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 5.2 below for additional details. `(Default value: 0)`

4.3 Corridor Specific Priority (CSP) Options

- *Core Pairs Table Containing Expert Corridor Importance Value (optional)*: a table, feature class or raster attribute table of the user's choice 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.
        - *Note*: User may need to manually type in the Field Names rather than finding them as drop-down options.
    - *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 Signature Raster (optional)*: Optional raster used to calculate the current climate signature (i.e. envelope) for each core, which feeds into the climate signature difference calculation for the two cores at the end of each corridor; see Gallo, 2019 and section 5.2 below for additional details.
    - *Modify the Advanced Climate Signature Parameters? (optional)* If this is checked, then the below parameters will turn from grey to black. If left unchecked, then the analysis will move forward with the assumption that the relative difference in climate between cores is much higher than the relative difference in climate at a core between time steps. Hence, the Current Climate Signature Raster will be used as a surrogate for the Future Climate Signature Raster, and all the below default parameter values will be used.
    - *Future Climate Signature Raster*: An optional raster used to calculate the future climate signature (i.e. envelope) for each core, which feeds into the climate signature difference calculation for the two cores at the end of each corridor; see section 5.2 below for additional details

- *Linkage Priority of Minimum Climate Analog Ratio*: This is A_{Rmin} , the lower left starting point of the curve in Figure 1 of the white paper. It is the value assigned as the Climate Analog Linkage Priority Value (A) for the core pair on the landscape that has the lowest Climate Analog Ratio I; which is C_{DT} / C_{S0} , (i.e. the climate value of the destination core (D) at the future time step, T, divided by the climate value of the starting (hotter) core at the present time, T = 0). `(Default value: 0.75)`
- *Linkage Priority of Maximum Climate Analog Ratio*: This is A_{Rmax} , the y-axis value of the lower right value of the curve in Figure 1 of the white paper. It is the Climate Analog Linkage Priority Value (A) of the core pair on the landscape that has the highest Climate Analog Ratio (R) , which is C_{DT} / C_{S0} , (i.e. the climate value of the destination core (D) at the future time step, T, divided by the climate value of the starting (hotter) core at the present time, T = 0). `(Default value: 0)`
- *Lowest Allowable Maximum Climate Analog Ratio on the "Value Curve"*:
    - This parameter is for adding realism to the model for rare situations. With the default value used, then the parameter only affects the model in these rare situations, so the user can skip learning about this parameter when learning the model for the first time.
    - The problem is more likely to occur when there are only a few cores, or when only looking a short time into the future. The problem occurs when two conditions occur: (1) the Maximum Climate Analog Ratio (R) for two cores on a landscape (Rmax) was just a bit over 1 [R is CDT/ CS0, (i.e. is the climate value of the destination core (D) at the future time step, T, divided by the climate value of the starting (hotter) core at the present time.)], AND (2) if the default value of 0 is used for *Linkage Priority of Maximum Climate Analog Ratio* (LPMCAR). If the *Linkage Priority of Maximum Climate Analog Ratio*value is 1 (the default), then this makes an extremely steep curve on the right side of the Value Curve. And in this case, a destination core that is just a bit hotter in the future compared to the current climate of the starting core, will be penalized extremely, which is much more than common sense dictates.
    - For once off analyses, this problem can be addressed simply by adjusting the value of LPMCAR higher, to something like 0.5 or 0.75. But, for iterative allocation algorithms like LandAdvisor (Gallo et al. 2020), using the default value of 0 is most useful in discriminating linkages during all iterations.
    - To deploy this *Lowest Allowable Maximum Climate Analog Ratio* parameter, the user defines the x-axis value that is the minimum allowable value associated with the right hand most part of the graph. If this user defined value is greater than the Rmax of the particular landscape, then this user defined value is the one that the model uses as the maximum Climate Analog Ratio of the Value Curve. The default value of 1.15 is a good balance of opposing factors for fixing the problem. For many landscapes Rmax is much greater than 1.15, so with this default value of 1.15 used, this entire parameter would then be ignored by the model. `(Default value: 1.15)`
- *Relative Priority of Achieving the Targeted Ratio*: The value of A (on the Y-axis of the chart in the white paper) that corresponds with $R_{targeted}$ on the graph. This value of A is referred to as $A_{Rtargeted}$. `(Default value: 1)`

- *Target Climate Analog Ratio*: The targeted value of R, $R_{targeted}$, that is the value on the X axis of the chart in the white paper that is the inflection point on the curve between R_{min} and R_{max} . For all but the most extreme edge cases, this is going to be the R that is the highest linkage priority value. `(Default value: 1)`
- *Climate Analog Linkage Priority Weight*: This is the relative weight of the Climate Analog Linkage Priority (A) of a linkage compared to the Climate Preference Linkage Priority Weight. These two weights should add to 1. The default value is 0.67 for now since this is a more established concept than Climate Preference and is also arguably more important. `(Default value: 0.67)`
- *Preferred Climate Signature Value for a Core*: At future time T, what is the preferred climate value of a core area? An initial approach to determining this value would be to look at a map of climate signature at the current time, and to look at the climate signature values of the places that currently have a preferred climate for the species and/or ecological processes that are being targeted. In other words, just because a linkage has a great climate analog match, does not mean it is a perfect climate-wise linkage. If it is matching a relatively hot/dry core to a core that is also relatively hot/dry in the future, it is not as good as if it were matching a cool/wet core to a core that is cool/wet in the future. `(Default value: 1)`
- *Relative Priority of Minimum Climate Preference Attainment Ratio*: This is L_{Gmin} , which is subjective. It is the Relative Priority of the Linkage's Climate Preference Attainment Ratio (L) of the core pair on the landscape that has the lowest Climate Preference Attainment Ratio (G). `(Default value: 0.5)`
- *Relative Priority of Maximum Climate Preference Attainment Ratio*: This is L_{Gmax} , which is subjective. It is the Relative Priority of the Linkage's Climate Preference Attainment Ratio (L) of the core pair on the landscape that has the highest Climate Preference Attainment Ratio (G). `(Default value: 0)`
- *Climate Preference Linkage Priority Weight:* This is the relative weight of the Climate Preference Linkage Priority (L) of a linkage compared to the Climate Analog Linkage Priority Weight (A). These two weights should add to 1. The default value is 0.33 for now since this is a less established concept than Climate Analog value, and would also likely be deemed less important in most expert workshops. `(Default value: 0.33)`

- 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. `(Default value: 0.33)`
  - *Permeability Weight*: Decimal value between 0 and 1 to be multiplied by the normalized permeability (inverse of the average resistance) of the corridor. `(Default value: 0.33)`
  - *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. `(Default value: 0.34)`
  - *Expert Corridor Importance Value Weight*: Decimal value between 0 and 1 to be multiplied by the normalized ECIV of the corridor. `(Default value: 0)`
  - *Climate Gradient Weight in CSP Calculation*: Decimal value between 0 and 1 to be multiplied by the weighted sum between climate preference priority value and climate analog linkage priority. `(Default value: 0)`
- *Minimum Linkage Priority Value Mapped (optional)*:
  - This optional parameter is the minimum allowable value for Linkage Priority that will be mapped. Any linkages with a value lower than this will not be mapped. This filters out poor quality linkages and insures that the blended map will only contain high

quality linkages. The linkage table of the linkages that are not mapped should have a code for this type of removal.

4.4 Blended Priority Options

- Blended Priority weighted sum weights (should sum to 1) used to create the blended_priority output raster:
    - *Truncated Corridors Weight*: Weight to be multiplied by the truncated least cost corridors output (e.g. project_corridors_truncated_at_200k). `(Default value: 0.5)`
    - *Linkage Priority Weight*: Weight to be multiplied by the each linkage's linkage_priority raster in memory. `(Default value: 0.5)`

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. (See below section).

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 (in toolbox/scripts).

- CALCCSPBP (number): Calculate Corridor Specific Value (i.e. Linkage Priority) (CSP) or CSP & Blended Priority (BP) No_Calc=0, CSP=1, CSP_BP=2
- 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)
- 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)
- CANALOGNORMETH (number): climate analog normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- CPREFERNORMETH (number): climate analog normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- NORMCORRNORMETH (number): normalized corridor normalization method (use 0 for score range normalization; any other value for maximum value normalization)
- MAXCSPWEIGHT (Boolean): relative max CSP value weight in CPV calculation
- MEANCSPWEIGHT (Boolean): relative mean CSP value weight in CPV calculation

- HIGHERCE_COOLER (Boolean): higher climate envelop values are cooler (Boolean)

- KEEPINTERMEDIATE (Boolean): keep intermediate outputs for troubleshooting purposes

5 Other Usage Notes

5.1 Upgrading

For those upgrading to version 3.0 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.

5.2 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 Signature datasets, which allow a Climate Signature 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.

5.3 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.
    - Also, you cannot rename a LM Project folder, even keeping it in place, and expect LP to run on that folder.

5.4 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).

6 Community

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. The source code repository is at https://github.com/linkagescape . We welcome any comments and suggested edits to the latest version of this and other user guides available in the repository as Word documents.

7 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

8 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., E. Butts, T. Miewald, and K. Foster. 2019a. Comparing and Combining Omniscape and Linkage Mapper Connectivity Analyses in Western Washington. Conservation Biology Institute. https://doi.org/10.6084/m9.figshare.8120924

Gallo, J., G. Aplet, R. Greene, J. Thomson, and A. Lombard. 2020. A Transparent and Intuitive Modeling Framework and Software for Efficient Land Allocation. *Land*. https://doi.org/10.3390/land9110444

Gallo, JA. 2019a. Software for prioritizing habitat linkages based on climate gradients, climate analogs, or a balanced blend. https://doi.org/10.6084/m9.figshare.7689080

Gallo, JA. 2019b. Video: Software for prioritizing habitat linkages based on climate gradients, climate analogs, or a balanced blend. International Conference for Conservation Biology, Kuala Lampur, Malaysia, July 25. https://doi.org/10.6084/m9.figshare.9161864

Gallo, JA. 2019c. Slides: Software for prioritizing habitat linkages based on climate gradients, climate analogs, or a balanced blend. International Conference for Conservation Biology, Kuala Lampur, Malaysia, July 25. https://doi.org/10.6084/m9.figshare.9072662

Gallo, J. A., J. Strittholt, G. Joseph, H. Rustigian-Romsos, R. Degagne, J. Brice, and A. Prisbrey. 2019b. "Mapping Habitat Connectivity Priority Areas That Are Climate-Wise and Multi-Scale, for Three Regions of California." Conservation Biology Institute. https://doi.org/10.6084/m9.figshare.7477532.

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

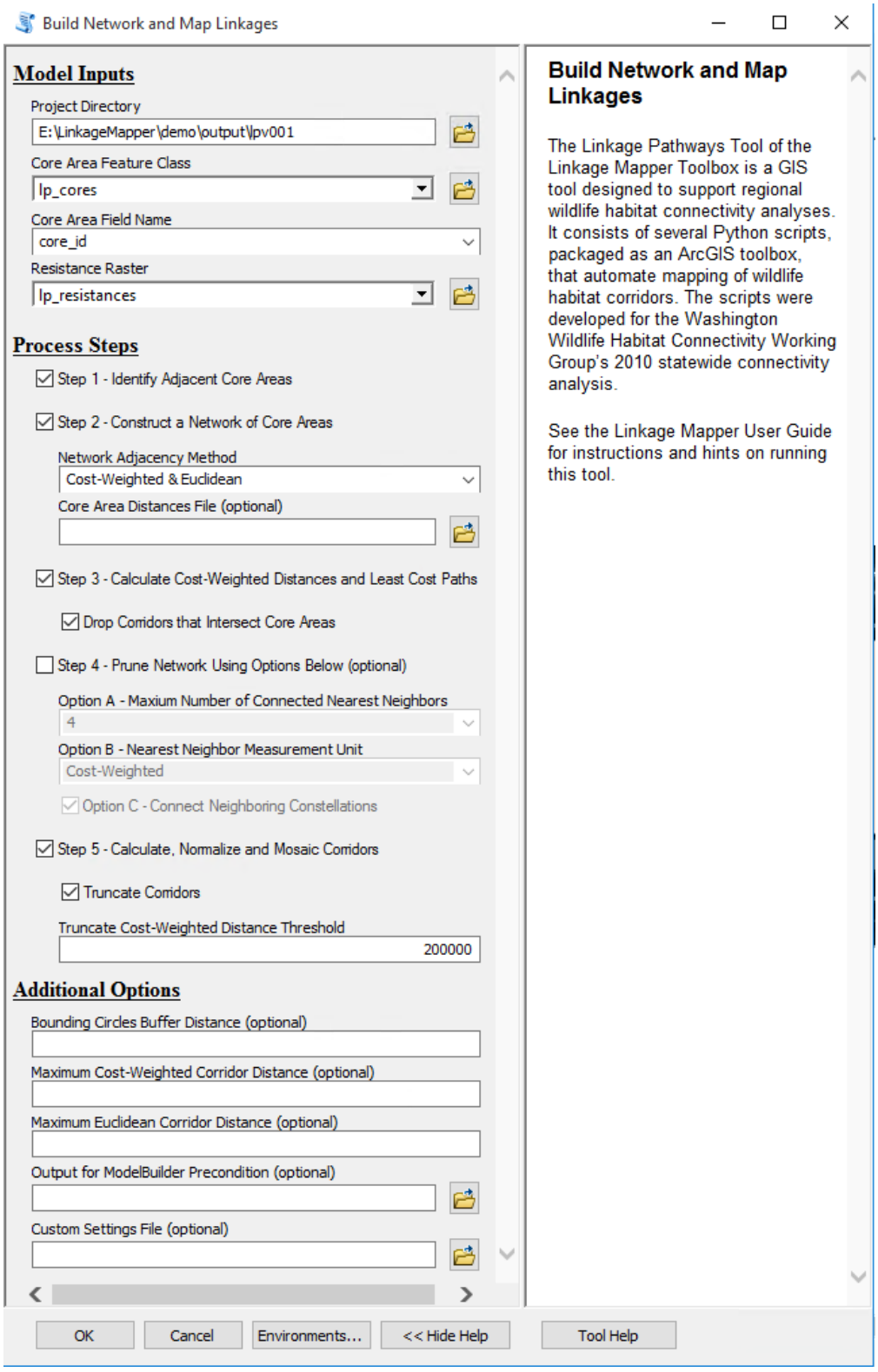
Spencer, Wayne, Justin Brice, Deanne DiPietro, John Gallo, Michelle Reilly, and Heather Rusigian-Romsos. 2019. "Habitat Connectivity for Fishers and Martens in the Klamath Basin Region of California and Oregon." Conservation Biology Institute. https://doi.org/10.6084/m9.figshare.8411909.

Wade, Alisa A., McKelvey, Kevin S., and 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.

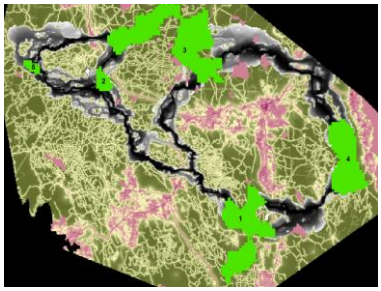
9 Linkage Priority Tutorial

9.1 Run Linkage Pathways, then Linkage Priority Tool with Defaults

- Open *LP Demo.mxd* in ArcMap or the *LP Demo* map in *ArcGIS Pro Demo.aprx*.
- Use the catalog window to make a folder within the demo/output folder called lpv001
    - Optional: examine the resistance surface and core areas and see if you can predict where the linkages will be modeled, and where they will be wide and narrow.
- Open Linkage Mapper and run the **Build Network and Map Linkages** tool in "Linkage Pathways Tool" toolset.
    - Set lpv001 as the Project Directory, use lp_cores, core_id, and lp_resistances as per the Linkage Pathways Tutorial, and the default settings. Includeshaving "Truncate Corridors" (under Step 5) clicked on. (This will clip the width of the linkage to be 200,000 cost weighted distance units from the least cost path.)
- The screengrab below from ArcGIS Desktop is how your settings should look before you press run, if you have run the tool using ArcGIS Desktop Advanced or ArcGIS Pro.
    - If you don't have ArcGIS Desktop Advanced or ArcGIS Pro, you will also need to select distances_lp_cores.txt (provided in the data folder) as the Core Area Distances Text File. (See LM user guide for info on how to create such a file)

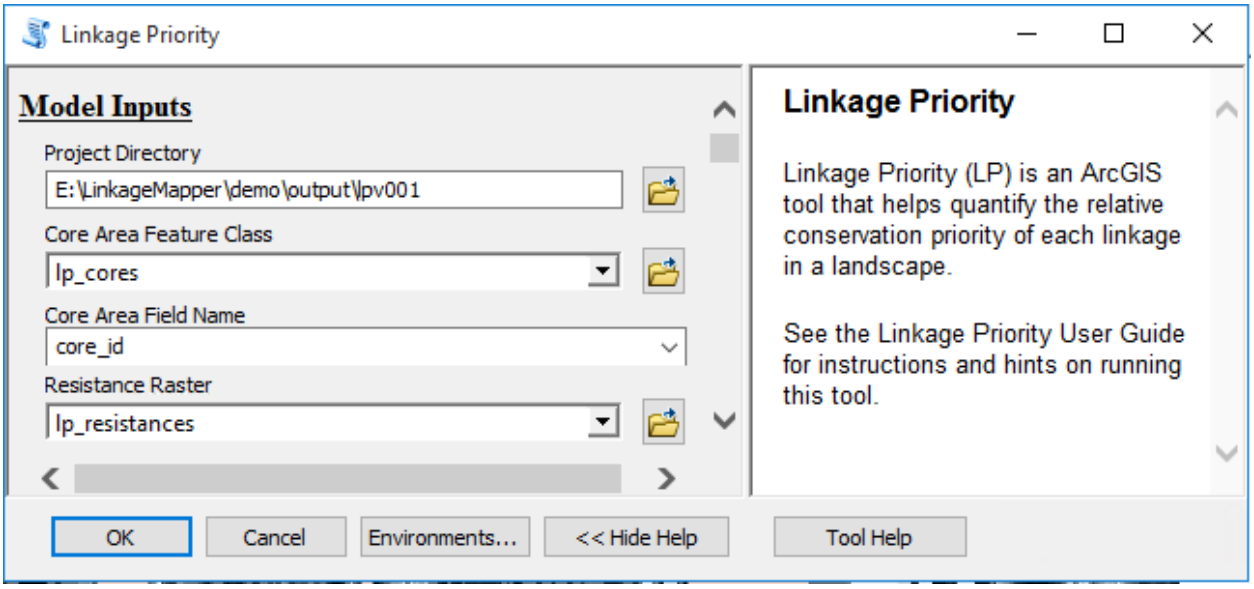


- Click **OK** to run the tool.
    - Optional: You have now made your linkages, please see if they met your expectations by adding them to the map: …demo\output\lpv001\output\corridors.gdb\lpv001_corridors_truncated_at_200k

It should look like: 

- See the Linkage Pathways tutorial for more information on them.
- Optional: click the cores and linkages on and off and think about how you would rank the linkages in order of importance.

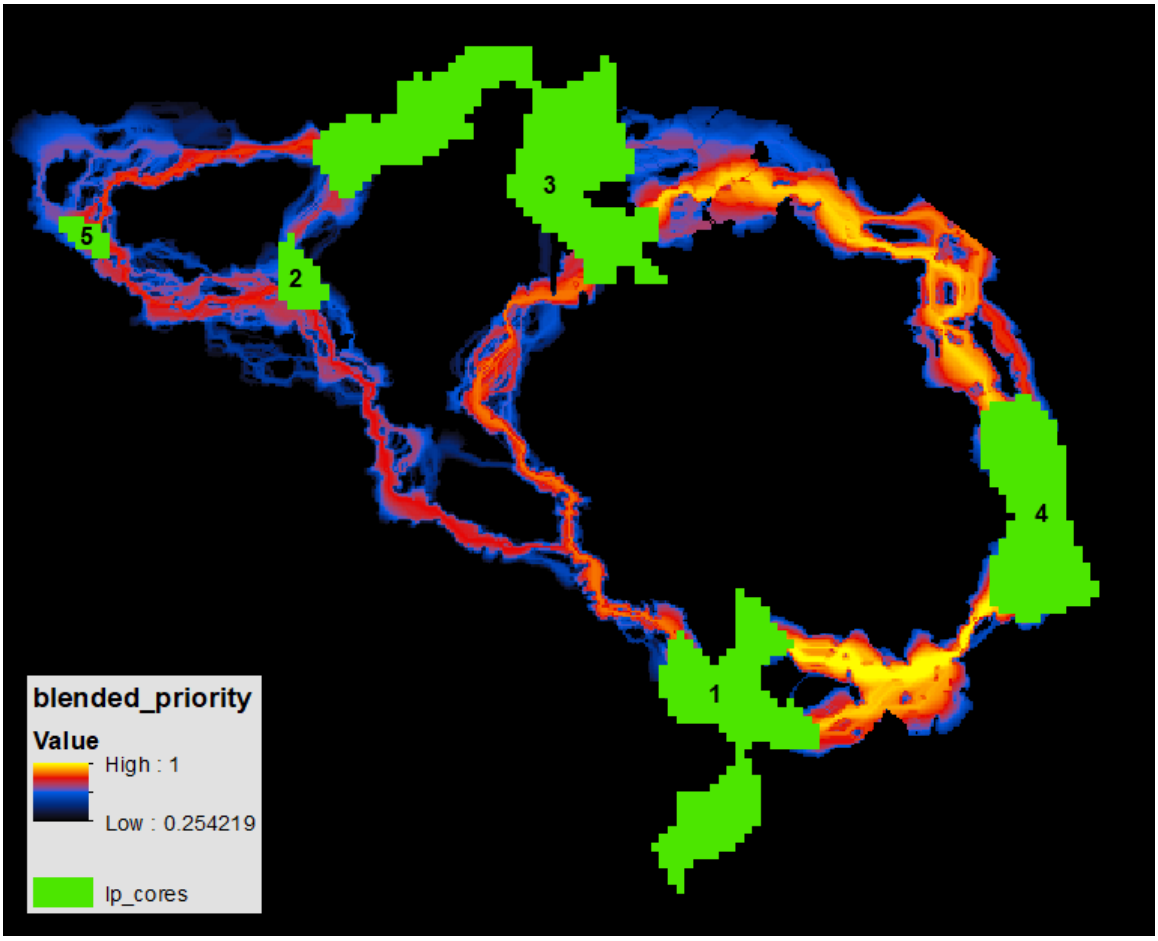
- Then, open the **Linkage Priority tool** in the Additional Tools toolset, point to the same inputs, and use the default settings:



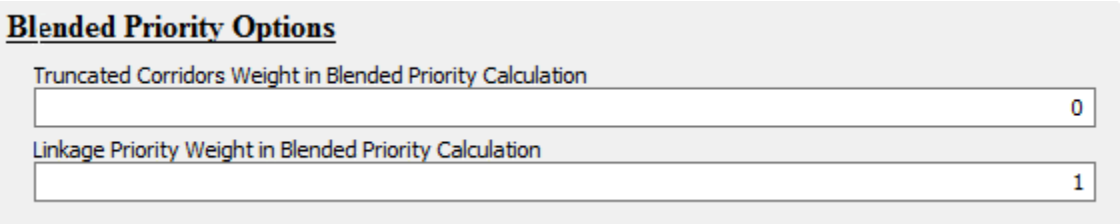
- Click **OK** to run the tool.
- After completion, add the dataset demo\output\lpv001\output\corridors.gdb\blended_priority to your map, and symbolize it with a Minimum-Maximum stretch.

Symbology tip: Custom color ramps for Linkage Mapper are available in ArcGIS style files saved in toolbox\styles folder. See the relevant ArcGIS help page on how add custom styles to your application.

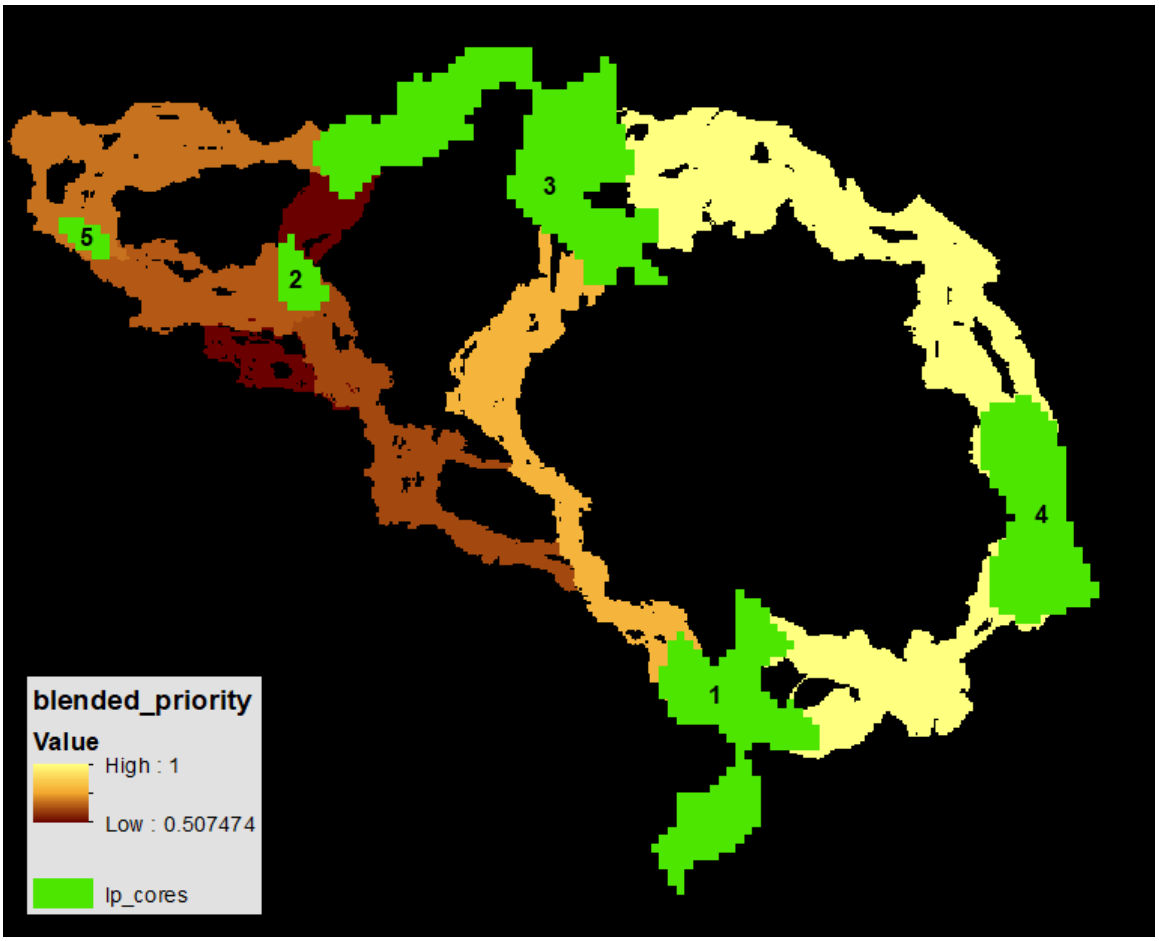
The output is referred to later as the "Default Run" and with the custom color combo (inverted) it should look like the following after you turn off the resistance surface:



- The output above shows that, based on default parameters, the most important linkage is between cores 1 and 4, closely followed by linkage 3-4. Default parameters: only using closeness, permeability, and core area value to determine linkage priority, and for core area value, only using average core resistance value, size, and area/perimeter weight; even weights.
- To save time, continue using the lpv001 directory, and move to the next section.
    - Optional: <u>If you do not want to overwrite your previous run outputs</u>,
        - Make a new folder called lpv002 and run **Build Network and Map Linkages** tool again, and then run Linkage Priority Tool with the changes below to the default values.
        - Alternatively, you can copy your lpv001/output folder and paste it and rename the copy something like lpv001/output1.
- Sometimes it is useful to see the priority value of each linkage mapped explicitly. To get this, change the weights of the blend, so that only Linkage Priority gets a weight:



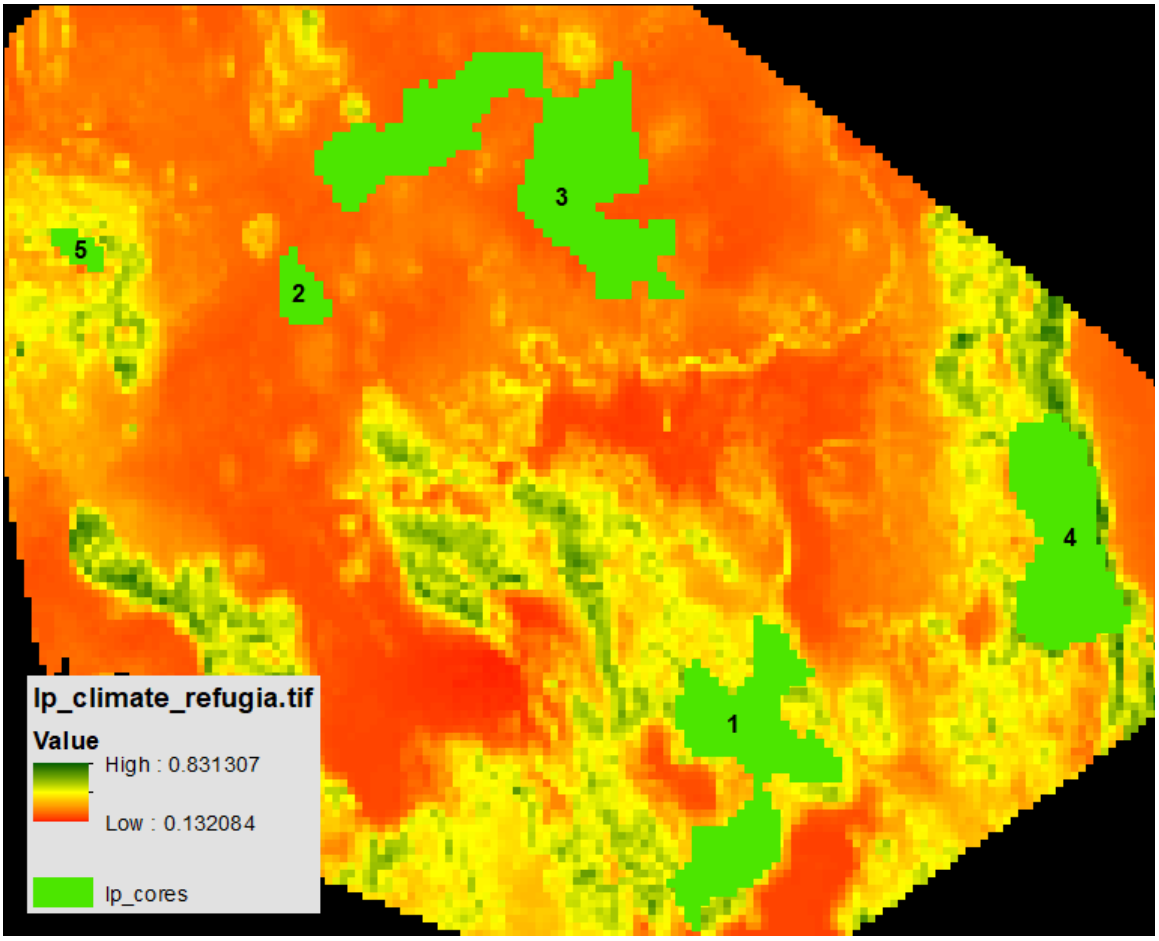
Yielding:



9.2 Add Other Core Area Value (e.g. Climate Refugia)

In addition to the default considerations for Core Area Value, LP has several **optional features**, including considering 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 climate refugia areas. A dataset, lp_climate_refugia.tif, has been added to the demo maps to demonstrate this capability, it has higher values for areas of more stable climate and more topographic heterogeneity (from https://databasin.org/datasets/d58de1a0b08443fea53c25b70804866c).

- Optional: Take a moment to examine the layer, click on and off the core areas, and predict how it will change the results.



- Add it to the model run, as per the following, and use the following parameters to focus solely on the impact of this criterion

Core Area Value (CAV) Options

Other Core Area Value Raster (optional): lp_climate_refugia.tif

Resistance Weight in CAV Calculation: 0

Size Weight in CAV Calculation: 0

Area/Perimeter Weight in CAV Calculation: 0

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: 1

Closeness Weight in CSP Calculation: 0

Permeability Weight in CSP Calculation: 0

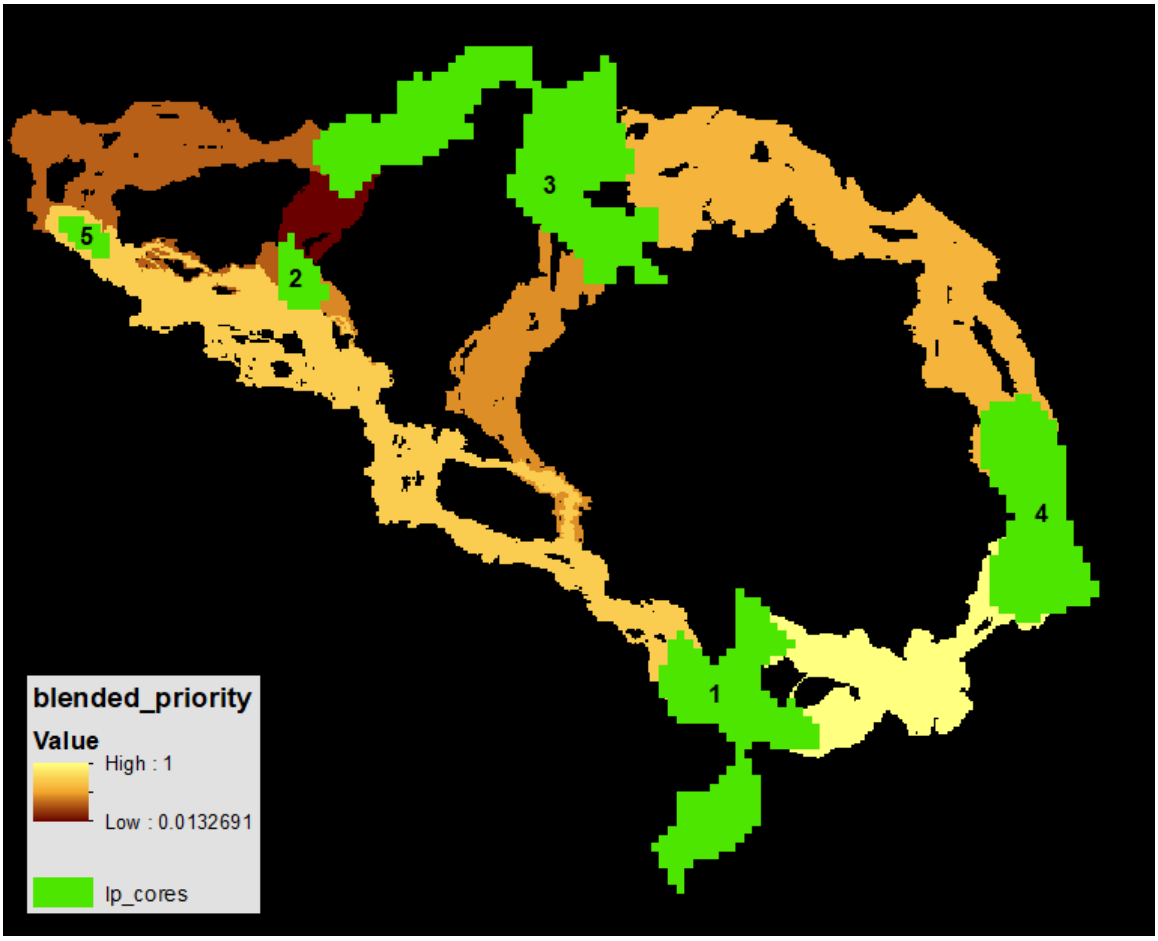
Core Area Value Weight in CSP Calculation: 1

Blended Priority Options

Truncated Corridors Weight in Blended Priority Calculation: 0

Linkage Priority Weight in Blended Priority Calculation: 1

Yielding:

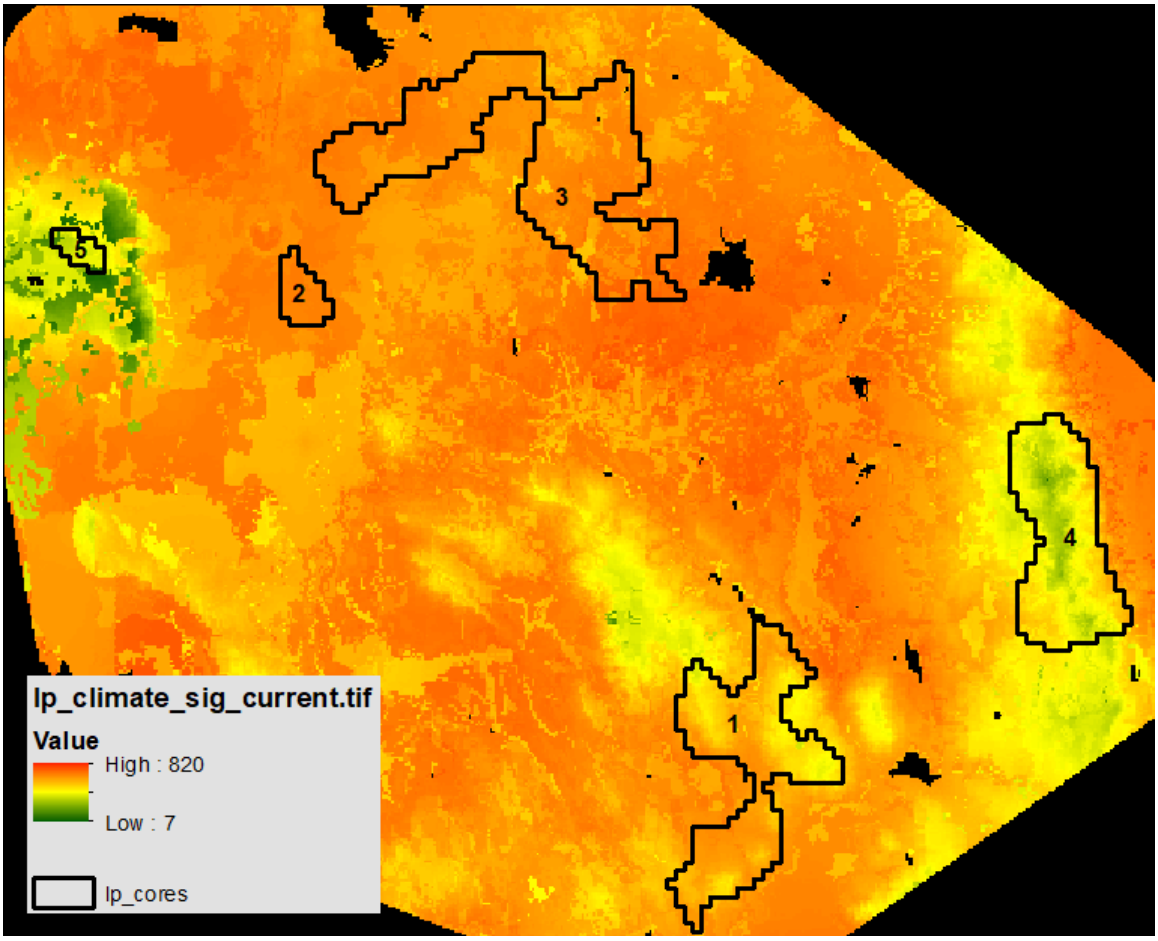


- Note how the relative importance of linkages 2-5 and 1-4 are now higher. This is because cores 4,1, and 5 have more micro-refugia, and hence a higher average refugia score, than the other cores.
- Pro-tip:
    - To see the relative climate refugia value per core area, open the cores attribute file (after the model run) and look at the "ocav" field (other core area value). Higher value corresponds to more refugia.
    - To see the priority values as least cost paths, load link_maps.gdb/lpv001_LCPs and style CSP_Norm

9.3 Using Climate Signature to Prioritize Climate Analogs

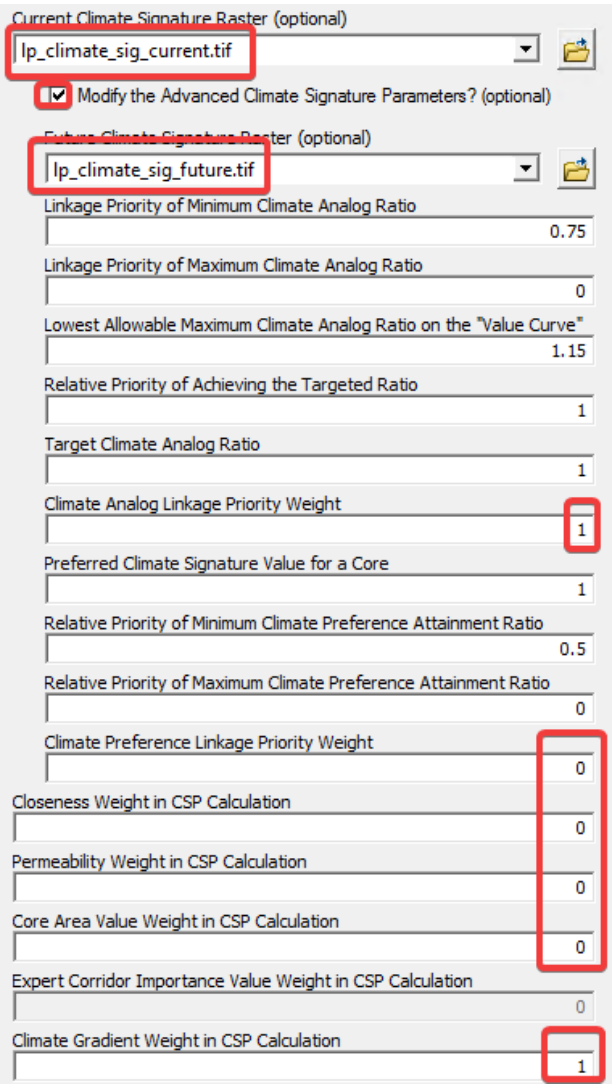
Another one of LP's **optional features** for prioritizing corridors is **climate signature**. We are defining climate signature as a numerical value that represents the relative temperature and amount of precipitation in an area over a period of time, such as a year. In version 3.0, this treatment has been significantly improved compared to version 2.0. See section 1.2 "Climate-wise Options" for more details, and the draft white paper that it links to.

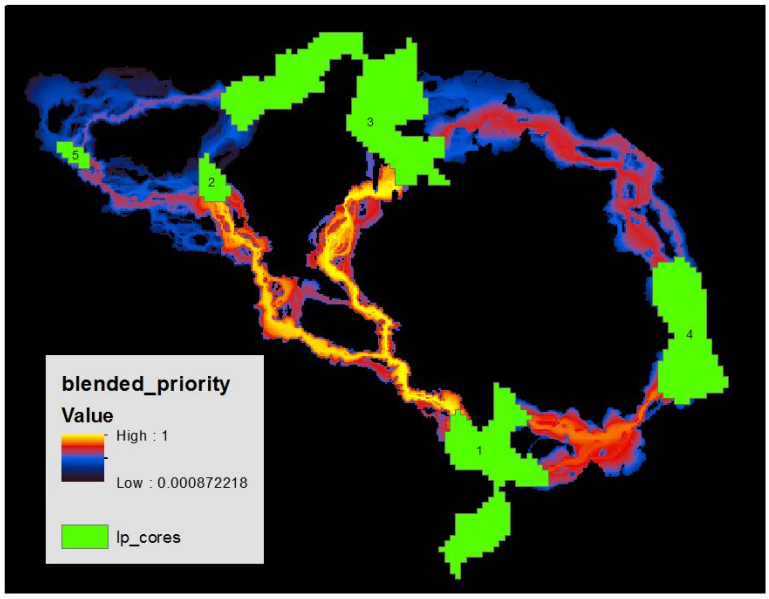
First, let's examine the climate signature input layer climate_signature_current (below screengrab). (Climate Water Deficit, which has both temperature and precipitation in one metric: https://databasin.org/datasets/dbd45814e4db43dea4472c3a3ccacd9b.) Higher numbers represent hotter/drier conditions. The climate signature of a core is calculated as the mean value of this layer.



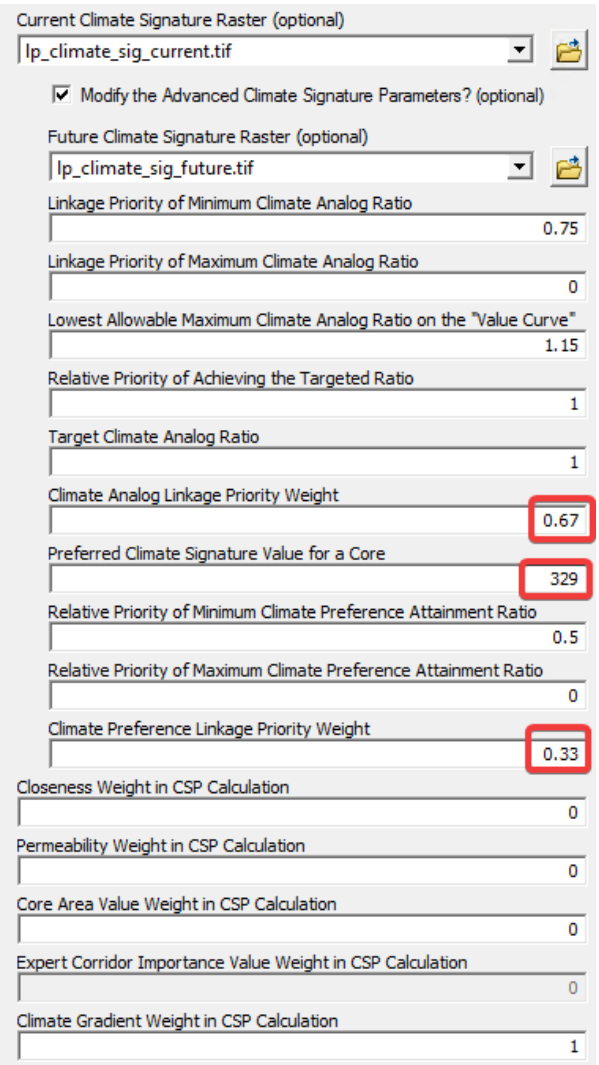
- There is a similar sample layer for the future climate projections (~2070-2099): https://databasin.org/datasets/fd8adae0ab9149c0b200f11ab9e2d54b
- Pro Tip: after a model run, the mean current climate signature value per core is the field in the cores layer called cclim_env. And for the future, it is fclim_env
- By visual inspection, you can see that core area 5 is currently the coolest/wettest, and by looking at the attribute file, you can see that core 2 beats out core 3 as the hottest/driest.

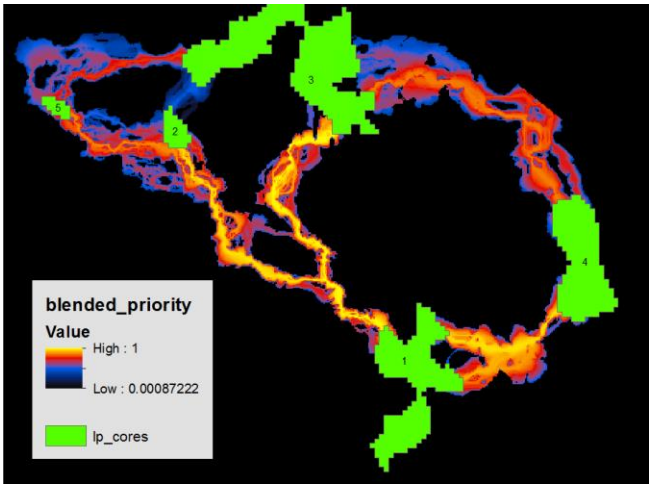
First, lets start with the default values for the climate gradient analysis, including future considerations, and ignoring the climate preference options. Lets give this parameter full weight and the others such as permeability a weight of 0. Here are those changes, in red. All other pareters shown, and not shown, are the default values. Here also is the result, using min/max styling:





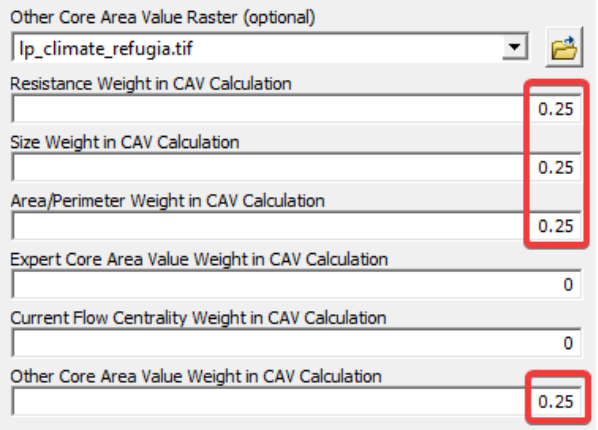
To add in the nuance of climate preference discussed in the white paper, we'll open the results window, click on the most recent run, and make a few changes: giving climate preference the weight of 0.33 as per the default parameters, and using the climate signature value of the coolest core, core 5 (329, see the Pro tip, above) as the preferred value of a core, all else being equal.

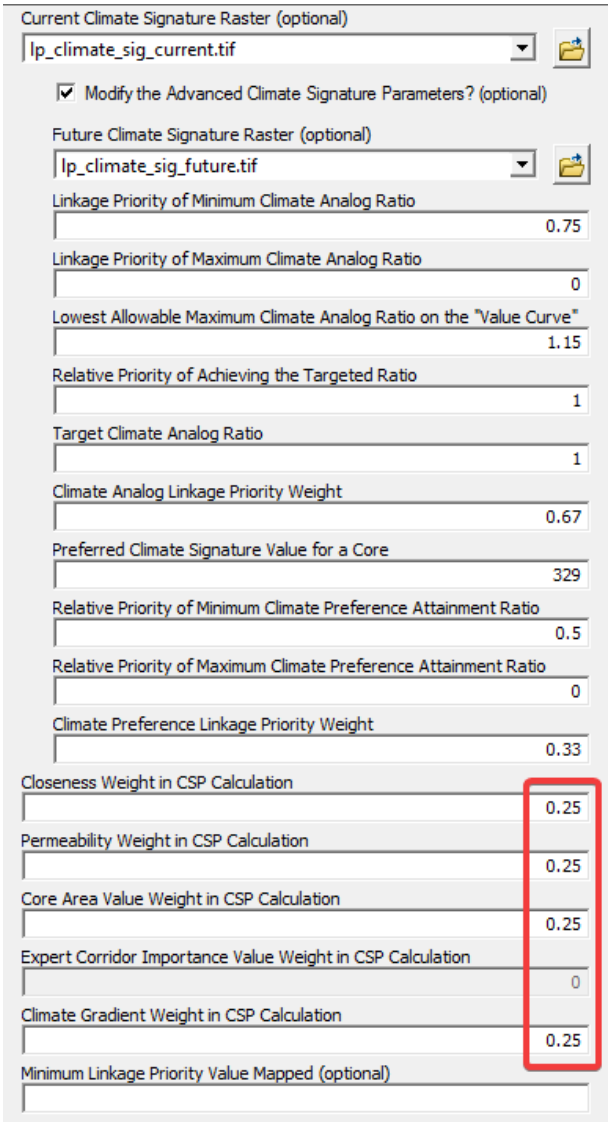


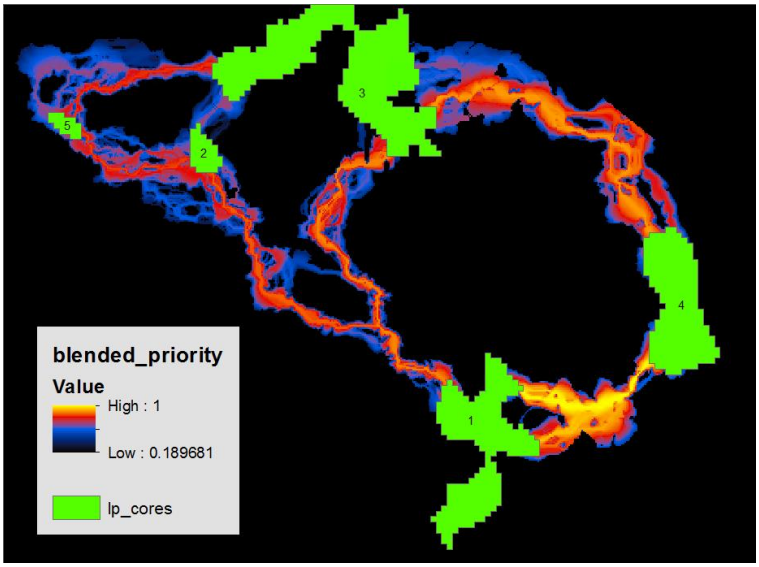


Compared to the previous run, this gives linkages that end in a cooler core a higher priority, all else being equal. See for example how linkage 2-5 improves compared to linkage 2-3. It is beyond the scope of this tutorial at this time to illustrate other aspects of the climate gradient module. If you would like these, please contact the corresponding author.

9.4 Combine the above sections into a single model run.







Now, with a much a higher degree of confidence, we can say that given the data we have, the criteria considered, and the even weights among them, that the linkage between cores 1 and 4 is the highest prirotity for investing resources, and the one between 2 and 3 the lowest priority.

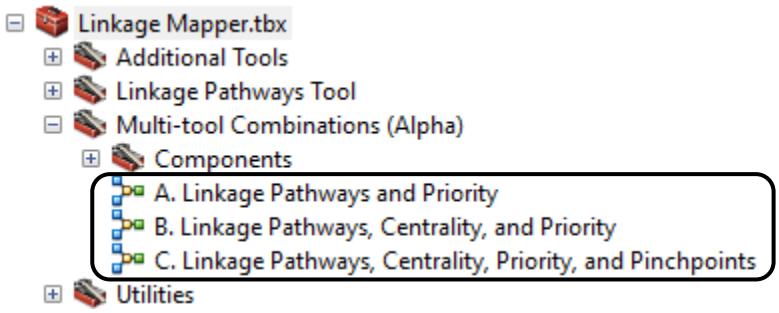
10 Advanced Linkage Priority Tutorial

10.1 Shortcut for Multiple Runs

*The following is experimental, and a solid understanding of ModelBuilder is recommended. *

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 lpv001 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 at the same time.

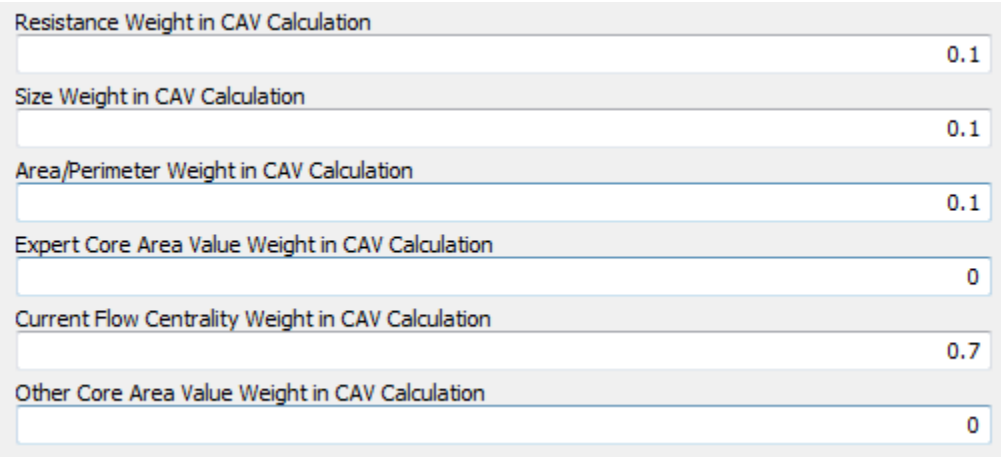
Click “Edit” on one of these tools:



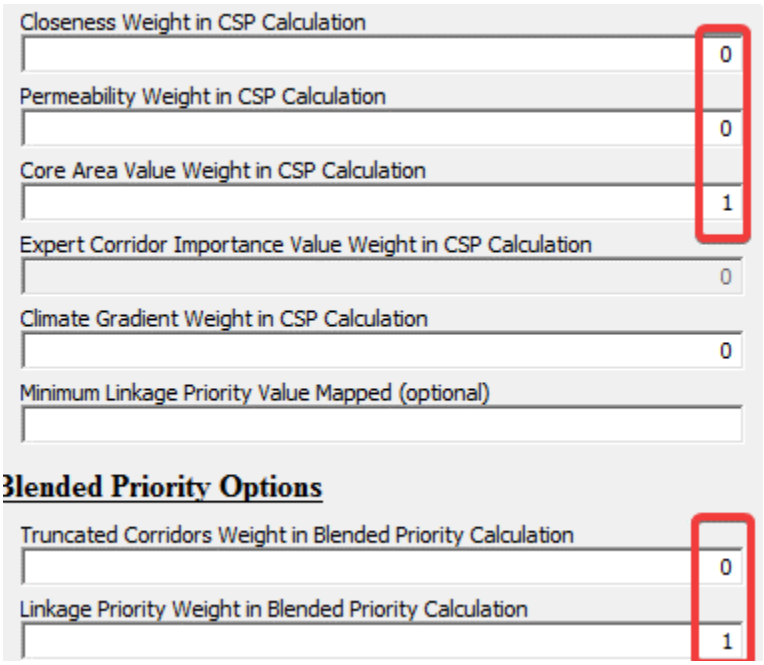
Change the "Project Directory" value to a new name. Run as much of the model as you can (the first step). Then validate the model. Then edit any parameter values as necessary. Save, and run the entire model.

10.2 Add Centrality

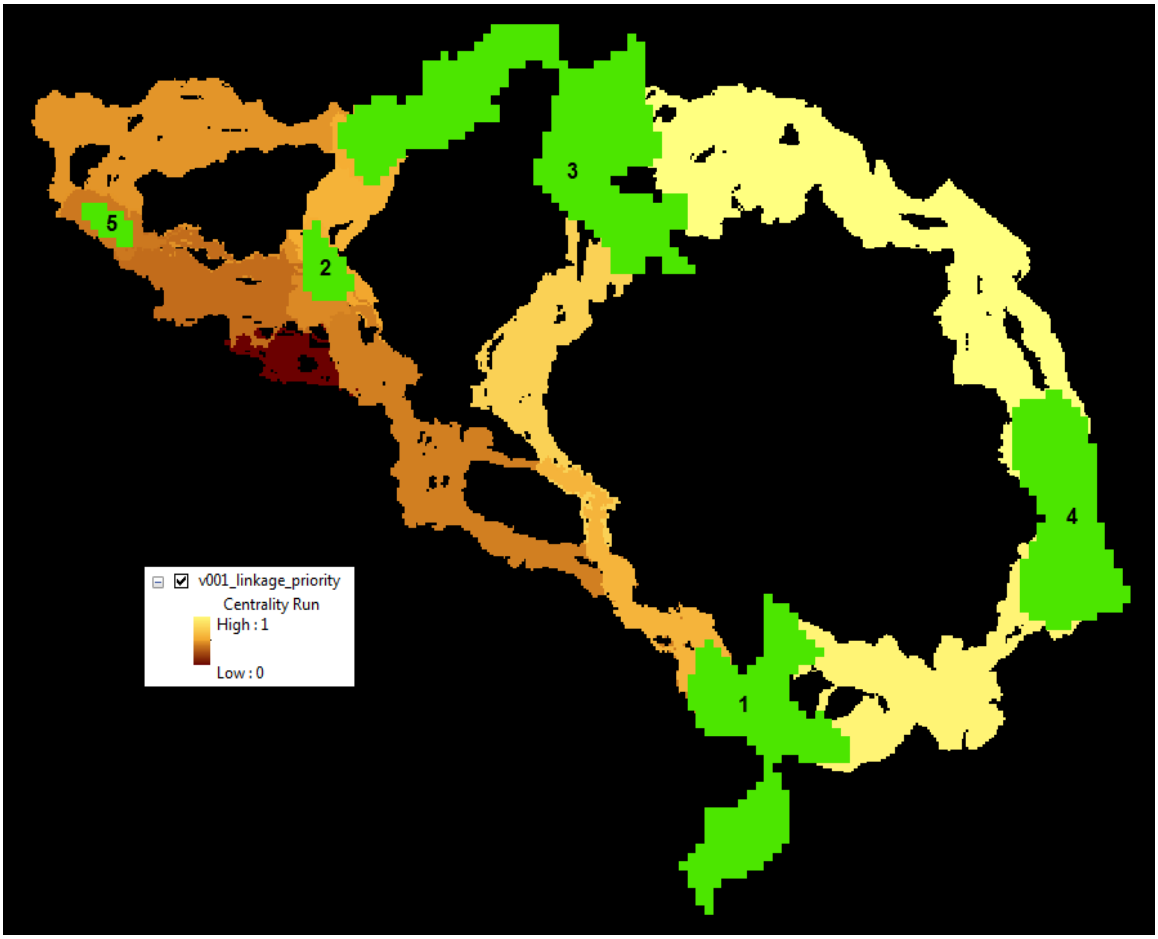
Another one of LP's **optional features** for prioritizing corridors is **core centrality**. This incorporates the outputs of Centrality Mapper as an input. See the Centrality Mapper user guide for more information on that tool. To use it here, run Centrality Mapper tool after running Build Network and 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):



Further, run all other parameters at default values except the following:



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.

10.3 Inspect Core Area Value Component Calculations

The components of core area value 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	cclim_env	fclim_env	ocav	nocav	ecav	necav	CF_Central	ncfc
1	551.527101	606.540892	0.47658	0.733917	0	0	0	0
2	660.676139	694.809832	0.112789	0	0	0	0	0
3	641.103547	687.653051	0.124194	0.023007	0	0	0	0
4	407.489955	445.748322	0.608473	1	0	0	0	0
5	329.203261	359.256842	0.367829	0.51452	0	0	0	0

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.

10.4 Export Corridor Importance Value

Export Corridor Importance Value is a feature that allows you to enter in relative values for linkages based on expert opinion, or any other consideration, such as metapopulation dynamics, or a combination of the two. (When combining, these need to be combined in advance, and the resulting values are entered in here.)