Appendix S1 – Additional Tables and Figures

Maher et al. Erosion of refugia in the Sierra Nevada meadows network with climate change.

Table S1. Correlations among connectivity measures between meadows

	Rivers as Barrier (Distance)	Rivers as Barrier (Presence)	Rivers as Vector (Distance)	Rivers as Vector (Presence)	Roads	Topography	Null
Rivers as Barrier (Distance)	1.000	0.960	0.048	0.573	0.591	0.584	0.611
Rivers as Barrier (Presence)	0.960	1.000	0.065	0.640	0.645	0.637	0.667
Rivers as Vector (Distance)	0.048	0.065	1.000	0.193	0.130	0.082	0.169
Rivers as Vector (Presence)	0.573	0.640	0.193	1.000	0.875	0.789	0.995
Roads	0.591	0.645	0.130	0.875	1.000	0.770	0.888
Topography	0.584	0.637	0.082	0.789	0.770	1.000	0.802
Null	0.611	0.667	0.169	0.995	0.888	0.802	1.000

Table S2. Simple linear models of log10 transformed mean connectivity values for meadows with various scaled preditors.

Model Name	Equation
Area × Elevation × Latitude × Longitude	5.086713** + 0.242691**(Area) + 0.206145**(Elev) - 0.074113**(Long) + 0.043178**(Lat) - 0.020770*(Area×Elev) - 0.107235**(Area×Long) - 0.067208**(Area×Lat) + 0.104160**(Elev×Lat) + 0.083251**(Elev×Long) + 0.143990**(Long×Lat) + 0.019310(Area×Elev×Long) + 0.007457(Area×Elev×Lat) + 0.041273**(Area×Lat×Long) + 0.014156**(Elev×Lat×Long) - 0.014994**(Area×Elev×Lat×Long)
Area × Latitude × Longitude	5.105893** + 0.264076**(Area) + 0.073426**(Lat) + 0.080877**(Long) – 0.108528**(Area×Long) – 0.140537**(Area×Lat) + 0.159853**(Lat×Long) + 0.048539**(Area×Lat×Long)
Elevation × Latitude × Longitude	5.072587** + 0.220490**(Elev) +0.81040**(Lat) - 0.042568**(Long) + 0.114659**(Elev×Lat) + 0.094197**(Elev×Long) + 0.136856**(Lat×Long) + 0.015954**(Elev×Lat×Long)
Area × Elevation	4.952412** + 0.148941**(Area) +0.163039**(Elev) + 0.000395(Area×Elev)
Latitude × Longitude	5.092976** + 0.112731**(Lat) + 0.121206**(Long)+0.152728**(Lat×Long)
Elevation	4.95243** + 0.16897**(Elev)
Area	4.95248** + 0.155505**(Area)
Longitude	4.95428** + 0.080556**(Long)
Latitude	4.95428** - 0.072586**(Lat)

** *P<0.001*; * *P*<0.01

Fig. S1. Geographic extent of study area and locations of National Parks. Areas in red designate Jepson ecoregions associated with the Sierra Nevada; those in shades of blue are considered part of the Cascade, Modoc Plateau and Warner Mountains subregions; and yellow designate the eastern Sierra Nevada subregion. White polylines identify the boundaries of the three National Parks to provide spatial context. Black polygons represent the 5894 meadows we used for evaluation. The gray hillshade is a digital elevation model for the watersheds associated with California.

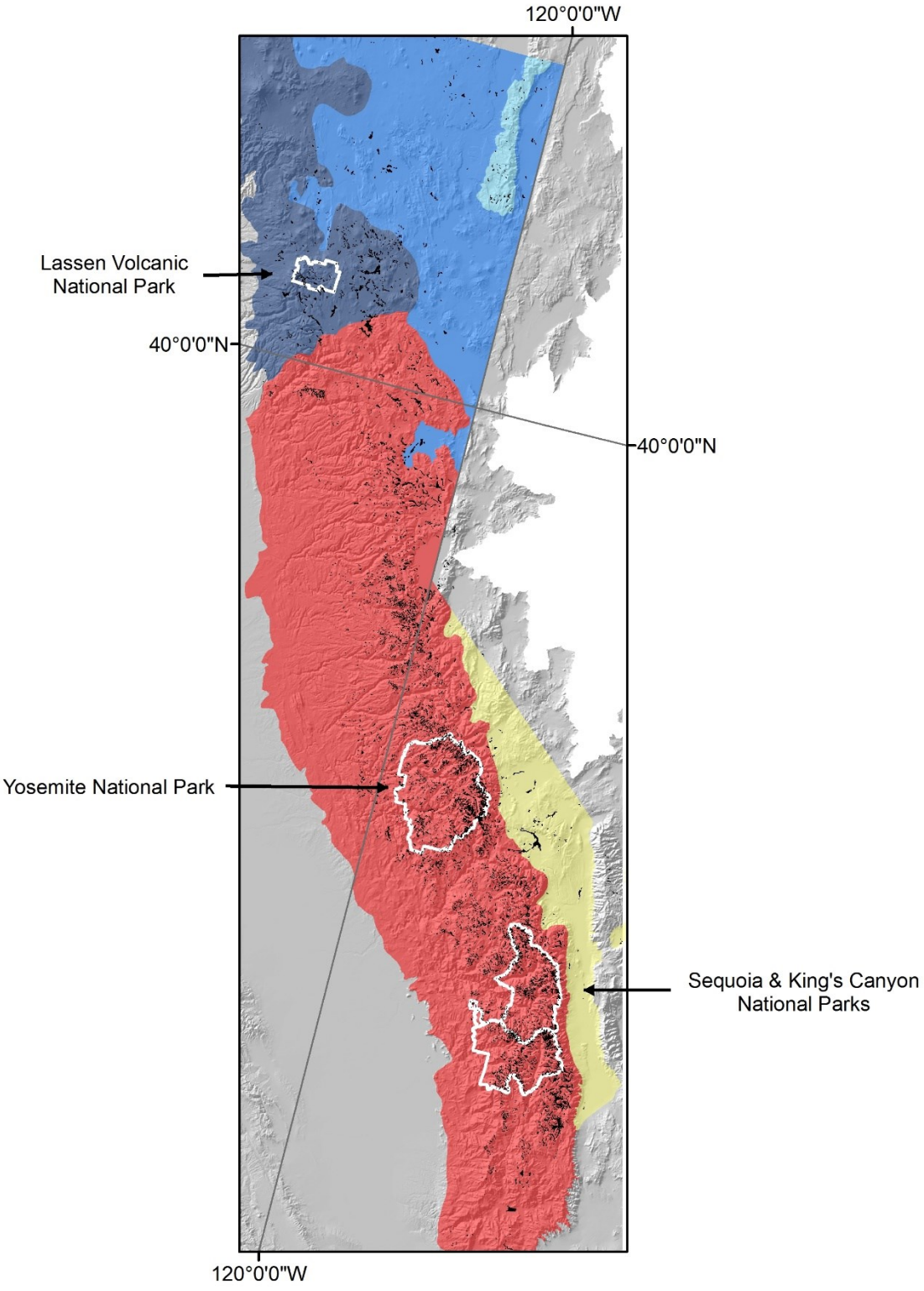

120°0'0"W
Lassen Volcanic
National Park
40°0'0"N
40°0'0"N
Yosemite National Park
Sequoia & King's Canyon
National Parks
120°0'0"W

Fig. S2. Patterns in connectivity based on four hypotheses of isolation. Each hypothesis was represented by at least one friction surface: presence (as barrier, A; as vector, C) and distance from watercourses (as barrier, B; as vector, D); distance from roads (E); elevationally weighted distance (F), and uniform (G). We present each summary map (darker blue is higher connectivity) over a hillshade surface to highlight the potential relationships between connectivity and topography, zoomed onto the vicinity of Yosemite National Park.

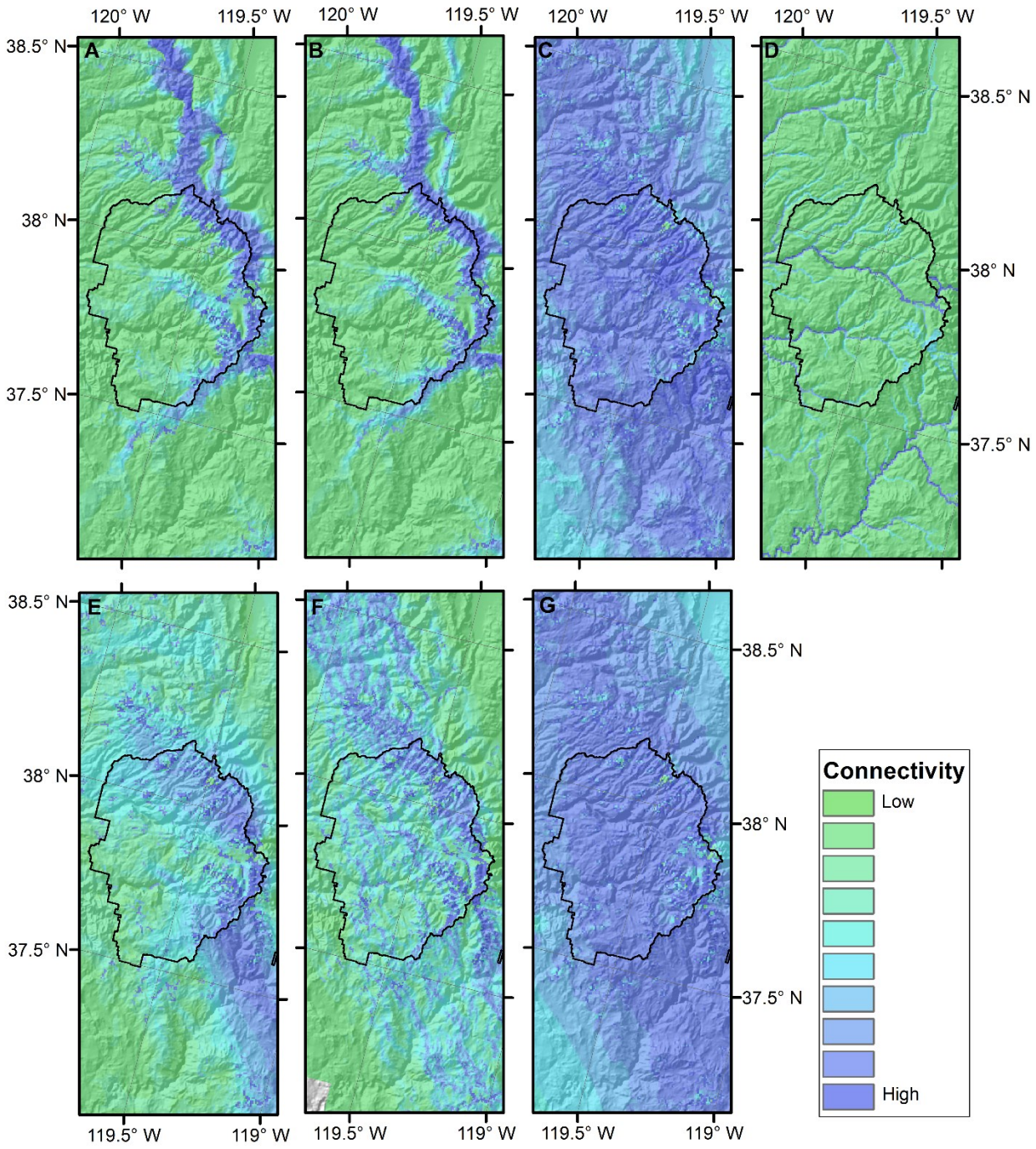

A
B
C
D
E
F
G
120° W
119.5° W
119° W
38.5° N
38° N
37.5° N
Connectivity
Low
High

Fig. S3. Violin plots of connectivity values for meadows. The distribution of connectivity values varied based upon friction surfaces and hypothesis of isolation. Watercourses as barriers had greater breadth in values and wider quartiles, whereas watercourses as vectors with a binary friction surface, topography, and the null friction surface had less spread.

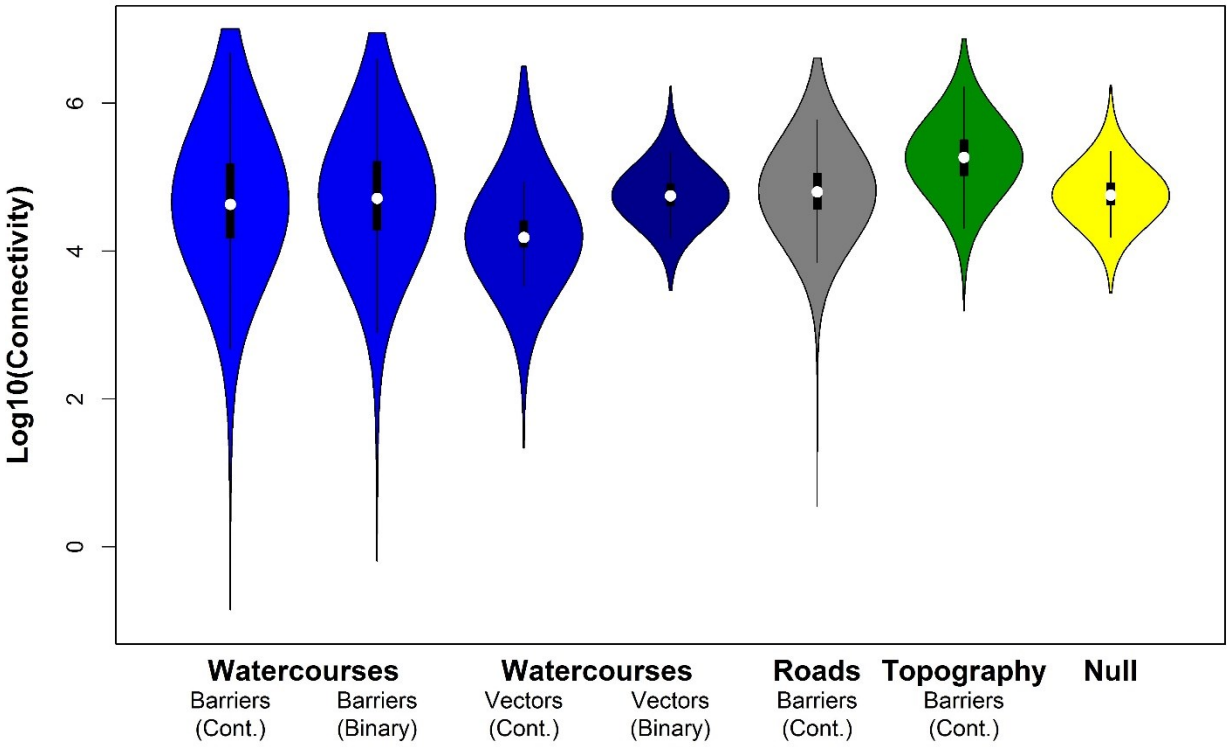


Fig. S4. Frequency of connectivity with elevation and size. The stacked histograms show how differently connected meadows are distributed by elevation (A) or size (B). Blue bars represent WC meadows; yellow bars are MC meadows; red bars are LC meadows. WC meadows tend to occur at high elevation and are larger than other classifications of meadows.

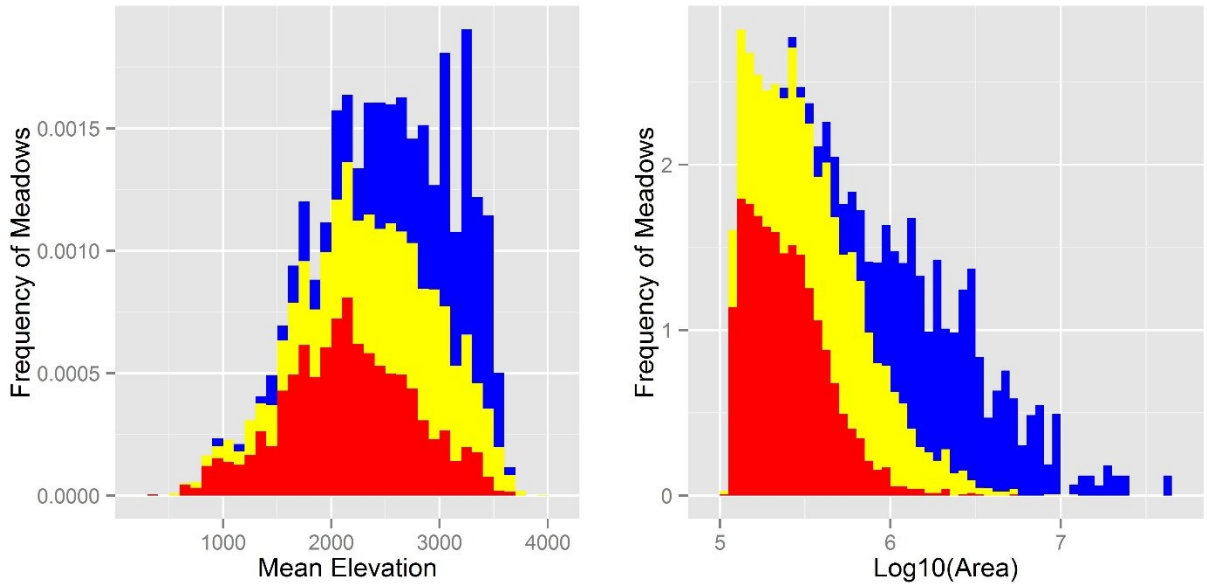
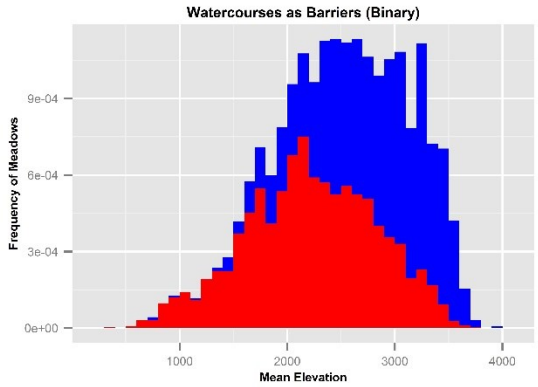
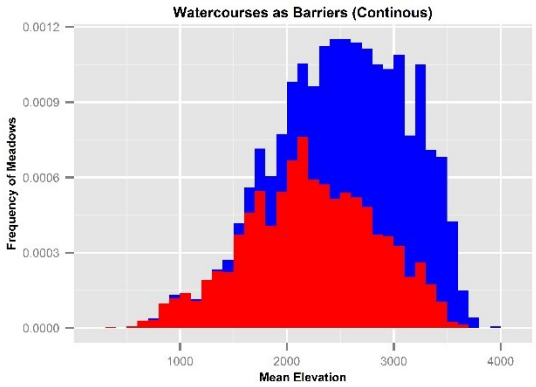
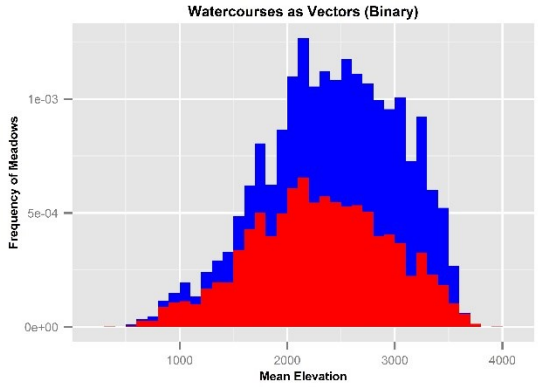
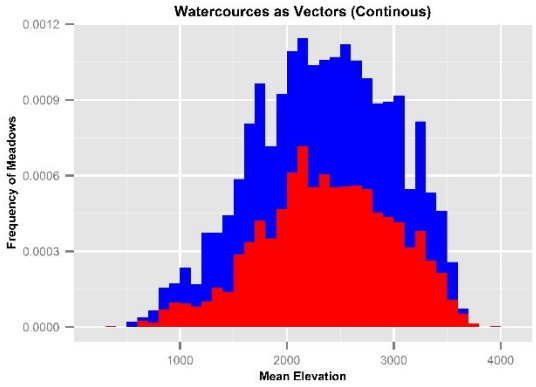


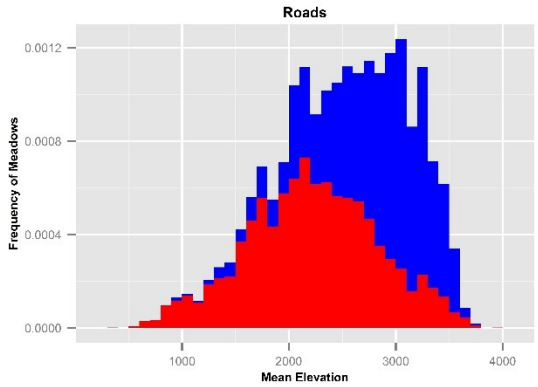
Fig. S5. Stacked histograms for individual connectivity measures associated with different resistance surfaces. For each resistance surface, meadows in the upper quartile of connectivity values (blue) are found at higher elevations than the remaining meadows (red).

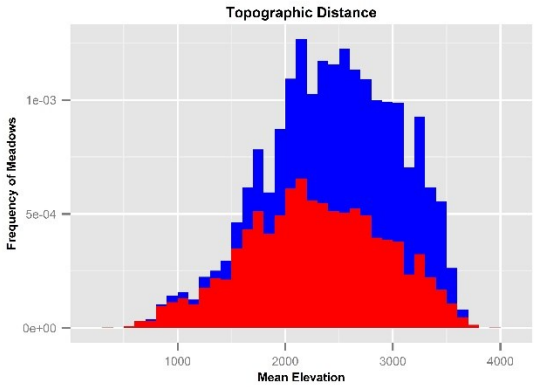

Watercourses as Barriers (Binary)
Frequency of Meadows
9e-04
6e-04
3e-04
0e+00
1000
2000
3000
4000
Mean Elevation


Watercourses as Barriers (Continous)
Frequency of Meadows
0.0012
0.0009
0.0006
0.0003
0.0000
1000
2000
3000
4000
Mean Elevation


Watercourses as Vectors (Binary)
Frequency of Meadows
1e-03
5e-04
0e+00
1000
2000
3000
4000
Mean Elevation


Watercources as Vectors (Continous)
Frequency of Meadows
0.0012
0.0009
0.0006
0.0003
0.0000
1000
2000
3000
4000
Mean Elevation


Roads
Frequency of Meadows
0.0012
0.0008
0.0004
0.0000
1000
2000
3000
4000
Mean Elevation


Topographic Distance
Frequency of Meadows
1e-03
5e-04
0e+00
1000
2000
3000
4000
Mean Elevation

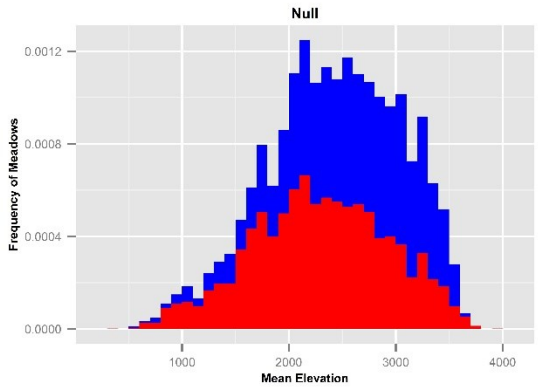
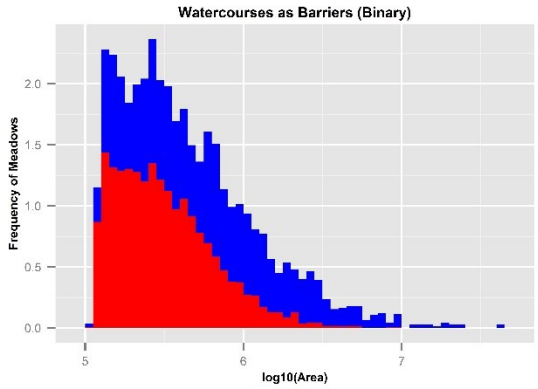
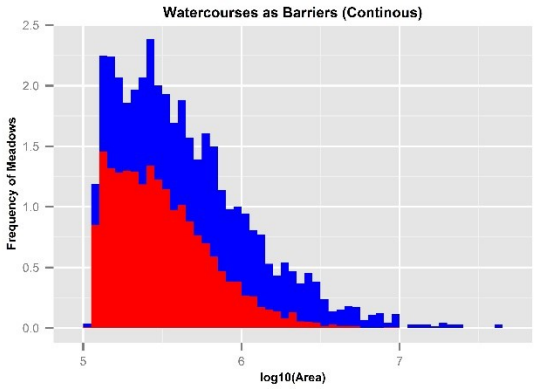
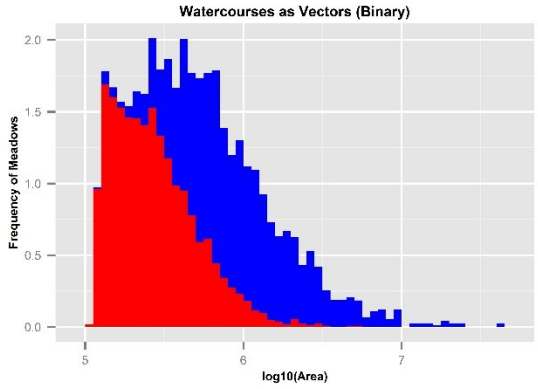
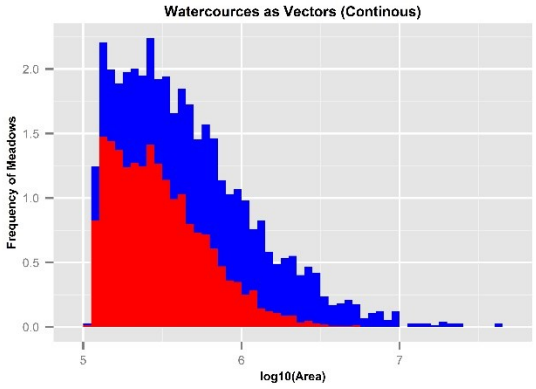

Null
Frequency of Meadows
0.0012
0.0008
0.0004
0.0000
1000
2000
3000
4000
Mean Elevation

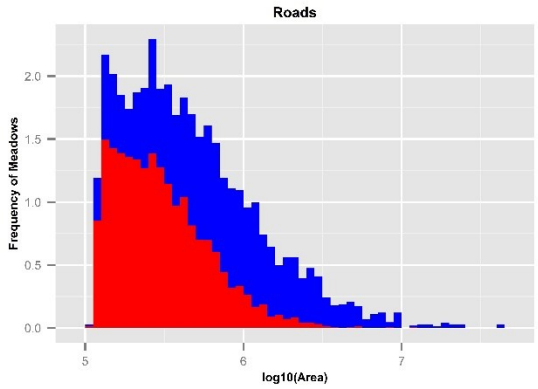
Fig. S6. Stacked histograms for individual connectivity measures associated with different resistance surfaces. For each resistance surface, meadows in the upper quartile of connectivity values (blue) tend to be larger meadows than the remaining meadows (red).

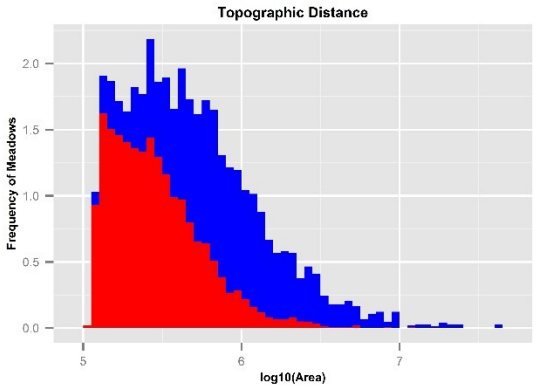

Watercourses as Barriers (Binary)
Frequency of Meadows
log10(Area)


Watercourses as Barriers (Continous)
Frequency of Meadows
log10(Area)


Watercourses as Vectors (Binary)
Frequency of Meadows
log10(Area)


Watercources as Vectors (Continous)
Frequency of Meadows
log10(Area)


Roads
Frequency of Meadows
log10(Area)


Topographic Distance
Frequency of Meadows
log10(Area)

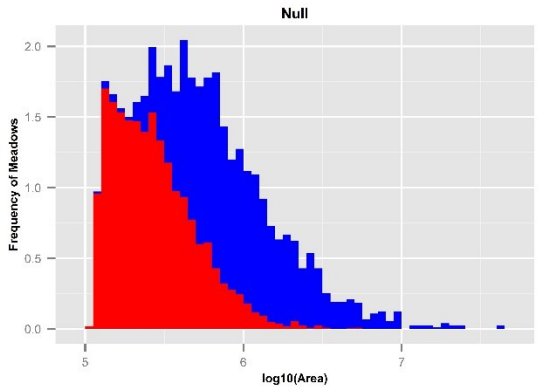

Null
Frequency of Meadows
log10(Area)

Fig. S7. Geographic distribution of well-connected meadows. Meadows in blue were the classified as well-connected (see text for definition) of the seven resistance surfaces, whereas more-connected meadows are show in yellow; the least-connected are show in red.

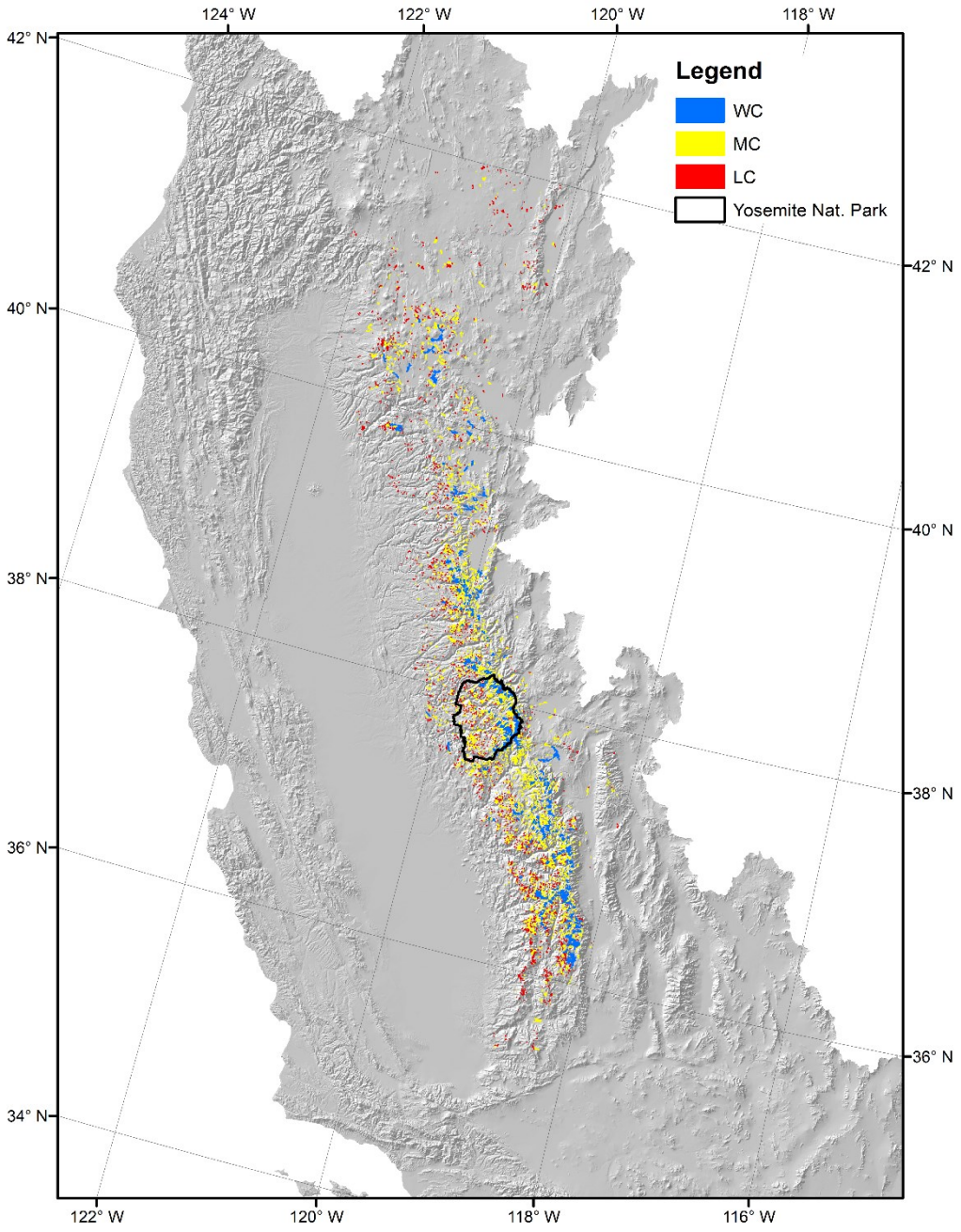


Fig. S8. Elevation distribution of climate refugial meadows under 4 future climate projections. In each window, lightest gray is the distribution of meadows, increased hue represents climate refugia for subsequent eras (end of the 20th century, 2010-2039; 2040-2069) and those in red represent expected climate refugia in 2070-2099. Each row represents a different combination of climate change variables, and each column is a potential outcome based on circulation model and scenario. Thresholds for displayed climate refugia are 1°C for mean annual temperature and 10% mean annual precipitation, and 10% 1 April SWE and 2 months/year of extreme minimum temperature.

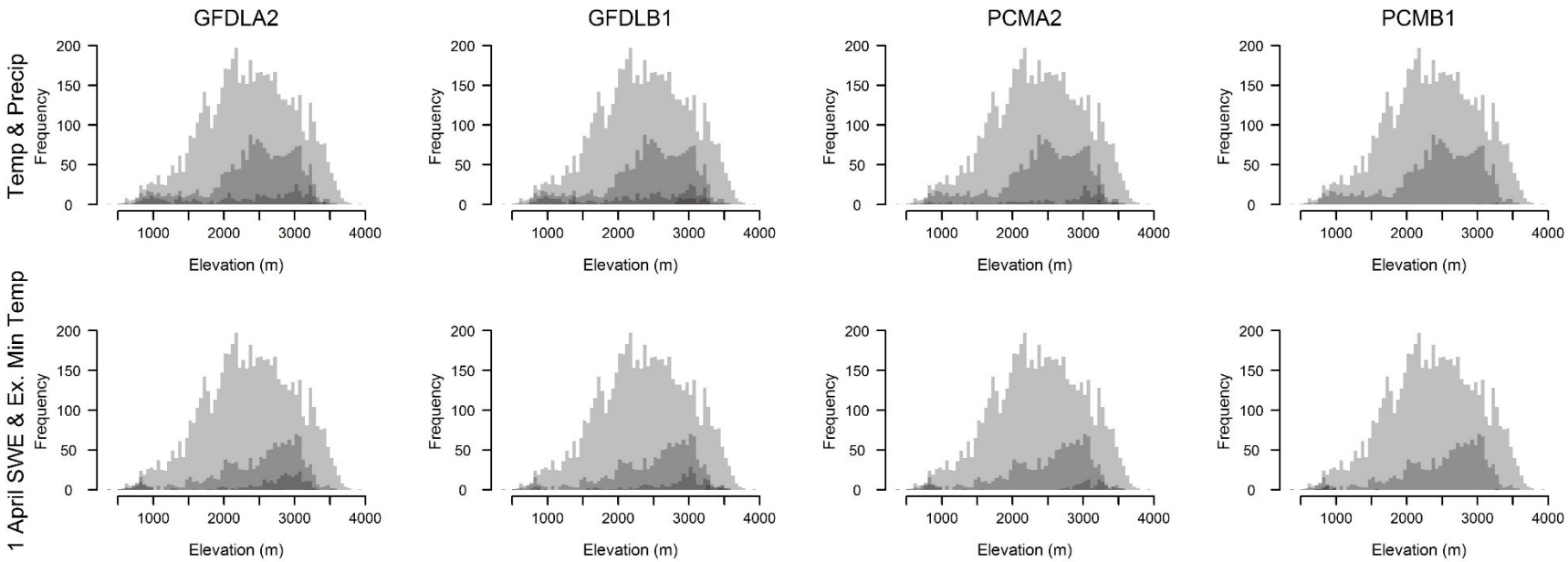

GFDLA2
GFDLB1
PCMA2
PCMB1
Temp & Precip
1 April SWE & Ex. Min Temp
Frequency
Elevation (m)
0
50
100
150
200
1000
2000
3000
4000

Fig. S9. Expectation of well-connected, potential refugial meadows using GFDL circulation models. Maps show WC meadows that are within in 1°C in annual temperature in blue, and MC meadows in yellow under A2 scenarios. Change is the difference in expected annual temperature from the historical period (see text). Overall, it is expected that most well-connected meadows will change beyond the historical conditions, except those in the southern Sierra Nevada.

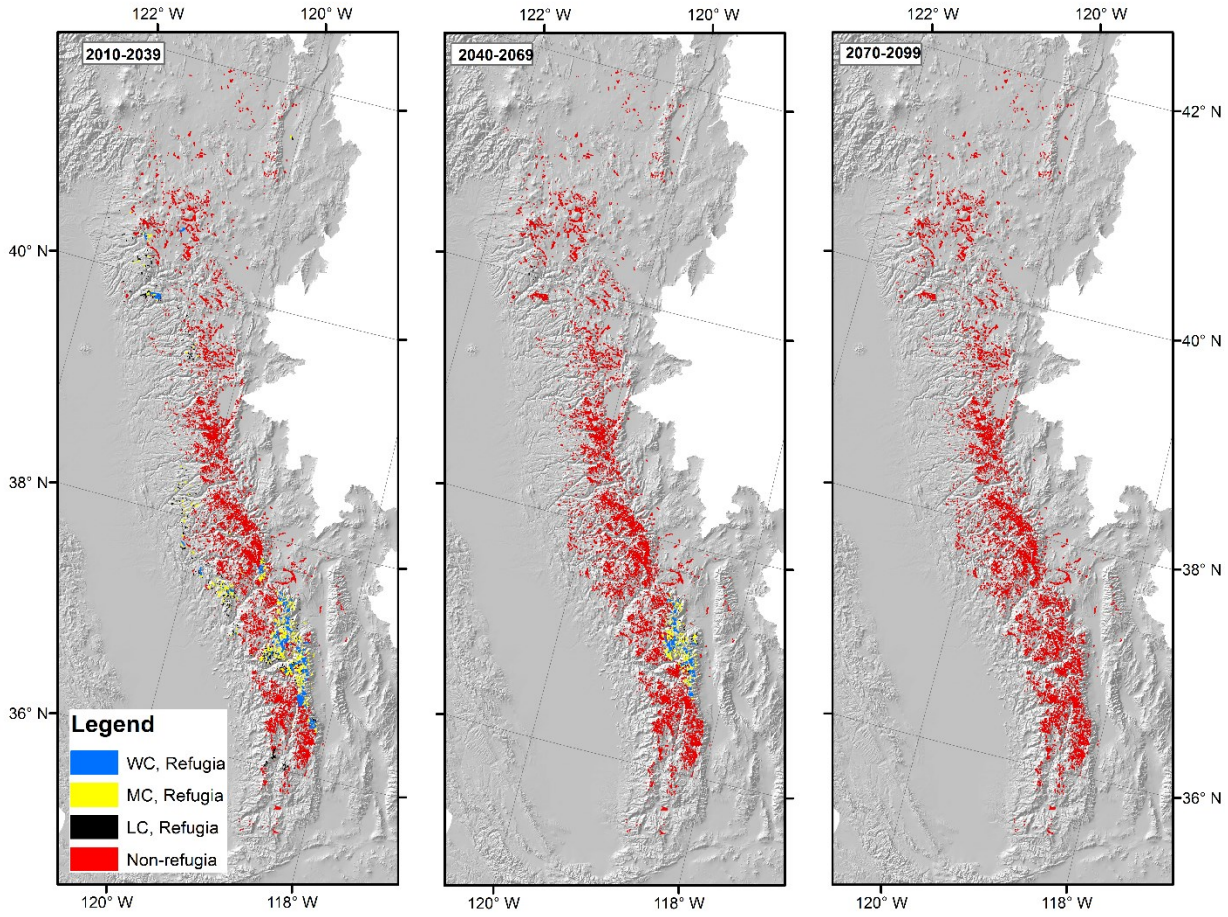


Fig. S10. Expectation of well-connected, potential refugial meadows using GFDL circulation models. Maps show WC meadows that are within in 1°C in annual temperature in blue, and MC meadows in yellow under and B1 scenarios. Change is the difference in expected annual temperature from the historical period (see text). Overall, it is expected that most well-connected meadows will change beyond the historical conditions, except those in the southern Sierra Nevada