Mapping Habitat Connectivity Priority Areas that are Climate-wise and Multi-scale, for Three Regions of California

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About the Cover: This is the view from the Sutter Buttes, looking west across the Sacramento Valley to the Coast Range in the distance, with Snow Mountain visible. This is the approximate pathway of a priority linkage across the valley (See Figure 24). Photo by Alan Grinberg

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Acknowledgements

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Thank you to those that provided important data: Rich Inman, Todd Esque, Patrick Huber, Joe Hobbs, Mark Freese, Healy Hamilton, David Theobald, Alan and Lori Flint, Tim Sheehan, Steve Greco, and Barry Baker. Thank you also to Wayne Spencer for expert opinion, and advice on model outputs; to Dominique Bachelet, Alexandra Syphard, Roy C. Averill-Murray, and Bill Boarman for providing topical advice and guidance; to Dustin Pearce for providing interrelated GIS work; and to Anne Greene for an editorial review.

Introduction

Habitat connectivity is a cornerstone of conservation, as its key goal is to connect an increasingly fragmented landscape, allowing for gene flow between wildlife meta-populations (Taylor et al. 1993; Beier & Noss 1998). A well connected landscape is also critical for the viability of many species in the face of climate change, as it allows for movement necessary to track suitable climate (Beier et al. 2008; Keeley et al. 2018).

This is an “action research” project that makes scientific products necessary for conservation decision-making, while also applying additional methods to explore scientific frontiers. It is anticipated that the applied work will help the most locally, and the exploration of novel methods will help more with the global biodiversity challenge.

The applied conservation science assignment was to prioritize and map areas important for wildlife habitat connectivity within several regions in California: the Modoc Plateau, the Sacramento Valley, and the West Mojave Desert (Figure 1). These regions are important for alternative energy expansion in order to meet California’s ambitious plans to reduce greenhouse gas emissions by 2030. Identifying critical pathways for wildlife movement in these regions would help the state avoid or minimize impacts in these areas. In general, there are two ways to conserve connectivity in a region – (1) conserve more habitats in key areas that facilitate movement and (2) mitigate landscape features that impede movement, such as roads, railroads, and urban development (Ament et al. 2014). Our connectivity analysis results were used in combination with other conservation factors to answer these questions: what areas should be conserved or avoided? What areas may need mitigation for any kind of development?

In the past decade, connectivity modeling techniques have blossomed (i.e. the table of eight tools in Ament et al. 2014) with resistance-surface based modeling being the most commonly used (Wade et al. 2015). In this modeling (e.g. Circuitscape, Linkage Mapper, UNICOR, etc.), each cell of a raster is assigned an estimated “resistance to movement” across the cell by a species, and then swaths of land with low resistance to movement can be identified, and delineated as linkages. This modeling often uses core areas of quality habitat that are connected by the linkages.

This resistance-surface based modeling traditionally used the focal species approach, which includes the habitat preferences of a particular species in defining the resistance surface. This helps ensure that the mapped cores and linkages would conserve this species in addition to other biodiversity (Wade et al. 2015). The modeling can also be applied using the general “naturalness” of the physical environment (structural connectivity approach). This structural connectivity of a landscape ignores the preferences of specific organisms to specific habitat types and other ecological factors. It only considers resistance to movement of animals in general, by mapping resistance of man-made structures, aquatic features, etc. (Kadoya 2009). This is also known as naturalness-based connectivity (Krosby et al. 2015).

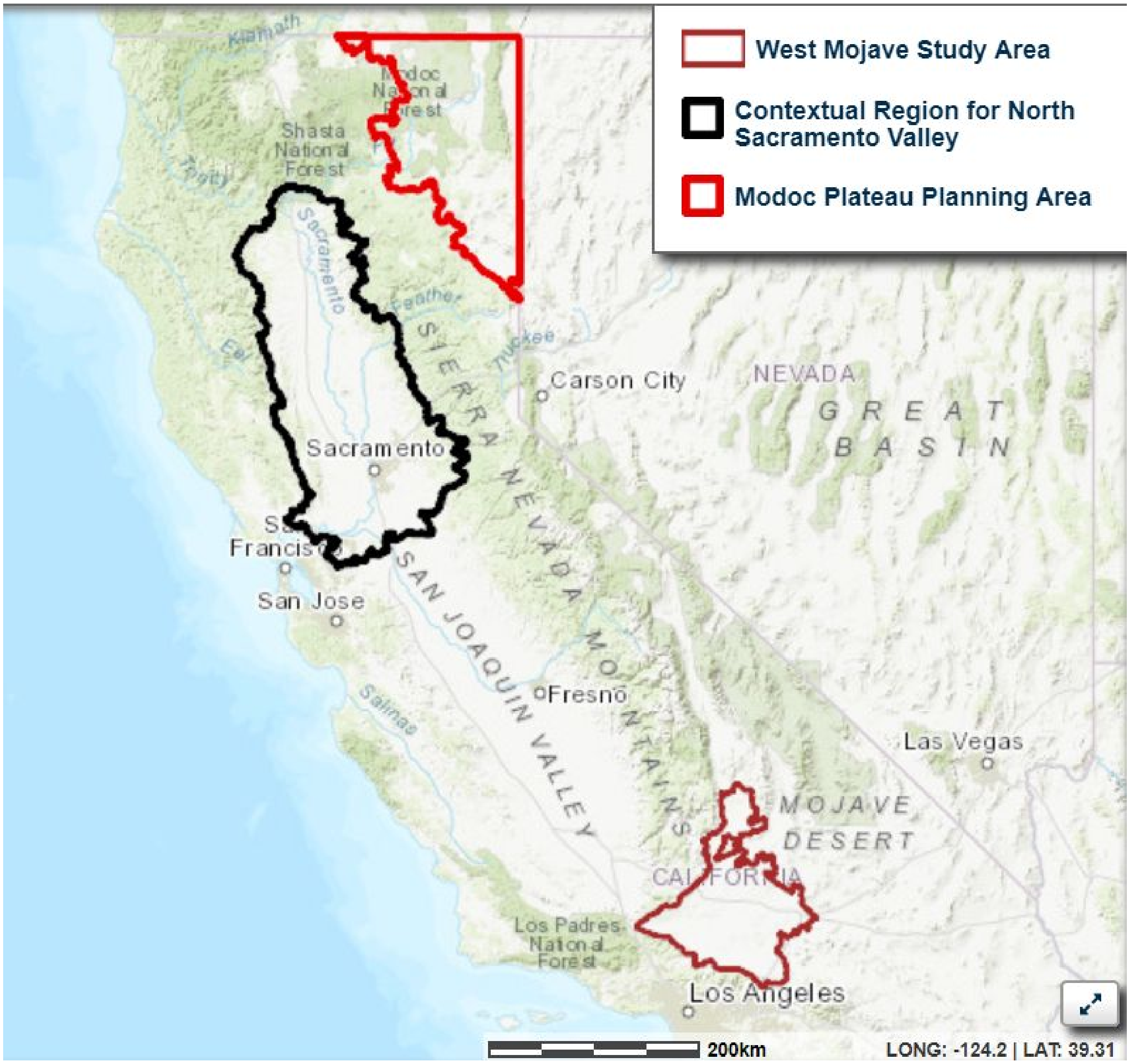

Figure 1: [The three Study Regions.] (Most maps in this reports are "screen grabs" from databasin.org, and are hotlinked to their online, interactive map.)

An emerging practice is to consider and combine both approaches (focal species and structural) when mapping connectivity (Washington Wildlife Habitat Connectivity Working Group 2012; Krosby et al. 2015). They can be thought of as the coarse filter and fine filter approach to connectivity that work best in conjunction, much like habitat representation and single species conservation are thought of as complementary approaches to making sure nature as a whole gets represented in reserves, but also that important species do not “fall through the cracks” (Noss & Cooperrider 1994).

When combining multiple model outputs, the envelopes (geographic extent) of the linkages are often overlaid (Penrod et al. 2013; e.g. Krosby et al. 2015). In other words, if one species of eight has a linkage in an area, and the other seven use an alternate linkage, both linkages are mapped with no indication or relative priority. This tends to result in much (e.g. more than half) of the region being identified as a core or linkage conservation priority, especially as more species are considered. While having a large percentage of the landscape identified as a conservation area meets some needs very well, it is not as helpful to those entities able to only conserve small portions of the landscape at a time.

In doing this action research, we explored three questions:

- How can we assist prioritization efforts by improving the way that connectivity models map conservation priority both within and among the linkages on the landscape?
- How can climate change considerations be better incorporated into habitat connectivity modeling and prioritization?
- How can the priority area maps for many focal species, and several structural (naturalness-based) connectivity analyses, be combined into a single map?

To explore the prioritization and climate questions, we used three tools within the Linkage Mapper software package and combined their outputs. The three tools are as follows:

- **Linkage Pathways Tool** (originally called Linkage Mapper) which maps the linkages and quantifies the value of each path within a linkage (McRae & Kavanagh 2011). This results in “least cost corridors”, the same overall product as the California Essential Habitat Connectivity Project (Spencer et al. 2010).

- **Pinchpoint Mapper**, which uses circuit theory (Circuitscape) to help quantify the conservation priority of portions of a linkage that are dangerously narrow (McRae 2012).

- The **Linkage Priority Tool** quantifies which linkages and core areas are most valuable (Gallo & Greene 2018). Core area priority value is a function of shape, mean resistance value, size, climate refugia, and expert opinion values, if available. Linkage Priority value is a function of the priority value of the cores being connected, and of the characteristics of each linkage, such as permeability (i.e., the mean resistance values along the least cost path), the length, the centrality, and expert opinion if available (Figure 2).

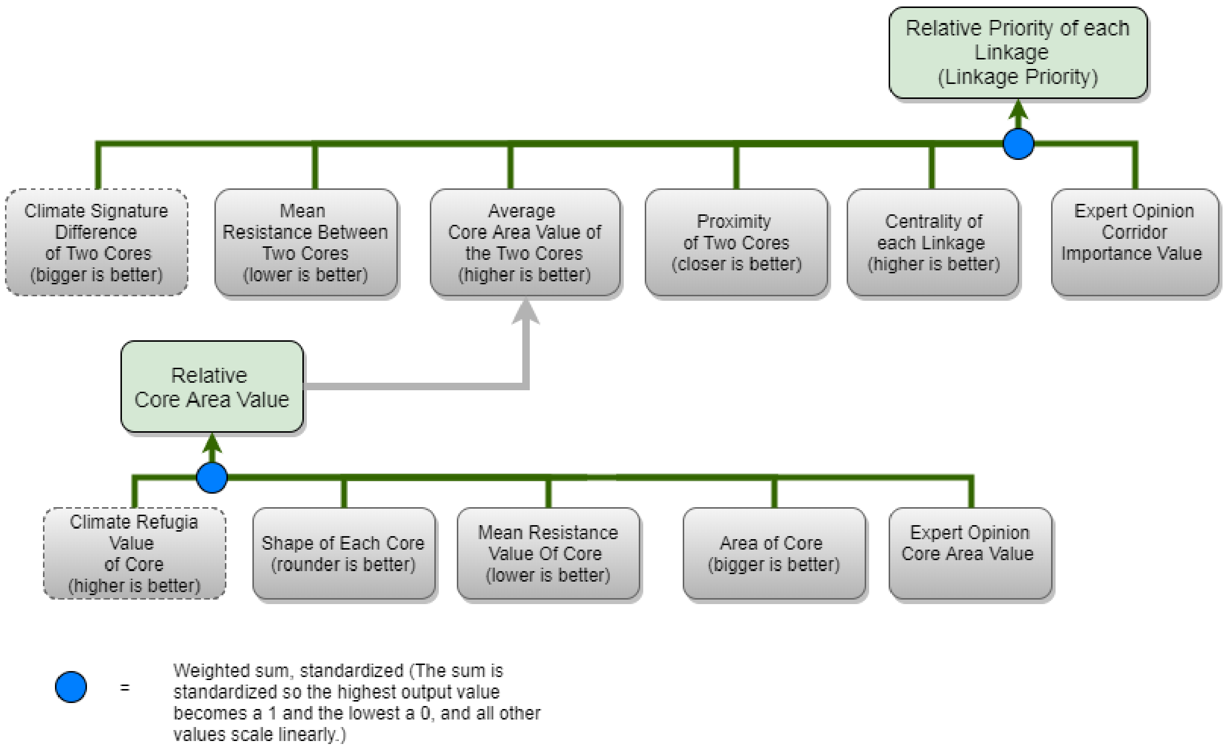

Figure 2: Conceptual diagram of the Linkage Priority Tool. Optional climate wise features have a dashed line.

Version 1.x of this software has been extensively used and field tested in connectivity analysis and mapping in the state of Washington (see various connectivity products generated to guide conservation planning at https://waconnected.org/) and elsewhere (e.g. Jones 2015). We added the Linkage Priority Tool to Linkage Mapper Version 2.0.

We provide outputs of these tools as stand-alone products as well as in their combination. By combining them, we are combining priorities at three scales: linkages at the scale of a landscape, pathways at the scale of a linkage, and pinchpoints at the most local scale. These tools, and others, are summarized on the Linkage Mapper Tools webpage.

There are many climate considerations that can be incorporated in connectivity modeling and mapping (Keeley et al. 2018). We incorporate two of these in our climate-wise modeling approach, both of which are included systematically in the Linkage Priority Tool of Linkage Mapper v2.0. First, we give higher value to pathways that facilitate climate-induced range shifts in species' habitats. Suitable climate for a species (i.e. the climate envelope) will shift, often towards higher latitude and elevation. In order for species to achieve the necessary range shift in response, there needs to be suitable habitat connectivity to allow the species to move. This is often termed range shift connectivity or climate gradient connectivity (Keeley et al. 2018). Secondly, we prioritize core areas and linkages that include climate refugia and microrefugia by giving them a higher value in the modelling process (Hamann et al. 2015; Keeley et al. 2018).

We explored two different approaches for synthesising the results of several focal species and structural connectivity analyses. In the Mojave, the portions of linkages identified as important to the focal species were added to the structural connectivity results if they were not already there. In the Sacramento Valley, the structural connectivity results and focal species results were combined in a weighted sum, and only the medium and higher valued results were mapped.

We provide here the methods of the three studies, followed by their results (with hyperlinks to the online maps), and then a brief conclusion. There is a short glossary of key terms and synonyms, followed by the references, and appendices of additional details.

Methods

Summary

We performed a structural connectivity analysis for the Modoc Plateau that included the aforementioned climate-wise considerations. We also repeated this approach for the West Mojave, but with some additions: we modeled structural connectivity making assumptions on movement behaviour relevant to small species or large species, and also modeled connectivity for two focal species (Mojave ground squirrel and desert tortoise). We combined these using the open source logic modeling framework called environmental evaluation modeling system (EEMS) (Sheehan & Gough 2016) which now integrates with Data Basin and an online viewer eemsonline.org. This resulted in a single map of connectivity conservation priorities, and also the ability view the intermediate products in an online graphical user interface. In the Sacramento Valley, we used a similar approach, but with four different structural connectivity considerations, and with four species (American badger, mule deer, bobcat, and tule elk). We combined these with a weighted sum, and removed the lowest valued results. In this report, we provide the most detail in the methods and results for the Modoc, then focus on the methods and results of the other two regions that are different. All three sections have appendices with additional detail.

Modoc Plateau Methods

Summary

We modeled structural connectivity at 270 m resolution. We combined linkage pathways (i.e. least cost corridors with varying widths) with pinchpoints and linkage priority considerations. We then combined linkages with core areas (using relative core area value) to yield a single "Connected Conservation Value" map layer. Regarding climate considerations, we gave higher priority to linkages that connected a large climate gradient to allow for range shift, and for linkages that connected cores that had high scores for climate refugia.

Resistance Surface and Core Areas

We first created a 270 m resolution "High Contrast Landscape Intactness" surface by combining 18 data layers in an EEMS logic model (Conservation Biology Institute 2018 and Appendix A). We then inverted it and combined it with a map of human modification that was lower contrast in values with more smoothing, (Conservation Science Partners 2016), an initial map of structural resistance. But initial Linkage Mapper runs of the connectivity model based on this initial surface yielded linkages passing through lakes and rivers. Water barriers were not getting high enough resistance values, so we burned in higher values for these features to create an "Enhanced Resistance Surface". Thus, our landscape resistance surface is representative of winter conditions, when water bodies are full. Furthermore, contextual conditions of roads (such as road density or distance from urbanization) were causing Linkage Mapper to erroneously infer road crossings or underpasses where they do not exist on the landscape. To address this, we burned in constant values to roaded reporting units of the Enhanced Resistance Surface. Hence, all road cells of the same class have the same minimum value, and the resistance values near roaded reporting units reflect contextual values, such as road density. The detailed methods and diagrams are covered in Appendix A.

Core areas were created from a statewide layer which provides an estimate of terrestrial landscape intactness, (i.e. condition), based on the extent to which human impacts such as agriculture, urban development, natural resource extraction, and invasive species have disrupted the landscape across the State of California (Degagne et al. 2016). Terrestrial intactness values are high in areas where these impacts are low. It be found here: Landscape Intactness (1 km), California. Landscape intactness values classed as "Very High" (greater than 0.75 on the scale ranging from -1 to 1) were selected, then areas less than 10 sq km were dropped leaving us with the cores dataset.

Climate Inputs

For climate signature, we needed a single layer that incorporated both the temperature and precipitation aspects of climate. We used climatic water deficit (CWD), which is Potential

Evapotranspiration minus Actual Evapotranspiration. Evapotranspiration is a function of temperature, precipitation, and land cover. The potential evapotranspiration is how much water would have been transpired by plants at a location if there was an unlimited amount of water. Hence, hot and dry areas will have a high CWD. For the current climate signature on the landscape, we used the 1981-2010 average CWD, and for the future climate signature, we used the 2070-2099 modeled CWD which is the average derived from seven global climate models (Flint et al. 2013).

For climate refugia, we first created the evenly weighted sum between topographic heterogeneity and climate stability (between the present climate and the climate of 2046-2075). (We used the shorter timeframe to measure stability, for increased certainty, and the longer timeframe for signature, for increased variance.) We then calculated the mean value of this climate refugia layer for each core area, to get the climate refugia value of each core area, assuming that a species that exists in an area of high topographic heterogeneity has less distance to travel to find suitable micro-climate refuge than a species that exists in a homogenous landscape.

Connectivity Analyses and Synthesis

We implemented the Linkage Pathways, Pinchpoint Mapper, Centrality Mapper, and Linkage Priority Tools. The final parameter values for the models and input data layers (Appendix D) were based on the West Mojave parameter values, which were determined using an iterative expert opinion and stakeholder feedback approach (see West Mojave Methods Chapter).

We then synthesized the outputs to make the Connectivity Conservation Priority layer. We started the synthesis with the standard conventions of weighted linear combination (Malczewski 1999; Malczewski & Rinner 2015). Before combining, each layer was linearly normalized such that the highest value of the layer was a 1 and the lowest was a 0 (i.e. score range normalization). An overview of this synthesis is provided in Figure 3.

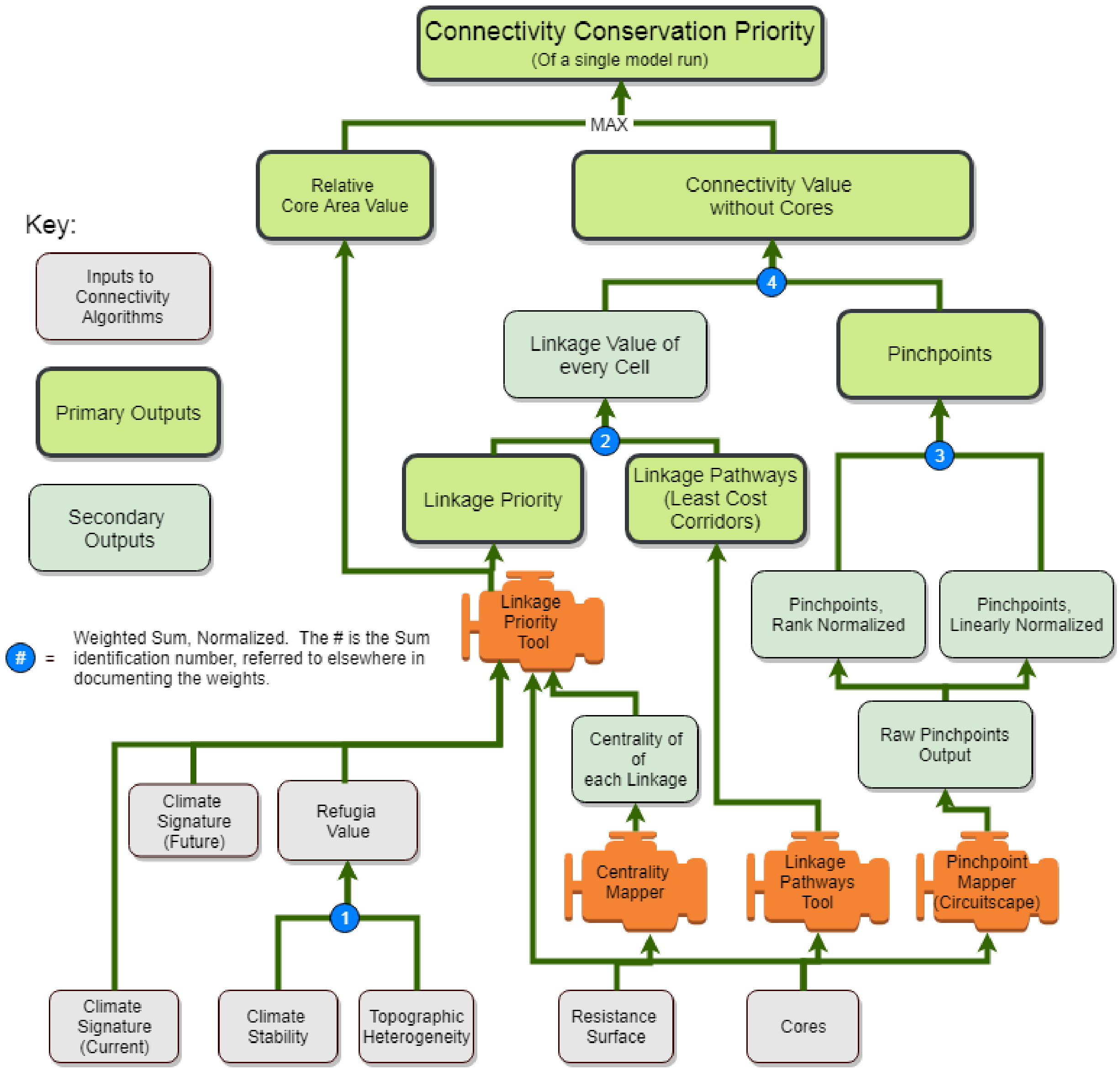

Figure 3: Connectivity Conservation Priority of a Single Run. Weights for Modoc were as follows (Sum #: Weight 1, Weight 2): (1: 0.5, 0.5) (2: 0.75, 0.25) (3: 0.5, 0.5) (4: 0.67, 0.33). The Relative Core Area value ranged from 0.6 for the lowest value core to 1 for the highest value core.

The Pinchpoint Mapper synthesis was an evenly weighted sum of the linearly normalized pinchpoint mapper output of adjacent pairs (highlighting the few highly important pinchpoints on the landscape) and the rank normalized pinchpoint mapper output of adjacent pairs (highlighting the relative importance of the pinchpoints within each linkage). Linear normalizations are the most simple, but the drawback is that their histogram distributions can be skewed, returning non-intuitive results when combining with other skewed layers. Linkage Priority was given a higher weight than Linkage Pathways (0.75 vs. 0.25) to increase discrimination. Weighted sum

#4 was not even because it was felt that pinchpoint mapper was approximately ⅓, if not less, of the influence when it comes to connectivity conservation priority, not ½.

At the top level of synthesis, the core areas were combined with the linkages (with the maximum value of the two layers for each cell) to make a single layer. This allows the “Connectivity Conservation Priority layer” to be used in combination with other conservation assessment layers, such as rare species hotspots, etc. Core areas were not all assigned the same value. Rather, the relative core area values (ranging from 0-1) from the Linkage Priority Tool were used. Since even the worst core are on a landscape has high relative conservation value, the range of values for the core areas should be transformed before being combined with the linkages. We examined three ranges for the lowest valued cores to the highest (0.6-0.8, 0.6-1.0, and 0.8-1.0) and found the 0.6 to 1.0 range to be the best complement to the linkages layer for this particular regional context.

West Mojave Methods

Summary

The West Mojave methods were similar to those used for the Modoc Plateau but with additional “structural connectivity typologies” based on different modeling assumptions as well as two focal species analyses (Mojave ground squirrel and desert tortoise). We considered both climate-wise timeframes and more immediate timeframes. We implemented an approach for combining all six products into one usable map layer. The methods that are different than the Modoc Plateau or provided here.

Participatory Process

For all of the below steps, the CBI science team performed initial modeling and scoping, then presented these to an Environmental NGOs Science Advisory Team for feedback and revision. Model parameterization was based on knowledge and data of the well studied species of the area, aerial imagery, and feedback from stakeholders and expert advisors. In some cases there were many more than one iteration of refinements.

Connectivity Analyses and Synthesis

Rather than using one structural connectivity analysis, we used four “structural connectivity typologies” and combined the products. Such a typology is an explicit definition of the spatial and temporal factors targeted when choosing the methods and setting the parameter values of a structural connectivity model. For example, the three common time frames considered in different connectivity modeling analyses are short term (e.g. connectivity for seasonal migration of an individual), medium term (e.g. intergenerational dispersal), and long term (e.g. species range shift to account for climate change)(Keeley et al. 2018). Choosing methods and parameters to model for the medium term is a different typology than modeling for the long term. The same holds true for parameterizing a structural connectivity analysis to mimic how a small, slow moving species moves through the landscape versus doing so for a large, fast moving species. We modeled four typologies: 1) representing a small, slow moving species for the medium term or 2) long term, and 3) representing a large, fast moving species for the medium term or 4) long term (see Appendix D for parameter details and Appendix B for some more discussion on the concept).

To do this, we made resistance surfaces for the small species typologies, in a manner similar to that of the Modoc, except they did not include the Human Modification layer (Appendix D). For the larger species typologies, we used the Human Modification surface (Conservation Science Partners 2016), and augmented it with additional data not represented in the original layer (Appendix D). For the two long term typologies, we also modified the resistance surfaces to have lower resistance in areas that provided climate refugia (Appendix D). Core areas were derived based on selecting contiguous areas of low resistance (Appendix D).

We used the fuzzy logic model EEMS (Sheehan & Gough 2016) to combine the various outputs of each typology (Figure 4). The Least Cost Corridor and Linkage Priority outputs were combined using an evenly weighted average to create relative Linkage Value. Linkage Value was then combined with the Pinchpoint output also using an equal weighting. This process resulted in higher relative value to pinchpoints and less to linkage priorities compared to the Modoc. The same process and weights were used for the other three typologies.

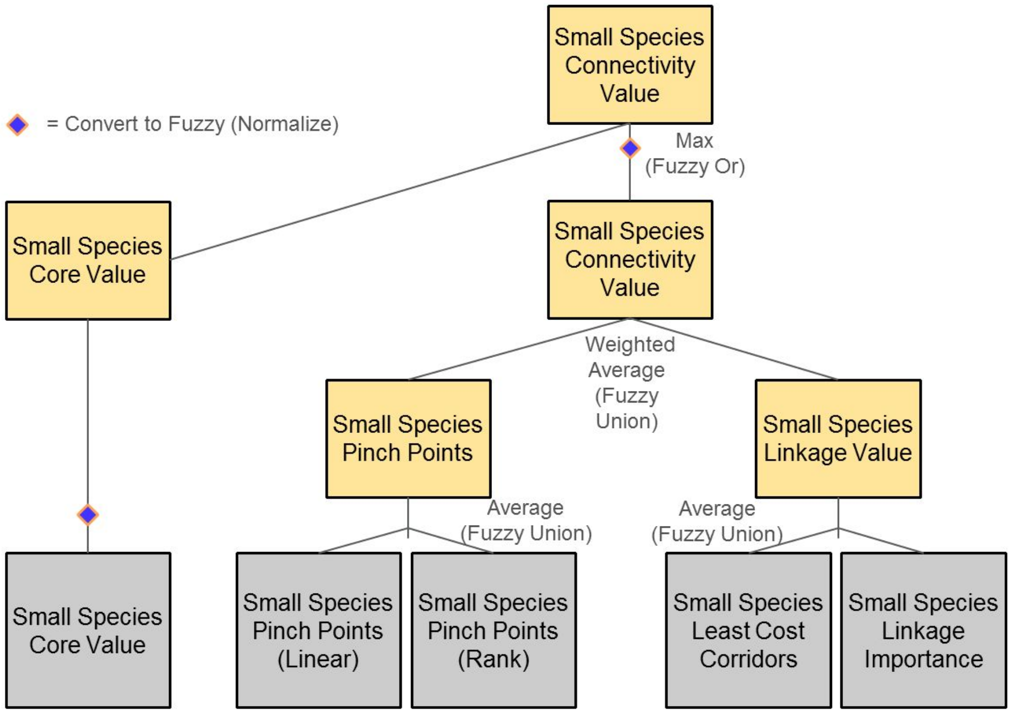

Figure 4. An alternate approach for combining the linkage mapper products for one structural connectivity typology.

Then the Stakeholder Scientist Advisory Committee requested that the number of different outputs be reduced to allow them to understand the process quickly and easily, since this was just one part of a larger Conservation Values model. Therefore we altered our approach reducing our outputs from four to two by combining our typologies. We made one for small species and one for large species, each incorporating both “medium-term connectivity” (i.e. dispersal, or demographic) and “long term connectivity” (i.e. climate-wise connectivity). Medium and long term results were integrated by limiting the long term connectivity results to within the spatial envelope (i.e. mapped linkage locations) of the medium term runs. Hence, this shows the locations of the linkages based on more immediate considerations, but maps the relative priority of cells within and among those linkages with climate change considered. In theory, there was the risk that the locations of the climate-wise linkages would not overlap fully with those of the demographic linkages, but in practice that drawback was minor. (see Appendix B for maps and links to online interactive maps).

We also modeled connectivity for two focal species, the Mojave ground squirrel and desert tortoise. These species were chosen by the Advisors because of their data richness and ecological importance.The resistance surfaces were based on combining the small species structural connectivity resistance surfaces with the species distribution models of each species. For Mojave ground squirrel, the core areas were defined based on high densities of observations, buffered by 100,000 cost-distance meters from the small species structural connectivity resistance surface. For desert tortoise, a higher number of observations existed so we relied on them exclusively to define core areas and destination areas, and combining them into one single core areas file. See Appendix B for the detailed methods for building the resistance surfaces, and core areas for each species. In addition to the demographic (medium term) runs, Climate-wise models were run for the Tortoise and Mojave Ground Squirrel. The differences with the Demographic runs were minor and the amount of material being provided to the stakeholders at this point of the process was becoming overwhelming. Hence, these were not incorporated into the synthesis. But they are important stand alone products, and are mapped and linked from Appendix B.

The two structural connectivity outputs were combined in an evenly weighted union (i.e. average) (Figure 5), giving areas important for both small and large species typologies extra high conservation priority.

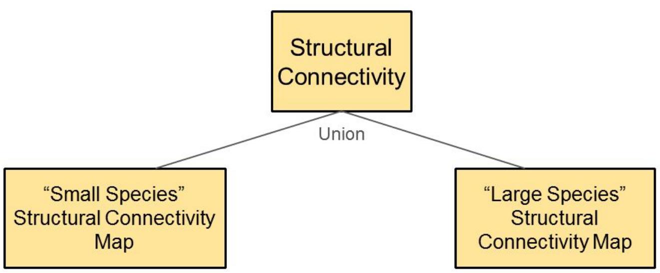

Figure 5: Synthesis of Structural Connectivity Layers

We then combined structural and focal species analyses by adding in to the above product the connectivity areas that were important for the focal species (Mojave ground squirrel and desert tortoise) but omitted in the structural connectivity (SC) analysis.

To do this, we used the medium-term (i.e. demographic dispersal runs) of each focal species. For each, we linearly rescaled the focal species output range to match SC (-1 to 0.857), and then subtracted SC from the focal species connectivity layer. We then only considered the positive values (where SC underestimates focal species connectivity), and rescaled these linearly to range from -1 to 1, where a value of 1 indicates severe underestimation. We then added the difference maps for Mojave Ground Squirrel and Desert Tortoise to get a combined difference map, identifying the portion of the landscape with the most severe underestimate of connectivity needs. This process yielded a small percentage cells on the landscape that were small, isolated fragments which we manually removed. We then normalized this layer to range from -1 to 0.857 (like the SC), called the Normalized Significant Connectivity Areas layer, and combined it with SC using an “Or” operator (Max). The final output, High Structural Connectivity, identifies areas important to both focal species and structural connectivity (Figure 9).

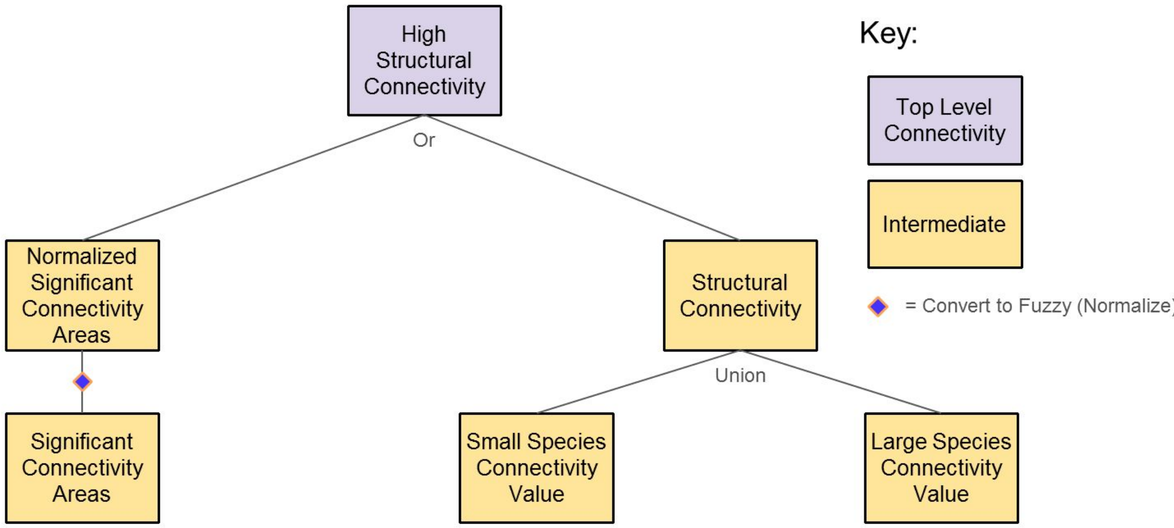

Figure 6: Synthesis of Structural Connectivity and Focal Species

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Sacramento Valley Methods

Summary

The Sacramento Valley methods were similar to those used for the Mojave but with different “structural connectivity typologies”, with four focal species instead of two, and with an alternate approach for combining all products into one single usable map layer.

Connectivity Analysis and Synthesis

We modeled habitat connectivity priorities for the Sacramento Valley by delineating population nodes (i.e. cores) for four focal species (mule deer, bobcat, American badger, and tule elk) and the linkages between them and evaluated their relative prioritization. These species were selected based on data availability, and for representing a variety of habitats. Again, the resistance surfaces were created by combining habitat suitability models specific to the species, but lacking in resistance factors such as roads, with structural resistance layers. The core areas were defines as contiguous areas of low resistance over a certain size threshold. The methods for the resistance surfaces and core areas are described in Appendix C.

We modeled structural connectivity under two assumptions regarding canopy cover: that tree canopy is highly important for animal movement in this largely agricultural valley and that all natural habitats are equally important. We also used two assumptions about node size: that nodes as small as 1 km^2 are important and that nodes must be a minimum of 8 km^2. Hence, we modeled four structural connectivity typologies representing species that are (1) small and have an affinity for canopy cover, (2) small and no affinity, (3) large and an affinity, and (4) large and no affinity. The resistance surfaces were derived similar to the Modoc methods, except with an underpass correction layer as well (bridges over water, indicating areas were animals can pass under roads), and canopy considerations burned into those two typologies (Appendix C). We ran all four of these products for current connectivity, and also for climate wise connectivity. The parameter values for the connectivity models are in Appendix D.

The methods for combining all the outputs from Linkage Mapper Toolbox for a single run were the same as for the Modoc (Figure 3), with slightly different weights. In the Sacramento Valley, we assigned equal weights of 0.5 to Linkage Priority and Linkage Pathways outputs while Relative Core Area value ranged from 0.6 to 0.8 for the highest value core. However, we recommend weighting Linkage Priority outputs higher as we did for the Modoc to better capture their importance.

While all sixteen results can each stand on their own, stakeholders also wanted us to try providing a single synthesis map. We first combined all sixteen outputs to create one integrated connectivity priorities layer using evenly weighted sums. But expert feedback was that we needed to simplify, and that in this region the long term view was imperative, so we instead only mapped and synthesized the eight climate-wise runs (Figure 7).

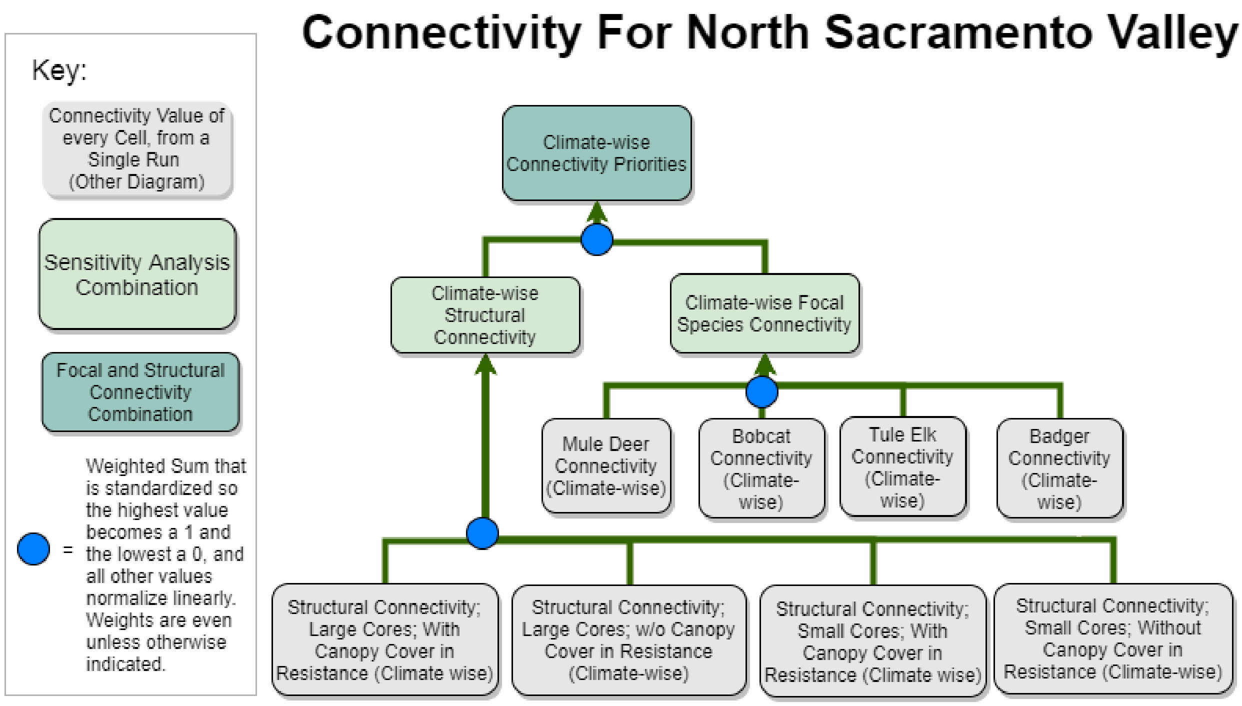

Figure 7 The approach used to combine the eight different connectivity analyses.

Results

All results are provided from one central location, a [Mapping Gallery in Basin Gallery](#).

Modoc Plateau Results

The input layers, as well as all the primary output layers diagrammed in Figure 3 are displayed by clicking them in the Layers Tab of [the online interactive map](#) on Data Basin. A few of them are provided here. The Linkage Pathways layer (i.e. Least Cost Corridors) is the traditional connectivity output (Figure 9). The Pinchpoints layer (using Circuit Theory) was normalized linearly to range from 0-1 and highlights the pinchpoints relative to the whole region (Figure 10), and if rank normalized, gives more emphasis to all pinchpoints (Figure 11). The relative Linkage Priority layer is the spatial representation of the table that gives a specific numerical value to every linkage (**Figure 8**). These are all combined in the Connectivity Value without Cores output, which can be overlaid by the core areas,mapped in black, to get a slightly more traditional looking map (Figure 13). The Relative Core Area Value (Figure 14) is one of the intermediate products in determining linkage priority, but is also normalized to range from 0.6 to 1.0 and combined with the above in the final synthesis to map the estimated Connectivity Conservation Priority layer of the entire landscape (Figure 15).

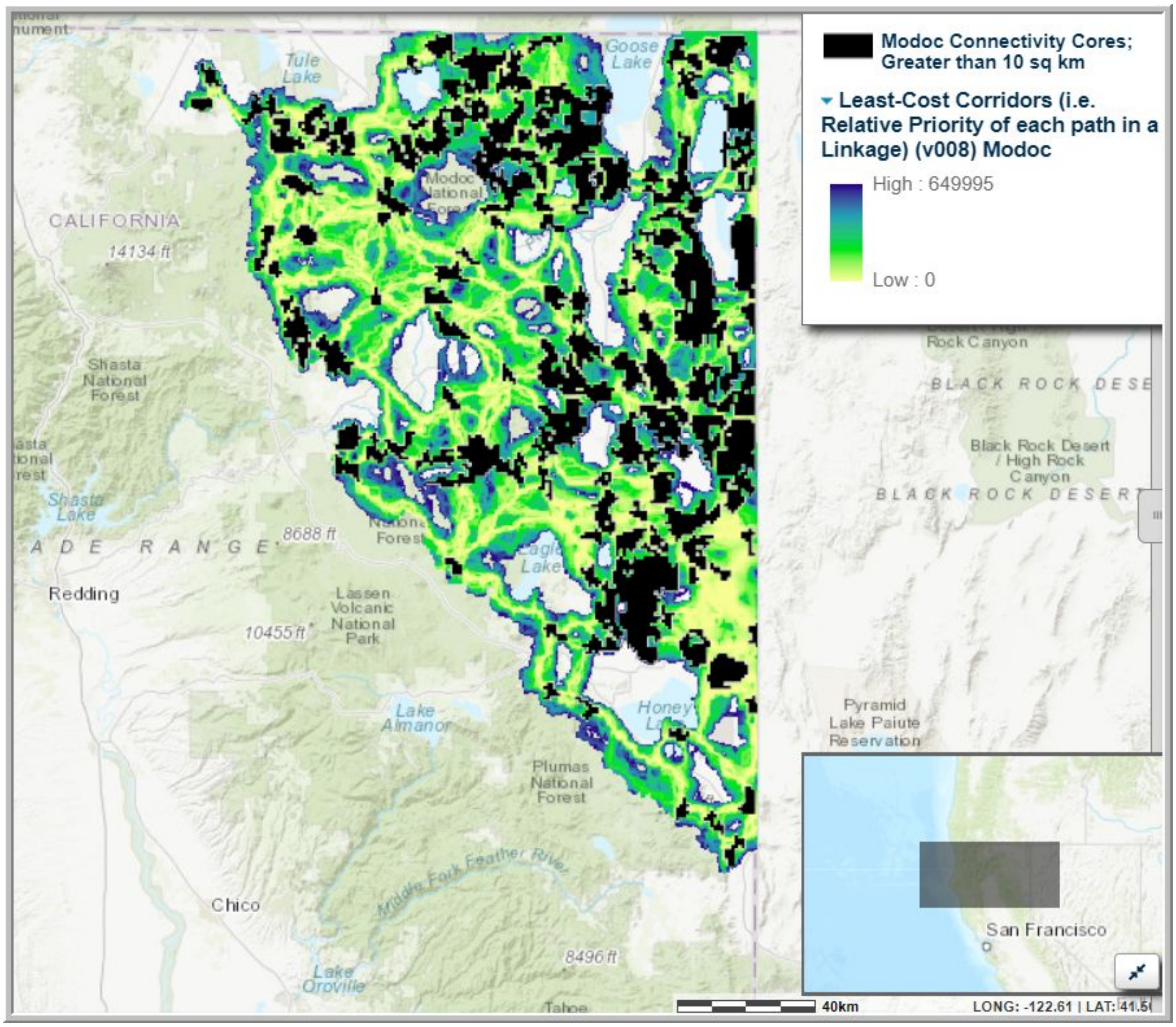

Figure 9 Core areas (in black) with Linkage Pathways layer (i.e. Least Cost Corridors) in which yellow is the best path (least cost).

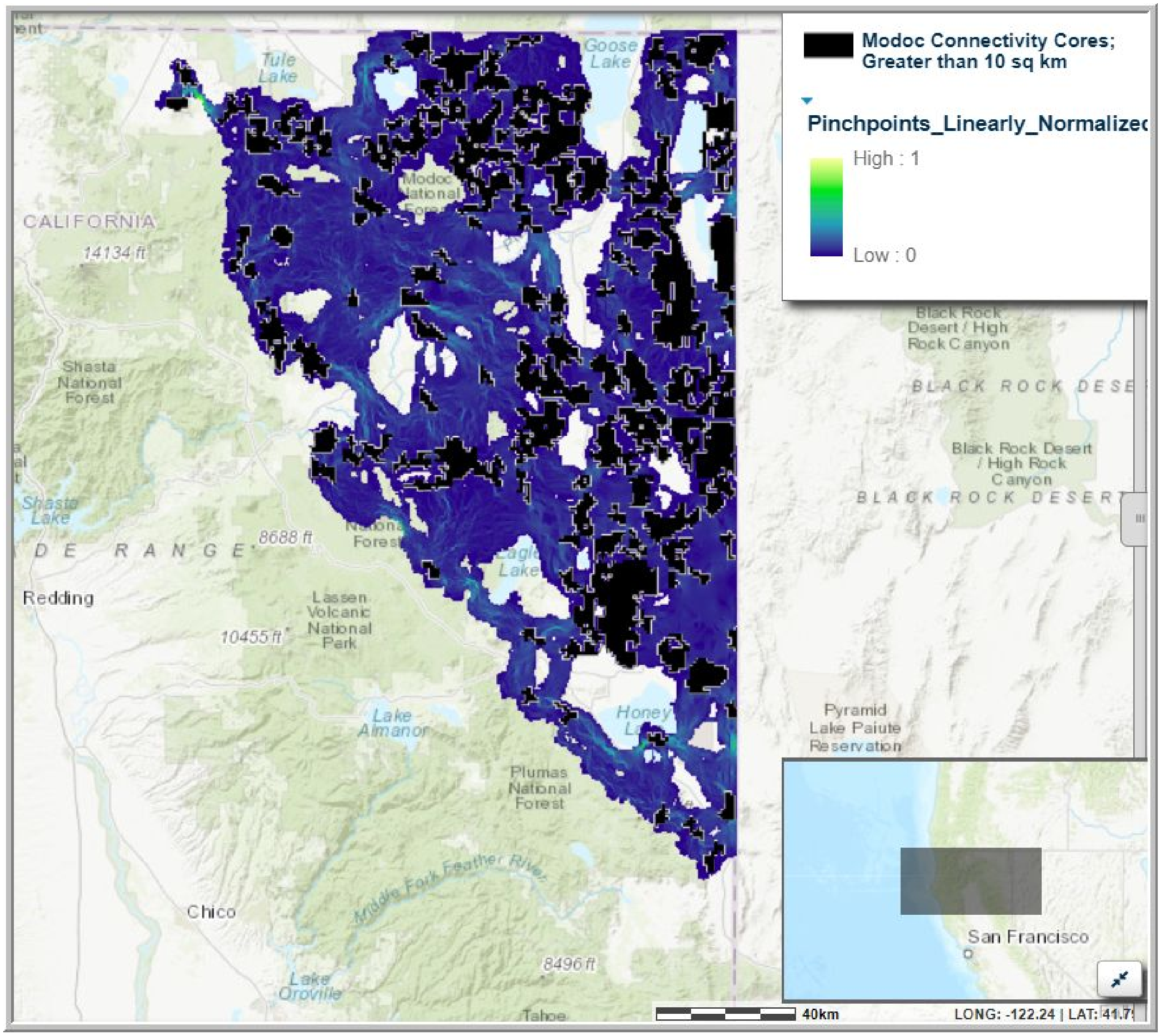

Figure 10 Pinchpoints (linearly normalized) shown here in yelloww/green, are areas where the functional linkages get narrow, and are important areas to conserve in order to link core areas (in black).

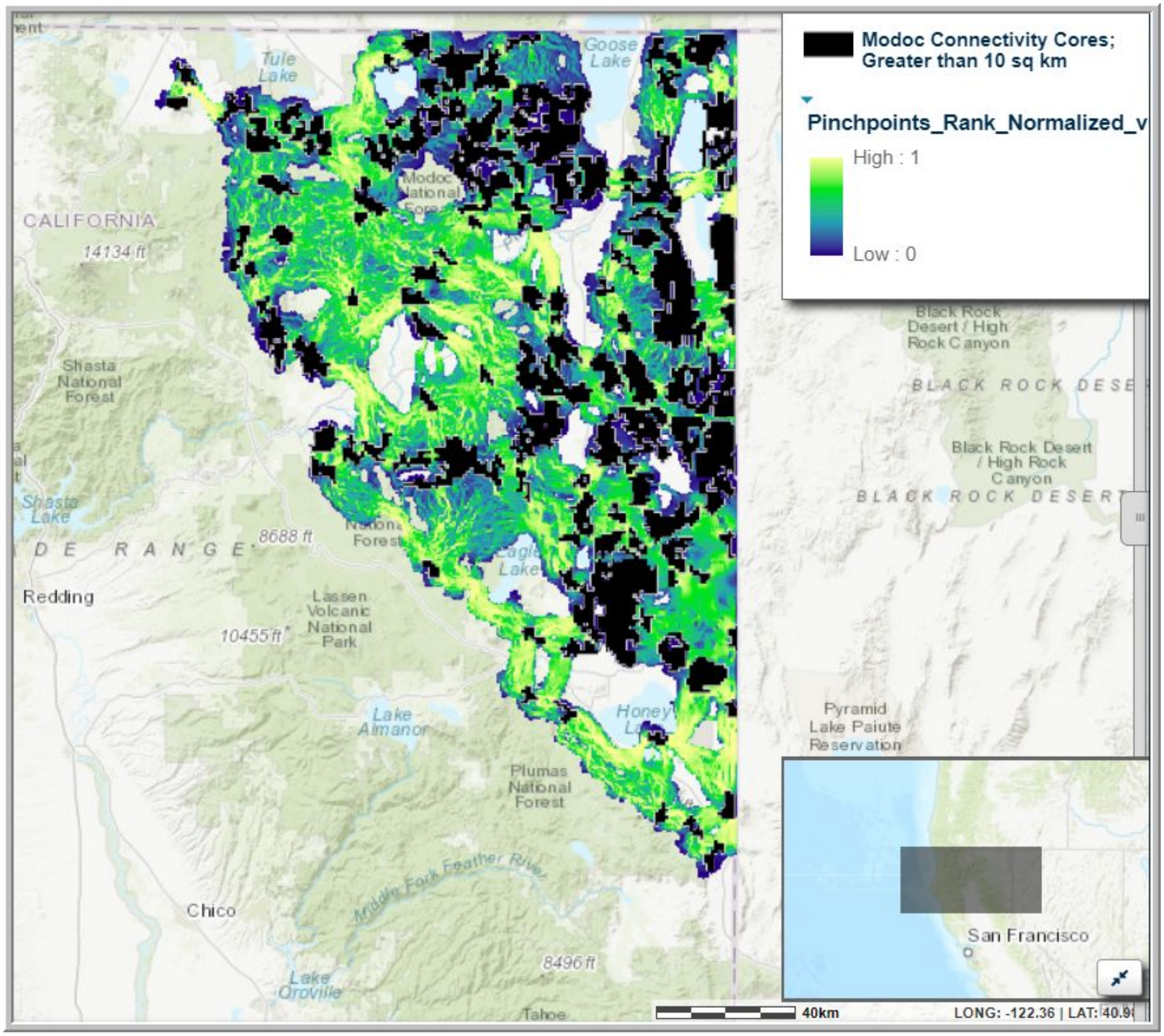

Figure 11 If the Pinchpoints are normalized by rank, as done here, a bigger picture emerges

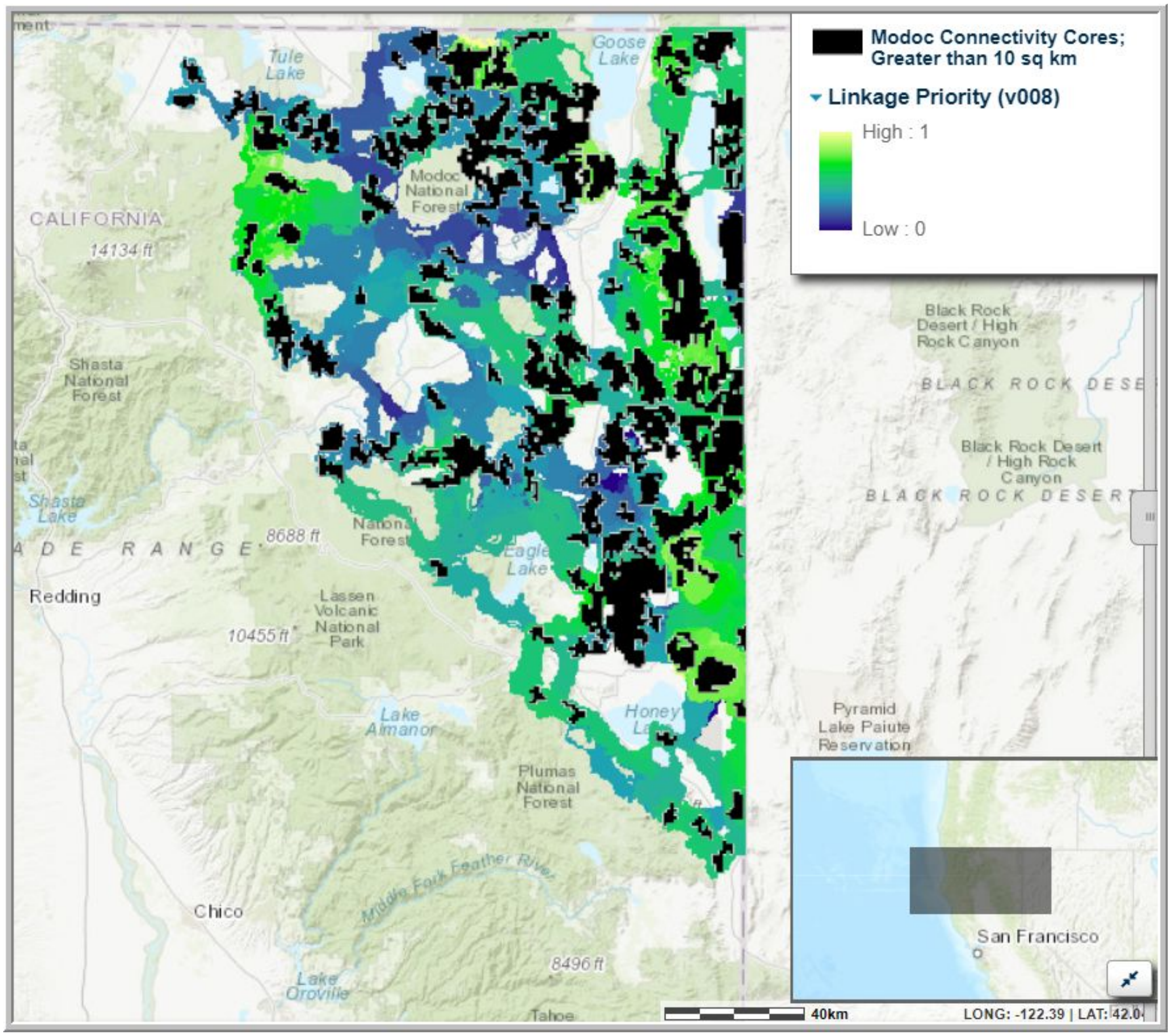

Figure 12 The visual representation of the Linkage Priority values.

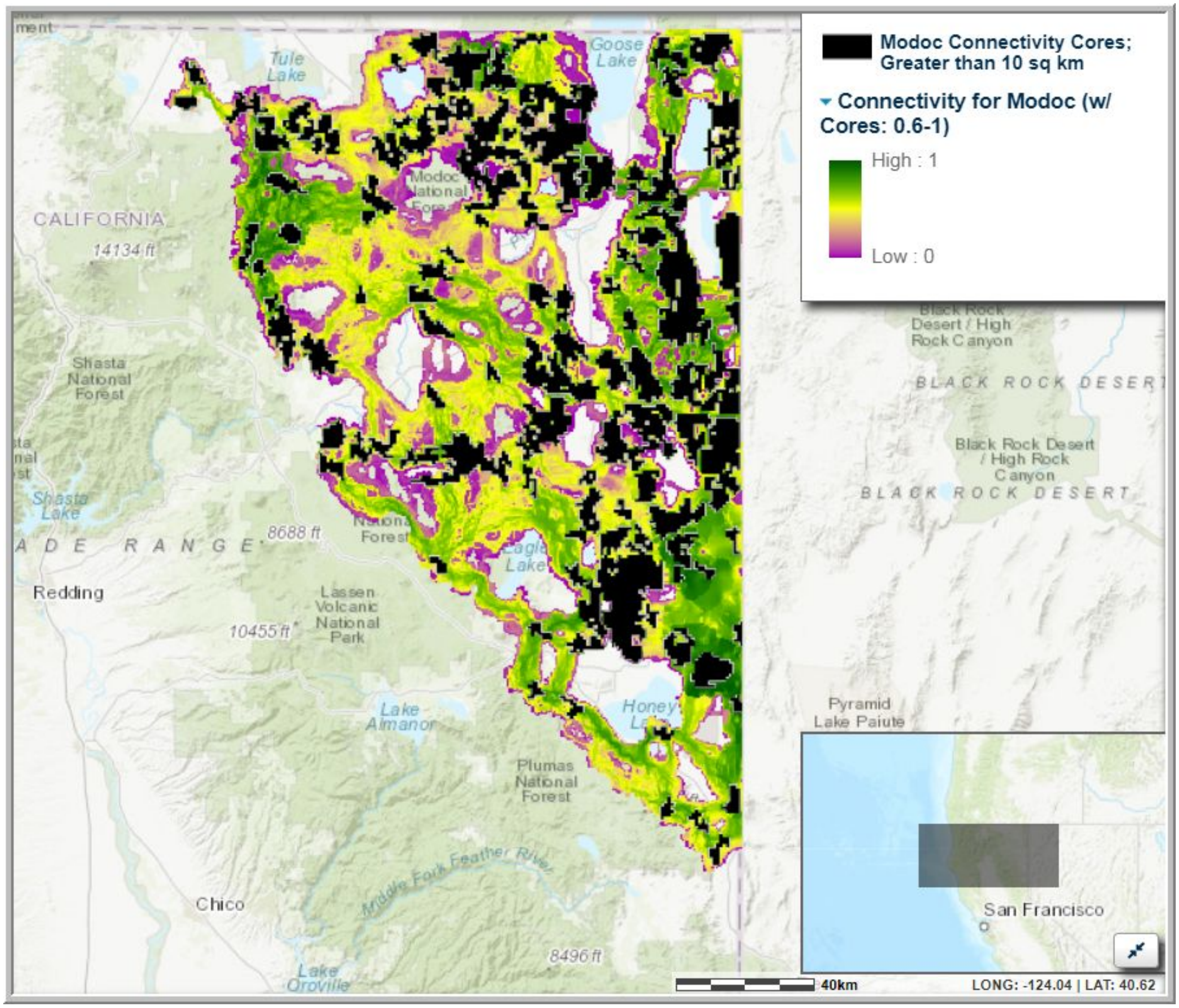

Figure 13: Core areas (in black) and connectivity value (which is a weighted combination of linkage pathways, pinchpoints, and linkage priorities, see Figure 3). (Online map location.)

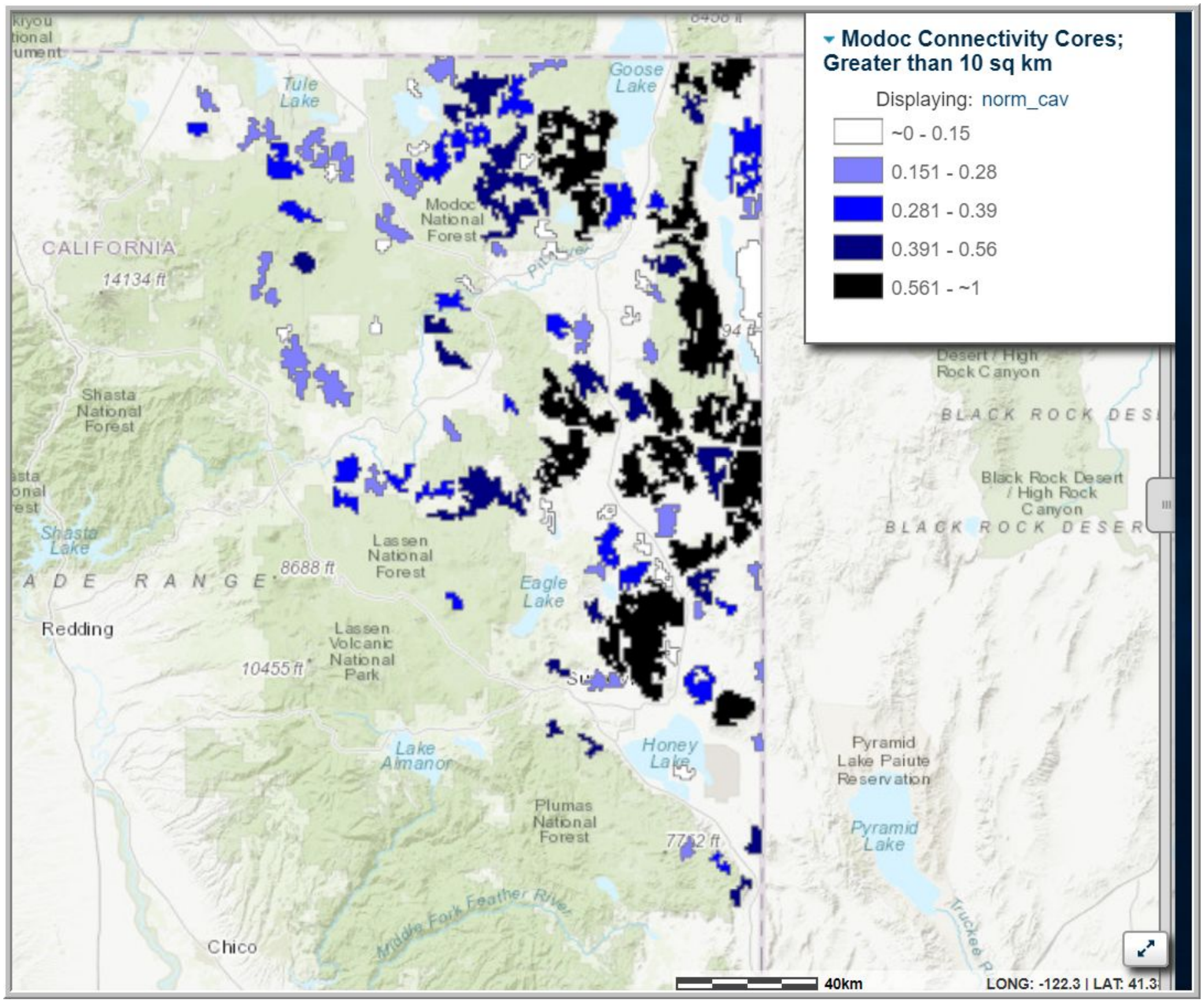

Figure 14 The estimated Core Area Value layer, linearly normalized from 0 to 1, as created by the inputs and parameter values used in the Linkage Priority tool.

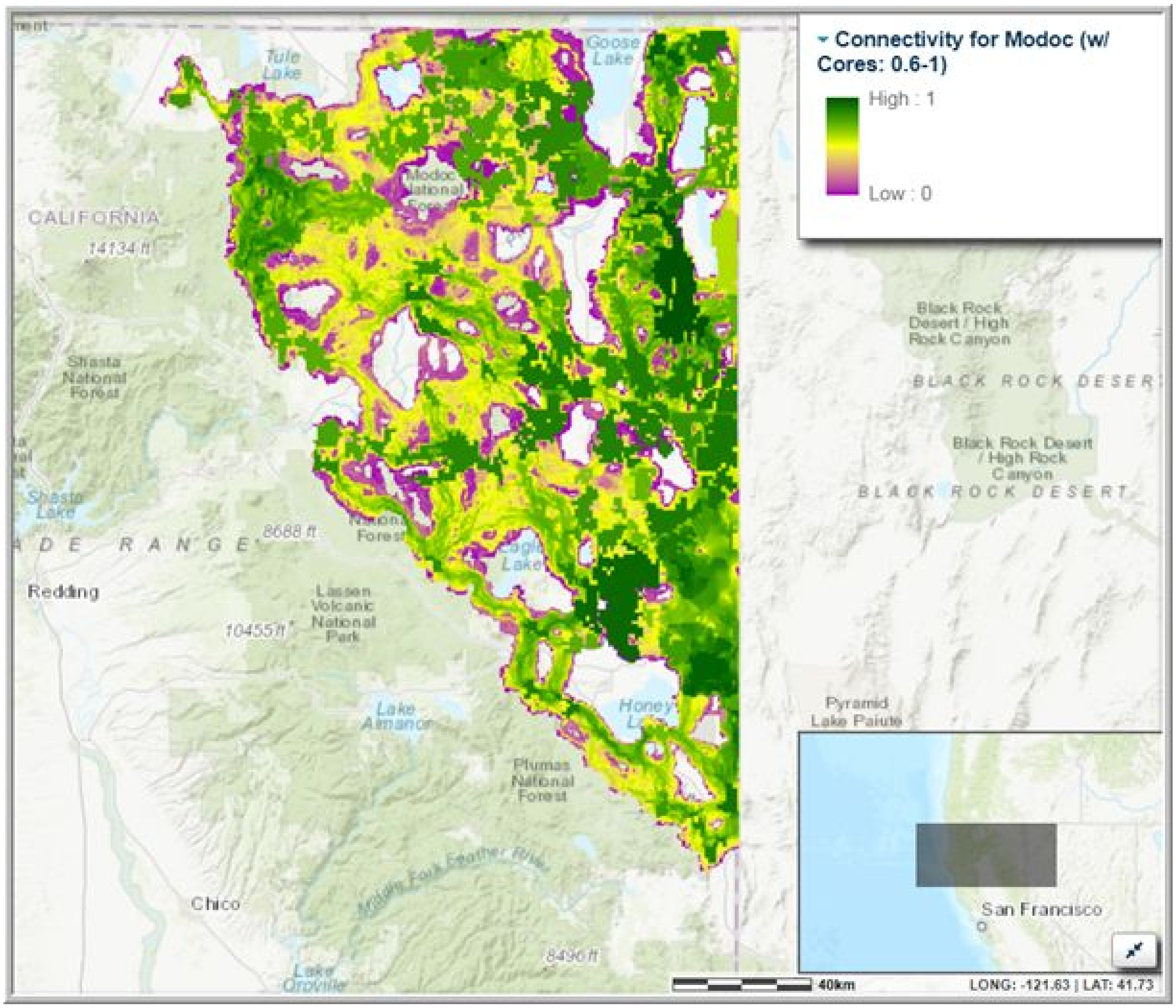

Figure 15: Connectivity Conservation Priority is single layer that combines the Connectivity Value of Figure 13 with Core Area Value of Figure 14 (diagrammed in Figure 3). (Online map location.)

West Mojave Results

The same set of intermediate products created for the Modoc Plateau were created for the West mojave for each focal species and each structural connectivity typology. The top-level focal species connectivity results are here (Figure 16 and Figure 17), as is the full synthesis map that combined the focal species and structural connectivity typologies (Figure 18). The inputs, intermediate outputs, and top-level outputs can be explored via two different graphical user interfaces (GUI). The first is with EEMS Explorer, by opening the Final Map and clicking on the logic model icon (Figure 19) and then clicking on the High Structural Connectivity Box in the

EEMS Explorer interface that pops up (Figure 20). From there, the user can click on input data layers, or click on a cell and see the values of all input and output layers.

The second GUI is within eemsonline.org, a separate web application, by navigating or hyperlinking to the West Mojave Least Conflict Model, Final, then clicking on the High Structural Connectivity box and underlying boxes (Figure 21). Pressing the gear icon allows the user to change the weights and operators, rerun the model, compare results, and send the link to the new model to collaborators.

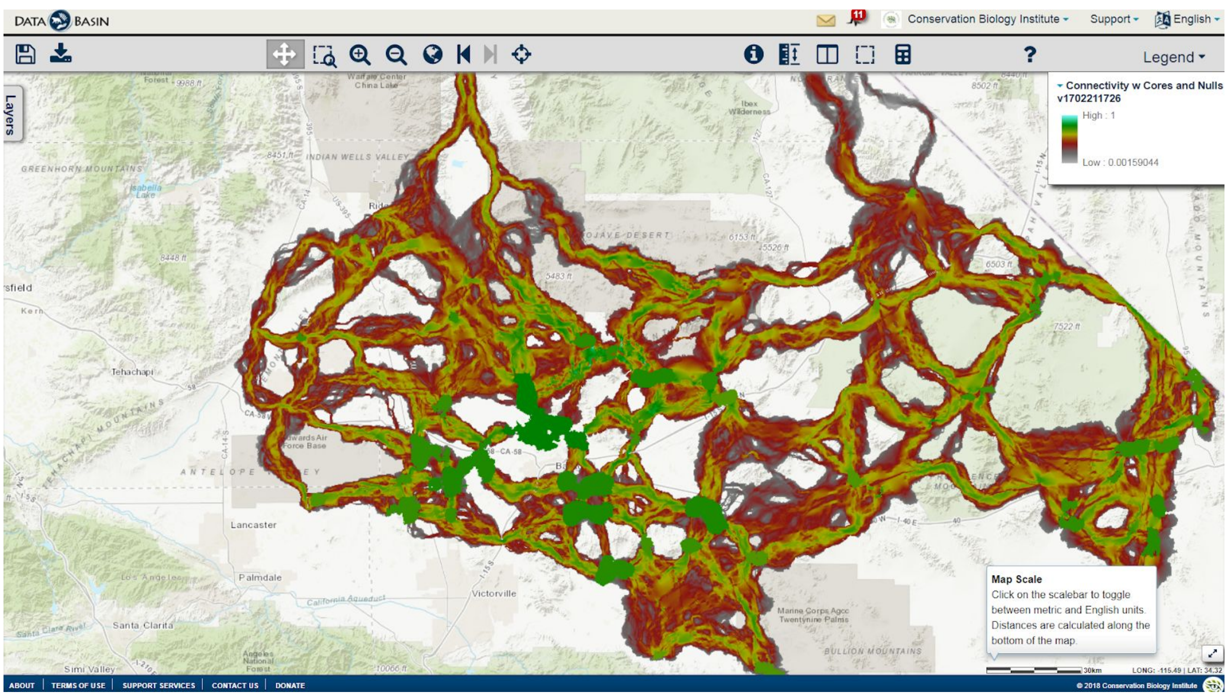

Figure 16: Desert Tortoise Connectivity Output (Demographic)

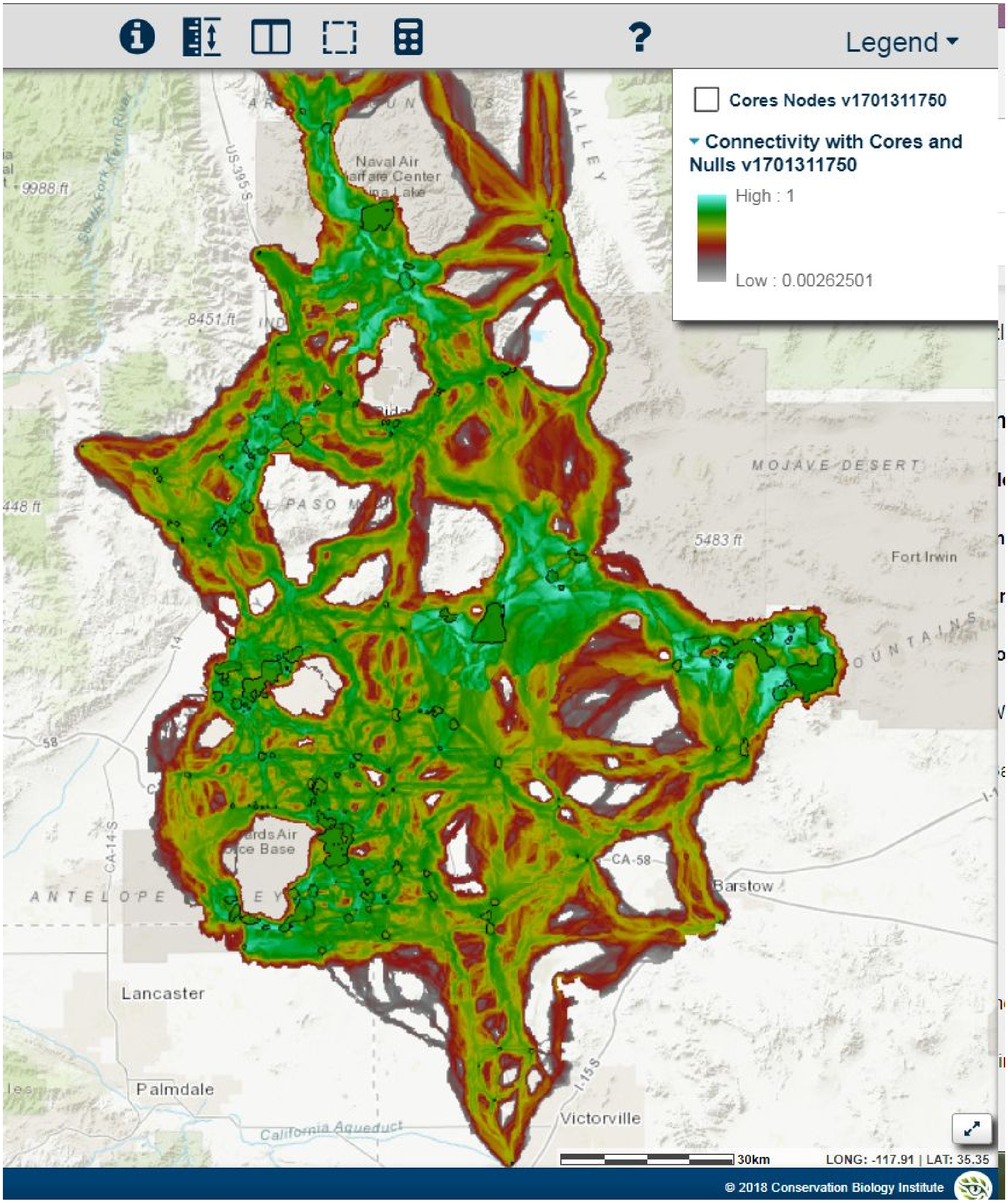

Figure 17: Mojave Ground Squirrel Connectivity (Demographic)

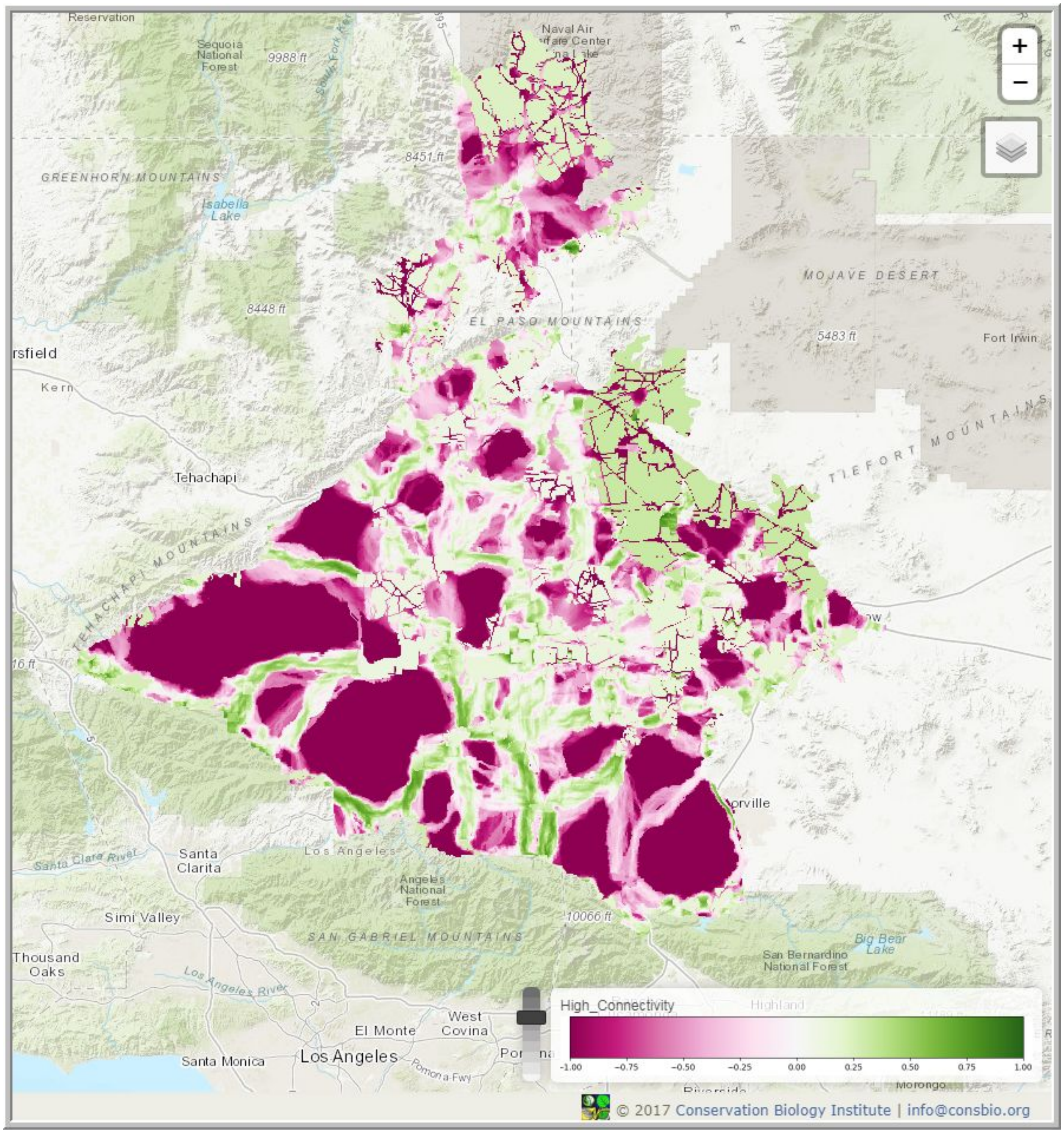

Figure 18: The “Connectivity Conservation Priorities” of the West Mojave Desert

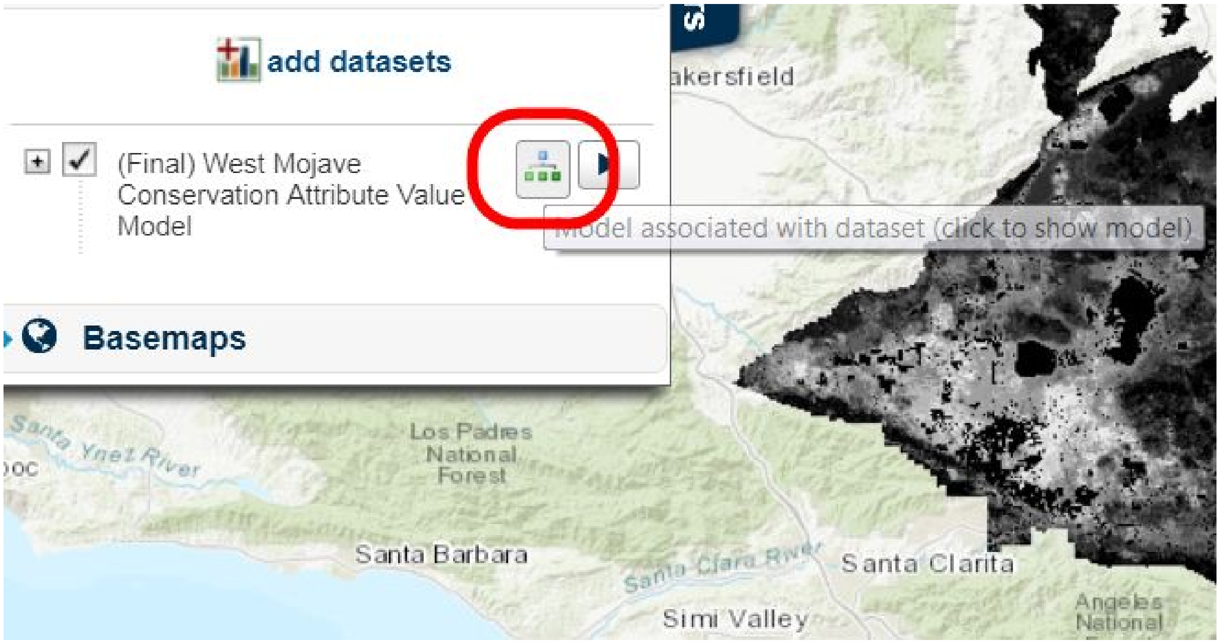

Figure 19: Click on the [logic model icon in the Layers tab]() to open EEMS Explorer

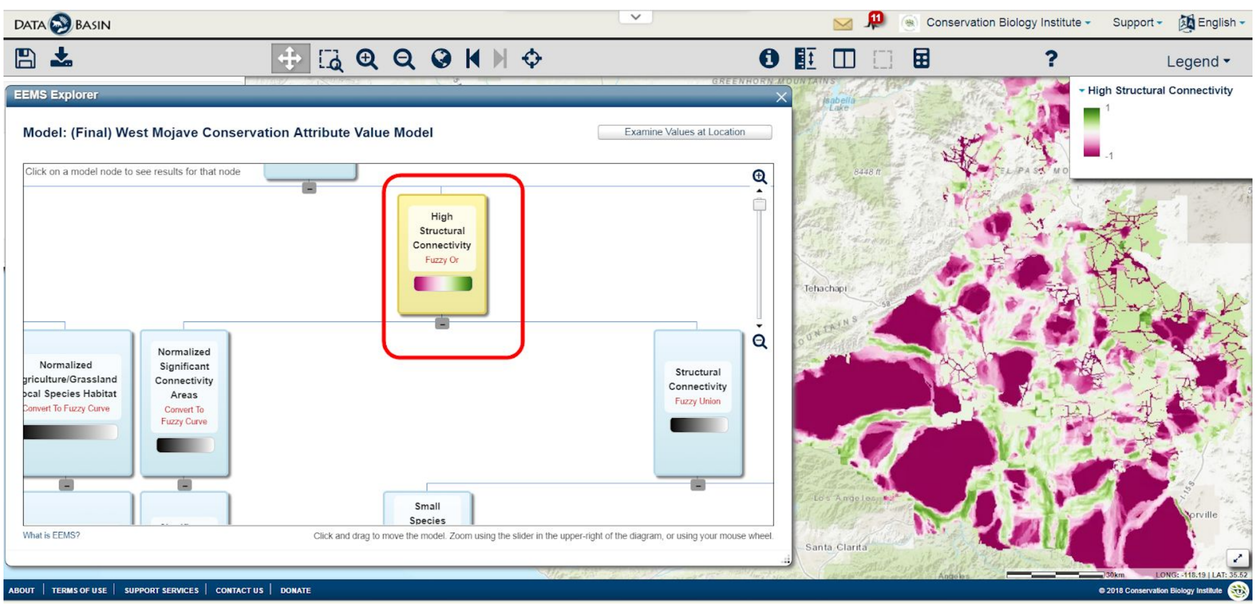

Figure 20: Click on the High Structural Connectivity box to view the final output. Users can click on the Examine Values at a Location for a deeper dive.

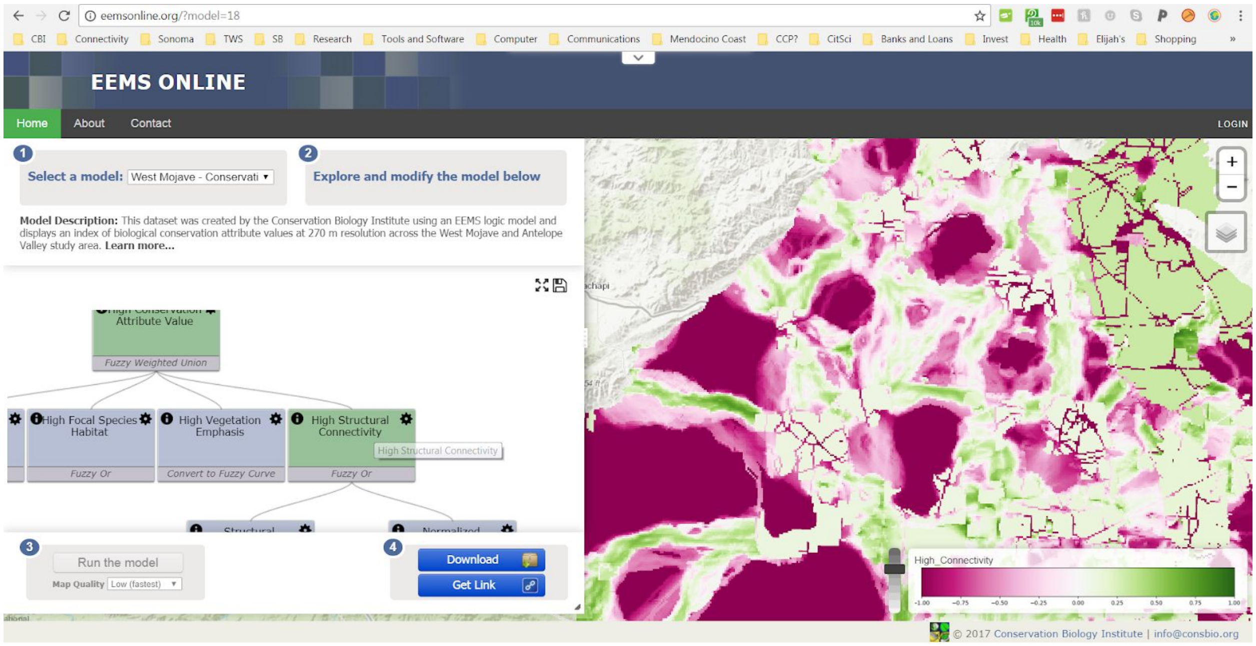

Figure 21: Alternatively, click on the High Structural Connectivity box in eemsonline.org GUI.

Sacramento Valley Results

The eight connectivity model results, depicted individually in Appendix C, are all accessible via the interactive online map in Data Basin. An example of one of them, American Badger, is shown here (Figure 22).

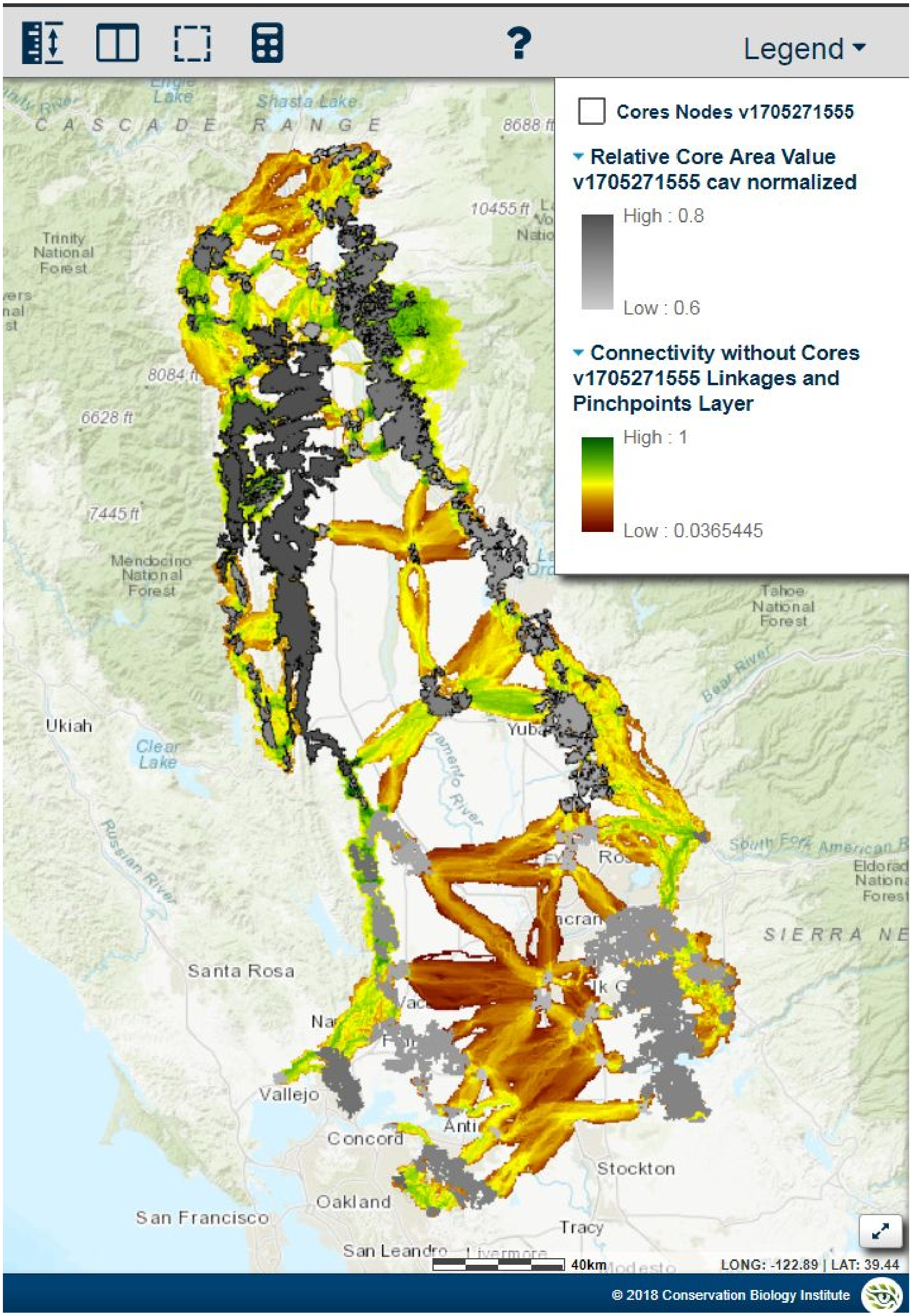

Figure 22: Badger Connectivity showing relative core area value, and relative connectivity value of a cell based on linkage pathways, pinchpoints, and linkage priorities that consider climate-wise and other ecological factors.

The synthesis of all eight of these results in one output (i.e. the top box of Figure 7) is provided here (Figure 23).

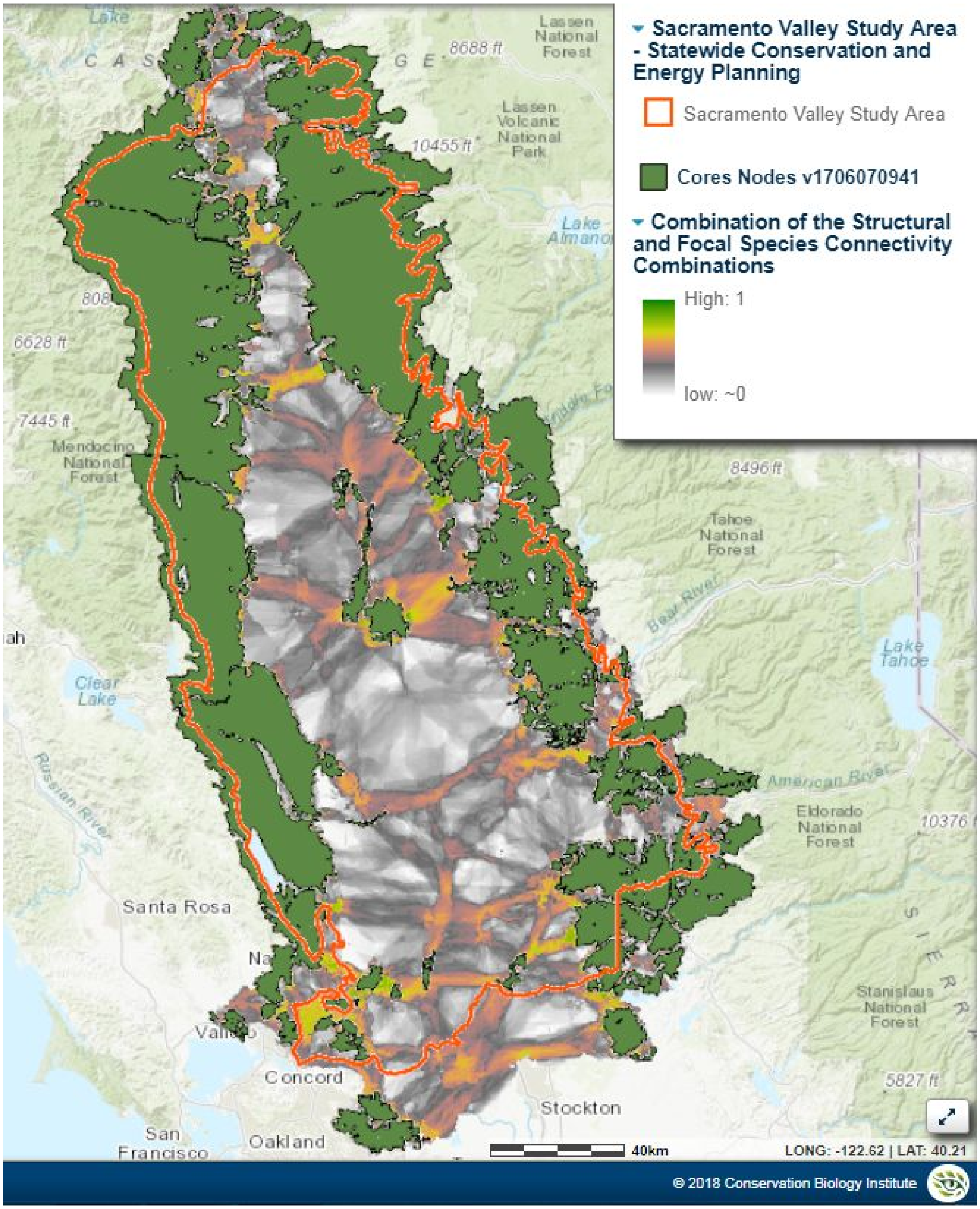

Figure 23 Synthesis of the Focal species and Structural Connectivity Typologies for the Sacramento Valley, using the Climate-wise Considerations.

In response to expert feedback suggesting our outputs mapped too much of the region with connectivity value, we implemented an automated approach to refine the area mapped as high connectivity conservation priority. We first selected all areas mapped as a value of 0.25 or greater (based on focal species observation points) and then rescaled the result linearly to range from 0-1 (Figure 24).

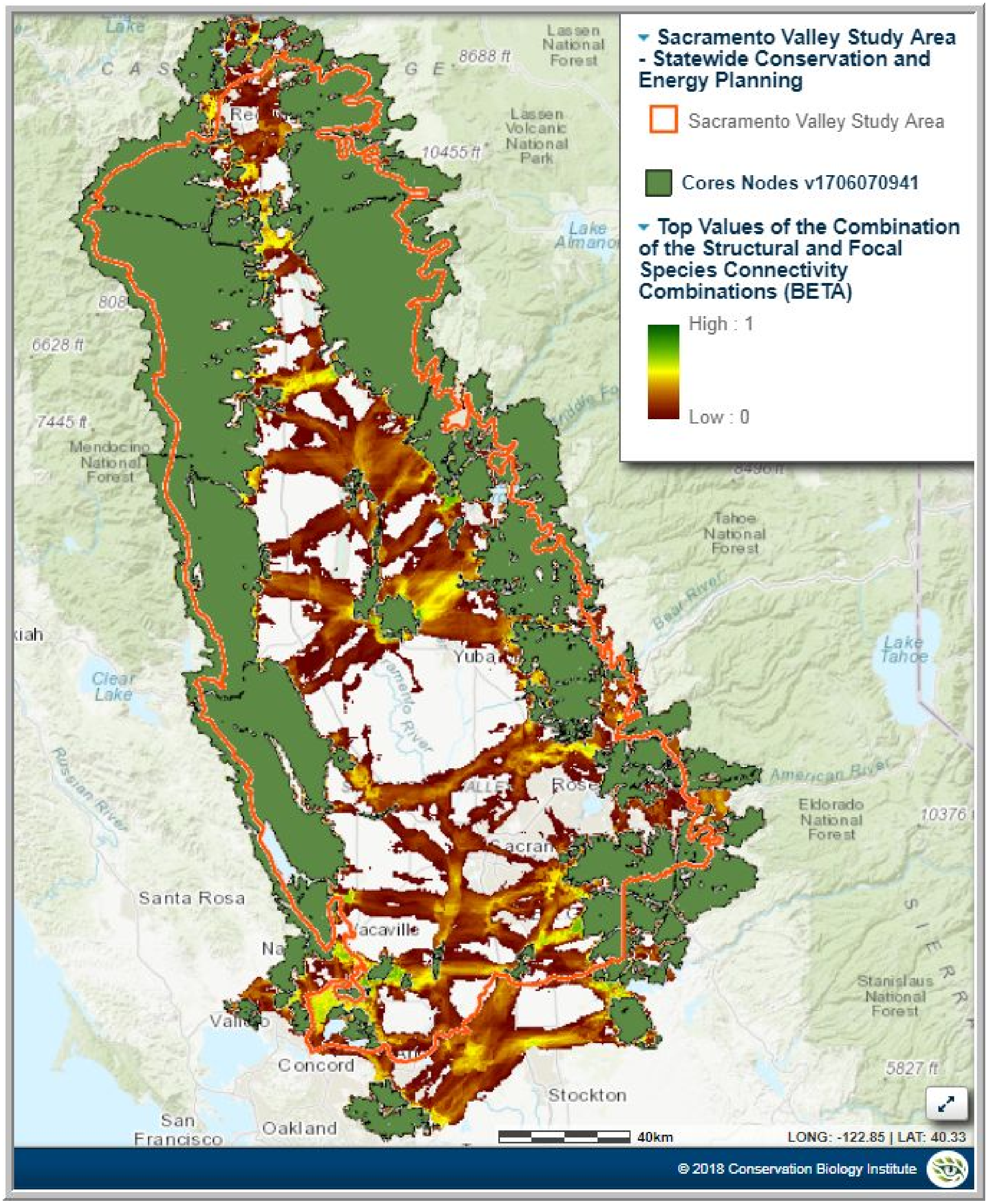

Figure 24. Synthesis: Estimated Connectivity Conservation Priorities for the Sacramento Valley (Climate-wise).

Users can explore final, input, and intermediate layers from the above Figures at the following hotlink, [Map: Synthesis of the Sacramento Valley Connectivity Results].

Conclusion

We met the applied science needs of this action research project as well as explored scientific frontiers. We met the applied science needs by mapping the core areas and linkage pathways (least cost corridors) for structural connectivity in three landscapes and for focal species in two of those three landscapes. These two products (cores and linkages) are map layers that are a part of every combination map online, and can be turned on by the end user.

We explored scientific frontiers in a variety of ways. We developed and implemented a new systematic approach towards climate-wise connectivity by both giving linkages higher priority if they connected core areas that had more climate refugia, and also if they span a large climate gradient from core to core, allowing for species range shifts. We also implemented new approaches to synthesizing varied aspects of connectivity and connectivity products into single maps and demonstrated their successful application in three regions of California.

Future analyses could be improved in a few ways. First, we recommend improving upon the final clipped synthesis map of the Sacramento case. Most of the small and isolated fragments of low connectivity value that remain after the clip appear to be are artifacts of the geoprocessing. They should be examined to determine if they are unlikely to contribute meaningfully to overall connectivity value, as expected. If so, how should they be systematically identified and removed. This could be done via a script that identifies and removes such artifacts, or by using a smoothing algorithm that uses the maximum value in a neighborhood (e.g. Liu et al. 2018)

Second, we recommend testing the use of eemsonline to facilitate the iterative process of evaluating various logic models, operators, and weights for building resistance surfaces, synthesizing products, and/or integrating outputs. This tool allows for easy interactive data exploration by science advisors where they can try different parameter values and compare, contrast, and share results. We demonstrate this approach for the Modoc resistance surface here, and for the synthesis of pinchpoint mapper, linkage pathways, and linkage priority here (without the cores mapped). Third, it would be good to give the user additional options for normalizing the linkage priority components, such as relative permeability, before they are combined.

Further, we have compiled a list of additional data, objectives and methods that would improve any future connectivity analyses in these three regions (available upon request). This includes using existing protected areas to help define the core areas, incorporating protected area status into “Other Core Area Values” of the Linkage Priority Tool, or “burning in” protected areas into the resistance surface as lower resistance than otherwise modeled (to help route planned corridors through existing protected areas).

Glossary

Here we briefly define some important terms used in this study, as well as key synonyms. If the term you are looking for is not here, please email it to the lead author for a definition that will be added to a future report for this region or elsewhere.

climate-wise connectivity: connectivity that specifically facilitates animal and plant movement in response to climate change (Keeley et al. 2018). (Syn. Long-term Connectivity, Climate Lens, Climate-smart Connectivity)

connectivity: “the degree to which the landscape facilitates or impedes movement” (Taylor et al. 1993) and, because of the widespread conversion and fragmentation of natural habitats by human activity, it has become an essential component of many successful conservation plans.

connectivity conservation priority: a value that is assigned to every cell on the landscape that estimates how important the conservation of that cell is to landscape connectivity, which is based on conservation of core areas connected with suitable habitat for movement of biodiversity.

core areas: significant habitat areas for the persistence of meta-populations of a species, or for multiple species. Also termed “Nodes” in some instances when they are mapped based on structural characteristics and not with any particular species in mind. (Syn: Landscape Blocks, Nodes)

corridors: swaths of the landscape that connect two or more significant (or core) habitat areas. Corridors can be designed to facilitate the movement of selected wildlife species (wildlife corridors) or they can be more general to accommodate plants and/or ecological processes (linkages). In this study, linkages and corridors were treated as synonyms several times.

demographic connectivity: connectivity designed to maintain meta-populations of species in the medium-term, such as facilitating the movement of adolescent males from one core area to another. See focal species in the introduction. (Syn: Medium-term Connectivity)

focal species: the more commonly used term for surrogate species. See definition for surrogate species.

long-term connectivity: see "climate-wise connectivity."

nodes: see "core areas".

North Sacramento Valley: This is the term that some stakeholders used for the entire Sacramento Valley (i.e. the northern half of California's great Central Valley). So, for the data layers, and any such mentions in this report, they are synonymous terms.

permeability: the degree to which a place is conducive to wildlife movement. The place can be a single pixel (cell) on the landscape, a linkage, or the landscape itself compared to other landscapes. The inverse of the resistance surface is often termed a permeability surface.

structural connectivity: the connectivity of a landscape based on lack of man-made structures, this ignores the behavioral response of organisms to habitat types and other ecological factors (Kadoya 2009).

species connectivity: also referred to as functional connectivity in the literature, describes the degree to which landscapes actually facilitate or impede the movement of specific organisms and processes (Wade et al. 2015).

surrogate species: are subsets of species which are "representative" of multiple species or aspects of the environment. These include umbrella, keystone, indicator, and flagship species. (Caro & O'Doherty 1999).

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Appendix A: Modoc Plateau Resistance Surface Details

Methods

Overview of Methods

The Modoc study area's enhanced resistance surface provides an estimate of general landscape resistance to animal movement (scaled from 10 to 800), with road and water barriers burned in for optimal performance in Linkage Mapper connectivity analysis. The Modoc Plateau study area is shown in Figure 1, and stops at the Oregon and Nevada borders due to data constraints; (some thematic input layers were only available for California). The final landscape resistance product, used to guide Linkage Mapper's connectivity algorithms in generating least cost corridor, pinch-point, and prioritized linkage results, was created using ESRI's ArcGIS ModelBuilder and the Conservation Biology Institute's EEMS (Environmental Evaluation Modeling System) fuzzy logic modeling framework. This connectivity resistance surface (Fig. 2) is not species-specific. It’s based on the condition of the landscape, (the extent and type of alteration due to human activity), which impacts species’ movements across the landscape. This is also known as a structural connectivity (Wade et al. 2015). It is an essential component of connectivity (Beier et al. 2011), and especially useful when financial resources are scarce and when large landscape structural patterns are adequate in addressing broad connectivity questions. Overall, our final output characterizes barriers to animal movement and the permeability of (ability for an animal to traverse) the landscape at 270 square meter resolution, based on the level and type of human disturbance present.

Figure 1. Location of the Modoc Plateau study area within the state of California.

In short, our methods were to combine two different characterizations of landscape condition, and add in expert-defined resistance for roads, and large water bodies. These additions allowed the subsequent connectivity modeling algorithm to more consistently respond to movement barriers.

The first characterization of landscape condition used in this analysis is termed “High Contrast Landscape Intactness” (Conservation Biology Institute, 2017). We created this fine-scale terrestrial intactness surface using EEMS logic modeling (details below). The second input dataset, termed “Human Modification”, was created by Conservation Science Partners (Conservation Science Partners, Inc. 2016; Theobald, 2013) and shows the degree of human modification based on stressors defined by The Human Activities Framework (Salafsky et al. 2008; http://cmp-openstandards.org/using-os/tools/threats-taxonomy/). We normalized these inputs to the same range and combined them to get an Average Landscape Resistance surface.

We then augmented this with an expert-defined and consistent resistance for four road classes, and large water bodies to yield the "Enhanced Resistance Surface" (Fig 2)..

(Details of these enhancements are summarized in Figure 7).

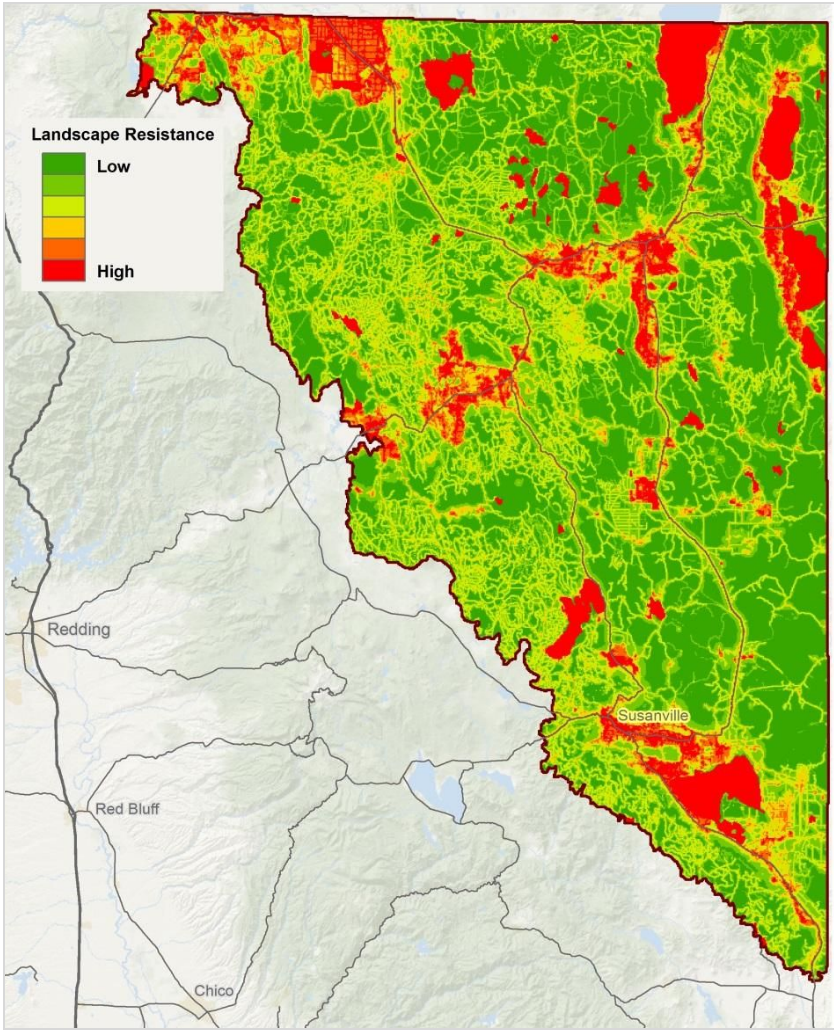


Figure 2. Enhanced Resistance Surface (version: MDC_TIRS_v6, H2b; ER v4_H2b_w_water), in six classes from High (disturbed from urbanization, agriculture, or resource development in red) to Low (relatively undisturbed in dark green) depicted within 270 m X 270 m reporting units. Model inputs include: 1. High-contrast landscape intactness (Conservation Biology Institute, 2017), 2. Human modification, a smoother representation of the landscape (Conservation Science Partners, 2016), and road and water features burned-in to improve performance in Linkage Mapper.

Note, the CBI High-Contrast Resistance Surface model is on EEMS Online.

Detailed Methods

High-Contrast Landscape Intactness (CBI, 2017): Background

Structural connectivity focuses on maintaining the connectivity of naturalness (i.e. intactness) across the landscape. Intactness is characterized by a lack of human disturbance in an area and considers an assemblage of spatially explicit indicators that define the condition of the landscape. Landscape intactness is high in places where anthropogenic impacts such as urban development and natural resource extraction are low. Different species may possess different tolerances to these conditions, but natural assemblages of species and natural patterns and processes are increasingly compromised as human influences intensify. Efforts to map and quantify the intactness of the landscape can be used to model structural connectivity in two ways: 1. By defining natural landscape blocks (i.e. cores) ; 2. By defining resistance to animal movement, when inverted.

A wide range of techniques has been used to map anthropogenic impacts; these efforts have introduced different names – human footprint, landscape integrity, landscape intactness, naturalness – but they are all attempting to quantify essentially the same thing. Some of the notable developments in the field are as follows, (with a focus on the western United States):

Early global attempts to map the human footprint were carried out by Bryant et al. (1997) and Sanderson et al. (Sanderson et al. 2002) and then rescaled for ecoregional use by Woolmer et al. (2008). In 2008, Leu et al. published the Human Footprint of the West, and in 2010 Spencer et al. carried out the California Essential Habitat Connectivity Project. Building off the California work, the Washington Wildlife Habitat Connectivity Working Group conducted statewide landscape integrity modeling and connectivity mapping for Washington at increasingly fine resolution (WHCHG 2010; WHCHG 2012). In 2013, Conservation Science Partners used the human activities framework (Salafsky et al. 2008) to map human modification in the western US at 270 meter resolution (Conservation Science Partners, 2016); (this dataset is utilized in our analysis). In 2015, The Nature Conservancy modeled terrestrial permeability for the Pacific Northwest in their Conserving Nature's Stage work (Buttrick et al. 2015).

For this project, we created our own high-contrast landscape intactness map for the Modoc Plateau and combined it with Conservation Science Partners's 2013 dataset to create a 270 meter resolution resistance surface to model species movement across the land.

High-Contrast Landscape Intactness (CBI, 2017): Logic Modeling

Landscape intactness values, (which were inverted to approximate landscape resistance), were generated using ArcGIS Model Builder and logic models constructed within the EEMS (Environmental Evaluation Modeling System) framework (executed within ArcGIS Model Builder and custom Python Scripts). A *logic model* is a cognitive map (Jensen et al. 2009) that presents various spatial data components and their logical relationships to evaluate a complex topic such as landscape intactness (Fig. 3). EEMS is a tree-based, fuzzy logic modeling system developed by the Conservation Biology Institute as an open source alternative to the EMDS (Ecosystem Management Decision Support) software package (Sheehan and Gough 2016; Reynolds 1999, Reynolds 2001). With the EEMS system, data from different sources and different numerical domains can be combined to answer complex questions, such as those concerning landscape condition, conservation values, or vulnerability to climate change (Sheehan and Gough 2016).

Logic models are created from spatial data layers that are arranged in a hierarchical fashion to answer a primary question that is located at the top of the diagram (Fig. 3). In this case, what is the level of landscape intactness within each 270m X 270m reporting unit in the study area? Data and analysis flows from the bottom up.

Unlike conventional GIS applications that use Boolean logic (1s and 0s) or scored input layers, logic models rely on fuzzy logic. Simply put, fuzzy logic allows the user to assign shades of gray to thoughts and ideas rather than being restricted to black (false) and white (true) determinations. All data inputs (regardless of the type—ordinal, nominal, or continuous) are assigned relative values between -1 (false) and +1 (true) up to six decimal places. There are many advantages of this modeling approach: (1) it is highly interactive and flexible; (2) it is easy to visualize thought processes; (3) the logic components are modular making it easy to include or exclude pieces of the logic design; (4) the logic can be managed using a number of different mechanisms; and (5) numerous, diverse topics can be included into a single integrated analysis.

As shown in Figure 3, raw spatial data source inputs are populated by one or more GIS data layers and aggregated to reporting units (gray boxes). Moving up the diagram, these data are arranged and analyzed to form intermediate map products (purple boxes), which are then arranged and analyzed to generate the final results (pink, orange, green boxes). One way the user controls the logic of the information is the arrangement of the various data inputs and intermediate products—the higher up in the diagram, the greater the influence on the final result.

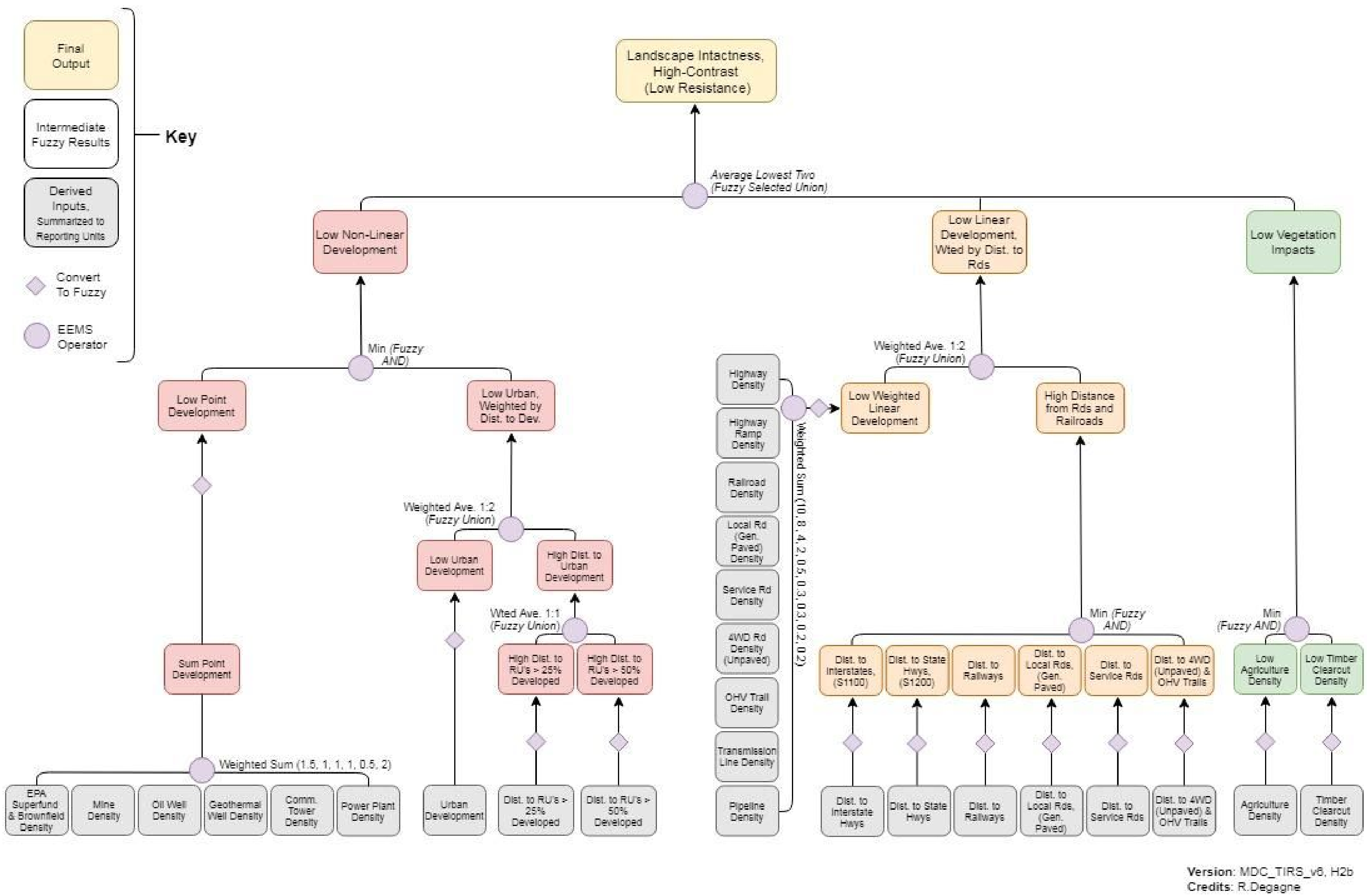


Figure 3. Logic model for high-contrast landscape intactness (version: MDC_TIRS_v6, H2b) for the Modoc study area.

Using fuzzy logic as the core modeling principle, logic model performance is achieved in several ways. For every spatial data input, the user determines how to assign the range of values along a truth continuum. For example, when trying to determine and map the most suitable habitat from the standpoint of road density for wildlife—the greater the road density, the greater is the risk to wildlife through habitat degradation and direct mortality. In our example shown in Figure 4, road density ranges from 0 km/km^2 to 24.5 km/km^2. To assign a fuzzy logic continuum for this range of values, one could assign a -1 to the high value (this value is totally harmful for wildlife or false) and a +1 to the lowest value (this value is totally beneficial for wildlife, or true, red line in Figure 5). However, mountain lion research has shown that mountain lion populations have a low probability of persistence in areas with road densities > 0.6 km/km^2 (Van Dyke et al. 1986). So, a more meaningful alternative to set fuzzy thresholds for this parameter would be that a road density of > 0.6 km/km^2 is totally false (-1) and 0 remains totally true (+1, green line in Figure 4). Of course, not all wildlife species have the same sensitivity to roads, but this example illustrates how the logic in the model can be altered for known thresholds.

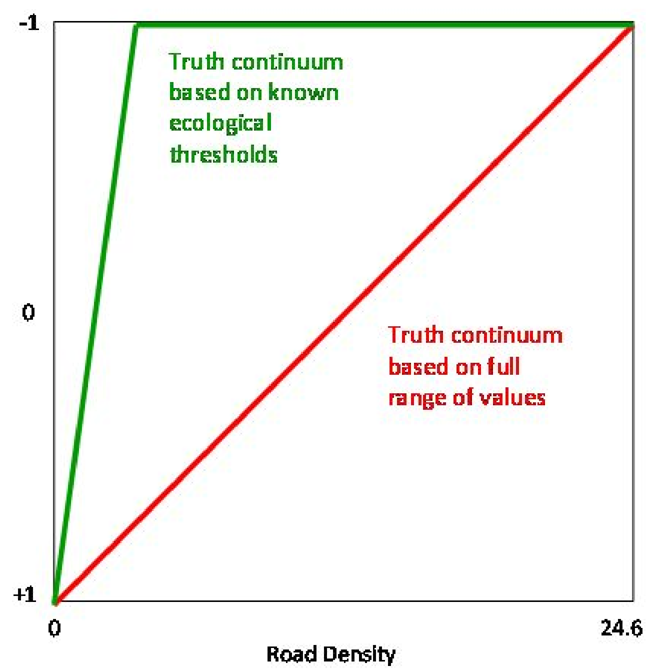


Figure 4. Diagram of two treatments of road density in fuzzy logic modeling illustrating important model control options, one based on a full range of values (red line) and the other based on a known threshold for road density (> 0.60 km/km^2 is totally false [-1], green line).

Individual thresholds used for each component in the high-contrast landscape intactness logic are provided in Table 1. (Note, some input components were created by summing several input values together before applying fuzzy thresholds.) Since this intactness resistance surface was structural in nature and not species-specific, thresholds were set based on expert opinion and iterative refinement of output patterns. As more literature becomes available on specific impacts of anthropogenic alteration on animal movement, this information can be used to further refine model thresholds.

Table 1. List of fuzzy logic data inputs for the high-contrast landscape intactness surface (version: MDC_TIRS_v6, H2b; Enhanced Resistance v4_H2b_w_water), showing data type, as well as true and false modeling thresholds for each item at 270 m^2 resolution.

Input	Data Type	True Threshold	False Threshold
Weighted Point Development (Pollution, Energy, Mining, Comm) (pts/km^2)	Count	0	8.5
Pct Urban Development	Percent Cover	0	40
Dist. From > 25 % Urban Development	Distance	0	1,000
Dist. From > 50 % Urban Development	Distance	0	3,000
Weighted Linear Features, Road Class Development (km/km^2)	Density	0	12
Dist. From Highways	Distance	0	1,500
Dist. From Railways	Distance	0	1,000
Dist. From Local Rds	Distance	0	500
Dist. From Service Rds	Distance	0	200
Dist. From 4WD & OHV Trails	Distance	0	200
Pct Ag Land	Percent Cover	0	100
Pct Timber Clearcuts	Percent Cover	0	60

Spatial data are integrated using one of several logic ‘operators’. The operators used in this analysis include: Weighted Sum, Weighted Average (or *Fuzzy Union*), Average Lowest (or *Selected Union*), and Minimum (or *Fuzzy And*). The Sum operator simply combines similar data into a single file before assigning fuzzy thresholds. Weighted Sum multiplies each input value by the specified weight and then sums the resulting values. Weighted Average (or *Fuzzy Union*) multiplies each input value by the specified weight, sums the resulting values, and then divides by the sum of the weights. Weights are shown in Figure 3. Average Lowest 2 (or *Selected Union*) finds the mean value of the lowest (*Falsest*) 2 inputs. Minimum (or *Fuzzy And*) causes the lowest value to dominate in the resultant map between two or more inputs. Table 2 describes the full range of logic operators available in the EEMS software package and the type of data (fuzzy or raw) the operator expects as input. In executing the logic model for the landscape, we processed the northern and southern halves of the landscape separately to bypass computer processing limitations, and then stitched results together in post-processing.

Table 2. Logic operators available in the EEMS software package.

EEMS TOOL	INPUT DATA	DESCRIPTION
AND	Fuzzy	Finds the AND value of the inputs (minimum value). (previously OrNEG in EEMS version 1.0)
CONVERT TO FUZZY	Raw	Converts a field's values into fuzzy values.
CONVERT TO FUZZY CATEGORY	Raw	Converts a field's values into fuzzy values by using the user defined category values and matching fuzzy values. Input values that are not in the user defined categories are assigned the user-defined default fuzzy value.
DIFFERENCE	Raw	Computes the difference sum for each row of the inputs.
EEMS EMDS AND	Fuzzy	Fuzzy logic operator for EEMS (Environmental Evaluation Modeling System). Finds the EMDS AND value of the inputs. The formula is min + [(mean - min) * (min + 1) / 2]
MAX	Raw	Finds the maximum for each row of the input fields.
MEAN	Raw	Finds the mean for each row of the input fields.
MIN	Raw	Finds the minimum for each row of the input fields.
NOT	Fuzzy	Logical NOT for fuzzy modeling. Reverses the sign of values of the input field.
OR	Fuzzy	Finds the truest value of the inputs (maximum value).
SELECTED UNION	Fuzzy	Finds the union value (mean) of the specified number of TRUEest or FALSEest inputs.
SUM	Raw	Computes the sum of the inputs.
UNION	Fuzzy	Finds the union value of the inputs (mean value).
WEIGHTED EMDS AND	Fuzzy	Finds the weighted EMDS AND value of the inputs. The formula is min + [(mean - min) * (min + 1) / 2] where the mean is weighted.
WEIGHTED MEAN	Raw	Finds the weighted mean for each row of the input fields.
WEIGHTED SUM	Raw	Finds the weighted sum for each row of the input fields. Multiplies each field by its weight before adding. Like a weighted mean without the division.

WEIGHTED UNION	Fuzzy	Finds the weighted union (mean) for each row of the input fields.
XOR	Fuzzy	Finds the fuzzy EXCLUSIVE OR value of the inputs by comparing the two truest values. If both are fully true or fully false, false is returned. Otherwise, applies the formula: (truest value - second truest value) / (full true - full false)

All intermediate and final spatial layers in a logic model are rendered as fuzzy outputs, which range from -1 (totally false) to +1 (totally true). However, for this project, the output of the high-contrast landscape intactness EEMS model was inverted to become a resistance surface and normalized to 10-800, to optimize performance in Linkage Mapper.

High-Contrast Landscape Intactness (CBI, 2017): Source Data

Data used as input to the high-contrast landscape intactness EEMS model were acquired from multiple sources. Data were either downloaded directly from the source or acquired from partner organizations. Table 4 lists all of the input data used in the analysis as well as data type and originator. Creating the final enhanced resistance surface for input into Linkage Mapper required the addition of one crucial dataset: Human modification in the western U.S. in 2011 at 270 m resolution (v20160512). This dataset was produced under a contract between Center for American Progress and Conservation Science Partners (CSP), Inc. It was generously made available for use by CSP (Conservation Science Partners, Inc. 2016).

The input data used to create the high-contrast landscape intactness EEMS model range in currency from 2011-2015; the majority of data portray the more recent condition of the landscape.
When creating the high-contrast landscape intactness model, it was often necessary to compare several datasets for a particular theme to determine those that were most appropriate for the modeling effort. Consequently, many more datasets were pre-screened and evaluated than were actually used in modeling. Several datasets were provided without metadata, or limited amounts of metadata. In these cases, the data were either not used or efforts were made to contact the data originators in order to obtain information about the data.

The high-contrast landscape intactness model integrates the following anthropogenic influences on the landscape: agriculture development (from FRAP Vegetation and CDL Cropscape), urban development (from LANDFIRE EVT and NLCD Impervious Surfaces), polluted areas (from EPA Superfund and Brownfield sites), linear development (OHV routes from owlsheadgps, road classes from TIGER, utility lines, railroads, and pipelines from various state and BLM sources), timber harvest clearcuts, point development (communication towers from the FCC), energy and mining development (from the state's Office of Mine Reclamation mine dataset, state geothermal wells, power plants, and state oil/gas wells). Overall, results are dependent on the quality of available input data for a given area. Further refinements to the model include stratifying road impacts by class, (i.e. different weighting for different types of roads), and taking distance to urban development and linear features into account.

The resulting map of the high-contrast landscape intactness EEMS model (Fig. 3) is shown in Figure 5.

This model also can be explored via EEMS Online where the input, intermediate, and output layers are accessible as online interactive maps showing the signature of human impact across the landscape: http://eemsonline.org?model=4gkfUC0B4ytq3jg8fD6QJcSSdHxKAs0A.

Table 4. Input data for the High-Contrast Landscape Intactness EEMS model.

Input	Data Type	Originator
Cropland Data Layer (CDL), Cropscape 2014	Raster	USDA National Agricultural Statistics Service
FRAP Vegetation (FVEG), 2015	Raster	CAL FIRE
Impervious Surfaces, National Landcover Dataset (NLDC) 2011	Raster	U.S. Geological Survey (USGS)
LANDFIRE Existing Vegetation Type (EVT) v1.3	Raster	LANDFIRE
Forest Practice GIS Timber Harvest Plan Clearcuts, 2000-2016	Polygon	California Department of Forestry and Fire Protection (CAL FIRE)
Off-Highway Vehicle (OHV) Routes, 2015	Line	Owlshead GPS
2015 Tiger Roads[1]	Line	U.S. Census Bureau TIGER database
CA Electric Transmission Lines, 110-500 kV	Line	CEC, Scott Flint
CA Power Plants	Point	U.S. Energy Information Administration
California Rail Network	Line	CalTrans
CA Mine Sites	Point	CA Office of Mine Reclamation
California Natural Gas Pipelines	Line	CEC, Scott Flint
California Oil and Gas Wells, 2016	Point	CA Department of Conservation, Division of Oil, Gas and Geothermal Resources
FCC Communication Towers	Point	Federal Communications Commission, WFDSS

CA Geothermal Resources	Table	CA DOC, Division of Oil, Gas and Geothermal Resources
EPA, Brownfield Sites	Point	Environmental Protection Agency (EPA),Facility Registry System (FRS)
EPA, Superfund Sites	Point	Environmental Protection Agency (EPA),Facility Registry System (FRS)
National Hydrography Dataset	Polygon	USGS, High Res. National Hydrography Dataset (NHD)

1. The TIGER roads dataset was created by merging multiple county level datasets.

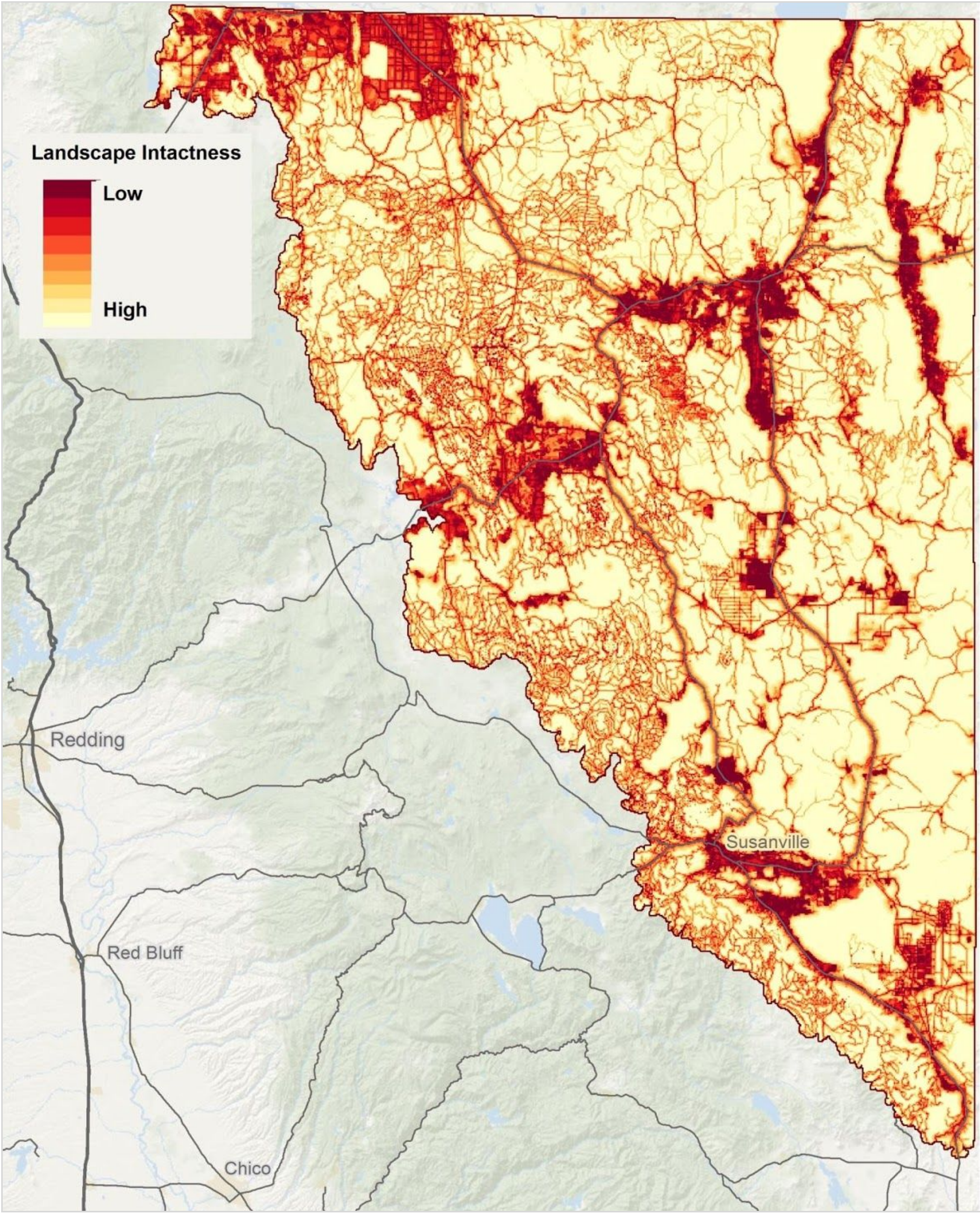


Figure 5. High-contrast landscape intactness, created by Conservation Biology Institute in 2017. Darker areas are impacted by stressors such as urbanization, agriculture, energy production and mining, transportation, and biological harvesting. Lighter areas are more intact, with less human activity. Model resolution is 270 m.

Human Modification (CSP, 2016): Methods

The following summary of the methods used to generate Conservation Science Partners' smoother representation of human modification of the landscape is taken directly from the data's documentation (Conservation Science Partners, 2016):

"To map the degree of human modification, a list of stressors (or threats to natural lands) was organized based on The Human Activities Framework (Salafsky et al. 2008; http://cmp-openstandards.org/using-os/tools/threats-taxonomy/). At the top level, stressors are organized into five Level I classes: residential and commercial development, agriculture, energy production and mining, transportation and service corridors, and biological harvesting. These are further broken into 1-3 specific activities, resulting in 11 Level II classes. For each stressor, specific datasets were used on which to calculate a specific indicator(s). In total, nearly two-dozen datasets were used to depict 14 types of human activities. Each of these datasets was based on readily available spatial data that represented multiple time periods.

For each indicator, two factors were calculated at a given location (cell): intensity and footprint. Intensity (I) is the degree to which an activity at a location generally modifies terrestrial and aquatic ecosystems, which is useful to differentiate effects of different types of land uses. For example, using a patch of land as pasture is likely to have a lower overall effect on the physical integrity of ecosystems than conversion to a parking lot. The second is the footprint (F), or the areal extent of a given human activity. In practice, the footprint is measured as the proportion of a raster cell (here 30 m) that is occupied by a given land use. Thus, the overall degree of human modification (H) at a location is calculated as: $H = I \times F$, where a value of 0.0 has no human modification and a value of 1.0 has high modification. Estimates of I and F for each indicator were made from two different sources: expert opinion or empirical datasets. For the empirically-based stressors, I was estimated as a value from 0.0 to 1.0 based on the relative amount of energy required to maintain a particular land use type, obtained from Brown and Vivas (2005). Thus, H accounts for a gradient of impact of human activities, has a direct physical interpretation, and the value remains a ratio data type so that differences within the range are meaningful (i.e. a value of 0.8 is twice the effect of 0.4), unlike most index-based approaches where values are converted to nominal or interval values. Note the H value was set to No Data (i.e., masked out) for locations (30-m cells) that intersected lakes, reservoirs, or rivers (represented by the USGS National Hydrography Dataset as waterbodies and river area maps; http://nhd.usgs.gov/; accessed June 2015).

To combine stressors and map the cumulative human modification, a method was used that minimizes bias associated with non-independence among several stressor/threats layers (Theobald 2013), and that assumes the contribution of a given threat decreases as values from other threats overlap. Locations with multiple threats will have a higher human modification value than locations with just a single threat (assuming the same value), but the cumulative human modification score converges to 1.0 as multiple human impact data layers are added. Individual factors were combined across multiple data layers using an "increasive" function (Theobald 2013), also referred to as a fuzzy sum (Bonham-Carter 1994)."

The results of Conservation Science Partners' human modification analysis (described above) is shown in Figure 6.

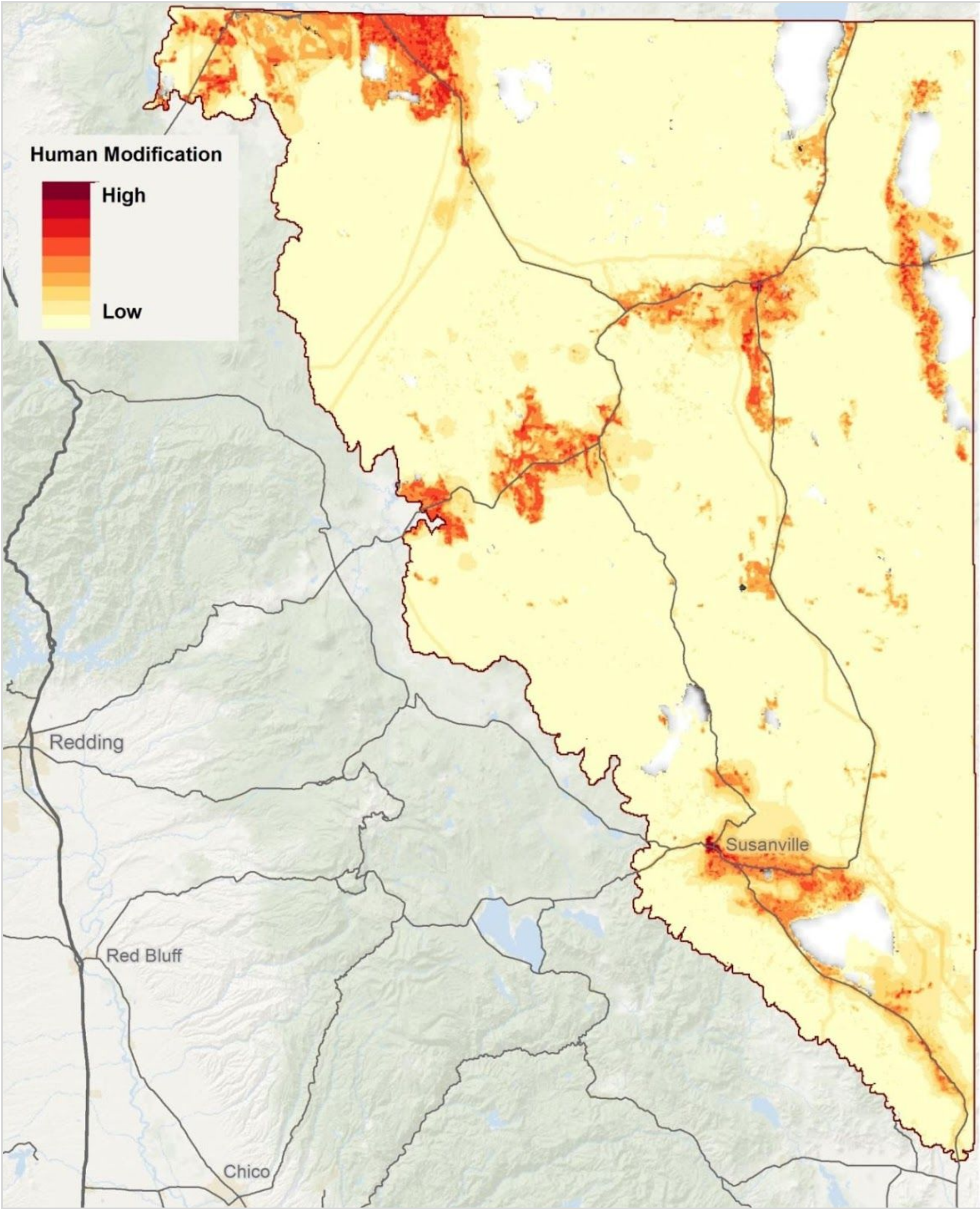
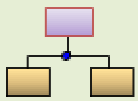
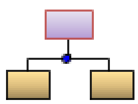
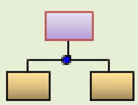
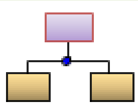
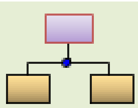


Figure 6. Degree of human modification in 2011 (version: v20160512), based on stressors (impacts to natural lands), created by Conservation Science Partners, Inc. 2016. Darker areas are impacted by stressors residential and commercial development, agriculture, energy production and mining, transportation and service corridors, and biological harvesting. Lighter areas have less human activity. Model cell resolution is 270 m.

Enhanced Connectivity Resistance Surface: Modeling Process

Creation of the final enhanced resistance surface can be summarized by five steps: *1. Preprocess All Input Data, 2. Calculate Densities for High-Contrast Landscape Intactness EEMS Modeling, 3. Execute EEMS Logic Modeling for High-Contrast Landscape Intactness, 4. Create Average Landscape Resistance Surface, and 5. Generate Final Enhanced Landscape Resistance Surface***.** These steps were carried out using a set of models developed in ArcGIS Model Builder in conjunction with custom Python scripts. Table 5 provides an overview of the functions that each model performed.

Table 5. Modeling steps used to create the enhanced resistance surface.

Model	Model Diagram	Model Overview
1. Preprocess All Input Data		Clips all input data to the study area and projects all input datasets to CA Teale-Albers NAD83; performs preliminary aggregation of datasets.
2. Calculate Densities for High-Contrast Landscape Intactness		Calculates a 270 m reporting unit density value for all components of the high-contrast landscape intactness model. Combines those density values into separate fields in a single feature class. This feature class is then used as input to the EEMS model (step 3).
3. Execute EEMS Logic Modeling for High-Contrast Landscape Intactness		Applies fuzzy logic within the EEMS model framework (Fig. 1-3). Calculates a landscape intactness value for each 270 m x 270 m reporting unit, based on input data, operators used, thresholds, and weightings applied.
4. Create Average Landscape Resistance Surface		Combines the two landscape condition datasets [1. High-contrast landscape intactness (CBI, 2017) and 2. Human modification (CSP, 2016)], after they are normalized to a common scale (Fig. 1-4).
5. Generate Final Enhanced Landscape Resistance Surface		Burns in road and water features at constant values to improve performance in Linkage Mapper connectivity analysis (Fig. 1-4).

Enhanced Resistance Surface: Results

The final enhanced resistance surface is based on the average of the two aforementioned models of landscape condition: 1) Conservation Biology Institute's high-contrast landscape intactness EEMS model (inverted to characterize resistance) (CBI,2017), which is suited to animals with smaller home ranges, and Conservation Science Partner's human modification (D. Theobald, 2016), which has a smoother surface.

The final result provides an estimate of general landscape resistance (scaled from 10 to 800), with road and water barriers burned in at constant values for reporting units for optimal performance in Linkage Mapper connectivity analysis. Overall, this output characterizes barriers to animal movement and the condition of the landscape at 270 sq. meter resolution, based on the level and type of human disturbance present. An overview diagram of the analysis is shown in Figure 7 (next page).

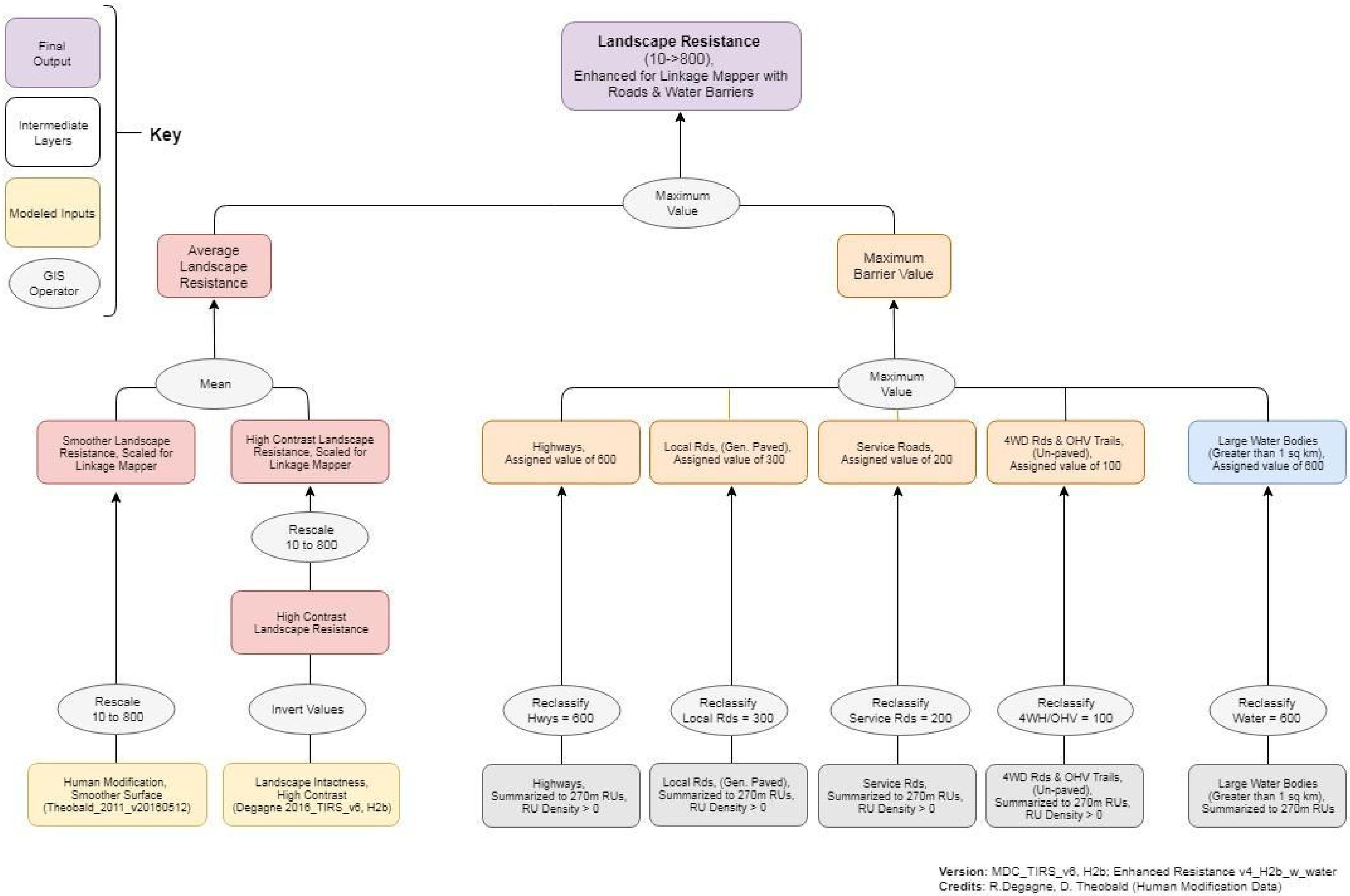


Figure 7. Logic model for enhanced landscape resistance (version: MDC_TIRS_v6, H2b; Enhanced Resistance v4_H2b_w_water)..

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Appendix B: Additional Methods and Results for Mojave

Model Inputs

Typologies

In the main body we introduces the concept of structural connectivity typologies. Here is some more discussion. Structural connectivity modeling is a quick way for modeling connectivity for a large number of species on a landscape, rather than doing it for many focal species. The parameters used in developing the input layers and in running the structural connectivity models will affect what types of species benefit the most from the resulting outputs. For instance, small species do not need large core areas (a parameter value), nor wide linkages (a parameter value), while the inverse is true for large species. Further, the parameters used will affect the relevant time frame of the outputs. The three common time frames considered are short term (e.g. connectivity for seasonal migration of an individual), medium term (e.g. intergenerational dispersal), and long term (e.g. species range shift to account for climate change)(Keeley et al. 2018). If we are most concerned about climate change and providing slow moving species with linkages that allow them to shift their ranges from current to future climatic conditions, then we will give higher priority to the linkages on the landscape that allow for this. Hence, the map of landscape connectivity conservation priorities that is considering fast and large species for the medium-term will look very different than one considering species that are slow and small for the long-term.

Resistance Surfaces

We first created a Structural Resistance Surface Basemap for the Mojave that was similar in methods and appearance to the Enhanced Resistance Surface of the Modoc Plateau, except it did not include the Human Modification product. This dataset provided an estimate of landscape intactness, (i.e. condition), based on the extent to which human impacts such as urban development, linear development, natural resource extraction, and agriculture have disrupted the landscape across the study site.

This dataset was originally created to characterize anthropogenic barriers to small animal movement and emphasizes liner features in terms of impact on the landscape. Additional model refinements include stratifying road impacts by TIGER class, (e.g. different weighting for different types of roads), and taking distance to urban development into account.

This 270 sq. m resolution dataset, updated November 2016, was created using EEMS. This spatially-explicit logic modeling hierarchically integrates numerous and diverse datasets into composite layers, quantifying information in a continuous rather than binary fashion.

Input data used to create this version ranged in currency from 2011-2015; the majority of data portrayed the more recent condition of the landscape.

The EEMS model integrates agriculture development (from FRAP Vegetation, and CDL Cropscape), urban development (from LANDFIRE EVT and NLCD Impervious Surfaces), polluted areas (from NHD treatment ponds and EPA Superfund and Brownfield sites), linear development (OHV routes from owlsheadgps.com, roads from TIGER (broken down by type), utility lines, railroads, and pipelines from various state and BLM sources), point development (communication towers from the FCC), and energy and mining development (from the state's Office of Mine Reclamation mine dataset, larger mine footprints, state geothermal wells, USGS wind turbines, solar footprints, renewable projects in development, oil refineries and state oil/gas wells).

Small Species, Demographic

(Note, to view this layer, click on the above hyperlink, then open the layers tab, then "Mojave Resistance surfaces Used.")

We started with the above Structural Resistance Surface Basemap. Then Playa boundaries were smoothed and burned into the combined layer (i.e. the Maximum value of the two layers was used), since most animals do not cross playas regardless of their high terrestrial intactness.

Small Species, Climate Lens

The above layer was used as a starting point, and then the Climate Refugia Value, which is the combination of Physical Refugia and Climate Stability described below, was added in a weighted sum to the above layer using a low weight (0.25 vs 0.75). The result was normalized to span from 0-1. The justification for this was that in mapping linkages for the long term, those that have a high climate refugia value are more important linkages in the long term than those that do not, all else being equal.

Large Species, Demographic

We started with the Human Modification Surface by David Theobald and team. This surface's patterns are smoother then the aforementioned Structural Resistance Surface Basemap, making it more suited to larger animals and those with larger home ranges. Then Playa boundaries were smoothed more broadly than for small species, to allow fuzzy values further from the perimeters, and this layer was burned into the combined layer, since most animals do not cross playas regardless of their high terrestrial intactness.

Large Species, Climate Lens

As per the small species surface, the above layer was used as a starting point, and then the Climate Refugia Value, which is the combination of Physical Refugia and Climate Stability described below, was added to the above layer using a low weight (0.25 vs 0.75). The result was normalized to span from 0-1.

Mojave Ground Squirrel, Demographic

(Note, to view this layer, click on the above hyperlink, then open the layers tab, then “Mojave Resistance surfaces Used.”)

The small species, demographic resistance surface (Structural Resistance surface basemap with playas burned in) was combined with the rescaled and inverted Mojave Ground Squirrel species distribution model using a mean value.

Mojave Ground Squirrel, Climate Lens

The small species, climate lens resistance surface, (e.g. Structural Resistance with playas burned in as more resistance, and refugia burned in as less resistance) was combined with the rescaled and inverted Mojave Ground Squirrel species distribution model using a mean value.

Desert Tortoise, Demographic

The small species, demographic resistance surface (Structural Resistance surface basemap with playas burned in, having a range from 1-1000) was combined with tortoise fence locations, which were burned in as extremely high resistance (10,000), making them essentially impassable. Then this layer was combined with the rescaled and inverted Desert Tortoise species distribution model using a mean value.

Desert Tortoise, Climate Lens

The small species, climate lens resistance surface, (e.g. Structural Resistance with playas burned in as more resistance, and refugia burned in as less resistance) was combined with tortoise fence locations, which were burned in as extremely high resistance, making them essentially impassable. Then, this layer was combined with the rescaled and inverted Desert Tortoise species distribution model using a mean value.

Cores

Large Species Core Areas

To generate the cores, the large species demographic resistance layer was combined with the Statewide Terrestrial Intactness layer, using a mean value, and then normalized to range from -1 to 1. This was then clipped to the extent of the analysis, and then all values over 0.5 were extracted, converted to polygon, and buffered by 1 meter, so areas that touch at the corner become connected. All areas over 10 sq. km were then selected. There is a secondary output made for every core area file, not used in this analysis, which is those core areas that are also protected in some way, including conservation easements.

Small Species Core Areas

The small species demographic resistance layer was combined with the Statewide Terrestrial Intactness layer, using a mean value, and then normalized to range from -1 to 1. This was then clipped to the extent of the analysis, and then all values over 0.5 were extracted, converted to polygon, and buffered by 1 meter, so areas that touch at the corner become connected. All areas over 4 sq. km were then selected. There is a secondary output made for every core area file, not used in this analysis, which is those core areas that are also protected in some way, including conservation easements.

Mojave Ground Squirrel Nodes

We use the concept of nodes in this connectivity model, rather than traditional concept of “core areas.” We augmented our MGS observations database (elsewhere, based on CNDDB and BISON, post 2000) with post-2000 observations from Rich Inman. The Inman data have been submitted to CNDDB, but not integrated yet. We mapped all these locations, and buffered each point by 100,000 cost-distance meters. Hence, we used the MGS resistance surface, which ranges from 1-1000. So 100 m at the lowest resistance would be a cost distance of 100, and of the highest resistance would be a cost distance of 100,000. Hence observations in really high quality habitat, according to the species distribution model and/or the input resistance surface basemap, result in a relatively large area node. Observations in poor habitat will have a small area node. Overlapping nodes were dissolved, and those that were less than 1 sq. km. were removed.

Desert Tortoise Nodes

Desert Tortoise Occurrence Points by Date (2000 - 2016), were merged with observations from the Desert Tortoise Distance surveys. This yielded a larger number of observations compared to MGS, so we made an observation density surface based (available upon request) on a focal mean of a 2.5 km radius about every cell on the landscape. Upon examining the results we then selected out the cells valued greater than 7 observations per surrounding circle (i.e. areas with higher densities of observations), and areas greater than 2.5 sq. km. These were classified as source core areas.

We also recognized that there were observations on the periphery, away from the cores, that are important for tortoise ecology. These were classified as destination areas. We hand selected these areas and used a similar method as for MGS. We buffered each of these points 300,000 cost-distance meters. Hence, we used the Desert Tortoise resistance surface, which ranges from 1-10,000. So 100 m at the lowest resistance would be a cost distance of 100, and of the highest resistance would be a cost distance of 1,000,000. Hence observations in really high quality habitat, according to the species distribution model and/or the input resistance surface basemap, result in a relatively large area node. Observations in poor habitat will have a small area node.

These two types of nodes were combined into a single layer, with all the source corea areas given an “expert core area value” of 1, and the destination areas an “expert core area value” of 0. This factor was included in the linkage mapper algorithm, thereby given higher value to linkages that connect two source cores rather than a source core and a destination. Linkages connecting two destinations got the least weight for this criterion. (In future iterations, ecav can be a function of the density of observations.)

Climate Inputs

Climate Stability

First, we used California Climate Exposure (Ensemble), 2046-2075. This is the change in predicted climate variables (aggregated to a single score) for every place on the landscape from what is "normal" (i.e. the climate there from 1971- 2000) compared to the future (the average from 2046-2075).

This product was normalized such that the highest value on the landscape becomes a 1, the lowest value becomes a 0, and all others scale linearly. Then the product was inverted, such that the 1 becomes a 0, and vice versa. We chose the name "Climate Stability" instead of inverted Climate Exposure. This normalized raster layer can be viewed here.

Physical Refugia

The following Input data (and methods) were combined according to this logic model (press download or view if it pops up pixelated): Terrain ruggedness, Solar radiation, Riparian vegetation, Waterbodies, Distance to water, and Spring locations.

The EEMS enabled vector coverage is viewable here.

The product was converted to raster using field: Physical_Refugia_Union_Wtd_Quarters_Fz and then normalized such that the highest value became 1, the lowest 0, and all other values scaled accordingly. This normalized raster layer can be viewed here.

Note, we combined the above two in an evenly weighted sum to get the Climate Refugia Value layer used as the input in Linkage Priority Tool.

Climate Signature

The climatic water deficit of the California Basin Characteristics model was used as an input. Climatic water deficit is potential evapotranspiration minus actual evapotranspiration. Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Potential evapotranspiration (PET) is how high this sum would be if there was unlimited water available from the plants and soil. Hence, hot, dry areas have a higher PET than ET, and thus, get a high cwd. This metric integrates precipitation and temperature climate variables. The way this is used is described in the linkage priority mapper algorithm is described below.

Additional West Mojave Results

Results from the Four Structural Connectivity Analyses

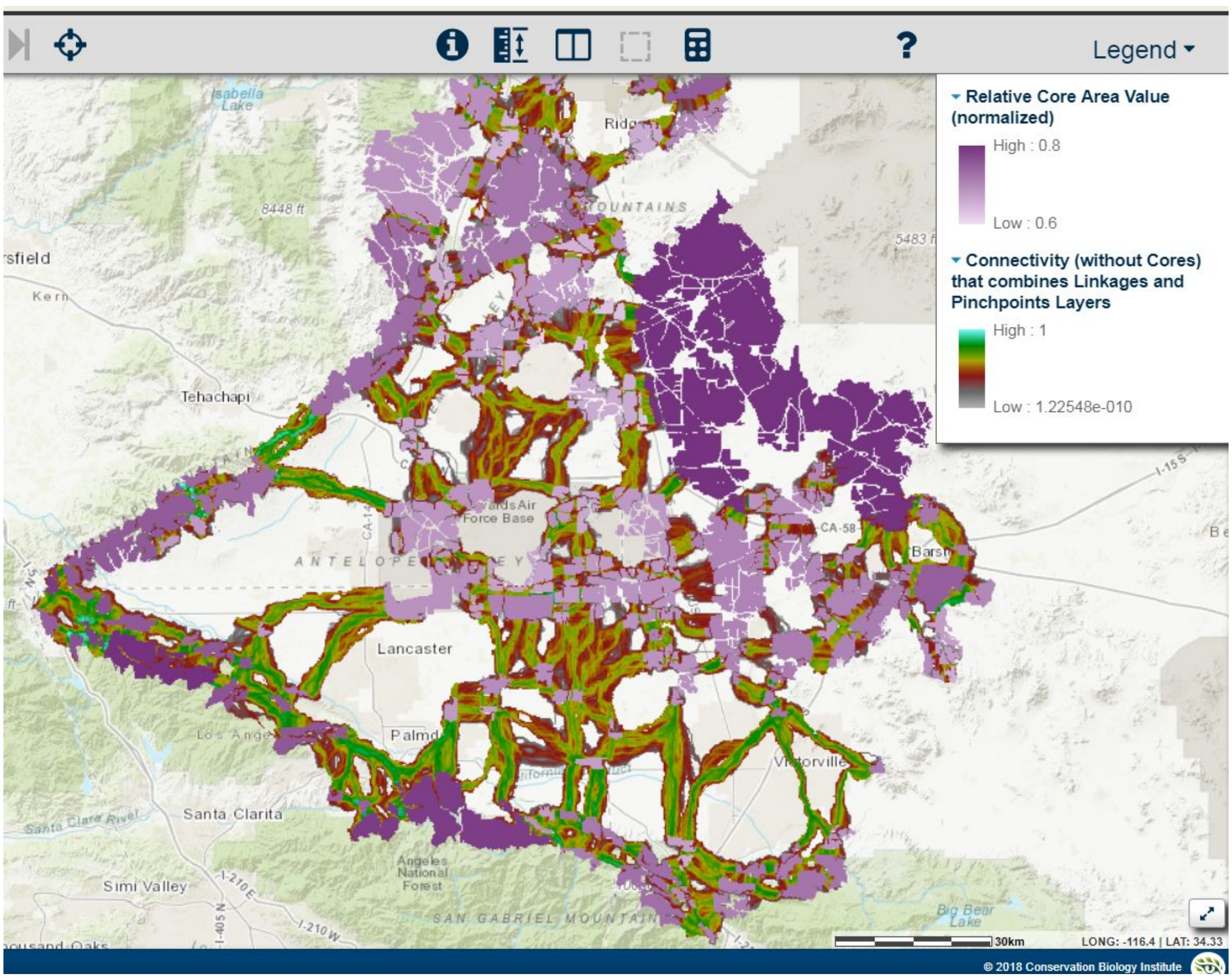

Figure 25: Structural Connectivity for the Small Species & Climate-wise Typology, Western Mojave

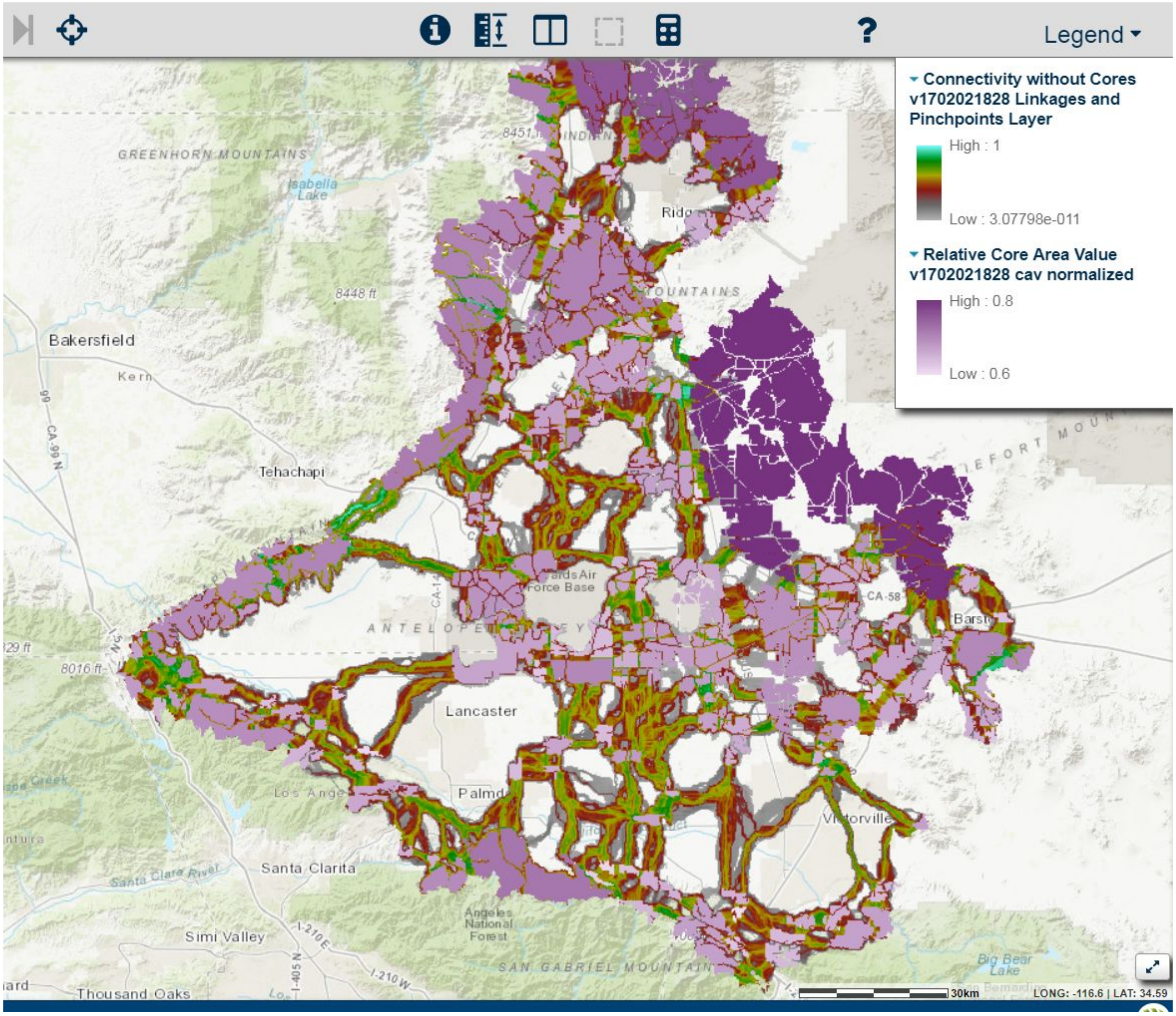

Figure 26: Optional: Show the [Small Species Dispersal Structural Connectivity Output]()

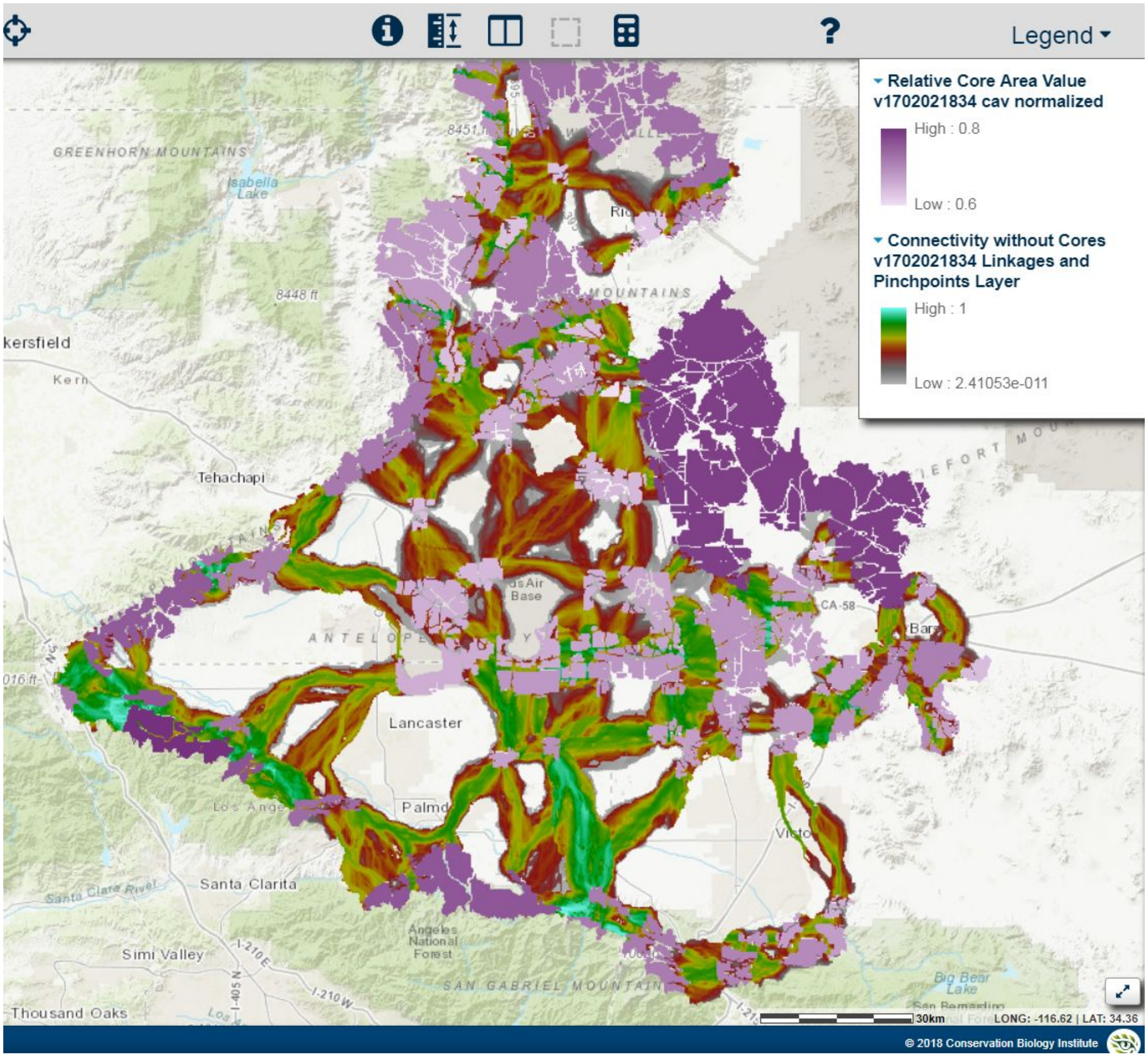

Figure 27: Structural Connectivity for the Large Species & Climate-wise Typology

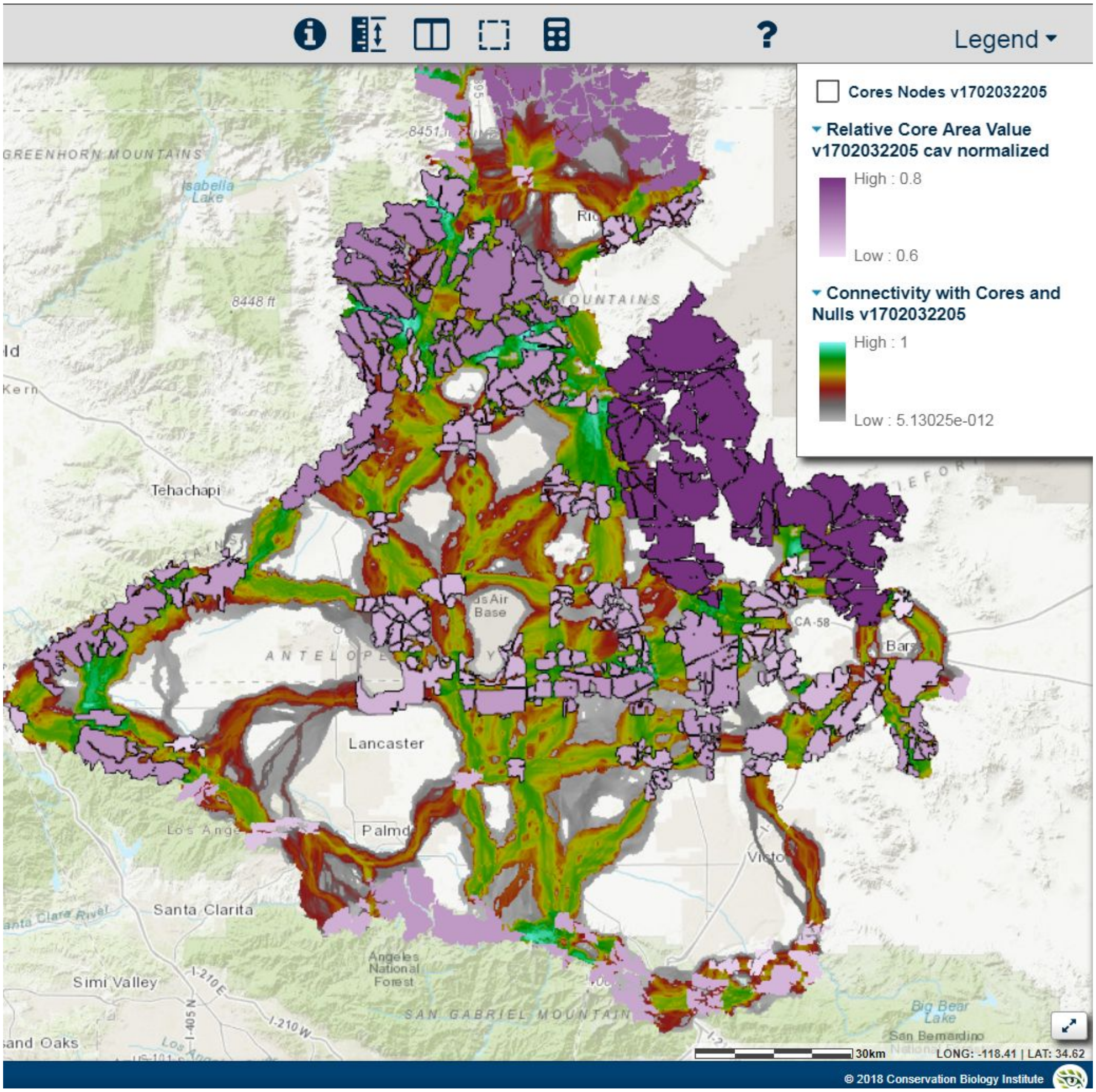

Figure 28: Structural Connectivity for the Large Species & Dispersal Typology

In addition to the results displayed above, additional West Mojave results are in the Outputs Folder on Data Basin (you may need to scroll down the page). The parameter values are in Appendix D.

Results from the Focal Species Connectivity Analyses

Here are the climate-wise results for the two focal species.

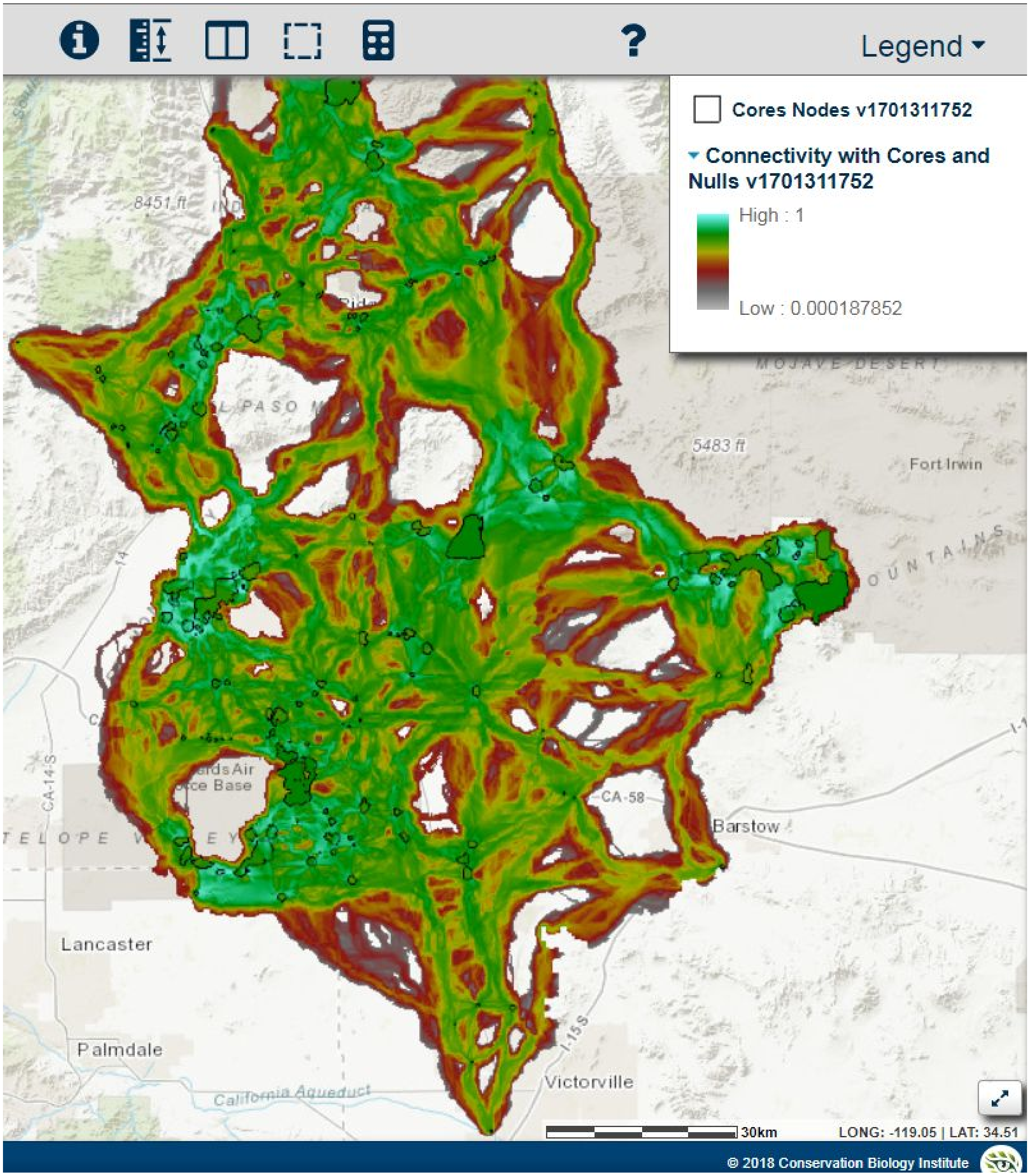

Figure 29 Mojave Ground Squirrel, Climate-wise Results.

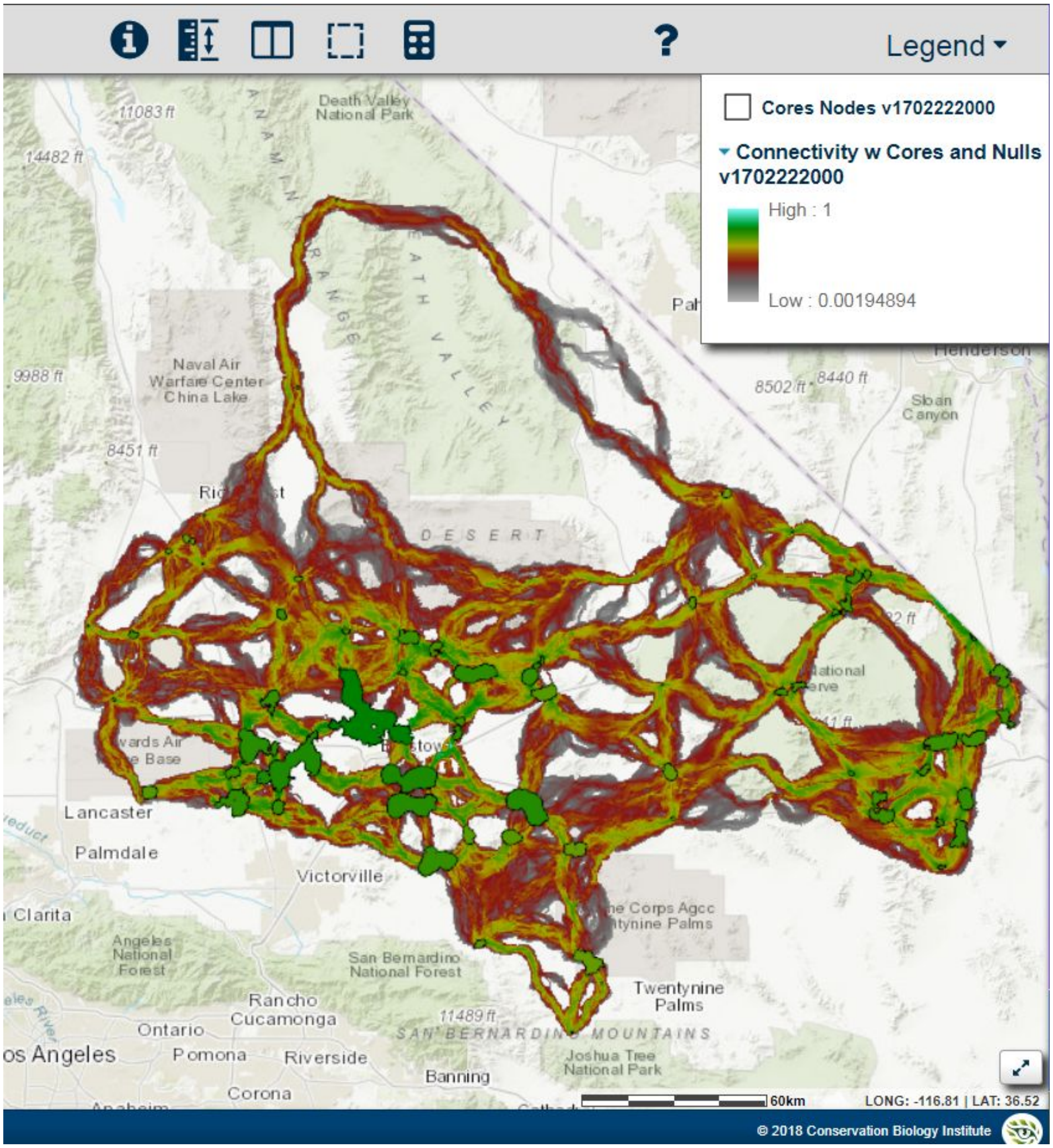

Figure 30 [Desert Tortoise Connectivity, Climate-wise]()

Appendix C: Additional Methods and Results for the Sacramento Valley

Resistance Surfaces

Structural Connectivity Resistance Surfaces

The two structural connectivity resistance surfaces for the Sacramento were created very similarly to the Modoc resistance surfaces, except they made two additional assumptions. First, they assumed that when roads cross over creeks or rivers, there is usually an overpass of some sort that most animals often pass under. Hence, these cells were mapped with less resistance (0.4 times) than the road cells to either side of the underpass. Here is the layer of "underpasses" (i.e. bridges over water, excluding canals). Second, for two of the typologies, we assumed that some species find refuge in tree canopy cover in the valley floor. We assumed that if there are no other tree copses or stands around, then the copse in question is more valuable to species movement than if there are lots of copses or even a forest around. The Canopy Cover "Stepping Stone" layer methods are summarized in the resistance surface logic model, provided in small print in Figure 31, with a more legible online online version of the resistance surface logic model provided here.

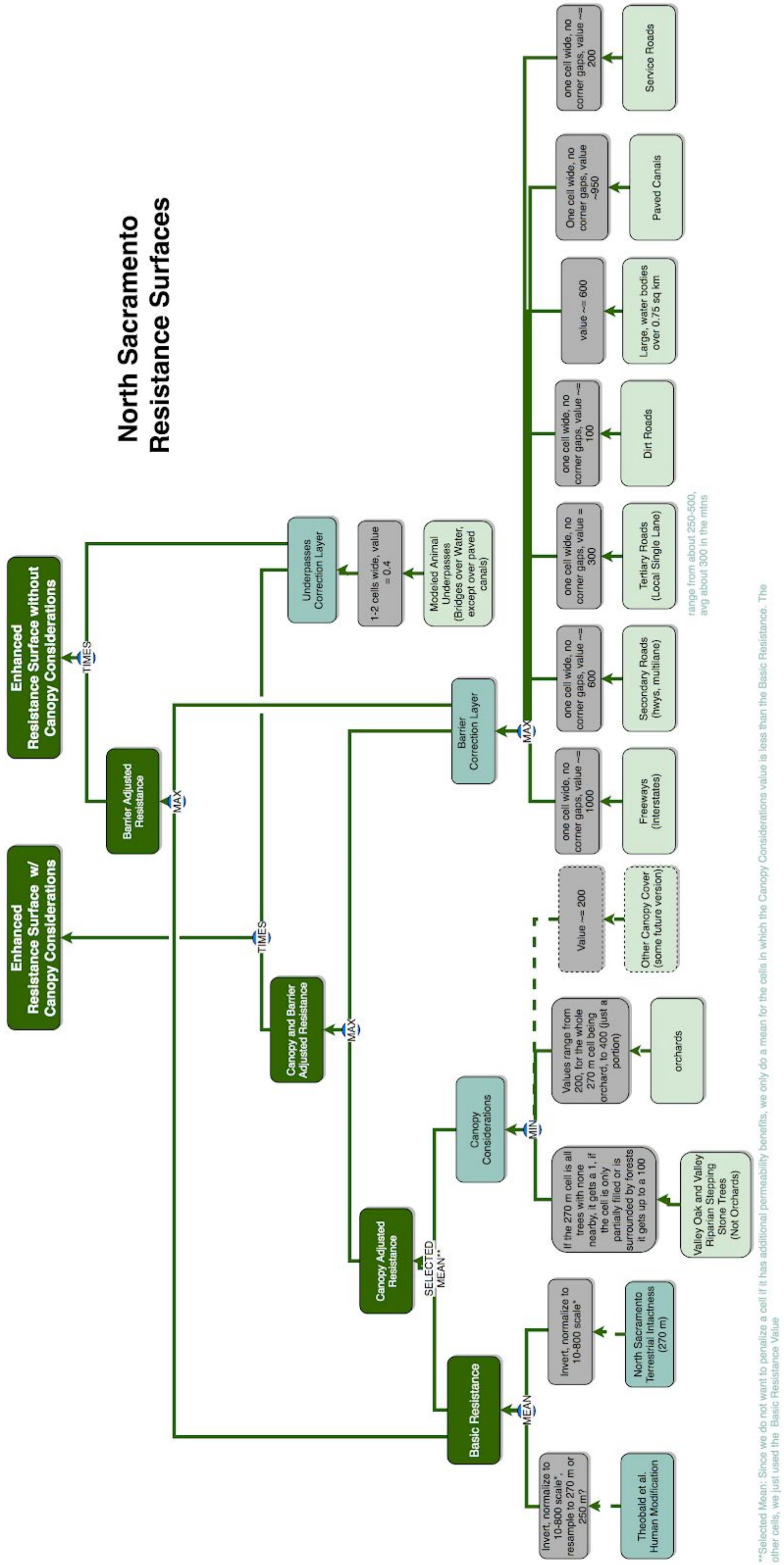

Figure 31 This is an overview logic model.

(Note: We tried using culverts, but found that they were not consistently digitized throughout the study area. Some long roads had no culvert data.) As of now, the lower value of the resistance surface is 10 (with a maximum of 1000). If additional data is gathered in the future that can classify extra high quality habitat, then these values can range from 1-10 and be combined into these resistance surfaces.

For the Sacramento Valley results, ***all resistance surfaces are mapped along with the results for that particular focal species or structural connectivity typology.***

For example, Connectivity for the “Large, Canopy preferring Species” Typology includes the following (Figure 32) if the pre-loaded sub-layers are turned off and Resistance is turned on:

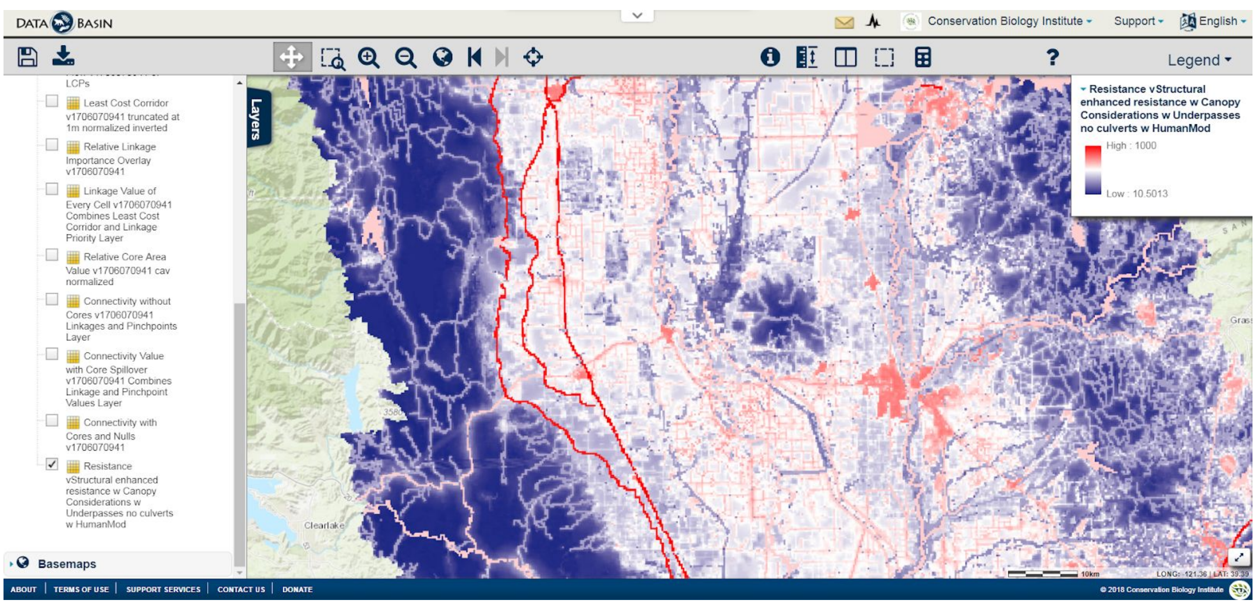

Figure 32 Enhanced Resistance Surface with Canopy Considerations

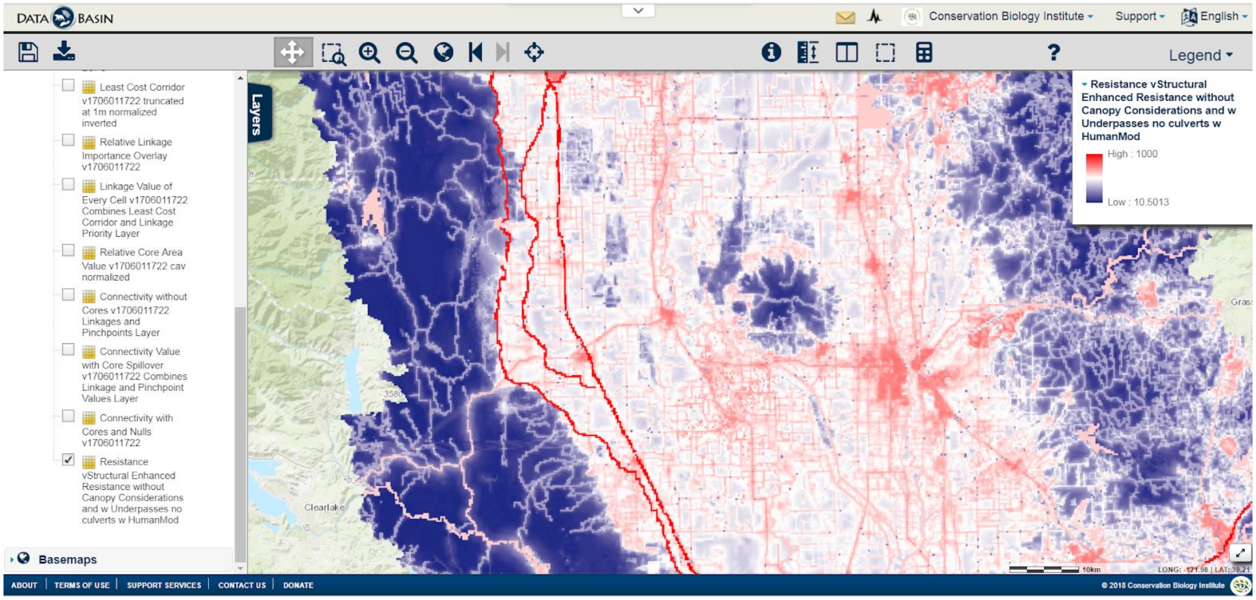

Figure 33 Enhanced Resistance Surface without Canopy Considerations

Focal Species Resistance Surfaces

Bobcat

Enhanced Resistance without canopy considerations was used. It was rescaled to 1-1000, then multiplied by 0.001, so it spanned from ~0 to 1. The Bobcat California Wildlife Habitat Relationship model (CWHR), was also scaled to 0-1. These two were multiplied, and the result was rescaled linearly to range from 10-1000.

Badger

Enhanced Resistance without canopy considerations was used. The Badger CWHR was scaled to 0-1 then rescaled linearly to range from 10-1000. The mean value of these two layers was used.

Mule Deer

Enhanced Resistance with canopy considerations was used. The Mule Deer species distribution model (SDM) was aggregated to 270 m cells, scaled to 0-1 then rescaled linearly to range from 10-1000. The mean value of these two layers was used.

Tule Elk

The Tule Elk Species Distribution Model obtained from Patrick Huber was rescaled linearly to 10-1000, and combined using a mean with the Enhanced Resistance with Canopy Considerations.

Core Areas

All core areas are mapped along with the results for that particular focal species or structural connectivity typology.

Structural Connectivity Nodes (i.e. "Cores")

Nodes for the large species typology (not considering canopy structure)

To identify the nodes, the resistance surface was first smoothed slightly, taking the mean value of a circle of 3 cell radius around each cell, and giving it that value. Then, all cells under 400 were selected. Also, all cells less than 400 of the original (non-smoothed) resistance surface were selected. The two results were combined in a union. The resulting areas that were greater than 800 ha (1976 acre) were then selected. (Note: this typology is sometimes referred to in Data Basin as "open habitat preferring species typology", but this is a slight misnomer, as it is only in comparison to the canopy preferring typology.)

Nodes for the small species typology (not considering canopy structure)

To identify these nodes, the same methods were used as for large species, except the final selection was for all areas greater than 100 ha (247 ac) instead ot 800 ha. This is because smaller species need less high quality habitat to form a viable metapopulation.

Nodes for the large species, canopy preferring typology

This method was started by mirroring the one for large species, except that it used the resistance surface that assumed canopy structure (e.g. riparian forest) had lower resistance to movement than open habitat, all else being equal. But since these high canopy cover areas ended up with a lower resistance value, the method yielded a set of nodes with a much higher mean area. In order to make the nodes about the same sizes as the non-canopy preferring typology, all unioned cell less than a value of 300 were selected, not 400.[1] The resulting areas that were greater than 800 ha (1976 acre) were then selected.

Nodes for the small species, canopy preferring typology

To identify these nodes, the same methods were used as the large species, canopy preferring typology, except the final selection was for all areas greater than 100 ha (247 ac).

Focal Species Core Areas

Bobcat Core Areas

[1] In future applications, if more similar outputs are desired, then using

The Bobcat resistance surface intermediate product that ranged from 0-1 was selected to include only values greater than or equal to 0.3. Then the resulting areas greater than 6 sq. km were selected.

Badger Core Areas

The Badger CWHR was scaled to 0-1, and all areas greater than 0.66 were selected. All areas greater or equal to 5 km^2 were then selected.

Mule Deer Core Areas

The Mule Deer Species Distribution Model was smoothed slightly to assign each cell the mean value of all cells within a 3 cell radius. Then this surface was normalized to range from 0 to 1. Then all cells greater than 0.15 were selected. Then all resulting polygons greater than or equal to 5 sq. km were selected.

Tule Elk Core Areas

Suitable Tule Elk core areas obtained from Patrick Huber were combined in a simple union with the known Tule Elk areas obtained from CDFW. Source data may be available upon request.

Other Focal Species

Giant Garter Snake and Red Fox

These species were also modeled but due to time constraints were not finalized nor integrated with the other four focal species. They were not required by the client or the contract. But they may be useful for biodiversity conservation and their methods, inputs, and results may be available upon request, depending on time availability.

Additional Results for the Typologies and Focal Species

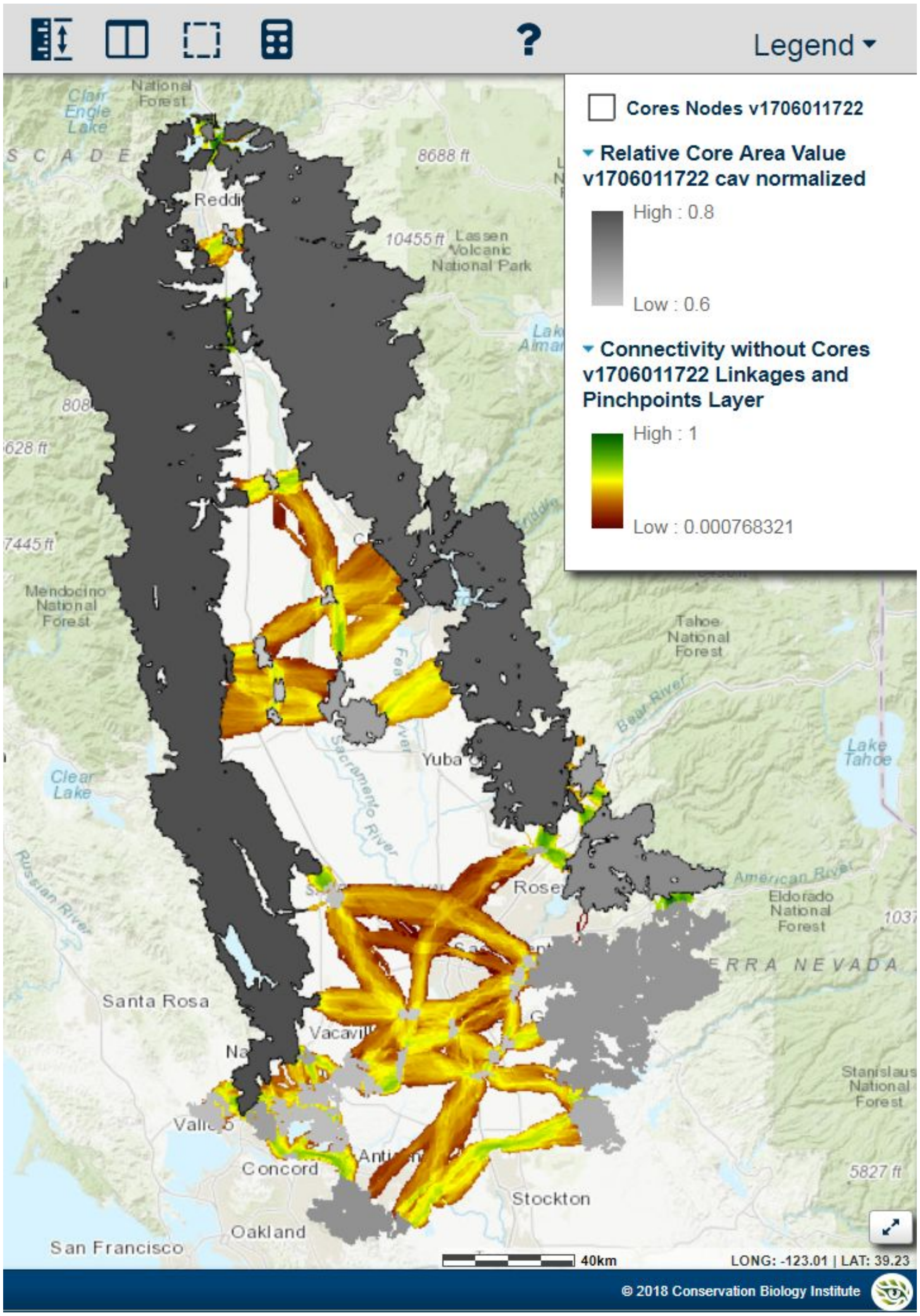

Figure 34: Large, Open Habitat Preferring Species (Climate-wise)

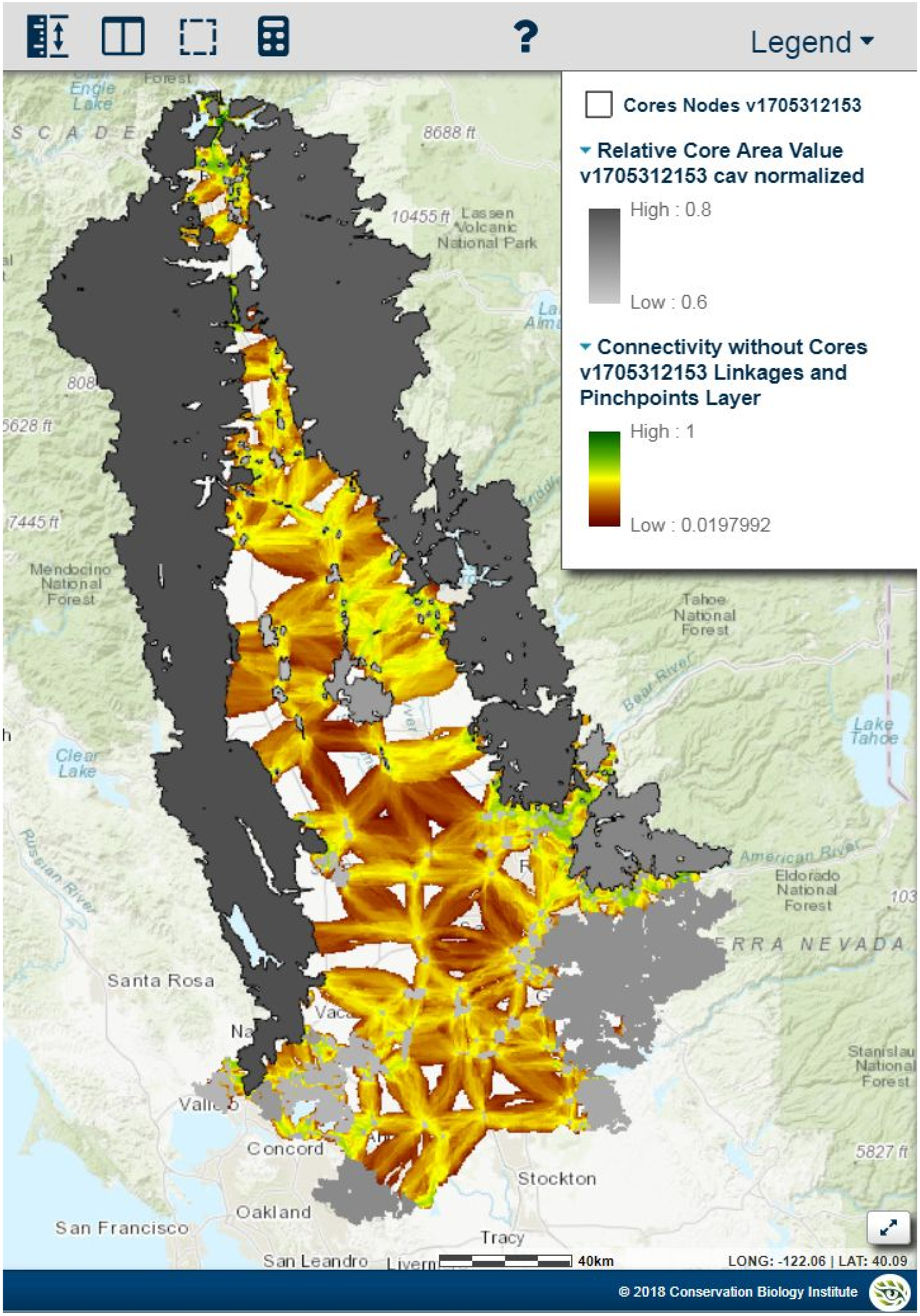

Figure 35: [“Small, Open Habitat Preferring Species” Typology (Climate-wise)]

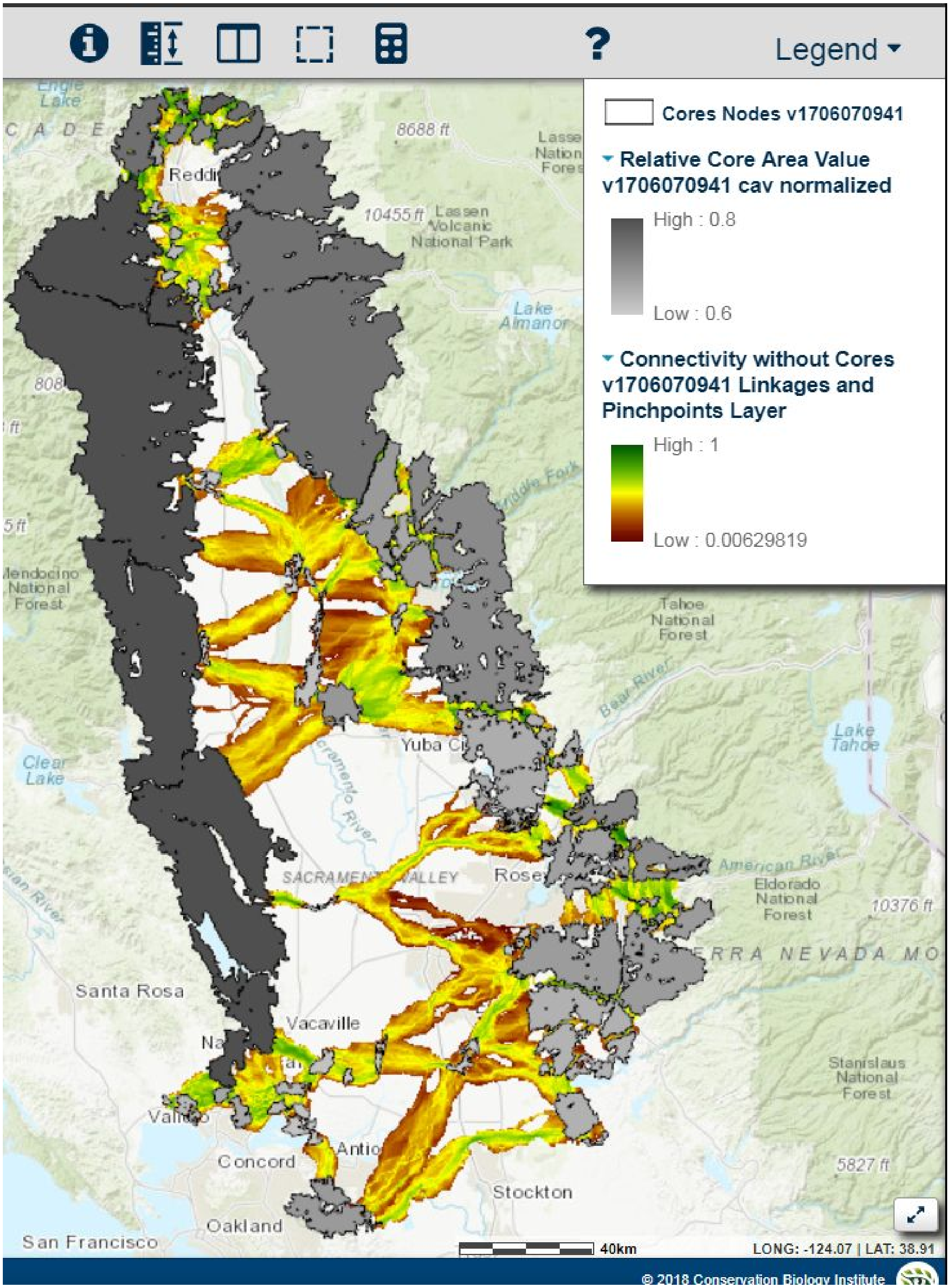

Figure 36: Connectivity for the "Large, Canopy preferring Species" Typology (Climate-wise)

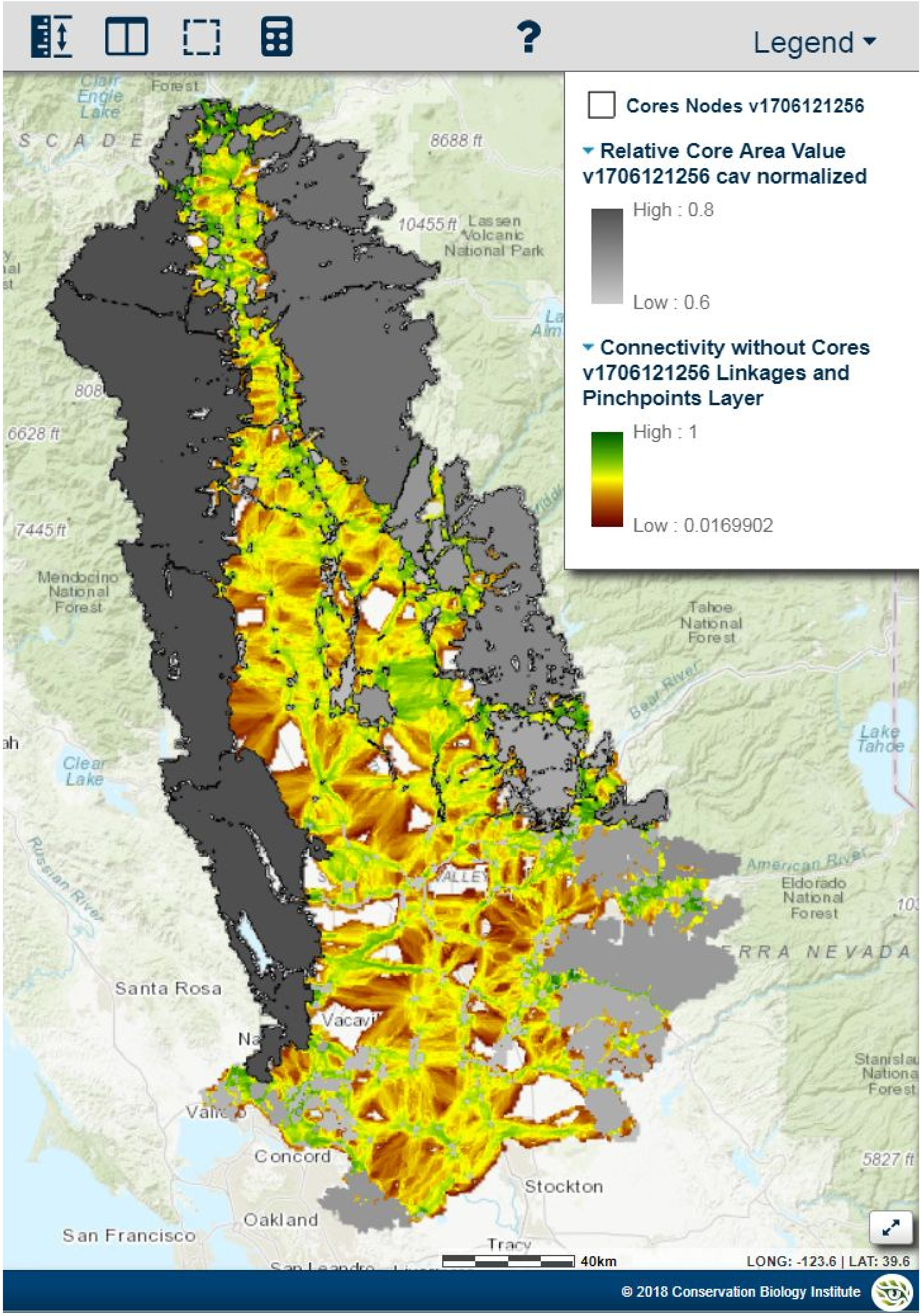

Figure 37: “Small, Canopy Preferring Species” Typology Connectivity (Climate-wise)

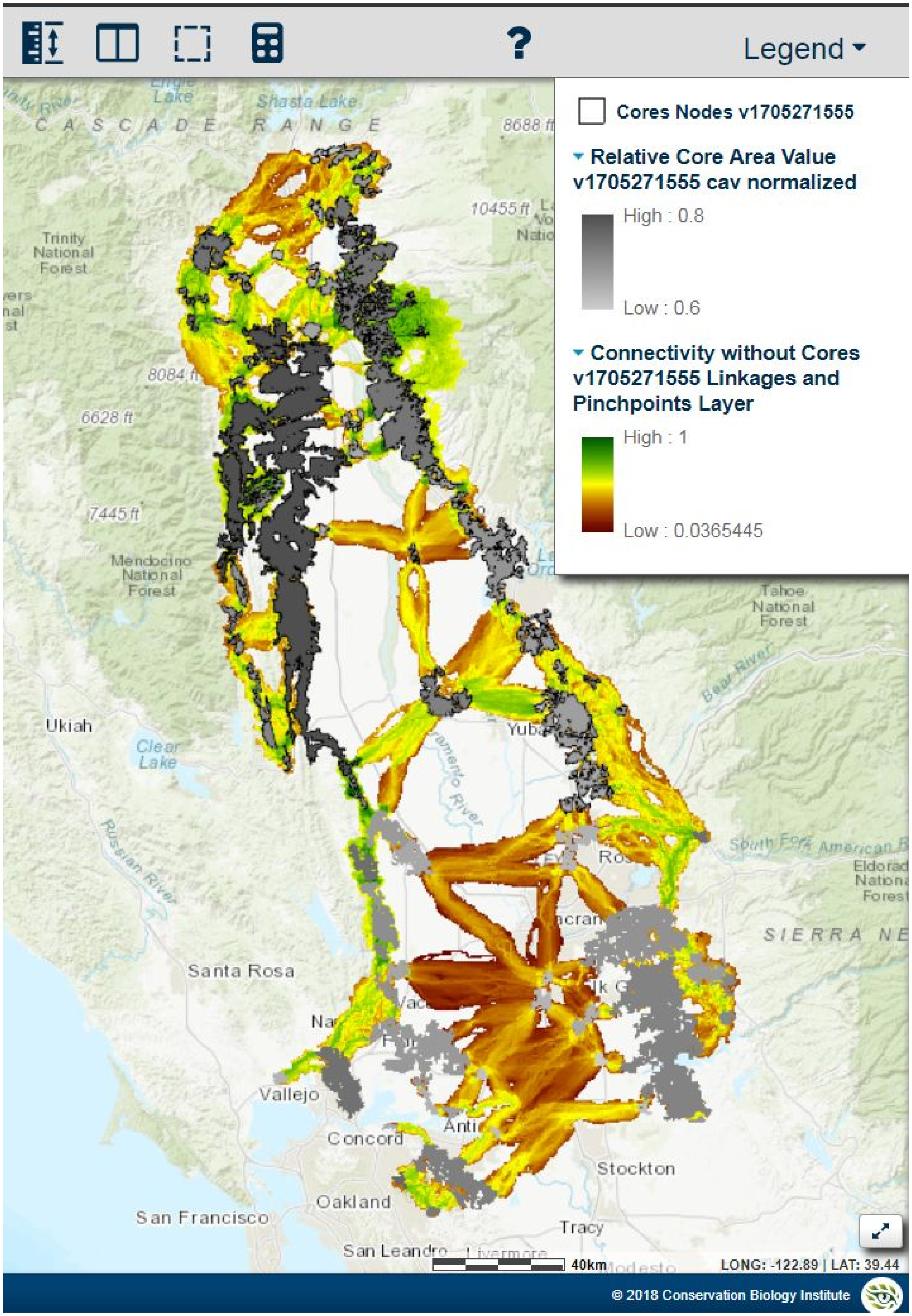

Figure 38: [Badger Connectivity (Climate-wise)]()

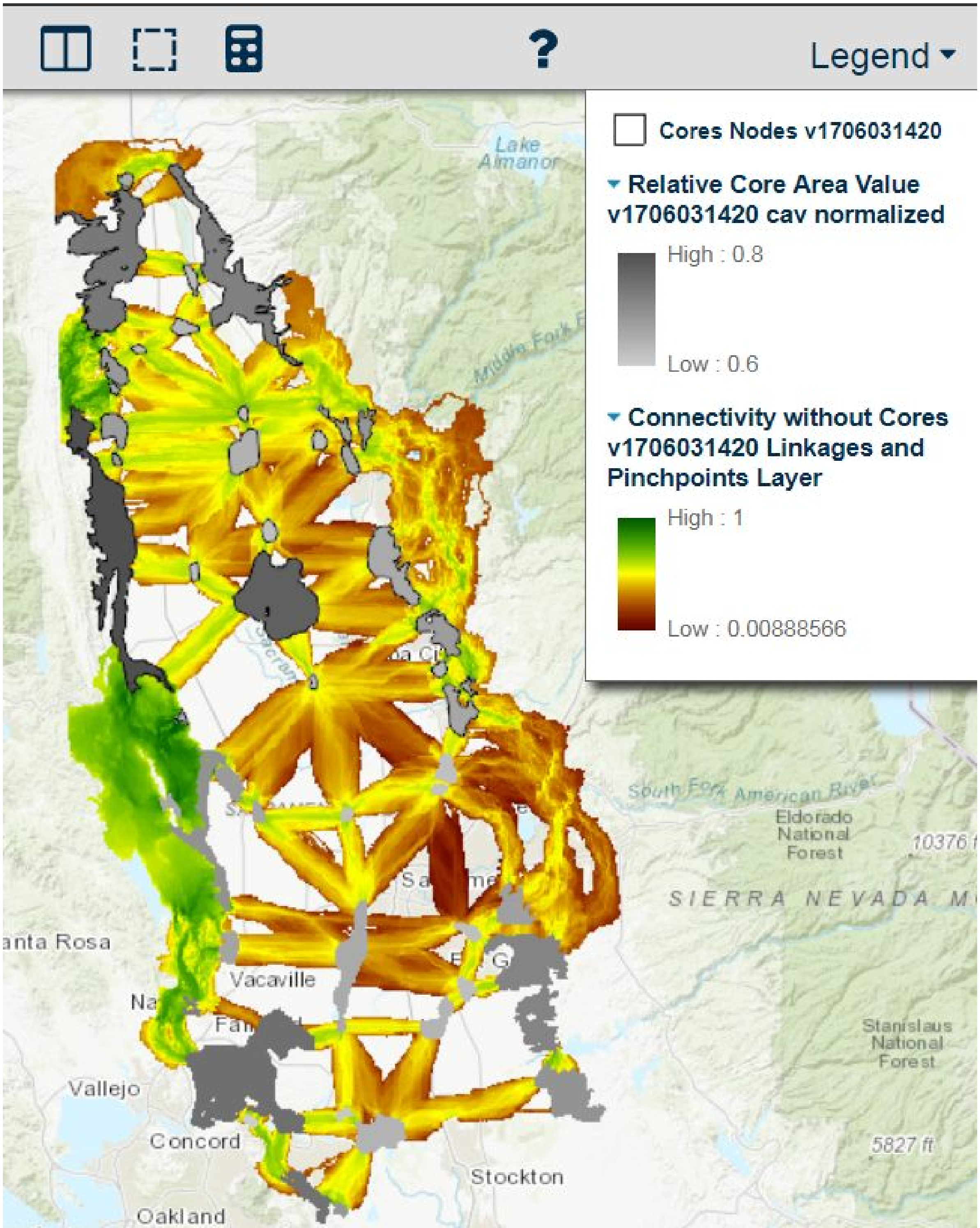

Figure 39: Mule Deer Connectivity (Climate-wise)

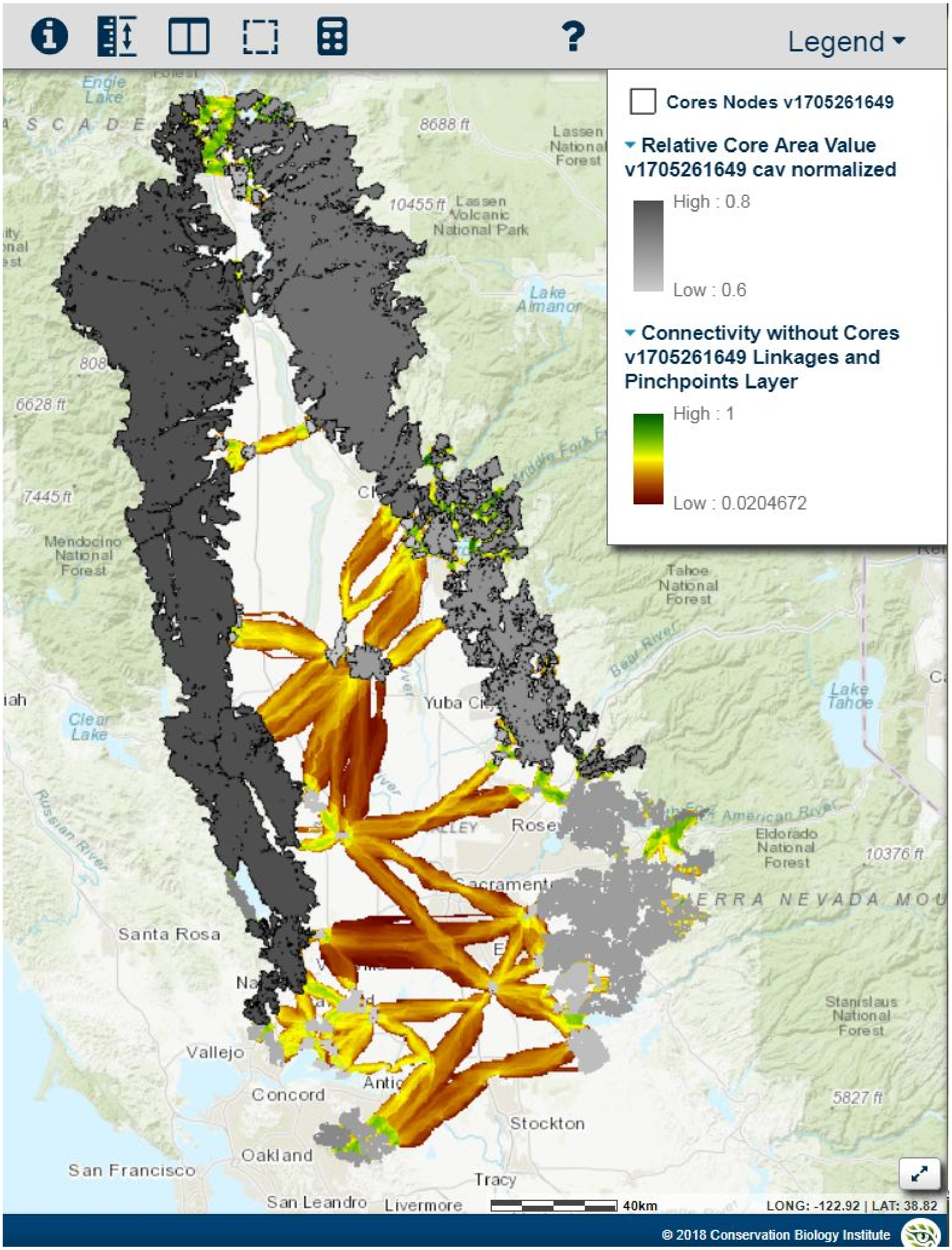

Figure 40: Bobcat Connectivity (Climate-wise)

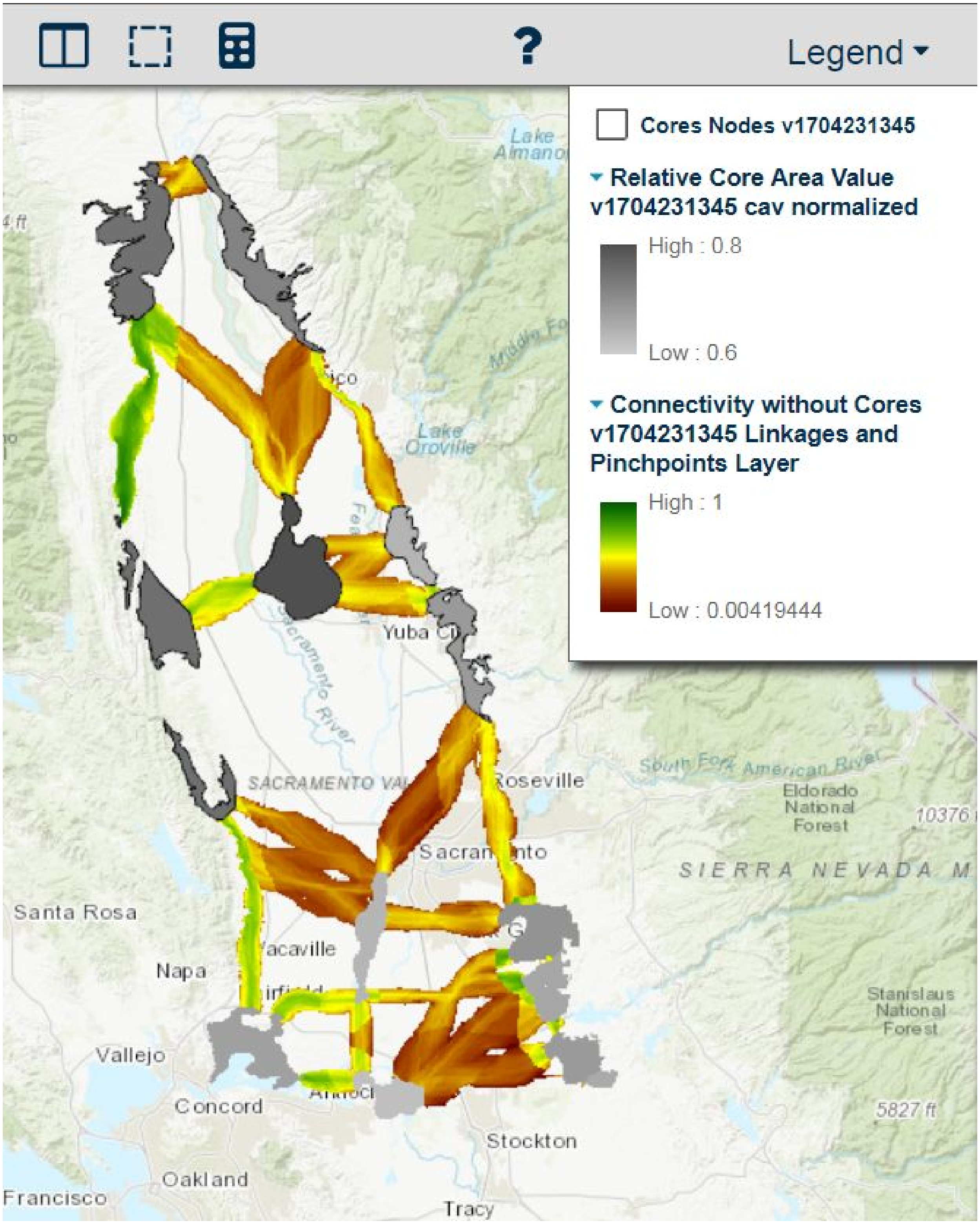

Figure 41: Tule Elk Connectivity (Climate-wise)

Appendix D: Key Parameter Values Used

Key parameter values used for the three studies are on the table in the following pages. The google spreadsheet is more legible and available here, and the temporary .pdf is slightly higher quality and is here.

Parameter Short Description	Parameter Short Name	Structural, Climate, All	Structural, Large, Demographic	Structural, Small, Demographic	Structural, Large, Climate	Structural, Small, Climate	Desert Tortoise, Demographic	Mojave Ground Squirrel, Demographic
Region	(Not a parameter)	Modoc Plateau	West Mojave	West Mojave	West Mojave	West Mojave	West Mojave	West Mojave
Connectivity Run Version #. Of when parameter is named, not necessarily when it was created.	VERSION	JB_MDC_v008	1702032205	1702021828	1702021834	1702021821	1702211726	1701311750
Mosiac non-normalized LCCs in step 5 (Boolean- set to True or False)	CALCNONNORMLCCS	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Truncate mosaic corridor raster at an upper limit, i.e., use width cutoff. (Boolean- set to True or False)	WRITETRUNCRASTER	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
CWD corridor width cutoff to use in truncated raster (Integer)	CWDTHRESH	650000	750000	750000	750000	750000	1000000	750000
Minimum cost distance- any corridor shorter than this will not be mapped (Integer)	MINCOSTDIST	None	None	None	None	None	None	None
Minimum euclidean distance- any core areas closer than this will not be connected (Integer)	MINEUCDIST	None	None	None	None	None	None	None
Save inidvidual normalized LCC grids, not just mosaic (Boolean- set to True or False)	SAVENORMLCCS	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Simplify cores before calculating distances,(Boolean),	SIMPLIFY_CORES	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
minimum relative permeability value (use 0 to keep all)	MINRELPERM	0	0	0	0	0	0	0
relative closeness weight in CSPWS calculation (this plus following three weights should sum to 1)	CLOSEWEIGHT	0.1	0.039	0.039	0.039	0.039	0.1	0.1
relative permeability weight in CSPWS calculation	PERMWEIGHT	0.266	0.32	0.32	0.24	0.24	0.3	0.3
relative corridor value weight in CSPWS calculation (should be non-zero I beleive)	CORRWEIGHT	0.002	0.001	0.001	0.001	0.001	0.001	0.001
relative core area value weight in CSPWS calculation	CAVWEIGHT	0.266	0.32	0.32	0.24	0.24	0.3	0.3
relative other corridor importance value weight in CSPWS calculation	OCIVWEIGHT	0.1	0.32	0.32	0.24	0.24	0.299	0.299
relative climate envelope difference weight in CSPWS calculation	CEDWEIGHT	0.266	0	0	0.24	0.24	0	0
proportion of top CSPWS values to keep (use 1 to keep all)	PROPCSPWSKEEP	0.012	0.01	0.01	0.01	0.01	0.03	0.02
relative max CSPWS value weight in CPV calculation	MAXCSPWSWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5	0.5
relative mean CSPWS value weight in CPV calculation	MEANCSPWSWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5	0.5
relative ECIV weight in OCIV calculation (Add an ECIV layer in the optional input)	ECIVWEIGHT	0.5	0	0	0	0	0	0
relative Current Flow Centrality (CFC) weight in OCIV calculation	CFCWEIGHT	0.5	1	1	1	1	1	1
ignore setting in Step 4 for Number of Connected Nearest Neighbours	IGNORES4MAXNN	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
minimum raw permeability value (use 0 to keep all)	MINRAWPERM	0	0	0	0	0	0	0
relative permeability normalization method(use 0 for score range normalization, 1 for max value norm)	RELPERMNORMETH	0	0	0	0	0	0	0
relative closeness value normalization method (use 0 for score range normalization; any other value for maximum value normalization)	RELCLOSENORMETH	0	0	0	0	0	0	0
calculate relative corridor importance; be sure to set SAVENORMLCCS	CALCRCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
normalized corridor normalization method (use 0 for score range normalization, 1 for max value norm)	NORMCORRNORMETH	0	0	0	0	0	0	0
resistance normalization method (use 0 for score range; 1 for maximum value normalization)	RESNORMETH	1	1	1	1	1	1	1
size normalization method (use 0 for score range; 1 for maximum value normalization)	SIZENORMETH	1	1	1	1	1	1	1
area/perimeter ratio normalization method (use 0 for score range; 1 for maximum value normalization)	APNORMETH	1	1	1	1	1	1	1
ecav normalization method (use 0 for score range; 1 for maximum value normalization)	EVACNORMETH	1	1	1	1	1	1	1
resistance weight in CAV calculation (this plus following two weights should sum to 1)	RESWEIGHT	0.35	0.45	0.45	0.32	0.32	0.4	0.4
size weight in CAV calculation	SIZEWEIGHT	0.15	0.45	0.45	0.32	0.32	0.3	0.4
area/perimeter ratio weight in CAV calculation	APWEIGHT	0.15	0.1	0.1	0.04	0.04	0.1	0.2
expert core area value weight in the CAV calculation	ECAVWEIGHT	0	0	0	0	0	0.2	0
Other Core area value weight in the CAV Calculation	OCAVWEIGHT	0.35	0	0	0.32	0.32	0	0
minimum corridor priority value (use 0 to keep all)	MINCPV	0	0	0	0	0	0	0
normalize RCI	NORMALIZERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
truncated raster normalization method (use 0 for score range normalization, 1 for max value norm)	TRUNCNORMETH	0	0	0	0	0	0	0
calculate edited and partially edited RCIs	CALCPERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
normalize ERCI	NORMALIZEERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
truncated corridors weight in PERCI calculation (this plus following weight should sum to 1)	TCWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5	0.5
ERCI weight in PERCI calculation	ERCIWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5	0.5
normalize PERCI	NORMALIZEPERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
keep intermediate outputs for troubleshooting purposes	KEEPINTERMEDIATE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE

Parameter Short Description	Parameter Short Name	Structural, Climate, w/canopy, smaller cores	Structural, Climate, w/canopy, larger cores	Structural, Climate, w/o canopy, large species	Structural, Climate, w/o canopy, small species	Bobcat, Climate	Tule Elk, Climate
Region	(Not a parameter)	"Sac Valley"	"Sac Valley"	"Sac Valley"	"Sac Valley"	"Sac Valley"	"Sac Valley"
Connectivity Run Version #. Of when parameter is named, not necessarily when it was created.	VERSION	1706121256	1706070941	1706011722	1705312153	1705261649	1704231345
Mosiac non-normalized LCCs in step 5 (Boolean- set to True or False)	CALCNONNORMLCCS	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Truncate mosaic corridor raster at an upper limit, i.e., use width cutoff. (Boolean- set to True or False)	WRITETRUNCRASTER	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
CWD corridor width cutoff to use in truncated raster (Integer)	CWDTHRESH	1000000	1000000	1000000	1000000	1000000	1000000
Minimum cost distance- any corridor shorter than this will not be mapped (Integer)	MINCOSTDIST	None	None	None	None	None	None
Minimum euclidean distance- any core areas closer than this will not be connected (Integer)	MINEUCDIST	None	None	None	None	None	None
Save inidvidual normalized LCC grids, not just mosaic (Boolean- set to True or False)	SAVENORMLCCS	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Simplify cores before calculating distances,(Boolean),	SIMPLIFY_CORES	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
minimum relative permeability value (use 0 to keep all)	MINRELPERM	0	0	0	0	0	0
relative closeness weight in CSPWS calculation (this plus following three weights should sum to 1)	CLOSEWEIGHT	0.1	0.1	0.1	0.1	0.039	0.1
relative permeability weight in CSPWS calculation	PERMWEIGHT	0.225	0.225	0.225	0.225	0.5	0.225
relative corridor value weight in CSPWS calculation (should be non-zero I beleive)	CORRWEIGHT	0.001	0.001	0.001	0.001	0.001	0.001
relative core area value weight in CSPWS calculation	CAVWEIGHT	0.225	0.225	0.225	0.225	0.16	0.225
relative other corridor importance value weight in CSPWS calculation	OCIVWEIGHT	0.224	0.224	0.224	0.224	0.15	0.224
relative climate envelope difference weight in CSPWS calculation	CEDWEIGHT	0.225	0.225	0.225	0.225	0.15	0.225
proportion of top CSPWS values to keep (use 1 to keep all)	PROPCSPWSKEEP	0.03	0.03	0.02	0.02	0.03	0.03
relative max CSPWS value weight in CPV calculation	MAXCSPWSWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5
relative mean CSPWS value weight in CPV calculation	MEANCSPWSWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5
relative ECIV weight in OCIV calculation (Add an ECIV layer in the optional input)	ECIVWEIGHT	0	0	0	0	0	0
relative Current Flow Centrality (CFC) weight in OCIV calculation	CFCWEIGHT	1	1	1	1	1	1
ignore setting in Step 4 for Number of Connected Nearest Neighbours	IGNORES4MAXNN	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
minimum raw permeability value (use 0 to keep all)	MINRAWPERM	0	0	0	0	0	0
relative permeability normalization method(use 0 for score range normalization, 1 for max value norm)	RELPERMNORMETH	0	0	0	0	0	0
relative closeness value normalization method (use 0 for score range normalization; any other value for maximum value normalization)	RELCLOSENORMETH	0	0	0	0	0	0
calculate relative corridor importance; be sure to set SAVENORMLCCS	CALCRCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
normalized corridor normalization method (use 0 for score range normalization, 1 for max value norm)	NORMCORRNORMETH	0	0	0	0	0	0
resistance normalization method (use 0 for score range; 1 for maximum value normalization)	RESNORMETH	1	1	1	1	1	1
size normalization method (use 0 for score range; 1 for maximum value normalization)	SIZENORMETH	1	1	1	1	1	1
area/perimeter ratio normalization method (use 0 for score range; 1 for maximum value normalization)	APNORMETH	1	1	1	1	1	1
ecav normalization method (use 0 for score range; 1 for maximum value normalization)	EVACNORMETH	1	1	1	1	1	1
resistance weight in CAV calculation (this plus following two weights should sum to 1)	RESWEIGHT	0.32	0.32	0.3	0.3	0.3	0.3
size weight in CAV calculation	SIZEWEIGHT	0.32	0.32	0.25	0.25	0.25	0.25
area/perimeter ratio weight in CAV calculation	APWEIGHT	0.04	0.04	0.1	0.1	0.1	0.1
expert core area value weight in the CAV calculation	ECAVWEIGHT	0	0	0.2	0.2	0.2	0.2
Other Core area value weight in the CAV Calculation	OCAVWEIGHT	0.32	0.32	0.2	0.2	0.2	0.2
minimum corridor priority value (use 0 to keep all)	MINCPV	0	0	0	0	0	0
normalize RCI	NORMALIZERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
truncated raster normalization method (use 0 for score range normalization, 1 for max value norm)	TRUNCNORMETH	0	0	0	0	0	0
calculate edited and partially edited RCIs	CALCPERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
normalize ERCI	NORMALIZEERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
truncated corridors weight in PERCI calculation (this plus following weight should sum to 1)	TCWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5
ERCI weight in PERCI calculation	ERCIWEIGHT	0.5	0.5	0.5	0.5	0.5	0.5
normalize PERCI	NORMALIZEPERCI	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
keep intermediate outputs for troubleshooting purposes	KEEPINTERMEDIATE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE

Parameter Short Description	Parameter Short Name	Deer, Climate	Badger, Climate
Region	(Not a parameter)	"Sac Valley"	"Sac Valley"
Connectivity Run Version #. Of when parameter is named, not necessarily when it was created.	VERSION	1706031420	1705271555
Mosiac non-normalized LCCs in step 5 (Boolean- set to True or False)	CALCNONNORMLCCS	FALSE	FALSE
Truncate mosaic corridor raster at an upper limit, i.e., use width cutoff. (Boolean- set to True or False)	WRITETRUNCRASTER	TRUE	TRUE
CWD corridor width cutoff to use in truncated raster (Integer)	CWDTHRESH	1000000	1000000
Minimum cost distance- any corridor shorter than this will not be mapped (Integer)	MINCOSTDIST	None	None
Minimum euclidean distance- any core areas closer than this will not be connected (Integer)	MINEUCDIST	None	None
Save inidvidual normalized LCC grids, not just mosaic (Boolean- set to True or False)	SAVENORMLCCS	TRUE	TRUE
Simplify cores before calculating distances,(Boolean),	SIMPLIFY_CORES	TRUE	TRUE
minimum relative permeability value (use 0 to keep all)	MINRELPERM	0	0
relative closeness weight in CSPWS calculation (this plus following three weights should sum to 1)	CLOSEWEIGHT	0.1	0.1
relative permeability weight in CSPWS calculation	PERMWEIGHT	0.225	0.225
relative corridor value weight in CSPWS calculation (should be non-zero I beleive)	CORRWEIGHT	0.001	0.001
relative core area value weight in CSPWS calculation	CAVWEIGHT	0.225	0.225
relative other corridor importance value weight in CSPWS calculation	OCIVWEIGHT	0.224	0.224
relative climate envelope difference weight in CSPWS calculation	CEDWEIGHT	0.225	0.225
proportion of top CSPWS values to keep (use 1 to keep all)	PROPCSPWSKEEP	0.02	0.02
relative max CSPWS value weight in CPV calculation	MAXCSPWSWEIGHT	0.5	0.5
relative mean CSPWS value weight in CPV calculation	MEANCSPWSWEIGHT	0.5	0.5
relative ECIV weight in OCIV calculation (Add an ECIV layer in the optional input)	ECIVWEIGHT	0	0
relative Current Flow Centrality (CFC) weight in OCIV calculation	CFCWEIGHT	1	1
ignore setting in Step 4 for Number of Connected Nearest Neighbours	IGNORES4MAXNN	TRUE	TRUE
minimum raw permeability value (use 0 to keep all)	MINRAWPERM	0	0
relative permeability normalization method(use 0 for score range normalization, 1 for max value norm)	RELPERMNORMETH	0	0
relative closeness value normalization method (use 0 for score range normalization; any other value for maximum value normalization)	RELCLOSENORMETH	0	0
calculate relative corridor importance; be sure to set SAVENORMLCCS	CALCRCI	TRUE	TRUE
normalized corridor normalization method (use 0 for score range normalization, 1 for max value norm)	NORMCORRNORMETH	0	0
resistance normalization method (use 0 for score range; 1 for maximum value normalization)	RESNORMETH	1	1
size normalization method (use 0 for score range; 1 for maximum value normalization)	SIZENORMETH	1	1
area/perimeter ratio normalization method (use 0 for score range; 1 for maximum value normalization)	APNORMETH	1	1
ecav normalization method (use 0 for score range; 1 for maximum value normalization)	EVACNORMETH	1	1
resistance weight in CAV calculation (this plus following two weights should sum to 1)	RESWEIGHT	0.32	0.32
size weight in CAV calculation	SIZEWEIGHT	0.32	0.32
area/perimeter ratio weight in CAV calculation	APWEIGHT	0.04	0.04
expert core area value weight in the CAV calculation	ECAVWEIGHT	0	0
Other Core area value weight in the CAV Calculation	OCAVWEIGHT	0.32	0.32
minimum corridor priority value (use 0 to keep all)	MINCPV	0	0
normalize RCI	NORMALIZERCI	TRUE	TRUE
truncated raster normalization method (use 0 for score range normalization, 1 for max value norm)	TRUNCNORMETH	0	0
calculate edited and partially edited RCIs	CALCPERCI	TRUE	TRUE
normalize ERCI	NORMALIZEERCI	TRUE	TRUE
truncated corridors weight in PERCI calculation (this plus following weight should sum to 1)	TCWEIGHT	0.5	0.5
ERCI weight in PERCI calculation	ERCIWEIGHT	0.5	0.5
normalize PERCI	NORMALIZEPERCI	TRUE	TRUE
keep intermediate outputs for troubleshooting purposes	KEEPINTERMEDIATE	TRUE	TRUE