

Supplementary Information for:

Multi-decadal records of intrinsic water-use efficiency in the desert shrub *Encelia farinosa* reveal strong responses to climate change

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Table S1. Full results of linear regressions of mean temperature, mean daily maximum VPD, and total precipitation by year between 1981 and 2019 at the study sites. All linear regressions were conducted using function “lm” in package “stats”, version 3.6.1. Asterisks denote significance of slope and intercept terms (*p<0.05, **p<0.01, ***p<0.001).

Site	Climate variable	Intercept	Slope	Std. error (slope)	Adj. R ² (model)	P (model)
Death Valley	Temperature	-53.415***	0.0368***	0.00725	0.394	<0.0001
Death Valley	VPD	-144.03**	0.0903***	0.0223	0.289	0.00024
Death Valley	Precipitation	3479.7*	-1.682*	0.827	0.0762	0.0492
Oatman	Temperature	-50.837***	0.0361***	0.00689	0.411	<0.0001
Oatman	VPD	-156.58**	0.0967***	0.0222	0.321	0.0001
Oatman	Precipitation	3501.9	-1.668	1.071	0.0361	0.128

Table S2. Full results of multiple linear regressions of carbon isotope ratio by temperature, VPD, and precipitation (n = 26 for Death Valley and n = 25 for Oatman).

Site	Predictor	Coefficient	Std. error	P (coefficient)
Death Valley	Temperature	-0.691	0.406	0.103
Death Valley	VPD	0.981	0.323	0.0061**
Death Valley	Precipitation	0.0019	0.0054	0.724
<i>Adj. R² = 0.696 P < 0.0001</i>				
Oatman	Temperature	-0.534	0.397	0.191
Oatman	VPD	0.726	0.282	0.017*
Oatman	Precipitation	-0.0012	0.0048	0.811
<i>Adj. R² = 0.771 P < 0.0001</i>				

Table S3. Full results of multiple linear regressions of iWUE by VPD and CO₂ concentration (n = 26 for Death Valley and n = 25 for Oatman).

Site	Predictor	Coefficient	Std. error	P (coefficient)
Death Valley	CO ₂	5.928	0.892	<0.0001***
Death Valley	VPD	0.465	0.0907	<0.0001***
<i>Adj. R² = 0.796 P < 0.0001</i>				
Oatman	CO ₂	6.023	0.705	<0.0001***
Oatman	VPD	0.314	0.0845	0.0012**
<i>Adj. R² = 0.874 P < 0.0001</i>				

Table S4. Annual summaries of raw climate, CO₂, and plant data used in the analysis. Detailed descriptions of variables are provided below the table.

Site	Year	Max VPD	Mean temp	Max temp	Total precip.	CO ₂ conc.	δ ¹³ CO ₂	Population size	Plants analyzed	Mean δ ¹³ C	Mean c _i /c _a	Mean iWUE
Death Valley	1991	17.41	10.16	18.04	86.18	352.18	-7.90	25	21	-26.10	0.61	85.71
Death Valley	1992	15.52	11.00	17.94	167.81	354.27	-7.93	879	69	-27.97	0.69	68.24
Death Valley	1993	14.50	10.08	16.74	200.49	357.05	-7.88	925	385	-28.27	0.71	65.30
Death Valley	1994	18.27	10.88	18.70	42.30	361.44	-8.03	921	71	-25.58	0.58	94.44
Death Valley	1995	15.25	10.90	17.90	161.44	362.07	-8.01	549	9	-28.03	0.69	69.89
Death Valley	1996	20.09	12.66	20.68	28.16	363.10	-8.07	510	7	-25.20	0.56	99.09
Death Valley	1997	18.44	11.82	19.18	45.93	365.17	-8.06	412	5	-26.42	0.62	87.20
Death Valley	1998	14.57	10.42	17.02	159.72	367.55	-8.09	320	280	-27.04	0.64	81.85
Death Valley	1999	18.28	11.12	18.88	10.33	370.39	-8.17	354	9	-27.65	0.67	77.03
Death Valley	2000	18.62	12.04	19.44	77.85	371.31	-8.18	309	0	NA	NA	NA
Death Valley	2001	15.82	10.32	17.22	70.39	373.56	-8.20	299	234	-27.36	0.65	81.01
Death Valley	2002	17.61	10.82	18.18	4.76	374.72	-8.20	140	0	NA	NA	NA
Death Valley	2003	17.23	11.98	18.96	66.91	377.89	-8.27	124	100	-26.42	0.61	92.43
Death Valley	2004	16.21	10.86	17.56	97.14	380.05	-8.28	137	8	-27.71	0.66	79.62
Death Valley	2005	13.77	11.20	17.22	225.06	381.40	-8.31	146	9	-29.46	0.74	61.70
Death Valley	2006	18.15	11.36	18.74	35.98	384.84	-8.39	223	10	-26.15	0.59	98.36
Death Valley	2007	20.17	11.68	19.34	3.01	385.75	-8.42	144	10	-24.96	0.54	111.51
Death Valley	2008	18.86	12.26	18.66	42.46	387.12	-8.38	129	10	-25.42	0.56	106.69
Death Valley	2009	17.92	11.80	18.56	68.26	388.51	-8.37	126	9	-25.72	0.57	103.72
Death Valley	2010	17.03	12.06	18.18	103.98	391.27	-8.47	120	113	-27.22	0.64	89.20
Death Valley	2011	16.17	10.92	17.78	66.65	393.69	-8.44	120	10	-27.70	0.66	84.20
Death Valley	2012	17.70	10.60	18.22	12.44	395.84	-8.48	115	25	-25.82	0.57	105.73
Death Valley	2013	18.30	11.18	18.42	27.57	399.26	-8.56	102	35	-24.78	0.52	119.08
Death Valley	2014	19.72	12.26	19.62	37.59	400.23	-8.53	80	32	-24.01	0.49	127.53
Death Valley	2015	20.05	13.42	20.36	58.38	403.29	-8.59	65	32	-25.74	0.56	109.83
Death Valley	2016	17.69	11.22	18.12	41.55	405.66	-8.62	57	53	-27.27	0.63	93.67
Death Valley	2017	17.62	12.26	18.60	86.49	409.07	-8.65	180	0	NA	NA	NA
Death Valley	2018	18.77	12.46	19.30	33.76	411.91	-8.68	170	113	-25.62	0.55	114.60
Death Valley	2019	15.36	10.60	16.86	86.61	410.73	-8.68	134	35	-26.52	0.59	103.98
Oatman	1991	18.40	12.38	19.20	138.31	352.18	-7.90	193	160	-25.62	0.59	90.42
Oatman	1992	16.44	12.96	19.18	228.27	354.27	-7.93	357	8	-28.61	0.72	61.93
Oatman	1993	14.81	12.04	17.78	268.69	357.05	-7.88	387	246	-28.54	0.72	62.54
Oatman	1994	19.04	12.64	19.50	71.53	361.44	-8.03	389	8	-25.23	0.57	97.96
Oatman	1995	15.42	12.54	18.34	175.91	362.07	-8.01	327	9	-28.23	0.70	67.87
Oatman	1996	21.47	14.92	21.76	23.74	363.10	-8.07	326	0	NA	NA	NA
Oatman	1997	19.88	13.98	20.40	81.33	365.17	-8.06	252	8	-26.21	0.61	89.37
Oatman	1998	16.58	12.44	18.46	176.94	367.55	-8.09	181	155	-27.13	0.65	80.94
Oatman	1999	20.66	13.66	20.56	35.28	370.39	-8.17	217	6	-24.80	0.54	106.30
Oatman	2000	21.84	14.48	21.16	41.06	371.31	-8.18	225	0	NA	NA	NA
Oatman	2001	17.20	12.30	18.48	93.28	373.56	-8.20	192	160	-27.62	0.66	78.36
Oatman	2002	19.99	12.90	19.56	9.81	374.72	-8.20	183	0	NA	NA	NA
Oatman	2003	18.59	13.88	20.14	117.89	377.89	-8.27	64	58	-27.08	0.64	85.63
Oatman	2004	18.46	13.00	19.22	63.22	380.05	-8.28	115	7	-26.60	0.62	91.20
Oatman	2005	13.84	12.34	17.74	240.99	381.40	-8.31	128	8	-28.31	0.69	73.79
Oatman	2006	20.97	13.54	20.38	16.42	384.84	-8.39	200	9	-25.67	0.57	103.41
Oatman	2007	21.58	13.50	20.44	24.21	385.75	-8.42	131	6	-24.30	0.51	118.63
Oatman	2008	19.21	12.82	19.28	94.02	387.12	-8.38	91	9	-25.67	0.57	103.93
Oatman	2009	18.98	13.38	19.72	99.18	388.51	-8.37	171	9	-26.13	0.59	99.27
Oatman	2010	17.13	12.46	18.64	157.91	391.27	-8.47	104	94	-27.76	0.66	83.44
Oatman	2011	18.00	12.64	18.96	88.37	393.69	-8.44	105	9	-27.10	0.63	90.80
Oatman	2012	19.15	12.80	19.46	29.22	395.84	-8.48	123	9	-25.50	0.56	109.21
Oatman	2013	19.82	13.02	19.60	60.86	399.26	-8.56	168	10	-25.18	0.54	114.64
Oatman	2014	21.76	14.34	21.14	25.07	400.23	-8.53	151	8	-25.50	0.56	111.03

Oatman	2015	21.15	15.04	21.38	81.58	403.29	-8.59	142	10	-25.03	0.53	117.79
Oatman	2016	20.29	13.48	19.86	43.12	405.66	-8.62	143	140	-25.78	0.56	110.40
Oatman	2017	19.11	14.24	20.08	118.31	409.07	-8.65	171	167	-27.15	0.62	96.20
Oatman	2018	21.07	14.76	20.96	27.50	411.91	-8.68	136	24	-24.86	0.52	123.25
Oatman	2019	16.82	12.58	18.20	92.81	410.73	-8.68	27	0	NA	NA	NA

Definitions and details of variables provided in Table S4:

Max VPD¹	The average of the daily maximum vapor pressure deficit (kPa) over the growing season (November through March of the sampling year).
Mean temp¹	The average of the daily mean temperature (degrees C) over the growing season (November through March of the sampling year).
Max temp¹	The average of the daily maximum temperature (degrees C) over the growing season (November through March of the sampling year).
Total precipitation¹	Total precipitation (mm) over the growing season (November through March of the sampling year).
CO₂ concentration²	The atmospheric concentration of CO ₂ (ppm) in Wendover, NV. Values for 1991, 1992, and 2019 were estimated using the linear regression between CO ₂ and year from 1993-2018.
δ¹³C_{CO₂}²	The δ ¹³ C value of atmospheric CO ₂ in Wendover, NV. Values for 1991, 1992, and 2015-2019 were estimated using the linear regression between the δ ¹³ C value of CO ₂ and year from 1993-2014.
Population size	The number of plants in the population. A plant must look dead for 3 consecutive years in order to be considered dead, so the population sizes for 2018 and 2019 are preliminary.
Plants analyzed	The number of plants whose δ ¹³ C values were analyzed from the sampling year.
Mean δ¹³C	The average δ ¹³ C value of all plants that were analyzed within the sampling year.
Mean c_i/c_a	The average ratio of c _i to c _a of all plants that were analyzed within the sampling year (see Equation 1 in Methods).
Mean iWUE	The average iWUE value of all plants that were analyzed within the sampling year (see Equation 2 in Methods).

¹Data from the PRISM Climate Group. See "Climate data" in Methods for details.

²Data from NOAA ESRL. See "δ¹³C value and concentration of atmospheric CO₂" in Methods for details.

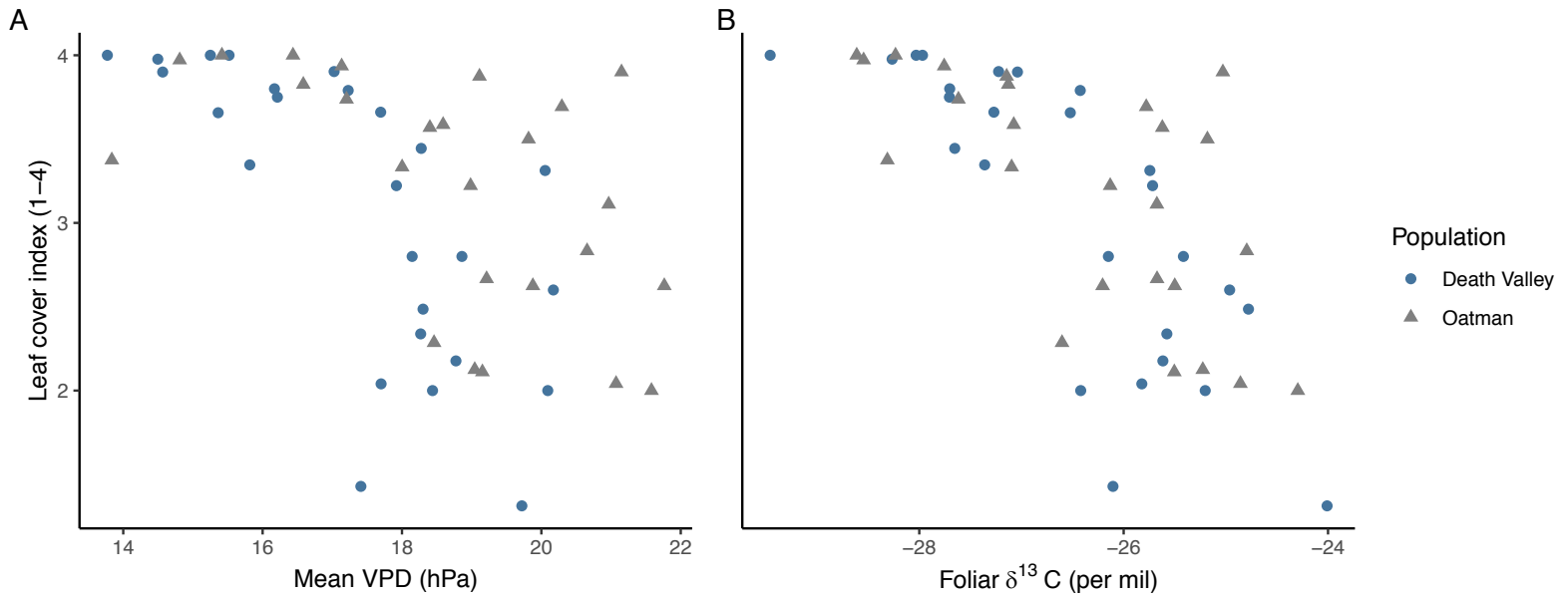


Figure S1. Population mean leaf cover is negatively and non-linearly associated with VPD (A) and $\delta^{13}\text{C}$ values (B) for both the Death Valley population (blue circles) and Oatman population (grey triangles). The proportion of each plant that was covered in leaves was estimated on a 1-4 scale, where values of 1 correspond with 1-25% leaf cover, 2 with 26-50%, 3 with 51-75%, and 4 with 76-100%. Generalized additive models (function “gam” in package “mgcv”) of leaf cover by $\delta^{13}\text{C}$ values explained 69.6% of the deviance in leaf cover for Death Valley (edf = 1.70, $p < 0.001$ for smoothing and parametric terms) and 44.7% for Oatman (edf = 1.23, $p < 0.001$ for smoothing and parametric terms).



Credits: U.S. Fish and Wildlife Service, Commission for Environmental Cooperation, Desert Landscape Conservation Cooperative (LCC)
 Created Jan. 24, 2020; data published September, 2004.
 Retrieved from: dlcc.databasin.org/datasets

Figure S2. Map of the U.S. desert Southwest showing the approximate locations of the study sites in the Mojave Desert.