Appendix B

Identifying and mapping climatically stable macro- and micro-refugia in New Mexico

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Megan Friggens, Ph.D.;
Karen Cooper; Max Smith, M.S.

United States Forest Service

Identifying Climate Refugia in New Mexico

Climate change is expected to lead to increased stress and range shifts in, and habitat loss by, many of New Mexico's wildlife species. The concept of climate refugia has recently emerged as a potential method for identifying areas that might provide relatively stable climatic conditions that allow species and populations to persist through time. Researchers with the USFS's RMRS used a variety of methods to identify indicators of climate refugia within New Mexico's landscapes. Refugia constitute areas that are expected to remain relatively stable in terms of climate (macrorefugia) or that contain features that are likely to buffer local areas from changes occurring at larger geographic scales (microrefugia).

The USFS researchers compiled more than 70 indicators of macro- and microrefugia that fall into several broad categories, including biodiversity, climate indices, disturbance, future change, land cover patterns, and topography. Both taxa-specific and overall composite scores for all taxa were developed based on different sets of indicators (Table 1). Data were obtained from the AdaptWest project, Bureau of Reclamation, DataBasin, EnviroAtlas, LandFire, US Geological Survey (USGS), USGS Gap Analysis Project , and WorldClim. Analysis was conducted using R 4.4.1 and ArcPro 3.2.2. To create composite indices representing climate refugia potential, the USFS: (1) identified the most important predictors of species richness; (2) used ordinary least squares to optimize variable selection (i.e., remove redundant variables); (3) calculated Z-scores to standardize data with varying ranges; and, (4) calculated a composite score for each 12-digit Hydrologic Unit Code (HUC12) based on equally-weighted Z-scores. The composite scores were mapped out across the State in terms of percentiles (Figure 1), with higher percentiles representing HUC12s with higher climate refugia scores. This distribution of HUC12s was then compared to the boundaries of 2017 SWAP Conservation Opportunity Areas (COAs) and used to determine the percent areas of COAs containing HUC12s with different likelihoods of encompassing climate refugia (Table 2).

Table 1. List of indicators used to identify climate refugia. Microrefugia are associated with soil properties, current climate conditions (uniqueness), and landscape diversity. Topographic and vegetation diversity indices were calculated using the Shannon diversity index. Random Forest and Generalize Linear Models were used to determine the relationship between diversity indices and species richness. Positive (+) and negative (-) associations are noted below. Strength of association is indicated by the number of symbols. Macrorefugia are represented by climate measures. Datasets are derived from future climate projections for mid-century time periods (~2050) under a Coupled Model Intercomparison Project 5 (CMIP5's), Representative Concentration Pathway 4.5 greenhouse gas emission scenario. Climate Velocity and Dissimilarity are multidimensional (consider both precipitation and temperature) measures of potential climate change. "x", "++", "--" used in taxa-specific indices. N/A = no significant relationship detected. * = used to estimate overall microclimate refugia, ** = used to estimate overall macroclimate refugia.

Microrefugia	All	Amphibians	Birds	Mammals	Reptiles
Heat Load Index Diversity	(++)	(--)	(++)	(++)	(--)
USNVC Macrogroups Diversity*	(++)	(-)	(++)	(++)	(+)
Vector Ruggedness Measure	(++)	(-)	N/A	(++)	N/A
Elevation Diversity	(+)	(--)	(++)	N/A	(--)
Existing Vegetation Height Groups Diversity	N/A	(--)	(+)	(-)	(--)
Topographic Position Index	x	x	x	x	x
Soil Bulk Density*	x	x	x	x	x
Water Storage Capacity, 100 cm (39 in)*	x	x	x	x	x
Climate Novelty*	x	x	x	x	x
Macrorefugia					
Backwards Climate Velocity (Cº/km/yr)			x	x	
Forward Climate Velocity (Cº/km/yr)		x			x
Dissimilarity**	x	x	x	x	x

Macrorefugia	All	Amphibians	Birds	Mammals	Reptiles
Change in Temperature, Wettest Quarter**	x	x	x	x	x
Change in Temperature, Driest Quarter**	x	x	x	x	x
Percent Difference Precipitation, Warmest Quarter**	x	x	x	x	x
Percent Difference Precipitation, Coldest Quarter**	x	x	x	x	x

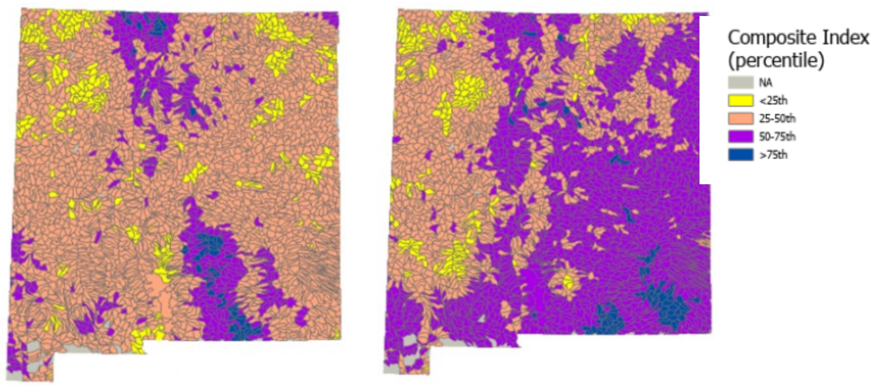

Figure 1. Taxon-specific composite indices (best climate + best landscape features) for two generalized species groups: birds and mammals (left); and amphibians and reptiles (right). Higher percentiles represent 12-digit Hydrological Unit Codes with highest scores indicating greater potential to contain refugia.

Table 2. To compare climate refugia potential among Conservation Opportunity Areas (COAs), we calculated climate and landscape composite scores for 12-digit Hydrologic Unit Codes (HUC12) based on a subset of indicators that had similar associations among all taxa. We categorized resulting scores by quantiles. The numbers below represent the percent of each COA containing each percentile category of refugia. Higher percentiles represent areas with greater potential to be refugia. Macro- and microrefugia are independent of one another. Darker shades indicate highest percentage of the area for each COA.

Conservation Opportunity Area	Overall Macrorefugia					Overall Microrefugia				
	NA	< 25th	25-50th	50-75th	>75th	NA	< 25th	25-50th	50-75th	>75th
Big Hatchet Mountains	30		26	44		30		63	7	
Black Range		0	2	7	91		36	45	18	1
Bootheel	35			55	9	35	29	35		
Gila Highlands	2				98		32	39	27	1
Gila River Headwaters					100		42	39	18	1
Jemez Mountains	7	31	46	16					6	94
Lower Gila River	3			34	65		1	28	41	28
Lower Pecos and Black Rivers		94	6					3	13	84
Mescalero Sands		8	79	13			44	39	14	2
Middle Pecos River		29	65	6			0	2	9	89
Middle Rio Grande		2	32	65	1		7	12	45	37
Mimbres River					100			71	29	
Northern Sacramento Mountains		51	14	35					2	98
San Francisco River	1				94	0	22	32	24	16
San Juan River	0		2	40	56	0		0	9	88
Zuni Mountains		5	34	56	5		31	49	9	11