

APPENDIX D: DETAILED MODELING METHODS

For this assessment, we used a novel complement of ensemble species distribution models (SDMs) and connectivity models linked with dynamic metapopulation models to advance connectivity planning accounting for climate change, land-use shifts, and uncertainty. Here, we describe the details of these three components of the modeling process.

The foundation of the modeling for this effort was species distribution models (SDMs), based largely on climatic-niche envelopes. SDMs allowed us to produce habitat suitability maps which we used to identify core habitat areas, assess landscape resistance for connectivity modeling, and assign patch values for metapopulation modeling. We developed ensemble SDMs for each focal species under historic conditions and then projected suitability, connectivity, and metapopulation persistence under four future climate scenarios to determine how and where connectivity may be able to help support persistence of biodiversity in the south coast ecoregion.

Climate Scenarios and Environmental Variables

To characterize habitat suitability for each of our five species, we used 90-m resolution environmental layers representing climate, impervious surfaces (land-use), stream density, and topography (Table C1). Historic climate variables were derived from 1971-2000 averaged Parameter-Elevation Regressions on Independent Slopes Model data (PRISM, Daly *et al.* 2006) and spatially downscaled to a Digital Elevation Model (USGS 2009). Projections of future climate originated from global climate model (GCM) projections that were first downscaled to the statewide-level using Localized Constructed Analogs (LOCA) downscaling (Pierce *et al.* 2014) to 1 km followed by further localized downscaling for southern California to 90 m resolution using the California Basin Characterization Model (CA-BCM; Flint and Flint 2012, Flint *et al.* 2013). Predicted climate variables for 2070-2099 were averaged for each scenario to represent predicted climate at the end of the century. Averaging over multiple years was done to minimize transient climate differences and because the definition of climate is 30-year average weather.

To project the distribution of future suitable habitat, future climate variables were substituted into habitat suitability predictor functions estimated from current climate data. To evaluate future climatic shifts on the suitable habitat and connectivity for our focal species, we selected two GCMs that spanned extremes of warmer-wetter (CNRM-CM5) and hotter, drier (MIROC5) conditions for southern California under two future greenhouse gas emissions simulations: one with substantially mitigated emissions, (Representative Concentration Pathways [RCP] 4.5) and the other with emissions produced under business as usual (RCP 8.5). We modeled habitat suitability and connectivity for all species under these four future climate scenarios: CNRM-CM5 RCP4.5, CNRM-CM5 RCP8.5, MIROC5 RCP4.5, and MIROC5 RCP8.5. For population modeling, we compared only the business as usual emissions scenario for the two climate models (CNRM-CM5 RCP8.5 and MIROC5 RCP8.5) as well as a model with no projected change in conditions in the future.

Table C1. Environmental and climatic variables used in species distribution and population models. Bolded scenarios were used in population modeling.

	Name	Description and source	Time variant
Climate	Source: Downscaled (to 90m) PRISM , MIROC5 RCP4.5, MIROC5 RCP8.5 , CNRM CM5 RCP4.5, CNRM CM5 RCP8.5		
	Bioclim 1	Mean temperature averaged over all months and the 30-year period preceding 2000 and 2100.	Yes
	Bioclim 2	Mean diurnal range (mean of monthly (max temperature-minimum temperature)) averaged over the 30-year period preceding 2000 and 2100.	Yes
	Bioclim 4	Temperature Seasonality (Monthly standard deviation *100) averaged over the 30-year period preceding 2000 and 2100.	Yes
	Bioclim 6	Minimum temperature of the coldest month averaged over the 30-year period preceding 2000 and 2100.	Yes
	Bioclim 12	Mean precipitation averaged over all months and the 30-year period preceding 2000 and 2100	Yes
	Bioclim 14	Precipitation of the driest month averaged over the 30-year period preceding 2000 and 2100.	Yes
	Bioclim 15	Precipitation seasonality (coefficient of variation across months) averaged over the 30-year period preceding 2000 and 2100.	Yes
Land use	Source: National Land Cover Database 2011(Jin <i>et al.</i> 2013)		
	Impervious surfaces	Used as a proxy for urban land cover	No
Water Resources	Source: Zimmerman <i>et al.</i> 2018		
	Distance to seasonal streams	Derived from Zimmerman <i>et al.</i> 2018; calculated as Euclidean distance to streams with low probability of year-round flow	No
	Distance to perennial streams	Derived from Zimmerman <i>et al.</i> 2018; calculated as Euclidean distance to streams with high probability of year-round flow	No
	Density of all streams within a 5km moving window	Density of all streams within a 5 km moving window	No
Topography	Source: National Elevation Dataset (USGS 2009)		
	Roughness Index	Total curvature derived from National Elevation Dataset with DEM Surface Tools (Jenness 2013)	No
	Percent Slope	Derived from National Elevation Dataset	No

Vegetation Vulnerability Assessment

Recognizing that not all species will respond directly to changes in temperature and precipitation variables, we also evaluated whether incorporating vegetation change or vulnerability would allow us to assess future distribution of our focal species more accurately. We accomplished this by creating an ensemble of vegetation resilience from the vegetation vulnerability conducted by Thorne and colleagues (2016) that we applied to the historic habitat suitability maps for each species. Ultimately, this scenario was only sufficiently divergent from the other scenarios for the California spotted owl. As such, we only included this scenario in population modeling comparisons for that species.

We created our vegetation vulnerability scenario using the exposure values under four future climate scenarios (CNRM CM5 RCP 4.5 and RCP 8.5 and MIROC ESM RCP 4.5 and RCP 8.5) from Thorne *et al.* (2016) at the end of the century. We determined ‘vulnerability’ for each scenario by adding together maximum projected exposure, which we called ‘Future marginalization’, and the overall change in exposure over time, which we called ‘Delta marginalization’. Following the assessment in the Thorne *et al.* (2016) report, we considered anything with a future marginalization of $\leq 80\%$ to be climatically suitable for the vegetation that currently occupies the area. We then linearly rescaled the combined vulnerability surface (Future marginalization + Delta marginalization), setting anything $\leq 80\%$ to 1 (*i.e.*, not vulnerable), and the maximum value, 180, as 0 (*i.e.*, the most vulnerable). In cases where there were no analog conditions, those cells were also assigned a 0, or the most vulnerable. Finally, to combine these surfaces, we averaged the rescaled vulnerability maps across the four scenarios. Finally, we multiplied this vulnerability score by the original habitat suitability value from our historic species distribution models. This approach allowed us to penalize cells according to their average vulnerability while using consensus values to address uncertainty where different scenarios vary in their vulnerability ratings. Because the data from Thorne *et al.* (2016) excluded urban and agricultural areas from their mapping and modeling efforts, we needed to assign those cells a scaling value. We chose to use a value of 1, thus retaining the original suitability value representing each focal species’ historic association with agricultural and urban areas.

Project extent and data limitations

Because our modeling approach is based on climatic niche envelopes to allow us to model change over time in response to shifts in climatic variables, there are limitations in our ability to predict suitability in the past and future with the highest accuracy. The two primary limitations we faced were related to the incorporation of vegetation and modeling of climatic conditions from more southerly locales (*i.e.*, Baja California, Mexico). We explored existing vegetation models for change under climatic shifts but did not find reliable projections of future vegetation that were suitable for use at the spatial extent and grain of the project. We did explore the option of creating our own vegetation change projections for the purposes of improving our models, but found this would have been a major undertaking, not within the scope of our project timeline or funds. Instead, we adapted the vegetation vulnerability as described above.

In an attempt to improve the quality and accuracy of our climatic niche models we explored expanding our modeling south into Mexico to ensure we had a range of climatic conditions modeled using historic data that would be analogous to projected future conditions in the southern California region. Unfortunately, we found that even historic climatic data sets did not

match in sources and scales and were not compatible with modeling suitability across the border. In addition, we found that the non-climatic data we applied to our SDMs (*i.e.*, urbanization, distance to water) were also not readily available in compatible forms to the data we have for the U.S. side of the border.

Ensemble Species Distribution Modeling

We used SDMs to predict the distribution of suitable habitat for our five focal species representing different habitat associations: mountain-conifer dependent spotted owl, shrub-dependent wren-tit, chaparral-dependent big-eared woodrat, riparian-dependent western toad, and the long-distance dispersing generalist bobcat.

Occurrence Data

For all focal species, we mined public databases (*e.g.*, eBird, iNaturalist, BIOS) and all unpublished literature for presence points for each species to obtain adequate sample sizes and geographic coverage across the study area (Table D2). To avoid including older data points in areas that have since been developed (thus artificially suggesting urban areas may be suitable based on these locations), we implemented a temporal cutoff, only using data from 1980 to present. We also filtered data so only locations with an accuracy of 500 m or better were retained.

In contrast to data collected as part of a thoughtful and thorough sampling regime, opportunistic data are subject to sampling bias. This sampling bias often results in inadequate representation of the environmental space, which leads to environmental bias in SDM model results and inaccurate model predictions (Phillips *et al.* 2009). To address sampling bias, we spatially restricted the sampling of background points when absence points were not available.

The data for big-eared woodrat, bobcat, and western toad required the selection of pseudo-absence or background points. From a visual inspection of the presence points for big-eared woodrat and bobcat, it appeared they were heavily biased toward primary and secondary roads in the study area. We confirmed this bias by sampling the presence points on a distance from roads surface. We counted the number of presence points within each 500 m distance from roads bin and randomly sampled the same number of background points in each distance from roads bin, generating a 3:1 ratio with the presence points for each species. Because western toad data were often gathered during stream surveys, they did not appear to be biased towards roads, and therefore, we did not bias the generation of background points for this species. For all three of these species, there was often a disparity in the distribution of occurrence points that was likely due to effort. With coordinated research and monitoring efforts focused in the coastal regions in San Diego, Orange, western Riverside, and Los Angeles Counties within our study region, these areas often had more data readily available on public databases. As such, we found model performance improved both quantitatively and qualitatively when we split the study area to address effort or reporting bias, generating a relative number of background points to occurrence points on a subregional basis.

Table C2. List of focal species selected for modeling with data sources identified. The number of occurrence points available and the number and type points (background or true absence) used in species distribution modeling for each species. ¹eBird 2016; ²California Department of Fish and Wildlife 2017; ³GBIF 2018a; ⁴GBIF 2018b; ⁵GBIF 2018c; ⁶BISON 2017; ⁷U.S. Forest Service 2017; ⁸U.S. Geological Survey (R.N. Fisher, *unpublished data*); ⁹NA HERP 2018; ¹⁰HerpMapper 2018 ¹¹Arctos 2016; ¹²National Park Service (S.P.D. Riley, *unpublished data*); ¹³San Diego Natural History Museum (Tremor *et al.* 2017); ¹⁴San Diego State University (M.K. Jennings, *unpublished data*); ¹⁵VertNet 2018.

Focal species (<i>Scientific name</i>)	Habitat association	Data sources	# presence points	Absence or background points	# absence/ background points
California spotted owl (<i>Strix occidentalis occidentalis</i>)	Coniferous and hardwood forest	eBird ¹ , CNDDDB ²	1,865	Absence	5,595
Wrentit (<i>Chamaea fasciata</i>)	Shrubland	eBird ¹	5,894	Absence	17,682
Western toad (<i>Anaxyrus boreas</i>)	Riparian, wetland, and upland scrub	GBIF ³ , BISON ⁶ , USFS ⁷ , USGS ⁸ , NAHerp ⁹ , HerpMapper ¹⁰	1,029	Background	3,087
Bobcat (<i>Lynx rufus</i>)	Generalist	GBIF ⁴ , BISON ⁶ , Arctos ¹¹ , NPS-SAMO ¹² , SDNHM ¹³ , USFS ⁷ , SDSU ¹⁴	507	Background	1,521
Big-eared woodrat (<i>Neotoma macrotis</i>)	Chaparral	GBIF ⁵ , BISON ⁶ , SDNHM ¹³ , VertNet ¹⁵	473	Background	1,419

Because the eBIRD database contains actual absence points in the form of observation locations where species are not seen, we were able to use these absences for modeling of the wrentit and California spotted owl. We randomly selected absence points to use in our modeling of wrentit and California spotted owl at a ratio of 3:1. We assumed absence locations to have the same sampling bias as presence locations and therefore did not spatially restrict absence points like we did for the other species.

Species Distribution Modeling

There are many models considered appropriate for analyzing presence-background data – all with various advantages and disadvantages (Elith *et al.* 2006, Franklin 2009). As such, using multiple models to produce a final ‘ensemble’ model has been proposed as the optimal way to estimate presence-background models (Araujo and New 2007). Ensemble models have been shown to produce more robust predictions and to perform better than any single model (Araujo and New 2007, Grenouillet *et al.* 2011).

We selected two regression methods (Generalized Linear Models [GLMs]; Generalized Additive Models [GAMs]) and three machine-learning methods (Random Forests [RF]; Boosted Regression Trees [BRT]; MaxEnt) for our suite of SDM models. We implemented all models in R (R Core Team 2017), using the *biomod2* package (Thuiller *et al.* 2016, 2005) for random forest, boosted regression, and generalized linear models, MaxEnt in the *dismo* package version 1.1-4 (Hijmans *et al.* 2017), and generalized additive models using the *mgcv* package (Wood 2011). We performed a 10-fold cross validation procedure for all models to assess model predictive ability. Across the 10 folds, we calculated the area under the receiver operating characteristic curve (AUC), and used this as our model performance metric.

We computed AUC-weighted ensemble suitability predictions, discarding models with $AUC < 0.7$. We used the final ensemble model for each species to predict habitat suitability across the study area and to generate the predictions under the four future scenarios. The bootstrapped accuracy averaged across ten subsamples of data for each of the five models was 0.95 for owls, 0.80 for wrentit, 0.85 for woodrat, 0.83 for Western toad, and 0.80 for bobcat. To project the distribution of future suitable habitat, we substituted future climate variables into the ensemble models.

The data and models for each species were reviewed and discussed with experts, and all models were quantitatively evaluated using cross-validation based on prediction of presence versus absence for withheld testing data. This was repeated with different subsamples of the data in each run for the most robust approach. The final species distribution models can be accessed [here](#).

Using the SDM suitability in the historic and future (2100) time periods as end points, we interpolated suitability at annual time steps in the intervening years. We then used these surfaces to generate resistance surfaces for the decadal connectivity modeling, define habitat patches for linkage and metapopulation modeling, and estimate carrying capacities of metapopulation patches.

Patch maps

For both the least cost corridor linkage modeling and the metapopulation model construction, maps of habitat patches must be established. For each year that was modeled or interpolated, we

generated habitat suitability maps that assign a continuous suitability value, ranging from 0 to 1, to each cell within the study area. To translate continuous suitability metrics to discrete habitat patches, we used the Core Mapper functionality in the Gnarly Landscape Utilities toolbox (Shirk and McRae 2013). Core Mapper works by selecting (i) a minimum within-pixel suitability threshold, (ii) a moving-window suitability threshold (with concomitant moving window radius), and a (iii) minimum core area threshold, which can be thought of as the area needed to allow for enough territories to have a viable population. With these parameters specified for each species (Table D3), Core Mapper identifies aggregations of suitable grid cells that serve as self-sustaining population “cores”. The network of these cores represents the meta-population within the study area. For each species, we ran Core Mapper for every time step, retaining suitability values within the core, and setting values outside the cores to zero.

Table D3. Core Mapper input values used to designate patches of core habitat for each focal species.

	Moving Window Radius (m)	Min Average Habitat Value	Minimum Habitat Value Per Pixel	Min Core Area size (km²)
Big-eared woodrat	422	0.45	0.25	4
Bobcat	1,260	0.35	0.15	25
California spotted owl	1,000	0.5	0.25	20
Wrentit	800	0.6	0.314	1
Western toad	232	0.55	0.343	4

Linkage Modeling

We took three complementary approaches to linkage modeling for this analysis: least cost corridor analysis and Circuitscape current flow for each of our focal species, and a species-agnostic geodiversity or land facet analysis. Our primary analysis employed a least cost corridor or least cost path analysis implemented in Linkage Mapper (McRae and Kavanagh 2011). This method allowed us to identify discrete linkages between core areas based on the lowest cost of moving through the landscape, represented by our resistance surface. The core and linkage framework for this approach also served as the inputs for the spatially-explicit metapopulation models. We ran least cost corridor analyses for each species under historic conditions (2000) and at ten decadal intervals (2010-2100) under the four climate scenarios. To compare a different approach to modeling connectivity for each species we generated a wall-to-wall surface that did not require designation of discrete habitat patches, we performed electrical circuit theory-based analyses using the program Circuitscape (McRae *et al.* 2008, 2013; www.circuitscape.org) under historic conditions for each species.

Least Cost Corridor Modeling

Habitat patch layers (described above) and resistance were used as the primary inputs for least cost corridor linkage modeling we performed for decadal time steps under each scenario. Recent studies on large mammals and birds have found habitat use was not linearly related to resistance

and that individuals are more tolerant of sub-par environmental features when dispersing than when occupying territories or home ranges (*e.g.*, Keeley *et al.* 2016, Trainor *et al.* 2013, Mateo-Sánchez *et al.* 2015). To account for this possibility we used a non-linear transformation to transform the habitat suitability values to resistance (Keeley *et al.* 2016). Resistance was calculated from the following formula: $100 - 99 * ((1 - \exp(-c * \text{habitat suitability})) / (1 - \exp(-c)))$, where we set $c=2$ for big-eared woodrat, $c=4$ for bobcat, $c=4$ for California spotted owl, $c=0.25$ for wrentit, and $c=2$ for western toad.

We ran Linkage Mapper using both the cost-weighted and Euclidean adjacency methods, and removing linkages that run through core areas. After generating the least cost corridors and mosaicking them into a single map, we then reviewed the outputs for each species for the historic period to determine appropriate cut off of the least cost corridor distance to apply for final delineation of the linkage network for each species. Once we selected the maximum normalized least cost corridor distance for each species (60 km for big-eared woodrat, 60 km for bobcat, 100 km for California spotted owl, 40 km for western toad, and 40 km for wrentit), we applied this cut off to all future scenarios as well. We did not apply species-specific dispersal limitations at this stage so as to allow for corridors to be developed that would accommodate species with similar habitat associations but not necessarily the same dispersal limitations. Instead, species-specific dispersal was integrated into the population models to assess functional connectivity and biological importance of each linkage.

Circuitscape Linkages

We followed our least cost corridor modeling with Circuitscape modeling implemented in Julia 0.7 to determine if any linkage zones were underrepresented strictly based on modeling approach. Due to computational limitations, we only performed this process for the historic condition and within the ecoregion, not the extended study area (Figure 1). We rescaled our resistance surfaces by a factor of three, producing a 270-m resistance surface for modeling. We generated source points across the study area by probabilistically sampling 1,000 points on the historic habitat suitability surface for each species. This sampling results in more points being placed in areas with higher habitat suitability than lower suitability. Circuitscape was run in pairwise mode and once cumulative current maps were produced for each species, we rescaled them from 1-100 and combined those surfaces across focal species. We generated a maximum current map by compiling the highest valued pixels for any given species, and an average current map by averaging the value for each pixel across all five species. We thresholded each of these surfaces, the maximum at ≥ 70 and the average at ≥ 80 , and used each of these outputs to compare to the multispecies linkage map and fill gaps.

Land Facet Linkages

In addition to the focal species linkages, we also generated corridors using a species-agnostic landscape approach focused on geodiversity (Comer *et al.* 2015, Theobald *et al.* 2015), or land facets (Beier and Brost 2010, Brost and Beier 2012), designed to identify linkages that retain a range of features defined by slope angle, solar insolation, topography, and elevation. This method was specifically developed as an approach to connectivity assessments under climate change that would be robust to the uncertainty in climate data and issues with scale. To execute the land facet modeling, we used ecologically-relevant landform data (Theobald *et al.* 2015) as the source for the individual facets. Of the 15 landforms in the original dataset, we selected three representing cool landforms (cool lower slopes, cool upper slopes, and cool peaks and ridges)

and two to represent grasslands (valley and narrow valley), which we were not able to incorporate with our focal species. To generate land facet linkages, we used the Land Facet Corridor Designer (Jenness *et al.* 2010) and Linkage Mapper (McRae and Kavanagh 2011). To execute the land facet modeling, we used the Land Facet Corridor Designer (Jenness *et al.* 2010) toolbox in ArcGIS.

We identified the areas of greatest density of each of the new landforms using the *Calculate Density Surface* tool in the Land Facet Corridor Designer toolbox by inputting each of the individual variables used to create the landforms: slope position (ridges/peaks, upper slopes, lower slopes, and valley bottoms), topographic position index (TPI), slope, and continuous heat load index (CHILI). That output was then used to generate termini polygons of the areas of greatest density of each land facet within our wildland blocks of interest. We also used the land facet density surface to create a Mahalanobis distance raster for each class of the land facet raster to be used in our corridor modeling as the equivalent of resistance. To standardize the scale of the Mahalanobis distance raster, we used the *Chi Square Raster Transform* tool. This creates a “resistance” or “distance” surface (on a 0 to 1 scale) to use in our corridor modeling where cells with a greater distance (closer to 1) from an area of high density of the land facet of interest have a higher resistance value. Finally, because the surfaces created thus far only include topographic variables and have not incorporated any other landscape features that may affect wildlife movement, we clipped this resistance layer using an urban raster mask generated from land-use data from the Southern California Association of Governments to exclude urban areas from our corridor modeling.

We used Linkage Mapper (McRae and Kavanagh 2011) to generate least cost corridors using the Mahalanobis distance surfaces as our resistance inputs and the termini polygons of high land facet density within large blocks of preserved lands as our target core areas to connect. This process generated raster corridor surfaces that can then be truncated to identify corridor extent. We selected cutoff values for each land facet raster that produced a contiguous corridor but was not too wide or expansive. We examined the final land facet corridors to identify unique corridors that had not been captured by our multispecies linkage and found that only valleys and narrow valleys were not already captured by our final multispecies linkage network.

Metapopulation Modeling

For the metapopulation component of our modeling approach, SDM predictions of habitat suitability defined the carrying capacities of metapopulation patches, and a demographic model determined the population dynamics within and across the patches. Each model simulation lasted 100 years, meant to represent the time horizon 2000-2100. To implement metapopulation modeling, we first input our core maps into the software package RAMAS GIS® 5.0 (described in Akçakaya and Root 2005) to link the time series of maps to the population model. RAMAS translates the suitability values within a pixel, summed across a core, to the carrying capacity of a population patch. We set initial abundances to some fraction (0.6-1) of the total carrying capacity. Each annual core and suitability map was input into RAMAS to allow population patches to grow or sink in size, changing the overall carrying capacities along with dispersal distances between patches. In addition to the carrying capacity changes due to climate-driven changes in suitability, we imposed random fluctuations (approximately 15% for bobcat and owls, 30% for Western toad, 40% for wrentit, and there were no fluctuations in the carrying capacity of woodrat) in the carrying capacity meant to reflect environmental stochasticity.

Once corridors were identified for each species, they were also integrated into metapopulation models. These models assumed that individuals were well-mixed within a patch and that distances between patches evolved with climate change. We considered the importance of existing corridors only and the amount of dispersal through linkages was dependent on species' ability, abundance of the giving patch, and carrying capacity of the final patch.

Demographic model

For spotted owl, wrentit, western toad, and bobcat we began with vital rates identified in COMADRE (Salguero-Gómez *et al.* 2016) and adjusted them to account for errors (spotted owl) and local conditions (wrentit, western toad, and bobcat) using local data sources provided by species experts we consulted. For woodrat we used a model developed by Stephen Rice that calculated survival and fecundity rates using survival and matrilineal data from Kelly (1990), Linsdale and Tevis (1951), and Matocq (2004). In a given year, each individual of a species either lives or dies with or without replacement subject to the typical matrix model equation:

$$\begin{bmatrix} n_1(t+1) \\ n_2(t+1) \\ n_3(t+1) \\ \vdots \\ n_w(t+1) \end{bmatrix} = \begin{bmatrix} f_1(t) & f_2(t) & \dots & f_{w-1}(t) & f_w(t) \\ s_1(t) & r_2(t) & \dots & 0 & 0 \\ 0 & s_2(t) & \dots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & s_{w-1}(t) & s_w(t) \end{bmatrix} \begin{bmatrix} n_1(t) \\ n_2(t) \\ n_3(t) \\ \vdots \\ n_w(t) \end{bmatrix} \quad (1)$$

Here $f_i(t)$, $s_i(t)$, $r_i(t)$, and $n_i(t)$ are the fecundities, survivals, survival-at-same-stage, and numbers of individuals, respectively, for each of the w stages (wrentit and woodrat models had $w = 2$ stages, bobcat had three gender-specified stages, Western toad also had three stages, and spotted owl had four stages). Only the western toad had non-zero $r_i(t)$, which means that an individual could remain a juvenile between years. Fecundity and survival are drawn each year from a distribution with specified mean and standard deviation. Thus, vital rates are meant to represent an additional source environmental stochasticity. To incorporate demographic stochasticity, vital rates for each individual were drawn from a Poisson distribution (for fecundities) or a multinomial distribution (for transition rates). Final mean vital rates used in the demographic models for each species are listed in Table D4.

Catastrophes

For wrentit and owl, we added local (within population, not across population) catastrophic drought that decreased vital rates in a given time step. Droughts were assumed to occur every 4-5 years, which is less than California's historic drought frequency, but consistent with species response frequency. We imposed periodic drought because the impact of drought on vital rates has been documented in the literature (Preston and Rotenberry 2006; LaHaye *et al.* 2004). We did not include a drought catastrophe in the metapopulation modeling for bobcat or woodrat as we did not have empirical data to determine if or how drought might negatively impact the vital rates of these species. For the western toad, although we would expect this species to be negatively impacted by drought, incorporating this catastrophe into the metapopulation modeling led to high instability in abundance, making the identification of priority corridors impossible. We therefore omitted drought catastrophes in the population modeling for this species as well.

We tested the importance of each linkage by comparing the final abundance of the metapopulation with each corridor activated individually and compared that to models where no corridors were active. We used the change in final abundance to calculate the percent increase in the metapopulation when the corridor was added. To focus on biologically important changes in landscape connectivity, we determined a minimum threshold above which we did not expect changes in final population size were due to chance alone. For corridors above this threshold, we calculated a relative importance on a scale from 0 to 1 where 1 was the maximum value observed across all scenarios. This threshold was especially important given all the sources of variability in the model.

Table D4. Mean vital rates for each species used in metapopulation models.

Big-eared woodrat

	Juvenile	Adult
Juvenile	0.3145	1.2113
Adult	0.3631	0.7125

Bobcat

	Female Kitten	Female Yearling	Female Adult	Male Kitten	Male Yearling	Male Adult
Female Kit	0	0.532	1.125	0	0	0
Female Year	0.6	0	0	0	0	0
Female Adult	0	0.681	0.769	0	0	0
Male Kit	0	0.532	1.125	0	0	0
Male Year	0	0	0	0.6	0	0
Male Adult	0	0	0	0	0.681	0.769

California spotted owl

	Juvenile	Subadult 1	Subadult 2	Adult
Juvenile	0	0.2	0.2	0.4
Subadult1	0.7	0	0	0
Subadult2	0	0.7	0	0
Adult	0	0	0.9	0.8

Western Toad

	Pre-juvenile	Juvenile	Adult
Pre-juvenile	0	50.5	1404
Juvenile	0.086	0.21	0
Adult	0	0.11	0.78

Wrentit

	Juvenile	Adult
Juvenile	0.615	1.14
Adult	0.424	0.742

Corridors and Dispersal

Once least cost corridors had been identified, they had to be integrated into the population model. Combining the spatial corridor identification offered by Linkage Mapper and the evolution of edge-to-edge distances provided by RAMAS was non-trivial. This required updating the permissible corridors every decade so that RAMAS would not allow flow of individuals between areas where the Euclidean distance was short but the cost distance was prohibitive. Regardless, the RAMAS population modeling framework is agnostic with respect to *how* an individual disperses between patches, and only cares about the amount that flows through patches. We made dispersal proportional to the time-evolving edge-to-edge distances between patches. We set the mean dispersal distance to 0.5 km for wrentits (Baker *et al.* 1995), 25 km for owls (Forsman *et al.* 2002), 1.5 km for woodrats (Smith 1965), 1.5 km for western toad (Brehme *et al.* 2018), and 18 km for bobcats (Jennings and Lewison 2013); maximum dispersal distance was designated as 2 km for wrentits, was 150 km for owls, was 3 km for woodrats, 3 km for western toad, and 50 km for bobcats.

Owls had exponentially declining dispersal with distance based on the shape of the dispersal curve at distances above 10 km in (Forsman *et al.* 2002; 10 km is roughly the radius of a larger non-breeding territories in Oregon, where the study was conducted). Bobcats also had exponentially declining dispersal with distance. For the remainder of the species, dispersal declined exponentially with the square of the distance between patches. This created more dispersal between closely spaced patches, and more overall dispersal given the imposition of the maximum dispersal distance. In addition, we fixed dispersal between any two patches such that (i) less than 10% of individuals in the “giving patch” went to any one adjacent patch, (ii) the fraction of individuals dispersing was a linear function of the number of individuals in the “giving patch”, and (iii) the fraction of individuals dispersing was a linear function of the carrying capacity of the receiving patch up to a threshold (typically around 100 individuals), where the threshold was defined by sensitivity tests to maximize the benefit of dispersal in the “no change” scenario.

Connectivity Scenarios

For each of the identified corridors, we ran a population model (i) in the presence of the corridor and no other corridors, and (ii) in the absence of the corridor with all other corridors active. We then compared the final abundance of (i) and (ii) to the final abundances of models with no dispersal and with full dispersal, respectively, to calculate % increase in the metapopulation when the corridor was added and % decrease when it was taken away. The results of (i) and (ii) largely mirrored each other, with some situations where a corridor was important in isolation, but redundant when removed from an otherwise fully connected landscape.

Finally, we ran trials to determine a threshold above which we thought that observed changes in corridor scenarios were due to the influence of a corridor and not due to random fluctuations in the stochastic models. This threshold was especially important given all the sources of stochasticity in the model: sampling births and deaths in a small population (*i.e.*, demographic stochasticity), year-to-year variability in vital rates, year-to-year variability in carrying capacity, and local catastrophes. By creating a system where reorganization of individuals between patches minimizes the impacts of environmental fluctuations, we created a model that maximizes the benefits of connectivity. A side effect of this parameterization is that the difference between identical runs can be anywhere from 1-3% of the overall final abundance.

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APPENDIX E: PRIORITIZATION FOR MULTISPECIES LINKAGE ASSEMBLY

Assembling a Multispecies Network: Overview

To address uncertainty in climatic projections and species' responses to those projected changes, we took a scenario-based approach. These scenarios allowed us to evaluate a range of potential outcomes to determine how connectivity may play a role in supporting the persistence of biodiversity over time under climate change. Because we modeled connectivity for our focal not only in the historic period, but also under four different scenarios at decadal intervals between 2010 and 2100, we had numerous outputs to evaluate. To consolidate those 205 connectivity outputs (41 per species for five focal species) into a single multispecies linkage network, we used a prioritization framework focused on key attributes to identify key core and linkage areas for each species to be included in this multispecies network. We used the Environmental Evaluation Management System (EEMS 2.02; Sheehan and Gough 2016) implemented in ArcGIS, a hierarchical decision-making tool based on fuzzy logic, to quantitatively prioritize patches within our established networks by deriving an overall value for each patch for each species based on our metrics of interest. This prioritization was a two-step process that involved first assessing the values of cores and linkage segments for each species, then ranking segments among species to be carried forward into the final network. The multispecies network was then assembled from a union of all species' cores and linkages based on a final priority that included the maximum priority value for any single species, the average priority value across all species, and the count of species represented in a linkage segment.

Within-species Prioritization

Given the scale and scope of the project, prioritization was critical to achieve a realistic and implementable multispecies linkage network. Our prioritization was based on inputs from four main categories (Figure E1; described in more detail below):

- linkage feasibility,
- connectivity/landscape value,
- climatic resilience consensus value,
- metapopulation persistence (which incorporates species-specific dispersal limitations)

Once all of the relevant metrics were identified, we rescaled them into fuzzy space using the EEMS tool. This involves reinterpreting metrics on a scale from being 'completely untrue', wherein they are assigned a value of -1, to being 'completely true', and thus receiving a value of 1. For our purposes, we considered our metrics on scales of low-to-high conservation value. For example, for landscape resistance, we assigned patches with the lowest resistance a fuzzy values of 1 (high priority value), and those with the highest resistance received assignments of -1 (low priority value). On the other hand, for proportion already conserved, the highest values received fuzzy values of 1, and low values received fuzzy values of -1. By rescaling our metrics in this way, they could then be considered concurrently. To simplify our prioritization model, we hierarchically combined metrics that were closely related to one another. The metrics of interest

can be found in Table E1, which lists the metric description, and how each value was “fuzzified” along with how the metrics were combined to create the final priority linkage for each species.

Linkage feasibility filtering accounted for factors that would affect how easy or difficult it would be to actually conserve linkages within the network, including percent of area already conserved, number of parcels, and average parcel size/unit area. The latter two metrics were included to serve as a proxy for the cost of conserving a given area based on the assumption that a larger number of small parcels would likely cost more than a few large parcels.

Connectivity and landscape value encompassed measures of betweenness (*i.e.*, importance of an individual linkage as a hub within a network), habitat quality metrics including the ratio of patch edge to overall area, impervious cover, and resistance, as well as consideration for whether a linkage overlaps with areas previously identified as important under the South Coast Missing Linkages (SCML; South Coast Wildlands 2008) or California Essential Habitats Connectivity (CEHC; Spencer *et al.* 2010) projects.

Climatic resilience consensus value accounted the value of linkages under climatic changes in the future based on the premise that the more evidence we have that certain linkages are important, the more confident we can be that it will provide climatic resilience value in the future. We calculated consensus two ways: 1) based on connectivity to climate analogs, and 2) accounting for how many time steps in our decadal modeling a linkage persists within each of the four climate scenarios. Our assessment of climate analogs evaluated climatic water deficit (Flint *et al.* 2013) that accounts for temperature and precipitation under two climate scenarios (warmer-wetter and warmer drier, both under business as usual emissions). We assessed linkage connections based on the climatic envelopes of historic and future conditions using the Linkage Priority Mapper tool (Gallo and Greene 2018). The importance of each linkage for connecting climate analogs was combined with closeness, permeability, and core area value to assign a final value. We assigned the climate envelope difference twice the weight of the other factors considered. For our accounting of the value of linkages over time and across scenarios, we evaluated consensus assuming the greater number of times a linkage was present, the more likely it is important for connecting present and future habitat patches.

Finally, **metapopulation persistence** was based on a prioritization determined through the Linkage Priority Mapper (Gallo and Greene 2018) using the relative importance value described above. As with the climate analog prioritization, relative importance of each linkage was determined by combining the relative importance value with closeness, permeability, and core area value. We assigned the relative biological importance twice the weight of the other factors considered. This priority value was calculated under the no change scenario, as well as two climate models (warmer-wetter and warmer-drier) under business as usual emissions. For spotted owl, we also included the more optimistic vegetation vulnerability model.

The climatic consensus metrics allowed us to assign greater value to areas where there was agreement about important linkages over time and across scenarios, providing greater support for decision-making under uncertainty. In contrast, by combining currently known landscape conditions such as impervious surface cover and percent land conserved with those that are less certain from our climatic modeling, our prioritization approach was grounded in empirical data while providing a robust framework for considering the value of linkages in the future for resilience in the face of climate change.

Specifically, we developed the priority linkage value for a patch using the following procedure:

Step 1: After fuzzifying initial input variables as described in Table E1, we calculated intermediate values for several metrics to combine or select among them, as appropriate.

- *Habitat Quality* was calculated by taking the EEMS Union (the mean of all inputs) of the fuzzified values of impervious cover, patch shape, and the habitat resistance values.
- *Network Connectivity* was calculated by taking the EEMS union of the fuzzified centrality and betweenness values.
- *Prior Designation* was calculated by taking the EEMS OR (the larger fuzzified value of the two inputs) of the proportion overlap with either the South Coast Missing Linkages (SCML) corridors or the California Essential Habitats Connectivity (CEHC) linkages.
- *Conservation Feasibility* was calculated by taking the EEMS selected union (the mean of the 2 largest of the inputs) of the parcels per patch, proportion already conserved and the average parcel size.
- *Climate Consensus* was calculated by first taking the larger of CNRM-CM5 RCP 8.5 linkage accounting between 2010 and 2100 or the connection to analogous conditions under the same scenario using climatic water deficit. We applied the same selection to the MIROC5 RCP 8.5 linkage accounting and connectivity to analogous conditions. Finally, we combined the selected value from each of these scenarios and combined them with the linkage accounting for the CNRM-CM5 RCP 4.5 and MIROC5 RCP 4.5 scenarios using an EEMS union.
- *Metapopulation Persistence* was an EEMS union of the metapopulation priority values under three different climate scenarios, No Change, CNRM-CM5 RCP 8.5 and MIROC5 RCP 8.5. For one of our species, the spotted owl, we also added a Vegetation Vulnerability scenario.

Step 2: We combined some of the intermediate values further.

- The *Connected Landscape* value was then obtained by taking the EEMS Selected Union (the mean of the 2 largest of the inputs) of *Habitat Quality*, *Network Connectivity*, and *Prior Designation*.

Step 3: *Connected Landscape*, *Conservation Feasibility*, *Climate Consensus* and *Metapopulation Persistence* values were combined in an EEMS union.

Step 4: The result of step 3 was combined with impervious cover in an EEMS AND which returns the smaller of the two inputs to ensure linkage segments that had a high degree of impervious surface (*i.e.*, urbanization) would be downgraded given the difficulty in restoring connectivity in these areas. This final value was the **Within-species Linkage Priority** value for each core and linkage segment.

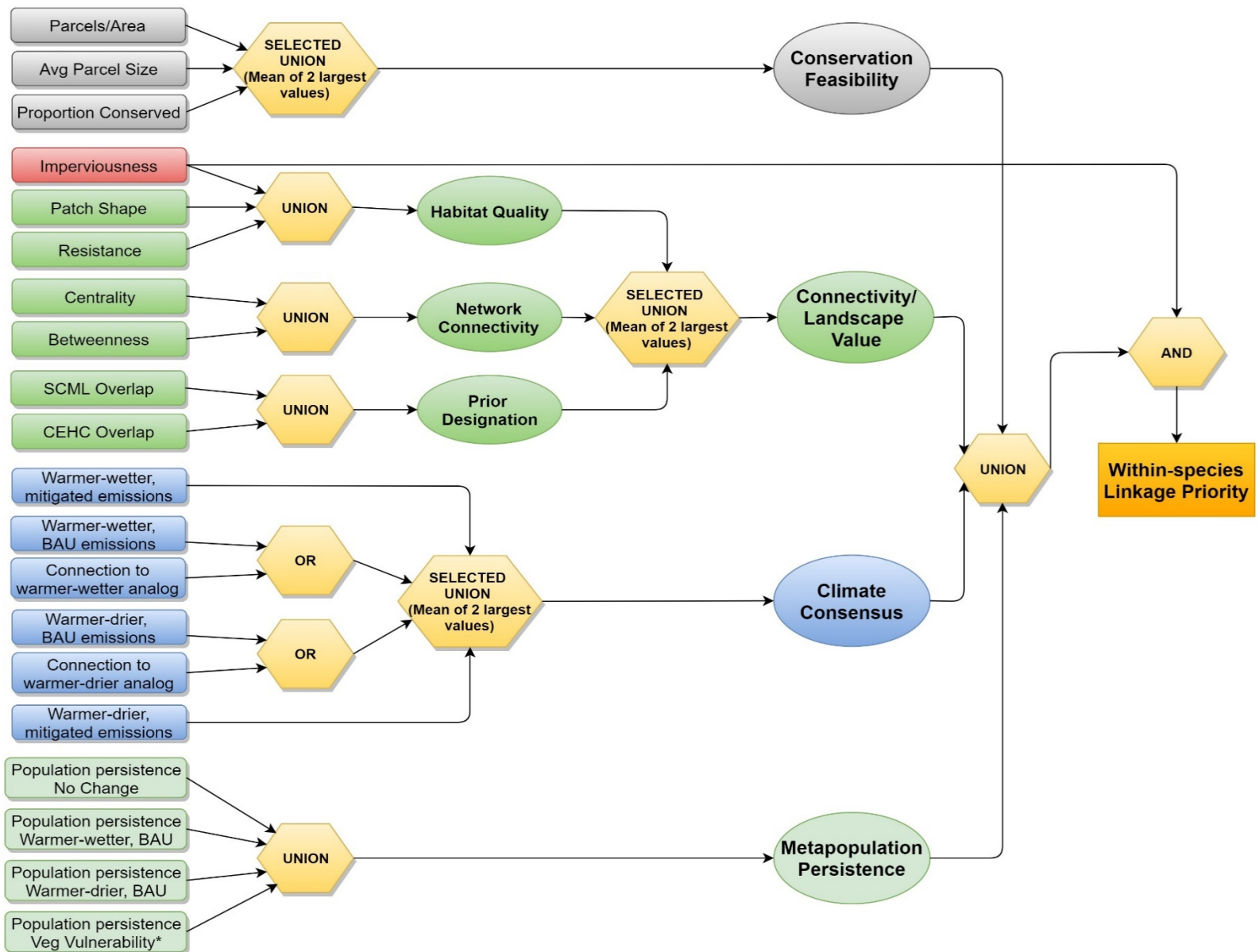


Figure E1. EEMS logic model for within-species linkage priority assessment.

Table E1. Range of input values and processing approach to fuzzify variables for the within-species prioritization model depicted in Figure E1.

Attribute	Description	Fuzzify Function	Combination 1	Combination 2	Combination 3	Final Combination
Parcels/Area	Number of parcels by patch area	Smaller = true	Mean of 2 most true = Conservation Feasibility		Mean of <i>Conservation Feasibility</i> <i>Connectivity/Landscape Value</i> <i>Climate Consensus</i> & <i>Metapopulation Persistence</i>	The smaller of <i>Imperviousness</i> and the mean of <i>Connectivity/Landscape Value</i> <i>Climate Consensus</i> & <i>Metapopulation Persistence</i> = Within-species Linkage Priority
Avg Parcel Size	Average parcel size within a segment	Larger = true				
Proportion Conserved	Proportion of segment conserved (CPAD)	Larger = true				
Imperviousness	Percent of impervious cover (NLCD)	Smaller = true	Mean of these 3 values = Habitat Quality	Mean of the 2 largest of the 3 values = Connectivity/Landscape Value		
Patch Shape	A measure of patch shape; edge to interior ratio	Smaller = true				
Resistance	Resistance as converted from habitat suitability for each species	Smaller = true				
Centrality	Number of bordering patches	Larger = true	Mean of these 2 values = Network Connectivity	Mean of these 2 values = Prior Designation		
Betweenness	Number of neighboring patches that use node as a hub to connect to other patches	Larger = true				
SCML Overlap	Proportion overlap – SC Missing Linkages	Larger = true				
CEHC Overlap	Proportion overlap - CA Essential Habitats Connectivity linkages	Larger = true		Mean of the 2 largest of 4 values = Climate Consensus		
CNRM-CM5, RCP 4.5	Count of decades where segment appears under CNRM-CM5 RCP 4.5 scenario	Larger = true				
CNRM-CM5, RCP 8.5	Count of decades where segment appears under CNRM-CM5 RCP 8.5 scenario	Larger = true	Largest value is carried forward			
CNRM-CM5, RCP 8.5 Analog	Priority value based on climate analogs for CNRM-CM5, RCP 8.5 scenario	Larger = true				
MIROC5, RCP 8.5	Count of decades where segment appears under MIROC5 RCP 8.5 scenario	Larger = true	Largest value is carried forward			
MIROC5, RCP 8.5 Analog	Priority value based on climate analogs for MIROC5, RCP 8.5 scenario	Larger = true				
MIROC5, RCP 4.5	Count of decades where segment appears under MIROC5 RCP 4.5 scenario	Larger = true				
Population No Change	Benefit of segment based on metapop model - No Change scenario	Larger = true	Mean of these 3 or 4 values = Metapopulation Persistence			
Population CNRM-CM5, RCP 8.5	Benefit of segment based on metapop model - CNRM-CM5, RCP 8.5 scenario	Larger = true				
Population MIROC5, RCP 8.5	Benefit of segment based on metapop model - MIROC5, RCP 8.5 scenario	Larger = true				
Population, Veg Vulnerability*	Benefit of segment based on metapop model - Veg Vuln scenario (*Used for spotted owl)	Larger = true				

Multispecies Prioritization

Once linkages were prioritized for each species, those with highest values were selected for inclusion in the multispecies network. To assemble this network, we created a union of the cores and linkages for all species from the historic framework and developed another EEMS model to then select the portions of the union that should move forward into the final network. This model first employed a UNION function to combine the maximum priority value of a segment for any given species with the average value across all five species. These values did not need to be ‘fuzzified’ first because they were outputs from the prior EEMS model and were already scaled from -1 to 1. We also created a count variable to identify linkage segments that served multiple species. We used a fuzzy category conversion for that metric, assigning segments for only one or two species a value of -1 and segments serving three or more species a value of 1. This addition allowed us to include important linkages through slightly more urban areas that may be constrained, but may play an important role in connected isolated urban habitat patches. We then used an OR function to calculate a final multispecies priority value based on segments that had either a high combined maximum and average value or served three or more species. Once we had that final multispecies priority value, we examined the output and determined that a threshold of 0.35 (on the fuzzy scale of -1 to 1) would allow us to delineate complete linkages while still being restrictive enough to be feasibly implemented. We selected all segments from the multispecies union that were above this threshold to form the basis of the multispecies network (Figure 5a). Once we established this basis using the highest priority segments from the least cost corridor models, we reviewed the output from our individual species Circuitscape models under historic conditions. We created both a multispecies average using the top 20% of flow and a maximum, selecting the top 30% of flow, after normalizing the outputs for all species (Figure 5b). We combined these thresholded flow surfaces and found there were some missing elements in the central part of our network in the eastern Los Angeles Basin and the San Gabriel Mountains, so expanded linkages in these areas accordingly. Finally, we reviewed our species-agnostic geodiversity land facet linkages and found that the facets providing connectivity along cool lower slopes, upper slopes, and peaks and ridges were well-represented by our focal species linkages. However, given the absence of a grassland-associate from our suite of focal species, only a portion of the valley and narrow valley linkages were covered by our species-based linkages. As such, we added these complementary linkage segments to the regional network (Figure 5c).

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APPENDIX F. INDIVIDUAL SPECIES PRIORITIZATION MAPS

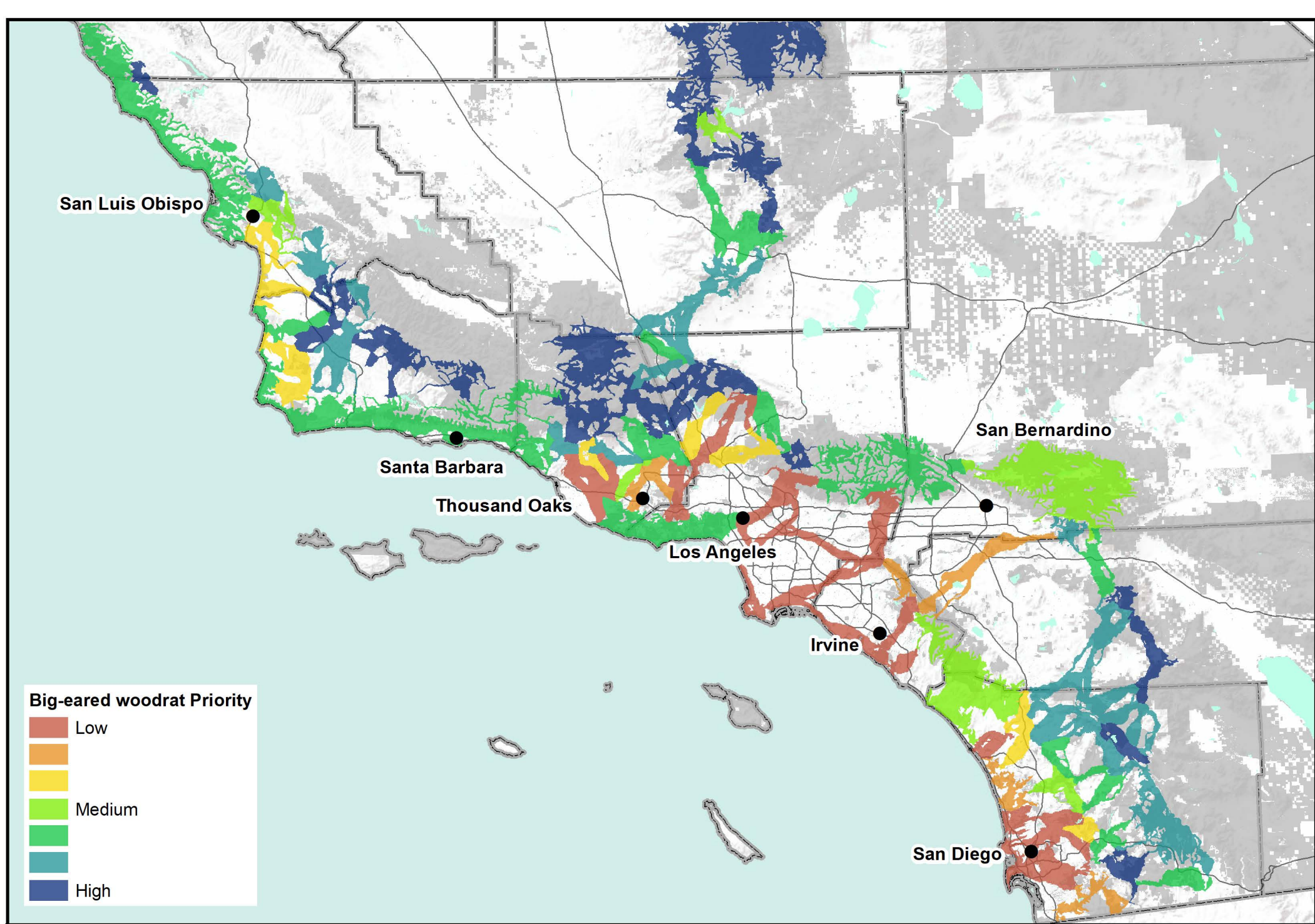
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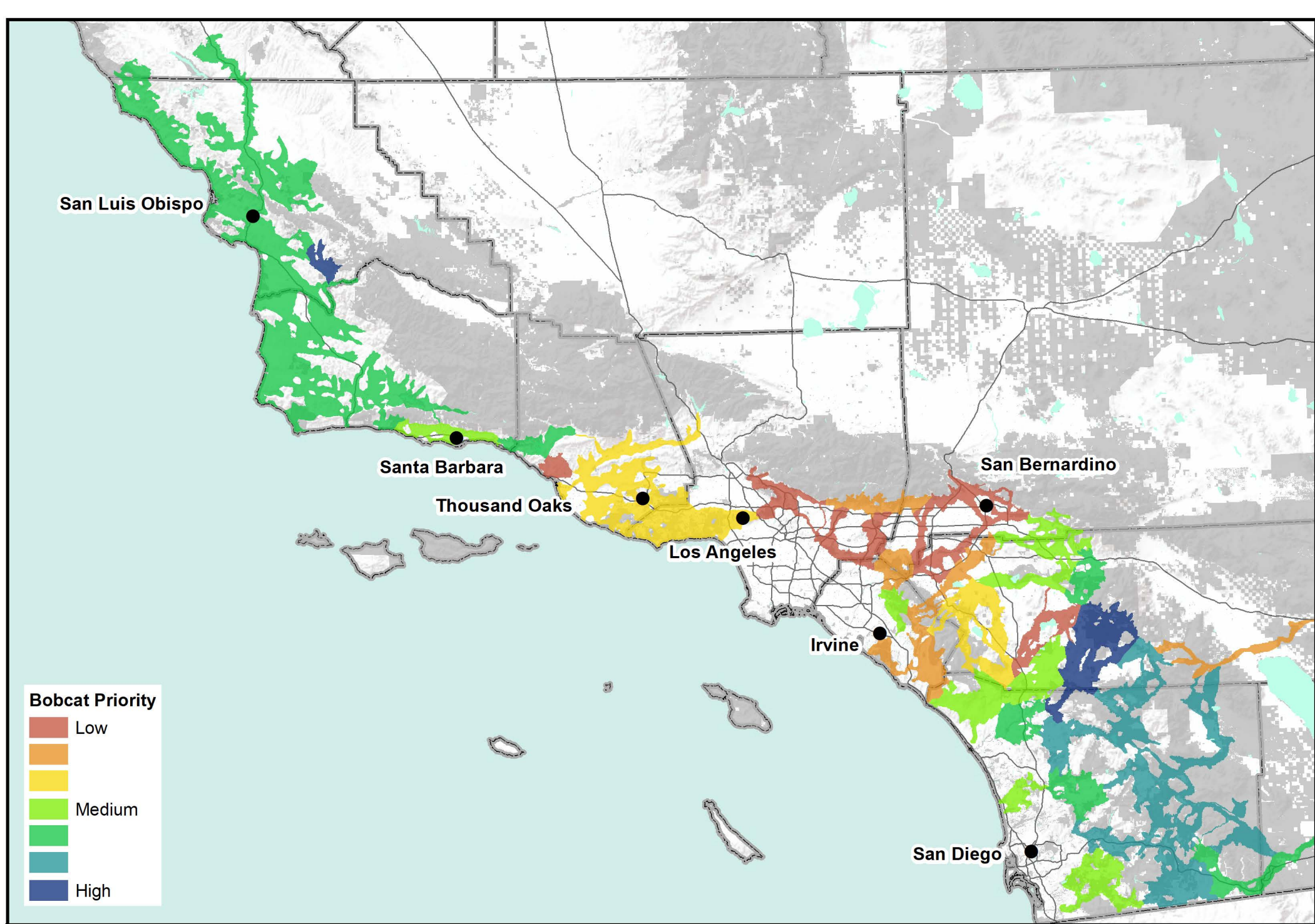
Page 2: Bobcat

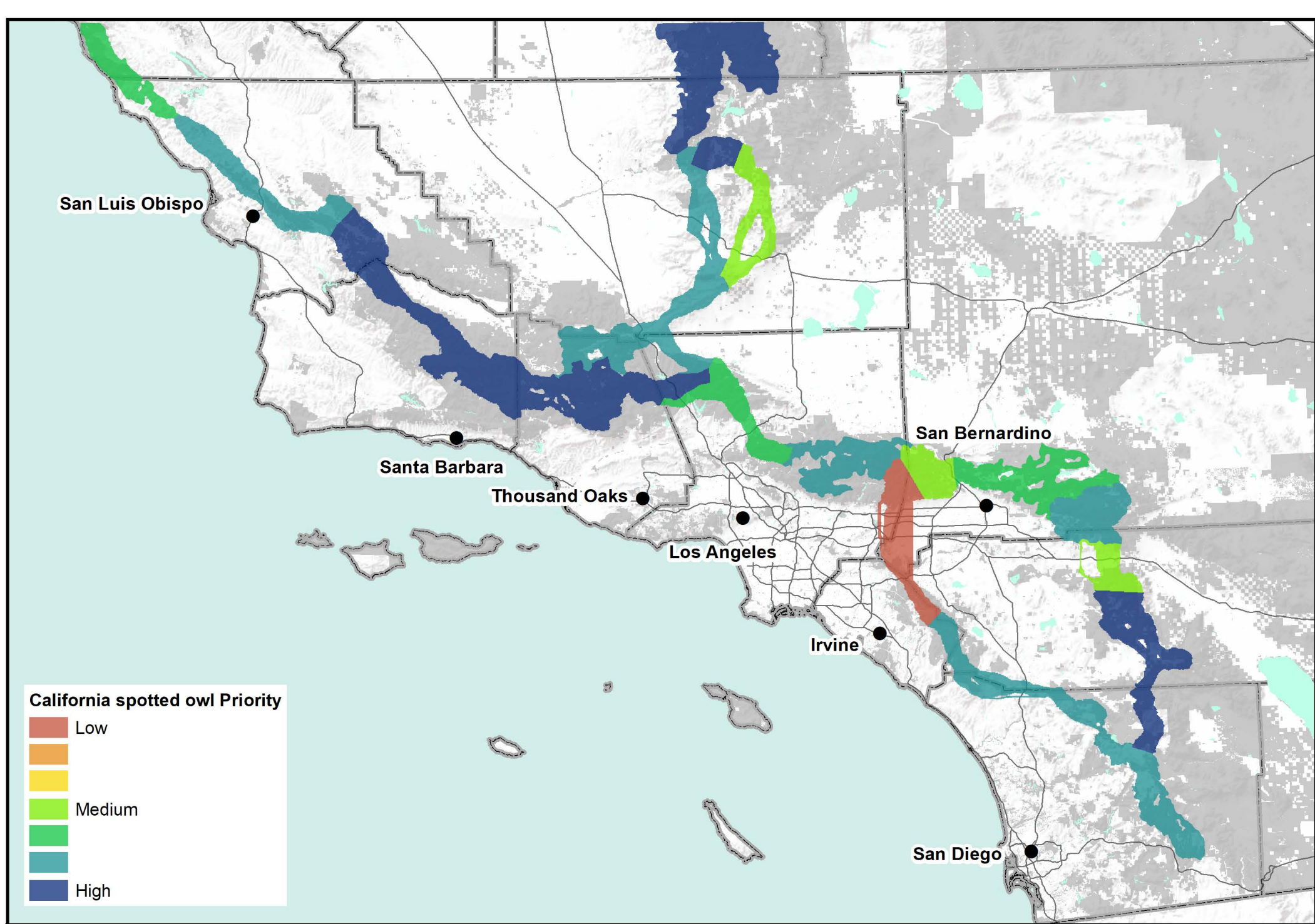
Page 3: California spotted owl

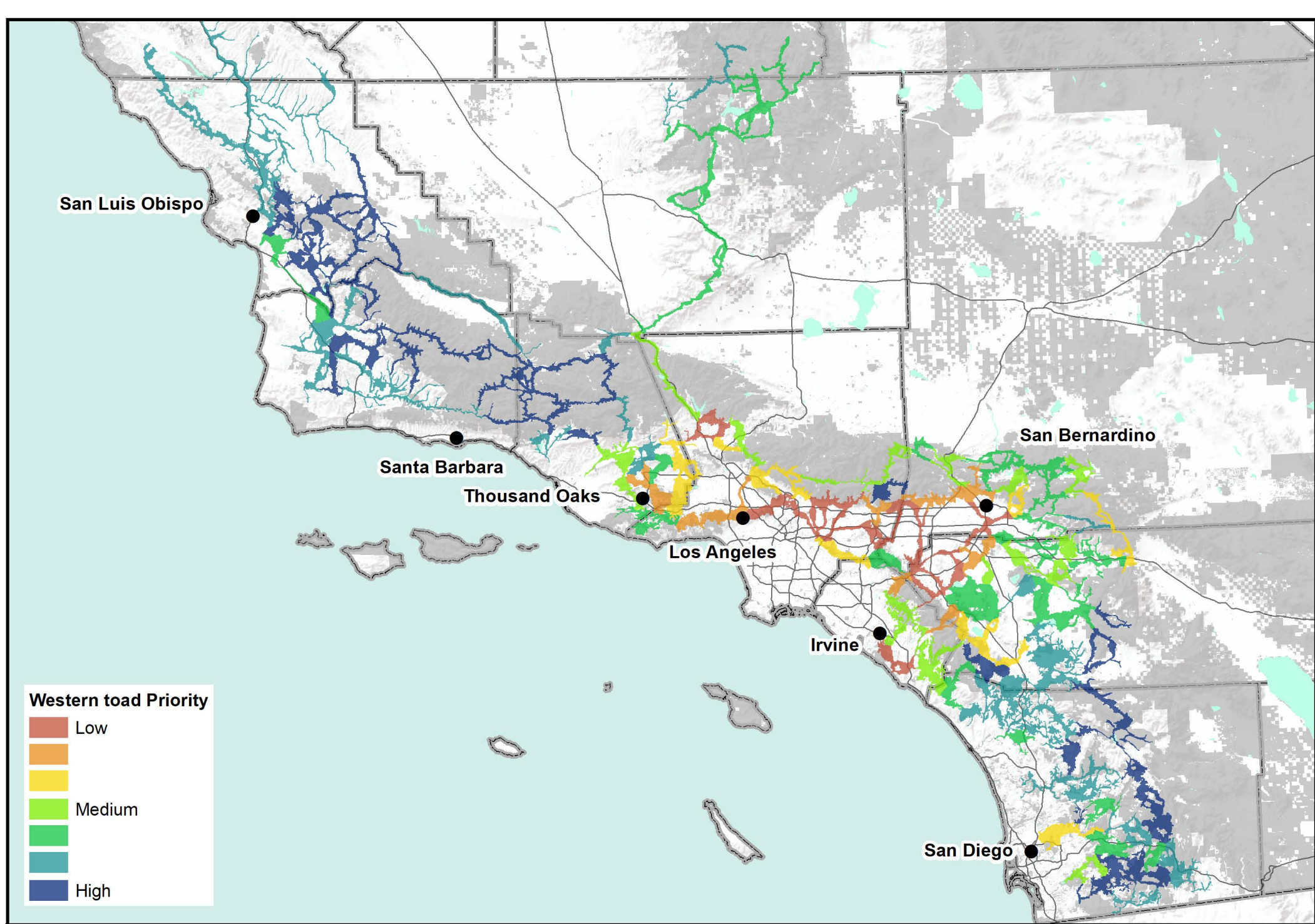
Page 4: Western toad

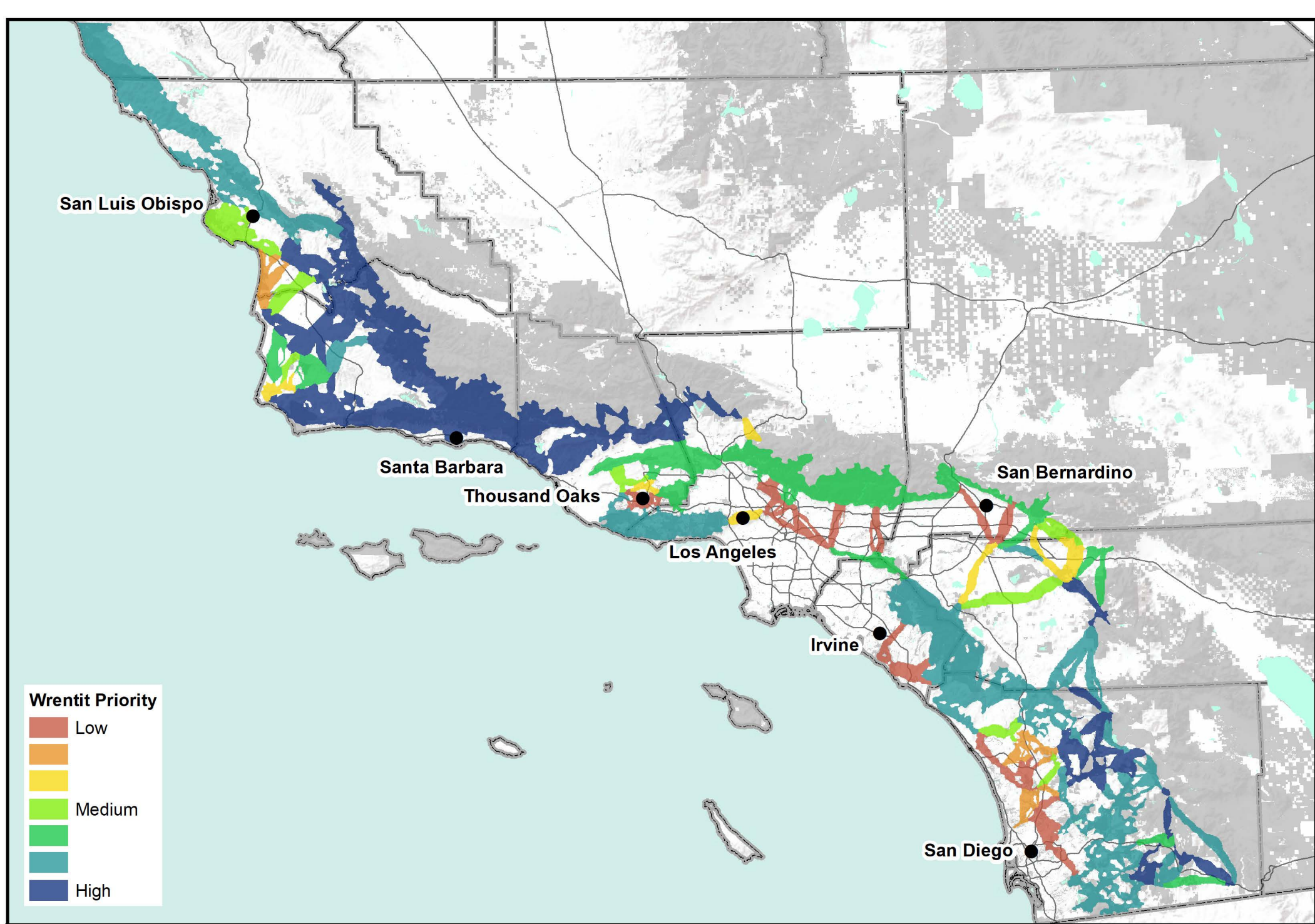
Page 5: Wrentit











APPENDIX G: STAKEHOLDER ENGAGEMENT PROCESS

A key component to the development of the geospatial and data products we produced for this project was stakeholder engagement. In order to create a connectivity plan that would be implemented and used in decision-making processes for conservation management and planning efforts, we solicited input from a targeted group of stakeholders at various stages of this project (Table G1). Through these engagement sessions, we gathered information that allowed us to create actionable science and decision support tools that would allow end users to integrate the Climate Resilient Connectivity linkage network plan into ongoing efforts.

Our initial engagement for the project started with a presentation in July 2015 and additional early meetings to discuss and refine research ideas with the California Department of Fish and Wildlife (CDFW) Region 5 staff. Through these collaborative conversations, we developed the proposal for what would become the Climate Resilient Connectivity Project. Although CDFW remained the primary stakeholder throughout our engagement process, we extended our outreach and solicitation of feedback to a much broader stakeholder audience that we continued building throughout the process with project discussions at over 20 meetings or events between 2015 and 2019. These stakeholders were engaged either during targeted Climate Resilient Connectivity Project workshops and meetings or through external meetings where updates on the project were provided.

Once we officially initiated the Climate Resilient Connectivity Project in March 2016, we broadened our stakeholder outreach, eventually contacting over 100 stakeholders from 23 organizations (Table G1). Our outreach and engagement sessions included four types of meeting formats: 1) full stakeholder meetings for all interested parties, 2) engagements with small groups of experts in planning and management, 3) one-on-one sessions with individual researchers or species experts, and 4) project overview presentations at numerous local, regional, national, and international conferences and meetings. During the project period, we convened six stakeholder meetings or presentations, five engagements with small groups, and numerous feedback sessions with experts at several stages of the project. The agendas, notes, and attendee lists from these meetings are included, in reverse chronological order, at the end of this Appendix.

We kicked off the Climate Resilient Connectivity Project in March 2016, holding a focal species selection workshop with core CDFW staff. We provided project updates for CDFW through mini-forum presentations in October 2016 and July 2017, bringing the full group back together again in July 2018 to review the products from our species distribution modeling. We reconvened again in early May 2019 to review the outputs of the population modeling and at the end of May 2019 to review the draft final linkage network and a prioritization developed for decision making using our data products. After we had an opportunity to refine these draft products based on stakeholder input, we conducted a training workshop for CDFW staff on implementing their own prioritization using our data. This involved a review of the existing models we had created, options for tweaking that model, and opportunities for creating brand new prioritizations to fit changing management or acquisition needs. We will also be engaging in a mock Land Acquisition Review Committee (LARC) meeting with CDFW to demonstrate how the data products and prioritization we have created could be employed during regular review process meetings.

In addition to targeted workshops and meetings dedicated to reviewing project activities, we also performed outreach to a number of organizations and audiences during the project period. We will have presented information about this project at six conferences: The Western Section of the Wildlife Society in 2016, The Natural Areas conference in 2016, the International Urban Wildlife Conference in 2017 and 2019, the San Diego Natural History Museum's State of Biodiversity conference in 2019, as well as The Wildlife Society conference in 2019. We have also highlighted this work in two regional climate summits, the San Diego Climate Summit in March 2018, and the Southwestern Tribal Climate Summit in August 2019. Finally, we had small engagement meetings or provided project updates over the project period to the following stakeholders: the Interagency NCCP Group, the Southern California Association of Governments (SCAG), the Wildlife Connectivity Working Group (WCWG), The Nature Conservancy (TNC), the Climate Science Alliance partners, and the Climate Science Alliance's Intertribal Working Group.

Table G1. Climate Resilient Connectivity stakeholders and organizational affiliations. Each individual's engagement in one or more workshops or meetings is listed (*including external meetings) and those who provided specialist input during the project are also identified.

Name	Agency	Attended 1 or more workshops/meetings*	Provided specialist input
Scott Quinnell	Caltrans	Y	
Amanda McGarry	CDFW	Y	Y
Andrew Valand	CDFW	Y	
Betty Courtney	CDFW	Y	
Brock Warmuth	CDFW	Y	
Carol Williams	CDFW	Y	
Christine Beck	CDFW	Y	Y
Christine Found-Jackson	CDFW	Y	
Daniel Blankenship	CDFW	Y	
David Mayer	CDFW	Y	
Diana Hickson	CDFW	Y	
Ed Pert	CDFW	Y	
Elyse Levy	CDFW	Y	
Eric Hollenbeck	CDFW	Y	
Eric Weiss	CDFW	Y	
Erinn Wilson	CDFW	Y	
Gail Sevens	CDFW	Y	
Hans Sin	CDFW	Y	
Heather Pert	CDFW	Y	
Jared Barr	CDFW	Y	
John Ekhooff	CDFW	Y	
John O'Brien	CDFW	Y	
Karen Miner	CDFW	Y	
Kelly Schmoker	CDFW	Y	
Ken Devore	CDFW	Y	Y
Kyle Rice	CDFW	Y	
Marilyn Fluharty	CDFW	Y	
Martin Potter	CDFW	Y	
Mary Larson	CDFW	Y	
Melanie Gogol-Prokurat	CDFW	Y	Y
Melissa Stepek	CDFW	Y	
Meredith Osborne	CDFW	Y	
Nancy Frost	CDFW	Y	

Name	Agency	Attended 1 or more workshops/meetings*	Provided specialist input
Patrick Tilley	CDFW	Y	
Paul Schlitt	CDFW	Y	
Rich Burg	CDFW	Y	
Rick Mayfield	CDFW	Y	
Russell Barabe	CDFW	Y	
Ryan Hill	CDFW	Y	Y
Sandra Hill	CDFW	Y	
Sarah Rains	CDFW	Y	
Scott Harris	CDFW	Y	
Simona Altman	CDFW	Y	
Steve Gibson	CDFW	Y	
Steve Goldman	CDFW	Y	
Terri Stewart	CDFW	Y	
Tim Dillingham	CDFW	Y	
Tim Hovey	CDFW	Y	
Victoria Tang	CDFW	Y	
Warren Wong	CDFW	Y	
Diane Terry	Climate Science Alliance	Y	
Udara Abeysekera	Climate Science Alliance	Y	
Dan Silver	EHL	Y	
Michael Beck	EHL	Y	
Danny Fry	Natural Communities Coalition	Y	
Jim Sulentic	Natural Communities Coalition	Y	
Milan Mitrovich	Natural Communities Coalition	Y	
Lisa Lyren	NAVFAC	N	Y
Seth Riley	NPS	N	Y
Lesley Hill	OCTA	Y	
Erin Conlisk	Point Blue Conservation Science	Y	
Geoff Geupel	Point Blue Conservation Science	N	Y
Renee Cormier	Point Blue Conservation Science	N	Y
Keith Greer	SANDAG	Y	
Kim Smith	SANDAG	Y	
Kristeen Penrod	SC Wildlands	Y	Y

Name	Agency	Attended 1 or more workshops/meetings*	Provided specialist input
India Brookover	SCAG	Y	
Amber Pairis	Scripps Center for Climate Change Impacts and Adaptation	Y	
Phil Unitt	SDNHM	N	Y
Scott Tremor	SDNHM	N	Y
Diane Foote	SDSU	Y	
Emily Haeuser	SDSU	Y	
Megan Jennings	SDSU	Y	
Pablo Bryant	SDSU	Y	
Rebecca Lewison	SDSU	Y	
Stephen Rice	SDSU	N	Y
Teri Biancardi	Sierra Club	Y	
Brian Cohen	TNC	Y	
Cara Lacey	TNC	Y	
Carrie Schloss	TNC	Y	
Chris Basilevac	TNC	Y	
Dick Cameron	TNC	Y	
John Randall	TNC	Y	
Liz O'Donoghue	TNC	Y	
Michelle Passero	TNC	Y	
Trish Smith	TNC	Y	
Doug Feremenga	Transportation Corridor Agencies	Y	
Valarie McFall	Transportation Corridor Agencies	Y	
Kurt Anderson	UC Riverside	N	Y
Chris Dellith	USFWS	Y	
Colleen Draguesku	USFWS	Y	
Jeff Phillips	USFWS	Y	
Jenny Marek	USFWS	Y	
Sally Brown	USFWS	Y	
Susan Wynn	USFWS	Y	
Will Miller	USFWS	Y	
Carlton Rochester	USGS	Y	Y
Kristine Preston	USGS	Y	Y
Robert Fisher	USGS	Y	Y

Name	Agency	Attended 1 or more workshops/meetings*	Provided specialist input
Charles Landry	Western Riverside County Conservation Authority	Y	
Rebecca Fris	Wildlife Conservation Board	Y	

Stakeholder Meeting Agendas and Notes

SDSU Climate Connectivity Prioritization Workshop for CDFW

Agenda

July 24, 2019, 1-3pm

1:00 – 1:15pm Review of prioritization for climate connectivity

- Changes we've made to the linkage network
- How have we revised prioritization strategies
- Demonstration of two approaches – linkages only for acquisition strategy, entire network for restoration/management targets

1:15 – 1:35pm Basics of the EEMS model

- Fuzzy logic
- Operators
- Model assembly

1:35 – 3:00 pm Hands-on Model Manipulation

- Connecting and running an imported model
- Adjusting parameters for an existing model
- Adding in new information into a model

Climate Resilient Connectivity Final Stakeholder Meeting**24 May 2019****10:30 PM – 12:30 PM****California Department of Fish and Wildlife****3883 Ruffin Road, San Diego, CA 92123****Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@sdsu.edu**

This is the final meeting of the Climate Resilient Connectivity project. During this meeting, we will review key findings, results, and deliverables. A draft of the final report will be submitted by May 31st, revised and then a final report will be submitted by September 2019.

Project goal: The goal of this project is to develop a regional landscape connectivity plan that identifies landscape linkages while accounting for species distribution shifts under climate change. The deliverables from the project are designed to

- provide information and context for decision-making under uncertainty
- complement existing fine-scale preserve designs for species or specific communities, not serve as a substitute
- maintain targets for preservation of biodiversity beyond rare/protected/listed species (**keep common species common**). Can complement work done on rare, habitat specialists
- be a component of growing conservation planning toolbox

Meeting Objective: To review key findings, results, and deliverables, focusing specifically on the deliverables viewed through [Data Basin](#)

Project Methods Summary

There are three key individual steps or elements to this connectivity project: species distribution modelling, metapopulation modelling, and linkage prioritization. Results from these individual elements have been presented at stakeholder meetings starting in March 2016. Stakeholder meetings were convened October 2016, July 2017, July 2018, mid-May 2019, end of May 2019.

Element 1: Focal species selection and habitat suitability modelling

Working directly with stakeholders, we identified 5 species that met the **keep common species common** intention of the project. These are wrentit, California spotted owl, western toad, bobcat and big-eared woodrat. We had attempted to include grasshopper sparrow but data limitations prohibited its inclusion.

For all focus species, we mined public databases (e.g., eBird, iNaturalist, BIOS) and all unpublished literature for each species. To avoid including older data points in areas that have since been developed (thus artificially suggesting urban areas may be suitable based on these locations), we implemented a temporal cutoff, only using data from 1980 to present. The data and models for each species were reviewed and discussed with experts, and all models were quantitatively evaluated using cross-validation based on prediction of presence versus absence for withheld testing data. This was repeated with different subsamples of the data in each run for the most robust approach. Species distribution models can be accessed [here](#).

Element 2: Population modelling - Understanding how population dynamics and connectivity are related

Corridors are recognized as being important to population dynamics and persistence. Spatially connected populations, called metapopulations, are formed as populations:

- **reorganize** when there are large fluctuations in birth and death across the landscape or when populations
- **recolonize** an area following disturbances (e.g., fire, drought, disease) that reduce populations in good habitat
- **fragment** when contiguous habitat split or **consolidate** when new habitat forms

Because of these processes, metapopulations are integrally linked to connectivity. We considered metapopulation outputs in the context of climate change by comparing population networks under a no change scenario at the end of the century to results from two climate change models: warmer-wetter (CNRM-CM5) and warmer-drier (MIROC5). You can review population model outputs by looking at a [package of side-by-side maps](#) that compare population projections with connectivity across 3 scenarios (no climate change, warmer-wetter, and warmer-drier).

Element 3: Linkage prioritization

Given the scale and scope of the project, prioritization is critical to achieve a realistic and implementable multispecies linkage network. Prioritization allowed us to select critical linkages for each species to be assembled into a regional multispecies network. Our prioritization was based on inputs from four main categories:

- linkage feasibility
- connectivity/landscape value,
- climatic resilience consensus value,
- metapopulation persistence (which incorporates species-specific dispersal limitations)

After we prioritized linkages for each species, we selected a combination of the segments that had either the highest maximum value for any single species, highest average value across all species, or was identified for three or more species. We used this selection as the framework for the multispecies network. To identify and fill gaps in this network, we reviewed two additional modeling outputs – those from Circuitscape models (based on the theory of electrical current flow) for each species, and land facet or topo facet linkages based on ecologically-relevant land forms (Theobald *et al.* 2015).

The final network identifies linkage segments and their source (species or land facet models) as well as priority areas that are already conserved in large blocks (>5,000 acres). We split the network into subregional management zones using major freeways. Finally, we generated a conservation priority based on:

- Species value – average species count and maximum priority value from single species models
- Conservation status – Proportion already conserved and proportional overlap with prior connectivity modeling efforts
- Future development risk – Proportion of area likely to be developed by 2100 under a business as usual model and a high population growth rate model (Sleeter *et al.* 2018)

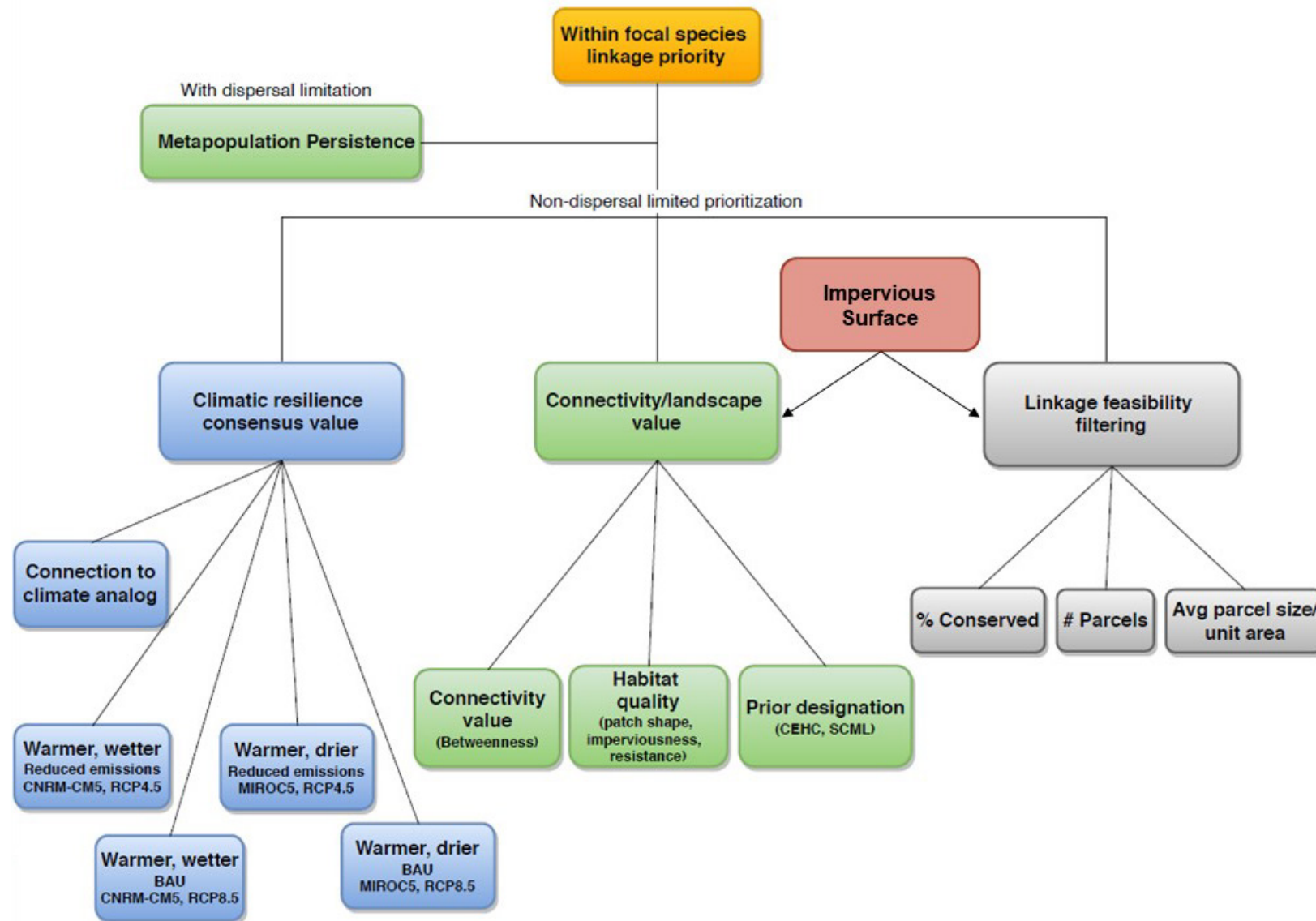


Figure 1. Conceptual model of linkage prioritization process for each focal species.

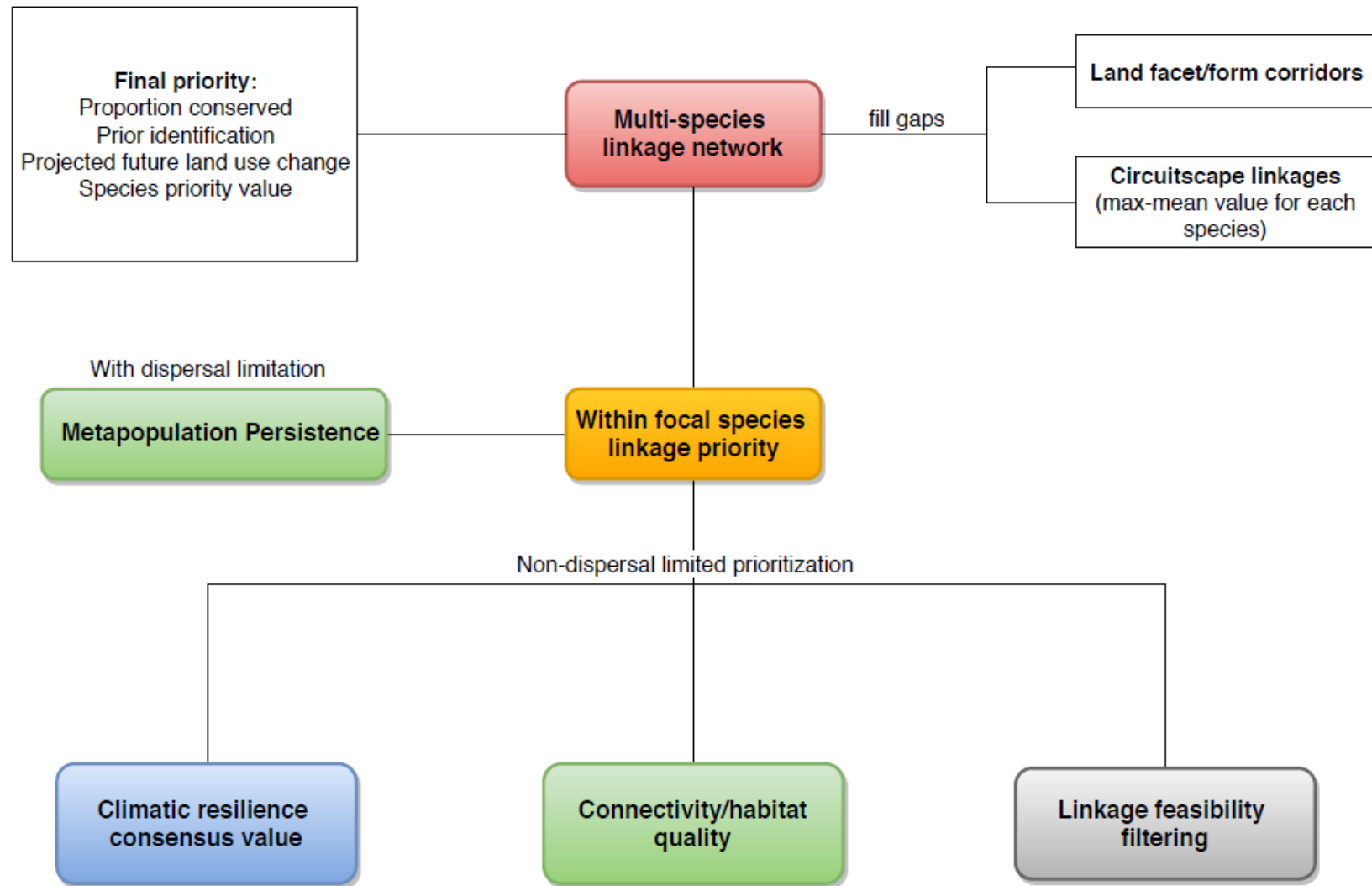


Figure 2. Conceptual model of how individual focal species linkages will be assembled into a single multispecies network.

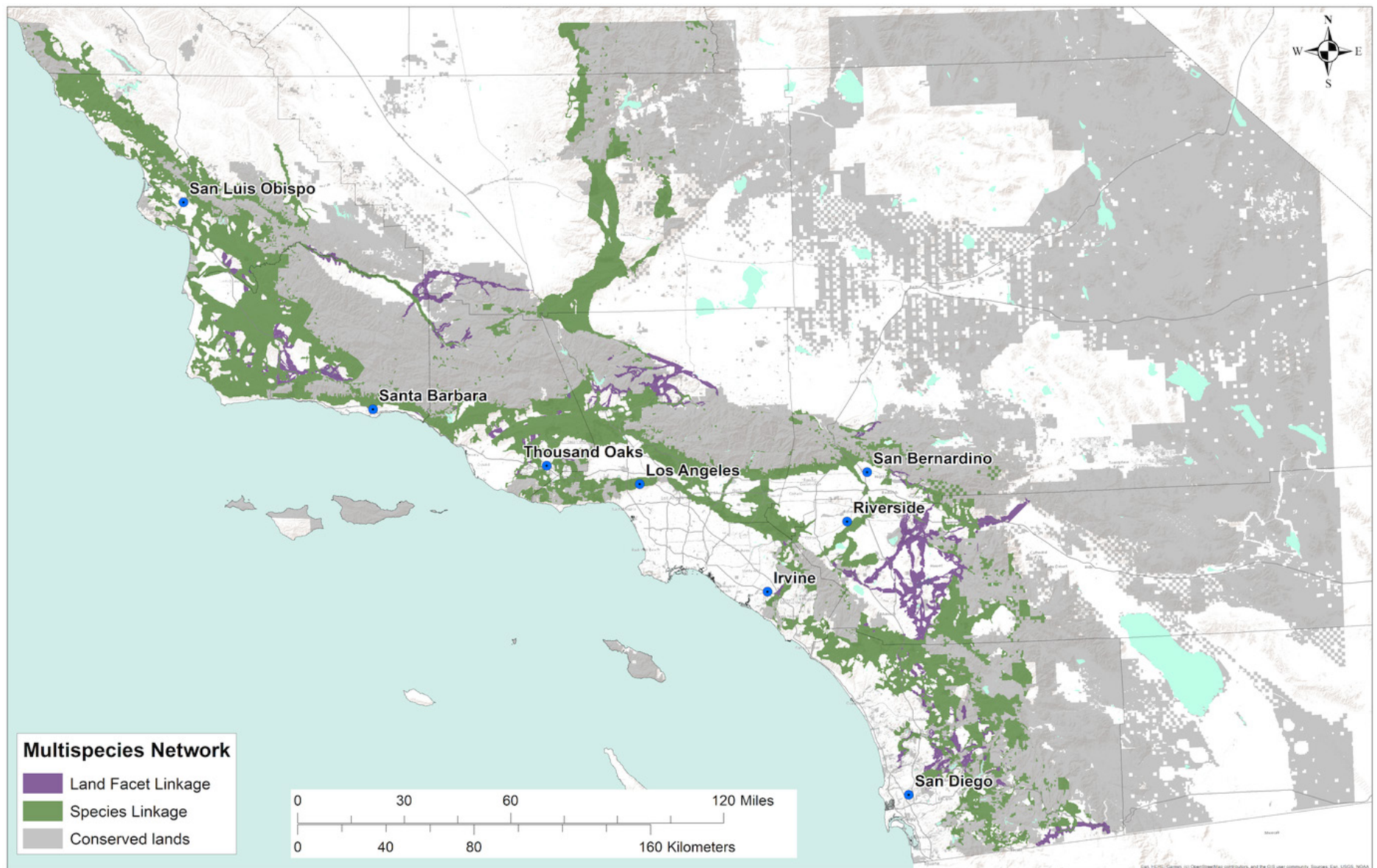


Figure 3. Multispecies linkage network displaying assembled species linkages, land facet linkages, and conserved lands

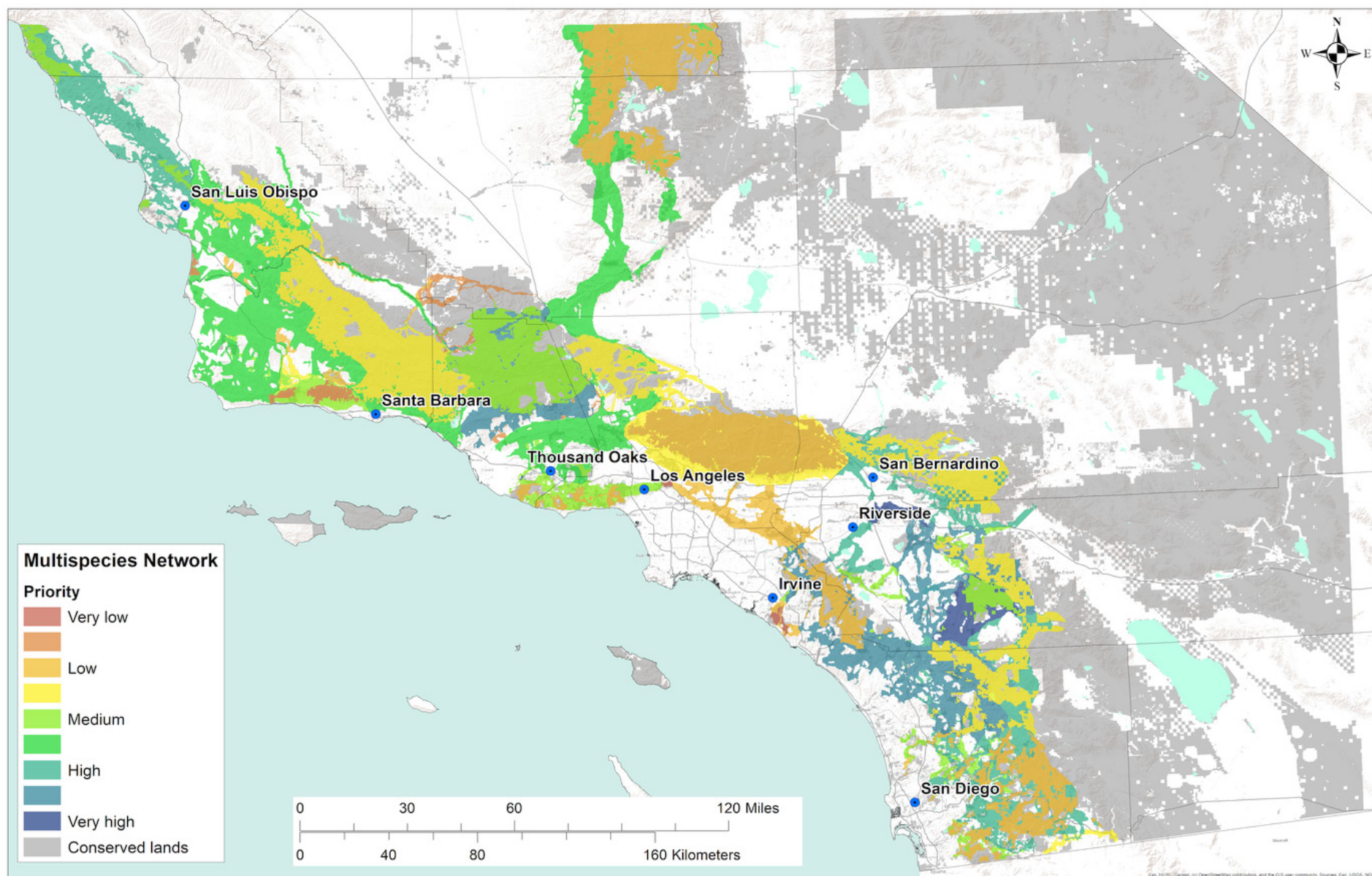


Figure 4. Multispecies linkage priority network based on multispecies value, proportion conserved, prior connectivity identification, and projected future development. Areas not already conserved and projected for development receive a higher priority in this model.

Climate Resilient Connectivity Stakeholder Meeting Summary

01 May 2019

1:00 PM – 3:00 PM

California Department of Fish and Wildlife

3883 Ruffin Road, San Diego, CA 92123

Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@sdsu.edu

Attendees (* denotes remote participants):

Gail Sevens, CDFW	Amanda McGarry, CDFW	*Karen Miner, CDFW
Eric Weiss, CDFW	Ken Devore, CDFW	*Chris Dellith, USFWS
Eric Hollenbeck, CDFW	Warren Wong, CDFW	*Rebecca Fris, WCB
Jared Barr, CDFW	Hans Sin, CDFW	*Jeff Philips, USFWS
Christine Beck, CDFW	Cara Lacey, TNC	*Melanie Gogol-Prokurat, CDFW
Dave Mayer, CDFW	Kris Preston, SDMMMP/USGS	*Trish Smith, TNC
Patrick Tilley, CDFW	Susan Wynn, USFWS	

Project goal: The goal of this project is to develop a regional landscape connectivity plan that identifies landscape linkages while accounting for species distribution shifts under climate change. The deliverables from the project are designed to

- provide information and context for decision-making under uncertainty
- complement existing fine-scale preserve designs for species or specific communities, not serve as a substitute
- maintain targets for preservation of biodiversity beyond rare/protected/listed species (**keep common species common**). Can complement work done on rare, habitat specialists
- be a component of growing conservation planning toolbox

Meeting Objective: To review data outputs for the Climate Resilient Connectivity Planning Project and solicit stakeholder input. We will also discuss next steps in the analysis and planning for this project.

Reviewed products included:

- 1) population model outputs
- 2) linkage prioritization plan
- 3) demonstration of the integrated population-connectivity approach with one focal species.

Meeting Summary

1) *Population model outputs – Understanding how population dynamics and connectivity are related*

Corridors are important to population dynamics and persistence. Spatially connected populations, called metapopulations, are formed as populations:

- **reorganize** when there are large fluctuations in birth and death across the landscape or when populations
- **recolonize** an area following disturbances (e.g., fire, drought, disease) that reduce populations in good habitat
- **fragment** when contiguous habitat split or **consolidate** when new habitat forms

Population Modeling Assumptions

- Individuals are well-mixed within a patch
- Edge-to-edge distances evolve with climate change
- Dispersal depends on:
 - species ability,
 - abundance of giving patch, and
 - carrying capacity of receiving patch
- High year-to-year variability (e.g., double-brooding and drought)
- Least cost paths were used to represent linkages in these models. Full width corridors were not modeled as the population models only recognize their existence and distance, not width or quality

Calculating relative importance of linkages

- We considered the importance of **existing** corridors only
- Assigned a minimum threshold above which we did not expect that changes in final population size were due to chance alone.
- On corridors above threshold, assigned relative importance on a scale from 0-1 where 1 was the maximum value observed across all scenarios.

Population Modeling Results

You can download a [package of side-by-side maps](#) that compare linkages under a no change scenario at the end of the century (left) to results from two climate change models: warmer-wetter (CNRM-CM5) and warmer-drier (MIROC5)

Under warmer-wetter and warmer-drier conditions for **wrentit and big-eared woodrat**, we found

- Dispersal-limitation that restricted the number and length of corridors
- Considerable habitat consolidation in the north where connectivity had limited benefit
- Some habitat fragmentation in the south
- We are continuing to explore connectivity within local networks (clusters) defined by graph theory

Under warmer-wetter and warmer-drier conditions for **bobcat and western toad**, we found

- Fragmentation for both species in the future reduces overall risk to the population because patches become separated and as such, are less likely to simultaneously experience events that would affect subpopulations (e.g., patch-scale fires)

- Corridors connecting patches of habitat that fragment under climate change are particularly beneficial
- As long-distance disperser, bobcats relied on long corridors, and overall, benefitted more from connectivity than our other species

Results for **spotted owls** were very different under all scenarios and demonstrated the most substantial climate change impacts

- With most of their habitat at high elevations, they lose too much habitat with ‘shrinking mountaintops’ and there is not enough habitat remaining to support a sustainable population
- This means there is little benefit of corridors in the future
- Even considering “optimistic” vegetation vulnerability scenario

2) **Linkage prioritization plan**

Given the scale and scope of the project, prioritization is critical to achieve a realistic and implementable multispecies linkage network. Our proposed prioritization is based on inputs from four main categories (described in more detail below):

- linkage feasibility,
- connectivity/landscape value,
- climatic resilience consensus value,
- metapopulation persistence (which incorporates species-specific dispersal limitations)
- **Linkage feasibility filtering** accounts for factors that would affect how easy or difficult it would be to actually conserve linkages within the network such as:
 - impervious cover,
 - percent of area already conserved,
 - number of parcels, and
 - average parcel size/unit area
- **Connectivity and landscape value** is based on measures of:
 - betweenness, or importance of an individual linkage as a hub within a network,
 - habitat quality metrics like the ratio of patch edge to overall area, impervious cover, and resistance, and
 - consideration for whether a linkage overlaps with areas previously identified as important under the South Coast Missing Linkages (SCML) or California Essential Habitats Connectivity (CEHC) projects.
- **Climatic resilience consensus value** evaluates the value of linkages under climatic changes in the future based on the premise that the more evidence we have that certain linkages are important, the more confident we can be that it will provide climatic resilience value in the future. We calculated consensus two ways:
 - based on connectivity to climate analogs (using climatic water deficit that accounts for temperature and precipitation) under two climate scenarios (warmer-wetter and warmer drier, both under business as usual emissions).
 - accounting for how many time steps in our decadal modeling a linkage persists within each of the four climate scenarios. The greater number of time steps across scenarios,

the more likely a linkage is important for connecting not only present but future habitat patches.

- **Metapopulation Persistence** is based on a prioritization calculated using the relative importance value described above.
 - This was calculated under the no change scenario, as well as two climate models (warmer-wetter and warmer-drier) under business as usual emissions. For spotted owl, we also include the more optimistic vegetation vulnerability model.

Once linkages are prioritized for each species, those with highest values will be selected for inclusion in the multispecies network. Finally, land facet or landform linkages will be modeled and those static landscape features that were not already represented will be integrated into the network.

3) *Review of Deliverables*

- Project report
- Prioritized multispecies linkage plan
- Conceptual model of the prioritization and spatial data for each species
- Maps of pinch points and barriers across the linkage network
- Other potential outputs that could be shared with stakeholders, as desired (e.g., Circuit flow maps, historic linkage flow maps)

4) *Project add-ons – SDSU's [CWC project](#)*

As there are several aspects of the project we'd like to build on and we have the opportunity with the newly funded "Connecting Wildlands and Communities" project that builds on this climate connectivity research, we plan to expand on our linkage analysis in the following ways:

- Validation with additional species
 - Population models for our secondary species: puma and mule deer
 - Other species of interest or conservation targets?
- Biodiversity value of linkages
- Connectivity to climatic refugia (temperature and drought)
- Fire risk to/from linkages
 - Type conversion risk
- Spatial targets for managing conservation targets vs multiple uses (e.g., recreation)

If there are other aspects you'd like to see added on, please contact Megan (mjennings@sdsu.edu)

5) *Next steps*

- Our next/final workshop will be held Friday, May 24 from 10:30 AM – 12:30 PM. We will review the linkage modeling and our prioritization in more detail in this meeting. We will also demonstrate use of the online platforms where we will host our data and exploration of the prioritization information.
- A draft final report will be prepared by May 31 for WCB, but we will continue refining the final products and final report based on input we receive on May 24. Final delivery of refined project materials will occur at the end of the CDFW grant period in September 2019.

- We have reviewed delivery of our data and prioritization model on Data Basin. These data can also be uploaded to BIOS for CDFW data integration. We would like feedback about whether end-users would want to be able to tweak the prioritization model themselves in EEMS online.

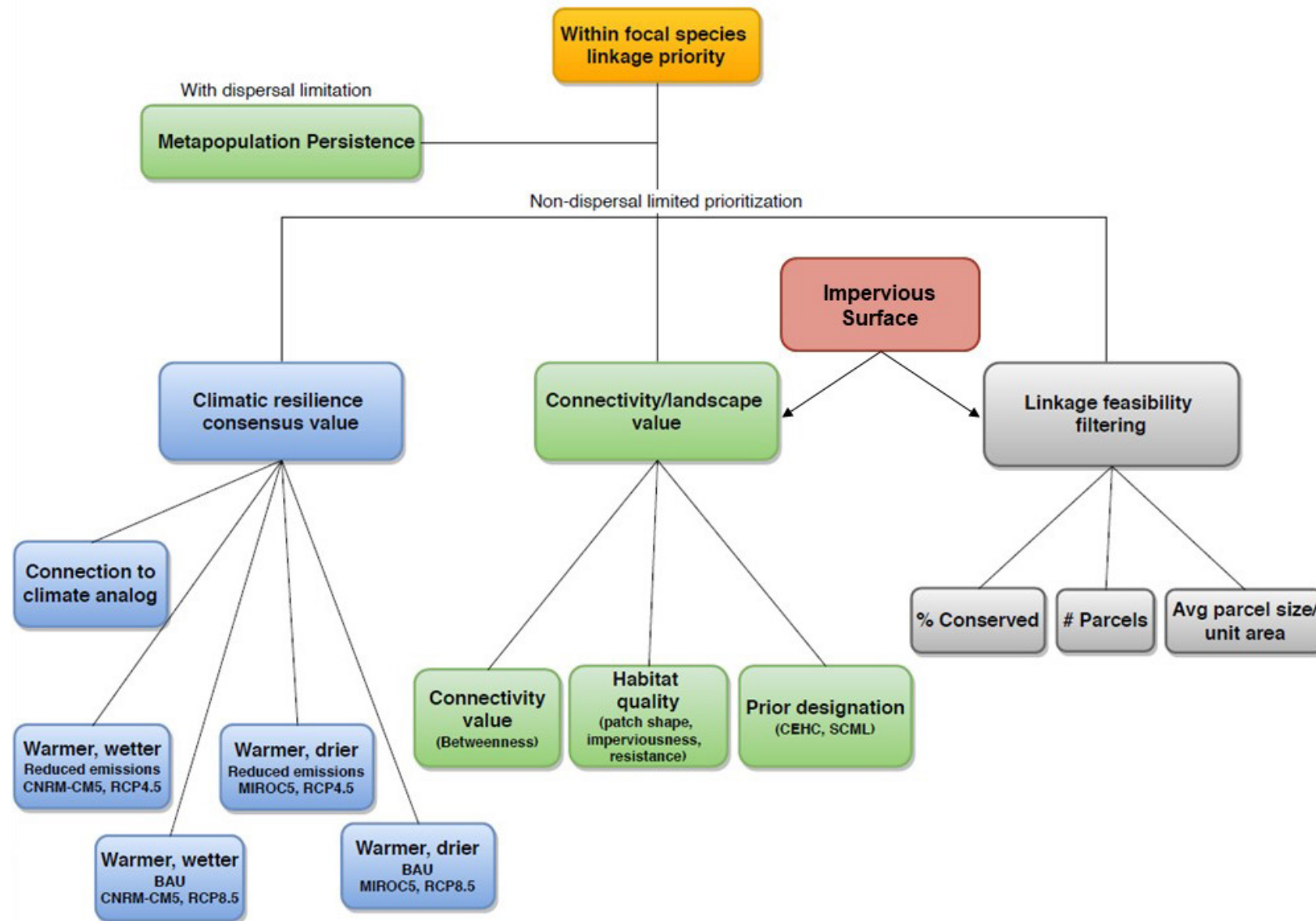


Figure 1. Conceptual model of linkage prioritization process for each focal species.

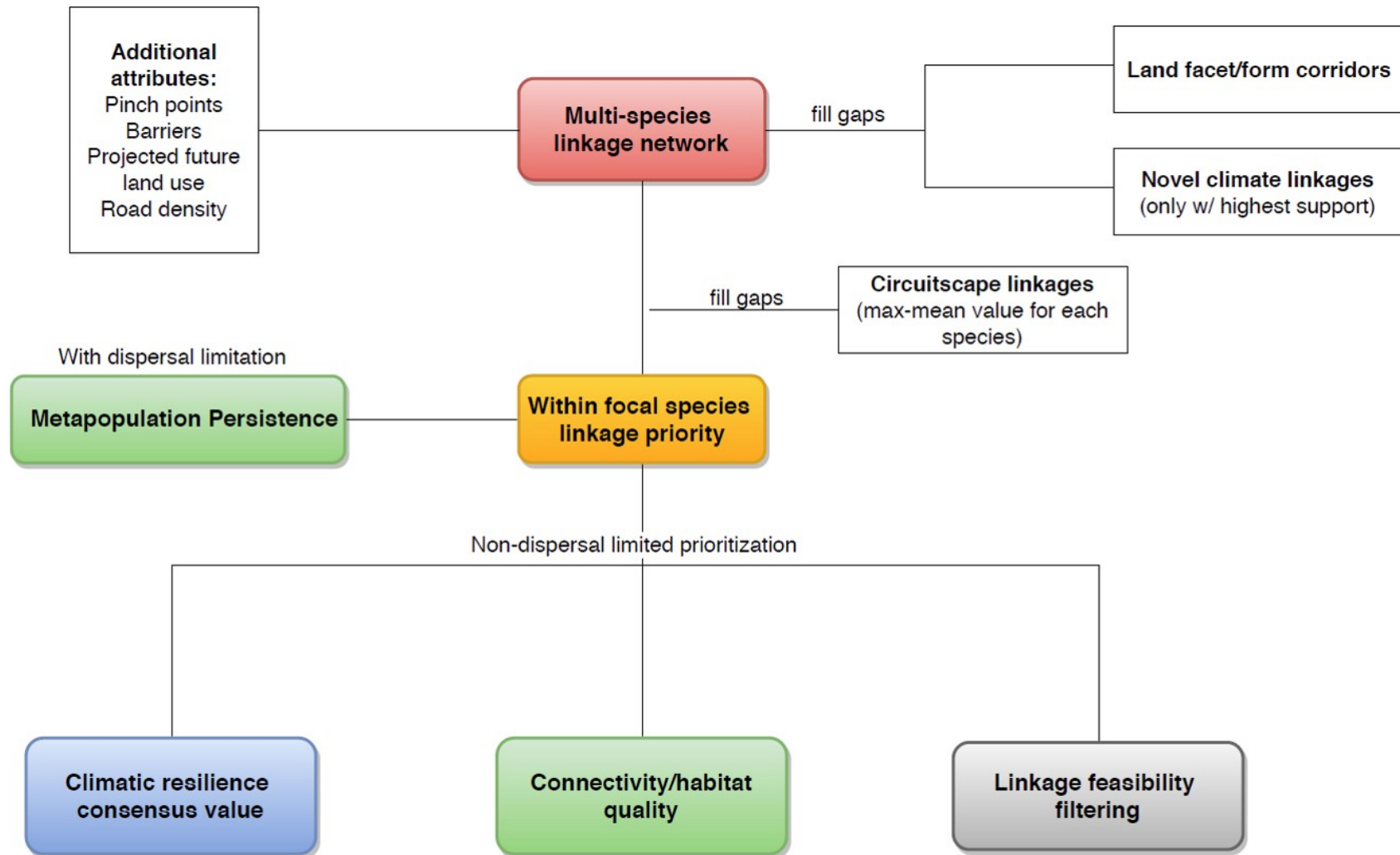


Figure 2. Conceptual model of how individual focal species linkages will be assembled into a single multispecies network.

Project Overview

To facilitate decision making under uncertainty, we developed a scenario-based focal species approach to model, assess, and prioritize landscape linkages. For this assessment, we used a novel complement of ensemble species distribution models (SDMs) and connectivity models linked with dynamic metapopulation models to advance connectivity planning accounting for climate change, land-use shifts, and uncertainty. We applied these methods to each species for four climate scenarios and are prioritizing landscape linkages across the region to assemble a single, multispecies linkage network.

Focal species selection

At initial stakeholder meetings, we discussed potential focal species for this project. We wanted to select species that would be representative of connectivity for a broader range of species and were representative of a range of habitat types and movement behaviors/patterns. Because the population models were an integral component of this project, we also needed to select species that had adequate demographic data to parameterize those models. Our initial selection included the following: bobcat (*Lynx rufus*), wrentit (*Chamaea fasciata*), California spotted owl (*Strix occidentalis occidentalis*), big-eared woodrat (*Neotoma macrotis*), western toad (*Anaxyrus boreas*), and western meadowlark (*Sturnella neglecta*). We also identified two additional species we would include in modeling efforts, as time allowed, the puma (*Puma concolor*), and mule deer (*Odocoileus hemionus*). Each model was developed using existing occurrence data for the species as well as climatic niche data, impervious surface data (to represent urbanization), and data on water availability. Initial models were reviewed and then refined based on input from species experts.

Of these six initial focal species, we found that habitat suitability models for one, the western meadowlark, were not accurate. In consultation with ornithologist at the San Diego Natural History Museum, Phil Unitt, we determined this was most likely a result of the species ability to utilize typically drier, desert habitats in wet years. As such, we investigated a range of potential other grassland bird species and determined that we would attempt to model the grasshopper sparrow (*Ammodramus savannarum*). We worked to develop and then improve this model based on discussions with Phil Unitt. However, there were limitations in our ability to clearly distinguish among high quality grassland habitats required by the species and degraded grasslands or coastal sage scrub vegetation. After input from our stakeholder review in July 2018, we made several final attempts to improve this model unsuccessfully and removed the species from our focal species list at that time. We will ensure grassland habitats are represented by land facet models that will be applied after we generate our multispecies linkage network. After input from our stakeholder group, we refined models for several other species, requested final expert opinion review and once received, we proceeded with population modeling.

Species distribution modeling (SDM)

After selection of each focal species, representing a range of habitat associations, movement behaviors/modalities, and taxonomic groups, we used ensemble species distribution models (SDMs) to map habitat suitability for our species under historic climatic conditions and project those conditions to 2100 under four future scenarios: warmer-wetter conditions (model CNRM-CM5) under mitigated emissions (RCP 4.5) and business as usual emissions scenarios (RCP 8.5), and warmer-drier conditions (MIROC5) under mitigated emissions (RCP 4.5) and business as

usual emissions scenarios (RCP 8.5). SDMs used input variables representing climatic conditions as well as impervious surface (a proxy for urbanization), slope and topographic position, and distance to water.

Project extent and data limitations

Because our modeling approach is based on climatic niche envelopes to allow us to model change over time in response to shifts in climatic variables, there are limitations in our ability to predict suitability in the past and future with the highest accuracy. The two primary limitations we faced were related to the incorporation of vegetation and modeling of climatic conditions from more southerly locales (*i.e.* Baja California, Mexico). We explored existing vegetation models for change under climatic shifts but did not find reliable projections of future vegetation that were suitable for use at the spatial extent and grain of the project. We did explore the option of creating our own vegetation change projections for the purposes of improving our models, but found this would have been a major undertaking, not within the scope of our project timeline or funds. Instead, we adapted the vegetation vulnerability data developed by Jim Thorne and colleagues from the University of California, Davis to explore future conditions with a vegetation component. Ultimately, this was only necessary and appropriate for the spotted owl, a species that was modeled to have a precipitous decline in the future when vegetation was not included in models. For the other species, this scenario was not divergent enough from our four climatic scenarios, and as such, did not warrant producing the fifth set of associated models.

In an attempt to improve the quality and accuracy of our climatic niche models we explored expanding our modeling south into Mexico to ensure we had a range of climatic conditions modeled using historic data that would be analogous to projected future conditions in the southern California region. Unfortunately, we found that even historic climatic data sets did not match in sources and scales and were not compatible with modeling suitability across the border. In addition, we found that the non-climatic data we applied to our SDMs (*i.e.*, urbanization, distance to water) were also not readily available in compatible forms to the data we have for the U.S. side of the border.

Linkage modeling

Based on the species distribution modeling surfaces in the historic and future (2100) time periods, we interpolated habitat suitability at annual time steps in the intervening years. We then used these surfaces to identify patches of suitable habitat using minimum suitability and area thresholds for each species. We converted habitat suitability to resistance using a non-linear conversion related to the species ability to traverse unsuitable habitats. The resistance and habitat patch layers were used as the primary inputs for least cost corridor linkage modeling we performed for decadal time steps under each scenario. We did not apply species-specific dispersal limitations at this stage so as to allow for corridors to be developed that would fit species with similar habitat associations but not necessarily the same dispersal limitations. Instead, species-specific dispersal has been integrated into the population models. To compare a different approach to modeling connectivity for each species, we performed electrical circuit theory-based analyses using the program Circuitscape. Our final linkage plan will be reviewed using these Circuitscape outputs to ensure no critical linkage zones were omitted from this final product.

Population modeling

Habitat patches and linkages were then used as spatial inputs for dynamic metapopulation models. These models were created using the annual time step habitat suitability models and the species demographic data gathered from the COMADRE database and refined based on local literature and review of southern California-specific data with species experts. We modeled population trajectories over 100 years under a no change scenario with no shifts in climatic conditions, and under the two extreme scenarios: warmer-wetter under business as usual emissions, and warmer-drier under business as usual emissions. For each model, we tested the value of each modeled corridor two ways: 1) by limiting all dispersal to only the selected corridor, and 2) by enabling all dispersal except for the selected corridor. In each case, we evaluated the overall value by looking at the overall change in the population's final abundance either by adding one corridor in, or by leaving one corridor out. These values were rescaled to and overall relative importance based on a lower threshold that was identified to be greater than the background variability for each species' model and an upper threshold, which was the absolute maximum value observed for each species across all models.

Linkage attribution and prioritization

For each species, linkages and core areas under historic conditions are being assembled and cleaned. From there, several attributes are assigned to allow for prioritization based on: connectivity and landscape value, climate consensus value, linkage implementation feasibility, and metapopulation persistence value (Figure 1). By creating the climate consensus value, the prioritization will assign greater value to areas where there is agreement across scenarios, providing greater support for decision-making under uncertainty. In addition, by combining currently known landscape conditions such as impervious surface cover and percent land conserved with those that are less certain from our climatic modeling, our prioritization approach is grounded in empirical data while providing a robust framework for considering the value of linkages for resilience in the face of climate change.

Once the prioritization for each species has been completed, high value linkages will be combined across species to map a single multispecies linkage network (Figure 2). Once this network is developed, we will review our species-agnostic land facet or landform linkages to determine if additional features that may support wildlife movement under climate change should be included in the final network.

**Climate Resilient Connectivity Workshop
Species Distribution Review Meeting**

13 July 2018

9:00 AM – 12:00 PM

California Department of Fish and Wildlife

3883 Ruffin Road, San Diego, CA 92123

Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@mail.sdsu.edu

Objective: To review draft data products for the Climate Resilient Connectivity Planning Project and solicit stakeholder input. These products include habitat suitability maps for focal species and initial corridor maps and population modeling outputs. We will also discuss next steps in the analysis and planning for this project.

1. Welcome and introductions
2. Review purpose, overview, and objectives
3. Presentation on current project status, data analysis, and map products to be reviewed
4. Input on map products (Please bring a laptop if you are able)
 - General questions/comments
 - Break out groups
5. Overview of draft corridor and population modeling outputs
6. Review conceptual plan for linkage prioritization
7. Future analyses, additional data inputs, future stakeholder input

**CONFERENCE CALL-IN #: (877) 873-8018
PARTICIPANT CODE: 165722#**

Web Conference Info

--> Join Skype Meeting<<https://meet.wildlife.ca.gov/laura.hampton/FNC67DYH>> Trouble Joining?
Try Skype Web App<<https://meet.wildlife.ca.gov/laura.hampton/FNC67DYH?sl=1>>
Help<<https://cdfwsp.ad.dfg.ca.gov/sites/DTD/ITOB/UCTeam/SitePages/Home.aspx>>
[https://www.wildlife.ca.gov/Portals/0/header_organization.png] CDFW Skype for Business, enjoy your meeting. [!OC([1033])!]

**Climate Resilient Connectivity Workshop
Species Distribution Review Meeting Notes**

13 July 2018, 9:00 AM – 12:00 PM

Contact: Megan Jennings / 760.214.2145 (mobile) / mjennings@mail.sdsu.edu

SDSU ACTION ITEMS:

- Coordinate with USGS to obtain additional western toad data and attempt to improve modeling of upland habitat conditions for the species. **UPDATE: we have data and an improved model we will be seeking input on from USGS.**
- Attempt to improve grasshopper sparrow model by creating a new historic-only model that includes vegetation. **UPDATE: we made several attempts to improve this model, making adjustments with vegetation and impervious surface and still had extensive overprediction in non-grassland areas. We suggest removing grasshopper sparrow from our focal species list and instead focusing on identifying grassland linkages with the land facet analysis.** Please contact Megan (mjennings@sdsu.edu) if you have concerns about this course of action.
- Review genetic data for California spotted owl, California gnatcatcher, and coast cactus wren to consider how those data could be used to inform our corridor selection/prioritization
- Generate maps of areas of greatest change and areas of greatest uncertainty for review
- Set up a future workshop near the end of 2018 to review the outputs from the connectivity and population modeling phase of the project

CDFW and other Stakeholders

- Provide input to Megan (mjennings@sdsu.edu) of additional invitees (outside CDFW, e.g., TNC) to participate in future workshops. Remember that this project is for the whole south coast region, so we don't want to be too heavily San Diego focused. We can conduct future workshops for outreach to local end user communities
- CDFW to specifically reach out to Region 6 counterparts to invite them to future sessions
- USFWS to continue to work on identifying participants from the Ventura FWO
- Amanda and Ken to determine if they can gather parcel data for the study region so we may include average parcel size across a corridor to assist with prioritization. We have this for San Diego County but need it for the remainder of the study region

Attendees (*online participants):

Megan Jennings, SDSU
Emily Haeuser, SDSU
Erin Conlisk, SDSU & Point Blue
Rebecca Lewison, SDSU
Amber Pairis, Climate Science Alliance
Udara Abeysekera, CDFW & CSA
Laura Hampton, CDFW & CSA
Diane Terry, CDFW & CSA

Gail Sevens, CDFW
Ed Pert, CDFW
Dave Mayer, CDFW
Hans Sin, CDFW
Rich Burg, CDFW
Simona Altman, CDFW
Eric Hollenbeck, CDFW
Paul Schlitt, CDFW
Warren Wong, CDFW
Amanda McGarry, CDFW
Christine Beck, CDFW
John Ekhooff, CDFW

Susan Wynn, USFWS
Will Miller, USFWS
Robert Fisher, USGS
*Melanie Gogol-Prokurat, CDFW
*Scott Harris, CDFW
*Victoria Tang, CDFW
*Andrew Valand, CDFW
*Brock Warmuth, CDFW
*Kelly Schmoker, CDFW
*Sarah Rains, CDFW

Meeting Objective: To review draft data products for the Climate Resilient Connectivity Planning Project and solicit stakeholder input. These products include habitat suitability maps for focal species and initial corridor maps and population modeling outputs. We will also discuss next steps in the analysis and planning for this project.

Note: Action items above were gathered from the items in **bold text** below.

Presentation on current project status, data analysis, and map products to be reviewed

8. Slides on the methods presented are available for download on the [Google Drive folder](#) established for this meeting/project
9. As a reminder, it is important to remember the goals of our modeling and appropriate uses of the data given these goals.
 - a. DO: use models for reserve design, preserve networks
 - b. DON'T: don't compare suitability values among species, don't rely on outputs outside primary study area (non-analog conditions that can't be modified into future), don't use individual scenarios for decision making, don't use SDMs for species management decisions (just about connectivity).
10. This portion of the meeting focused on a review of the origin of the project and the primary goals we're hoping to accomplish with meeting products. We also provided a high-level overview of the methods being used to complete the first phase of modeling for this project, species distribution modeling.
11. If there is anyone who would like more detailed information on our methods or results, please contact mjennings@sdsu.edu
12. We also gave a brief overview of the species distribution modeling outputs we would be reviewing in break out groups. Due to limited time and the number of products to review (1 historic (1970-2000) suitability model + 4 future (2070-2100) suitability projections for each of 6 focal species), each break out group focused on review of data products for 2 species.
13. **Note:** We recommend limiting the extent of our modeling outputs for final delivery to the south coast ecoregional boundary. We modeled beyond this extent to ensure we encompassed broader climatic conditions than along the coastal zone and to reduce the likelihood of edge effects in our modeling, but due to non-analog conditions and more limited data in this area, our confidence in projections in this expanded area is lower.

Input on map products

General questions/comments:

1. Can we work to incorporate genetic data on focal species or other species of interest?
 - a. We will look into this for the species discussed (*i.e.* California gnatcatcher, coastal cactus wren, California spotted owl)
2. In future products, can we provide information (maps?) on the intensity and distribution of change over time: *e.g.*, areas with the greatest change (delta) between the historic and the future and a version that captures areas of uncertainty (largest delta among scenarios)?
 - a. Yes, these can be some of the future/final products we work on

3. Suitability map symbology – can we display these with suitability cutoffs? Can water be distinguished more clearly
 - a. We can symbolize water differently in the future but because each species is different in suitability cutoffs and we're really most interested in a relative scale, not applying firm thresholds, we would prefer to not delineate "suitable" vs. "unsuitable"
4. How were data cleaned, vetted, and evaluated? Can we use additional data to validate the models?
 - a. From public databases (e.g., eBird, iNaturalist), we only used research grade observations. We also limited our data to only locations with a spatial error <500m. To avoid including older data points in areas that have since been developed (thus artificially suggesting urban areas may be suitable based on these locations), we implemented a temporal cutoff, only using data from 1980 to present. For several species where we were data-limited, we included older data, but cleaned those older points to remove locations in currently developed areas. The data and models for each species were reviewed and discussed with a species expert except for western toad because we were waiting on feedback from USGS.
 - b. Model evaluation is built into the methodological approach. We do this in two ways: 10-fold cross validation where we run the models 10 separate times with different bins of the data to ensure some segments of the data aren't biasing the output. In each of these 10 bins, we randomly select a different set of the data to be used as training and testing. In this approach, 80% of the data in each run are used to train or build the model while the remaining 20% are held back and used to validate the run to see how well the run predicts presence versus absence for the leftover training data. This is repeated with different subsamples of the data in each run for the most robust approach.

Species-specific comments

- *Spotted owl*: Model has very high accuracy at predicting suitability in the historic period. The future scenarios all appear dire for this species but could be inaccurate because the forests may be able to persist for longer than model shows providing opportunities for spotted owl to hold out. Genetic separation for this species has not been considered yet, but given the availability of the data for this additional validation, **we will be trying to add in an analysis of the genetic structuring for spotted owl before our next meeting.**
- *Wrentit*: The wrentit model also appears to do reasonably well in the historic period. Future suitability increases substantially along the central coast, most likely because what is currently a bit wet and cool for the species will become more suitable by the end of the century as conditions become warmer and drier. A question was raised about lack of occurrence points on the Palos Verdes Peninsula because we did not have any in our dataset but the model did predict moderate-high suitability in that area. **We will check with Kris Preston about suitability for the wrentit on the Palos Verdes Peninsula.** There was also a question about how representative wrentit may be for California gnatcatcher and coast cactus wren given concerns about persistence of these listed species and availability of genetic data to consider. **We will also work to obtain the genetic data**

for the California gnatcatcher and the coast cactus wren to consider how wrentit or other species corridors may perform for these sensitive species.

- *Grasshopper sparrow*: This model appears to be overpredicting suitability in the present condition. Generally, predicting habitat for grassland species and projecting future conditions appears to be challenging. For the grasshopper sparrow, without vegetation, the model was primarily responding to the impervious surface variable and as such, seemed to have trouble distinguishing between grasslands and areas of coastal sage scrub in the more coastal regions of our model. Interestingly, slope and topography did not come out as driving predictors in our models, which may have helped with this distinction. Although suggestions in the group included incorporating older data and removing impervious surface from the model to examine the temperature associations from areas that were once more coastal grasslands like the LA basin where temperatures may have been cooler to determine if topography arises as a more important variable. However, given the long history of development in this region and issues with the urban heat island effect, we propose an alternative approach:
 - o Given that most grassland species that are somewhat sensitive to development are likely to have similar issues in the modeling and our main goal is to ensure we capture connections between grasslands, **we propose to model grasshopper sparrow in the historic period only WITH vegetation to establish corridors.** We can weight these so the ones of greatest biological importance are retained throughout the prioritization process. Considering grasslands are projected to increase overall but modeling or assessing the *quality* of these grasslands will be extremely difficult, we expect this will be a reasonable approach that will still allow us to accomplish our goal of identifying linkages for connectivity between different habitat types.
- *Western toad*: These models performed reasonable well for identifying riparian areas and picking up the instream habitat for western toads but seems to be missing upland habitats. Robert Fisher has offered to assist in providing data that can be used to attempt to improve this model. **Megan will meet with Robert and if data can be obtained before the end of July, we will attempt to model using the presence-absence data he has OR to use the additional presence point to supplement our presence only modeling data set** to see if we can improve the projections of historic suitability for this species.
- *Bobcat*: Although the model for this species does a good job overall of distinguishing areas that are more and less suitable, the overall suitability values are lower than are likely realistic and the model appears to underpredict suitability at high elevations likely due to sampling/observation bias in the occurrence data. We did pull any/all available data we could obtain for the species and also implemented some spatial subsampling to improve model performance in areas where lack of observations were biasing the model toward reduced suitability. We believe we cannot significantly improve the quality of the suitability model for this species, but are confident in the corridors created for them because we can compensate for the reduced suitability in our conversion from suitability to resistance because the overall pattern of suitability is relatively accurate.

- *Big-eared woodrat*: This model turned out very well, accurately predicting woodrat affiliation for high elevation forests as well as dense shrublands and drainages. The future predictions also seem reasonable for this species.

Overview of draft corridor and population modeling outputs

1. We provided a preview of the historic corridor models, describing the two different methods (least cost corridors based on least cost path analysis and network flow based on electrical current theory) that will be used to construct the corridor network. We also gave an overview of the population modeling and how those results will be used to create a relative biological value for each linkage. Full presentations are available for upload from the project's [Google Drive folder](#).

Review conceptual plan for linkage prioritization

1. We shared the conceptual model for linkage prioritization, also detailed in the uploaded presentations.
2. The prioritization will focus on the value of each linkage in providing climate resilience and the overall connectivity value. Because we will be generating linkages for each species under historic conditions and under 5 future scenarios at decadal intervals using two different connectivity modeling methods, we will conduct the initial corridor selection and thinning, only attributing remaining corridors with high value in our final product.
3. After the meeting, there was a suggestion to remove corridors early on (prior to population modeling) that are already highly impacted. **We are currently working to identify a threshold of urbanization or percent impervious surface we would suggest using for this cutoff. We will solicit input on this value once we've reviewed the range of values we observe using the existing historic linkages across the landscape.**
4. Additional high-level attributes for decision making will be added to these for further consideration during decision-making. We will limit the number of things we include in this list and instead work directly with GIS analysts at stakeholder organizations to ensure the product we deliver is something they will be able to work with to customize.
5. One additional variable suggested for consideration for linkage prioritization was average parcel size across a linkage. If parcels are small and subdivided, the costs to acquire will be higher and there may be development plans that would also drive up acquisition costs. **We will work with CDFW and SCAG to determine if we can obtain parcel data for the entire study area for inclusion in our prioritization.**
6. **If you have other ideas about prioritization or eventual data delivery (current suggestions include GIS geodatabase, Data Basin for those without GIS software or experience, BIOS Connectivity viewer), please contact Megan (mjennings@sdsu.edu).**

Future analyses, additional data inputs, future stakeholder input

1. We plan to convene at least 2-3 more meetings with the stakeholder group to share connectivity and population modeling outputs and to share and refine the prioritization strategy. We will also target a workshop where we run through worked examples to ensure the end product we deliver has functionality for real-world decisions.
2. There has been expressed interest in being able to add on species in the future. Although that will not be part of this project, we can continue to discuss ways in which we may want to validate our

multispecies climate corridors for other species, including at-risk or data limited species. This would most likely involve a different and less intensive analytical process.

3. **If you have feedback about our process or thoughts about the modeling and delivery strategy we've presented thus far, please contact Megan with that info (mjennings@sdsu.edu).**

From: **Megan Jennings** <mjennings@mail.sdsu.edu>
Date: Mon, Jul 25, 2016 at 10:46 PM
Subject: Climate Resilient Connectivity Project Update
To: Erin Conlisk <erin.conlisk@gmail.com>
Cc: Sin, Hans@Wildlife <Hans.Sin@wildlife.ca.gov>, Courtney, Betty@Wildlife <Betty.Courtney@wildlife.ca.gov>, Sevens, Gail@Wildlife <Gail.Sevens@wildlife.ca.gov>, O'Brien, John@Wildlife <John.O'Brien@wildlife.ca.gov>, Larson, Mary@Wildlife <Mary.Larson@wildlife.ca.gov>, Mayfield, Rick@Wildlife <Rick.Mayfield@wildlife.ca.gov>, Hovey, Tim@Wildlife <Tim.Hovey@wildlife.ca.gov>, Frost, Nancy@Wildlife <Nancy.Frost@wildlife.ca.gov>, Pairis, Amber@Wildlife <Amber.Pairis@wildlife.ca.gov>, Burg, Richard@Wildlife <Richard.Burg@wildlife.ca.gov>, Pert, Ed@Wildlife <Ed.Pert@wildlife.ca.gov>, Devore, Ken@Wildlife <Ken.Devore@wildlife.ca.gov>, Botta, Randy@Wildlife <Randy.Botta@wildlife.ca.gov>, Beck, Christine@Wildlife <Christine.Beck@wildlife.ca.gov>, Blankenship, Daniel@Wildlife <Daniel.Blankenship@wildlife.ca.gov>, Dillingham, Tim@Wildlife <Tim.Dillingham@wildlife.ca.gov>, Potter, Martin@Wildlife <Martin.Potter@wildlife.ca.gov>, Osborne, Meredith@Wildlife <Meredith.Osborne@wildlife.ca.gov>, Barabe, Russell@Wildlife <Russell.Barabe@wildlife.ca.gov>, Wilson, Erinn@Wildlife <Erinn.Wilson@wildlife.ca.gov>, Found-Jackson, Christine@Wildlife <Christine.Found-Jackson@wildlife.ca.gov>, Fluharty, Marilyn@Wildlife <Marilyn.Fluharty@wildlife.ca.gov>, Mayer, David@Wildlife <David.Mayer@wildlife.ca.gov>

Dear CDFW Connectivity Stakeholders,

Thank you all for your valuable feedback this spring for our Climate Resilient Connectivity project for the South Coast. Erin and I wanted to update you on our progress over the last few months.

We appreciated all your input and suggestions regarding our focal species selection. After our last meeting, we reviewed available data, discussed our species and data options with experts, and finalized our focal species list. It was a difficult choice to narrow down, so we chose to create a prioritized list that was a little longer than we originally anticipated. We hope to get through every species, but ordered them such that we will be sure to have good diversity in our assessment if we're only able to complete modeling for the first 4 species.

Our first tier species are (in the order we will model them): bobcat, wrentit, big-eared woodrat (*Neotoma macrotis*), western toad, western meadowlark, and California spotted owl. For these first tier species, we have coalesced occurrence and demography data for the species distribution and population models.

We created a second tier in response to your input that consists of mule deer and mountain lion.

The other major update is that we have made a final selection of climate models we will be applying to the project. We have selected 2 recently updated models (CNRM-CM5 for warmer wetter, MIROC5 for hotter, drier) for our assessment and will use two emissions scenarios for each (low - RCP 4.5 and high - RCP 8.5), for a total of four models to assess. This should give us a good range to consider for our linkage development. These are also 2 of the 10 models that have been selected for California's upcoming Fourth Climate Assessment, so our project will be in sync with that statewide effort. We are particularly fortunate that Alan and Lorraine Flint from USGS have offered to downscale these data to a 90m resolution for our project area, which will greatly enhance our local-scale analyses. Waiting for the downscaling has caused a small delay in our progress, but it will be well worth it for the finer scale data.

Finally, we have also been looking into creating our own models of shrubland change over time as there is a lack of available information for chaparral in particular. This will aid us in our modeling of wrentit and woodrat habitat when we run our suite of models with vegetation change in addition to climate variables.

If you have any questions, please feel free to reach out to us. We will be contacting you soon to schedule a meeting in the fall to review the results of our distribution models for our first two focal species.

Regards,

Megan and Erin

mjennings@mail.sdsu.edu

erin.conlisk@gmail.com

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Megan Jennings, Ph.D.

Post-Doctoral Researcher

San Diego State University

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mjennings@mail.sdsu.edu

<http://www.conservativeecologylab.com/megan-jennings.html>

From: Megan Jennings [mailto:mjennings@mail.sdsu.edu]

Sent: Wednesday, March 30, 2016 1:57 PM

Cc: Erin Conlisk; Sin, Hans@Wildlife; Courtney, Betty@Wildlife; Sevens, Gail@Wildlife; O'Brien, John@Wildlife; Larson, Mary@Wildlife; Mayfield, Rick@Wildlife; Hovey, Tim@Wildlife; Frost, Nancy@Wildlife; Pairis, Amber@Wildlife; Burg, Richard@Wildlife; Pert, Ed@Wildlife; Devore, Ken@Wildlife; Botta, Randy@Wildlife; Beck, Christine@Wildlife; Blankenship, Daniel@Wildlife; Dillingham, Tim@Wildlife; Potter, Martin@Wildlife; Osborne, Meredith@Wildlife; Barabe, Russell@Wildlife; Wilson, Erinn@Wildlife; Found-Jackson, Christine@Wildlife; Fluharty, Marilyn@Wildlife; Mayer, David@Wildlife; Stewart, Terri@Wildlife

Subject: Climate Resilient Connectivity Follow-Up

Hello all,

Thank you for the productive meeting on Monday. Below is a summary of the meeting and our respective bits of homework.

What we need from you: Consider the list below carefully, making any further points about species we should or should not consider. Think about candidate coastal sage scrub and riparian species. Suggest further sources of data or folks to contact about data for any of our candidate species, particularly for Santa Barbara and Ventura Counties.

Please submit your suggestions and comments by Tuesday, April

12 to mjennings@mail.sdsu.edu and erin.conlisk@gmail.com.

We decided that the following organisms seemed like good choices for the reasons listed:

- 1) **Bobcat:** Lots of data and a focal species of Megan's dissertation and postdoctoral work
- 2) **Big-eared woodrat** (*Neotoma macrotis*): small mammal with shorter dispersal distances, occurs throughout the South Coast Ecoregion
- 3) **Western meadowlark:** a good grassland specialist occurring throughout the South Coast
- 4) **Spotted owl:** a good conifer-woodland specialist with data on how demographic rates change with climate change (but potentially not a great species for CDFW because it occurs primarily on USFS land?)

5) Second tier - Mountain lion: Lots of data and a focal species of Megan's dissertation and postdoctoral work. May be able to leverage and build off of ongoing work on connectivity for the species in S. CA.

NEEDED 1: A coastal sage scrub specialist to replace the California gnatcatcher. Potential ideas include: wrentit, sage sparrow, thrasher, rufous-crowned sparrow. Horned lizard may have potential given its shrub-association and urban-sensitivity.

NEEDED 2: A riparian specialist, ideally a herp. Potential ideas include: Western spadefoot toad, garden slender salamander, two-striped garter snake, spotted towhee (though more generalist than riparian-dependent), and Hutton's vireo.

Additional Species to Consider: (1) a game species (such as mule deer), and (2) Golden Eagle.

Species we decided NOT to consider further: Dulzura kangaroo rat, red-tailed hawk, red-shouldered hawk, red-winged blackbird, western toad, and great horned owl.

Megan and Erin's homework: We will look into data for the Western spadefoot toad, garden slender salamander, two-striped garter snake, and coast horned lizard, including contacting Brad Shaffer and Robert Fisher. We will also look into data for the wrentit, sage sparrow, thrasher, rufous-crowned sparrow, and spotted towhee, including contacting Geoff Geupel at Point Blue (PRBO) and Kristine Preston about the wrentit.

Again, thanks so much for your time and input on Monday; we look forward to the next meeting.

Cheers,
Erin and Megan

From: Megan Jennings [mailto:mjennings@mail.sdsu.edu]

Sent: Wednesday, March 23, 2016 9:47 PM

To: Stewart, Terri@Wildlife

Cc: Sin, Hans@Wildlife; Courtney, Betty@Wildlife; Sevrens, Gail@Wildlife; O'Brien, John@Wildlife; Larson, Mary@Wildlife; Mayfield, Rick@Wildlife; Hovey, Tim@Wildlife; Frost, Nancy@Wildlife; Pairis, Amber@Wildlife; Burg, Richard@Wildlife; Pert, Ed@Wildlife; Devore, Ken@Wildlife; Botta, Randy@Wildlife; Beck, Christine@Wildlife; Blankenship, Daniel@Wildlife; Dillingham, Tim@Wildlife; Potter, Martin@Wildlife; Osborne, Meredith@Wildlife; Barabe, Russell@Wildlife; Wilson, Erinn@Wildlife; Found-Jackson, Christine@Wildlife; Fluharty, Marilyn@Wildlife; Mayer, David@Wildlife

Subject: Re: State Wildlife Grant "Climate Resilient Connectivity" discussion for data holders and species experts

Hello everyone,

My colleague, Erin Conlisk, and I are looking forward to meeting with you all on Monday to kick-off this project. We've been working on locating occurrence and demographic data to help refine our candidate focal species list and I wanted to send you that list (below) so you can come prepared either with data or information on data sources. We plan to share maps and details that we've been able to gather thus far, and we hope Monday's discussion can help inform our selection of 3-4 primary focal species with 1-2 additional species we can add on if time and funding allow.

We are open to considering alternate species that are not listed below - however, we have established criteria for species selection to ensure we can meet our project goals. We'll describe this rationale in more detail Monday, and in the meantime, please keep the following in mind as you're thinking about species and available data:

1. Species adequately represented across the entire region (San Diego to Santa Barbara)
2. Available occurrence and demographic data (including survival, maturation, mortality, and dispersal rates)
3. Good indicators for many other species - not so specialized that they only tell us about a single species
4. Fills a role in a suite of complementary species - including different movement types and habitat associations

Candidate species for connectivity assessment:

Red-winged blackbird	<i>Agelaius phoeniceus</i>
Western toad	<i>Anaxyrus boreas</i>
Great horned owl	<i>Bubo virginianus</i>
Red-tailed hawk	<i>Buteo jamaicensis</i>
Red-shouldered hawk	<i>Buteo lineatus</i>
Dulzura kangaroo rat	<i>Dipodomys simulans</i>
Bobcat	<i>Lynx rufus</i>
Big-eared woodrat	<i>Neotoma macrotis</i>
California gnatcatcher	<i>Poliophtila californica</i>
Mountain lion	<i>Puma concolor</i>
California spotted owl	<i>Strix occidentalis occidentalis</i>
Western meadowlark	<i>Sturnella neglecta</i>
Two-striped garter snake	<i>Thamnophis hammondi</i>

I hope to see you all Monday,
Megan

--

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<http://www.conservativeecologylab.com/megan-jennings.html>