Supporting Information

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SI Methods

Patterns of Richness Associated with Years. For multiple regression models used to analyze patterns of richness (as well as for all other multiple regression models), analytical assumptions were rigorously investigated. In particular, collinearity was evaluated through the inspection of variance inflation factors (VIFs), which were almost always found to be less than 5 (exceptions are discussed below) (1). The Durbin–Watson (DW) statistic was generated as a check on autocorrelation, which can be a problem in time-series data. DW values were always close to 2, and never less than 1 or greater than 3, suggesting that autocorrelation did not bias our results. The normality of residual errors was checked by visual inspection of histograms. All analyses were done with JMP software, version 7.0 (SAS). To control for errors associated with multiple comparisons, we used the correction for table-wide false discovery rate at $P < 0.05$, as suggested by Benjamini and Hochberg (2). In general, we focused on standardized β coefficients from multiple regression models as a way to compare factors within and across models.

In addition to the covariate approach to control for variation in sampling effort, we also used the nonparametric richness estimator Chao 2 (3) to investigate the efficacy of sampling for the observed and reported patterns of richness. Chao 2 was calculated using the resampling technique as implemented in the program EstimateS, following the expectation that where sampling has been sufficient, values of Chao 2 will level off along the resampled curve. For a given site, this was done on a per-year basis, with the samples being the individual visits to a site (and the observations being the species recorded at that visit). We performed these calculations for a subset of sites and years, including sites that have relatively few species but many visits per year (such as sites at low elevations) and high-elevation sites with more species and fewer visits per year. We found that resampled estimates of Chao 2 leveled off under all conditions, suggesting that sampling has been sufficient even at sites with high richness and a short season (few visits per year).

Frequency of Occurrence at Castle Peak. The fraction of days in which a species is observed is, of course, sensitive to variation in the number of visits per year, and therefore we excluded a number of early years at Castle Peak that had a low mean number of visits per year (Fig. S3). Specifically, we excluded the first 8 years at CP, leaving 27 years from 1985 to 2007. Furthermore, we excluded species that were present in less than half of those 27 years. These data reduction steps were conservative: The results we found were generally stronger if excluded years and species were included. Following these steps, 57 species remained for analyses.

In addition to patterns analyzed across species at CP, we specifically examined temporal patterns for four species known to be specialists of the alpine habitat at CP: *Cercyonis oetus*, *Hesperia nevada*, *Oeneis chryxus ivallda*, and *Papilio indra*. The first three show negative trends in abundance at CP whereas the fourth does not, as follows: *C. oetus* ($F_{1,21} = 5.06$, $P = 0.035$, slope of days observed versus years = −0.012), *H. nevada* ($F_{1,21} = 29.95$, $P < 0.0001$, slope = −0.019), *O. c. ivallda* ($F_{1,21} = 1.04$, $P = 0.32$, slope = −0.0055), and *P. indra* ($F_{1,21} = 0.019$, $P = 0.89$, slope = 0.00090).

Analysis: Turnover. As with the study of elevational ranges (see *Methods*), turnover was compared between large blocks of years. Because this analysis did not depend on using years in common between sites (as with elevational ranges), we used the full data at each site by comparing turnover in species composition between the first half of the sampled years and the second half. Turnover was calculated as $T = (E + I)/(S_1 + S_2)$, where E = the number of species present in the first sample but absent from the second, I = the number of species absent from the first sample but present in the second, and S_1 and S_2 = the number of species across both samples (3). Turnover was calculated separately for ruderal and nonruderal species at all sites, reported in Table S5.

Climate Data. Using yearly averaged values (for the "biological year") is but one of many ways that climatic variables can be summarized. We have compared the performance of various metrics in analyses and found that the method used here is both powerful and simple. In particular, we have found that a finer resolution (breaking weather down by season or by month) can be informative, particularly for species-level (as opposed to community-level) data. However, we present here only the more coarse-grained approach of yearly averaged values, as more fine-grained analyses are beyond the scope of the present questions being addressed.

Proximity to a long-term weather station was considered when each study site was chosen. Thus, the majority of our sites have associated weather stations that are geographically close and climatologically a good match to the transects walked at each site (Table S1). At three of the sites (RC, WA, and CP), a relevant weather station was not available. For these cases, we have used the parameter-elevation regressions on independent slopes model (PRISM) to account for the effects of topography on temperature and precipitation (available at http://www.prism.oregonstate.edu; Oregon Climate Service, Oregon State University, Corvalis, OR). The PRISM dataset comprises current and historical interpolated weather statistics for the United States and has been in development for over a decade (4, 5). We selected the PRISM locations that correspond to butterfly monitoring sites, and downloaded the climate data for those locations.

Analysis: Patterns of Richness Associated with Climatic Variables. To investigate associations between butterfly richness and climatic variables, multiple regression models were run with richness as the dependent factor, and the following independent factors: number of visits per year (also including the quadratic term where appropriate; see *Methods*), average daily maximum temperature, average daily minimum temperature, and average daily precipitation. For two of these models, VIFs were found to be greater than 5. In these cases (at DP and CP), models were run twice, leaving out one variable each time, as shown in Table S7. Note that years was not included as a factor in these models addressing climatic variables. This is because the inclusion of years tended to greatly increase VIFs, which is not surprising given the associations between years and climatic variables (Table S6). We did, nevertheless, explore models that included years, and found that conclusions would often be similar (i.e., the sign of β coefficients for climatic variables did not change) but significance would sometimes be less for all factors, and would sometimes be seemingly inflated for some factors (as is symptomatic of collinearity issues).

We also investigated the possibility that ruderal and nonruderal richness would have different associations with climatic variables. To that end, models as just described were run including status (ruderal or nonruderal) as a categorical factor (Table S8).

Land-Use Data. Land-use data for California are available from the Department of Conservation's Farmland Mapping and Monitoring Program (http://www.conservation.ca.gov/dlrp/fmmp/Pages/Index.aspx). Data are available for specific counties, for census values that cover 2-year increments starting in 1984. We focus on the land-use category "urban and built-up land" that is reported as number of acres. Being county-wide, these data are at a crude resolution, and this is particularly true for the Sierran sites; SV is an exception, as census values are reported specifically for Sierra Valley (that includes our study site) rather than for the whole county. Although there has been essentially no development near the Sierran sites (WA, LC, DP, and CP), they are all in Nevada County, which has actually experienced a great deal of development at lower elevations, generally distant from the study sites (A.M.S., pers. obs.). Even in the absence of development (as at the montane sites), land may still be subject to changes in use that could affect butterflies. However, land use in and around the montane sites has been relatively static: In particular, grazing has been a minor factor in these communities. One exception to this is the removal of cattle from Bear Valley (at the LC site) more than 20 years ago. *Polites sabuleti* was extirpated at LC subsequent to that action, apparently because of changes in the cover and height of grasses (the larval hosts of *P. sabuleti*). At DP, limited grazing has occurred in meadows, although none of the taxa at DP are restricted to the impacted areas.

Before asking whether land-use and butterfly richness were correlated, we corrected for sampling intensity by taking the residuals at each site from models of richness (dependent variable) and visits (independent variable); this relationship was either modeled as linear or quadratic, if the quadratic was significant as before. We then averaged these residuals in 2-year increments to correspond to the 2-year census intervals in the land-use data. These averaged values were then compared to land-use values using Spearman's rank correlations, reported in Table S10.

Analysis: Associations Between Richness at Low and High Elevations. As above, we corrected for sampling effort by taking residuals from models of visits versus richness, using the quadratic term for richness where significant. For simplicity, we have analyzed averaged values for the valley (WS, NS, RC) and montane sites (WA, LC, DP, CP) that potentially receive colonists from the valley floor (similar results are obtained if sites are analyzed individually). Fig. 4 shows the relationships between ruderal valley richness and ruderal and nonruderal richness at elevation. Not shown in that figure are relationships between nonruderal valley richness and richness at elevations. These are as follows: Sierran ruderal versus nonruderal valley, $F_{1,18} = 0.0007$, $P = 0.98$; Sierran nonruderal to nonruderal valley: $F_{1,18} = 1.80$, $P = 0.20$; GC nonruderal to valley nonruderal: $F_{1,18} = 0.54$, $P = 0.47$; GC ruderal to valley nonruderal: $F_{1,18} = 0.014$, $P = 0.91$.

We also explored the possibility that there could be a lag effect in the association between ruderal valley richness and ruderal richness at higher elevations. This might happen if dispersing individuals contribute offspring in one year that successfully overwinter at higher elevations and contribute to populations in the subsequent year. Relationships involving a lag effect were not significant: Sierran ruderal versus ruderal valley, $F_{1,18} = 0.70$, $P = 0.41$; GC ruderal versus ruderal valley, $F_{1,18} = 1.68$, $P = 0.21$.

1. O'Brien RM (2007) A caution regarding rules of thumb for variance inflation factors. *Qual Quant* 41:673–690.
2. Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: A practical and powerful approach to multiple testing. *J R Stat Soc B* 57:289–300.
3. Magurran AE (2003) *Measuring Biological Diversity* (Blackwell, Malden, MA).
4. Daly C, Gibson WP, Taylor GH, Johnson GL, Pasteris P (2002) A knowledge-based approach to the statistical mapping of climate. *Clim Res* 22:99–113.
5. Di Luzio M, Johnson GL, Daly C, Eischeid JK, Arnold JG (2008) Constructing retrospective gridded daily precipitation and temperature datasets for the coterminous United States. *J Appl Meteorol Climatol* 47:475–497.

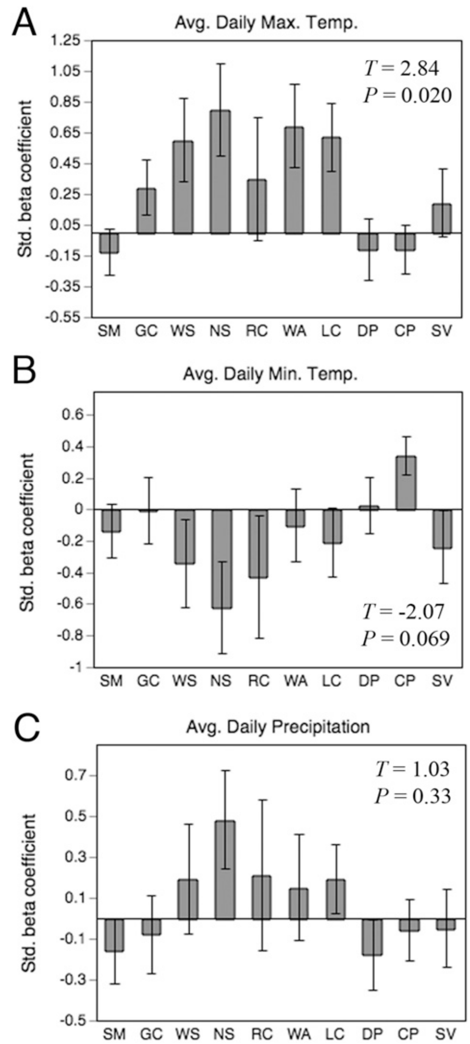

Fig. S1. Partial results from multiple regression models analyzing associations between climatic variables and patterns of richness. Shown here are < coefficients (and associated SEs) from multiple regression models at each site. Positive values, for example, indicate a positive association between the particular climatic variable and butterfly richness. *T* and *P* values in the *Upper Right* of each panel correspond to single-sample *t* tests asking whether the distribution of < coefficients across sites (for each climatic variable) is significantly different from zero.

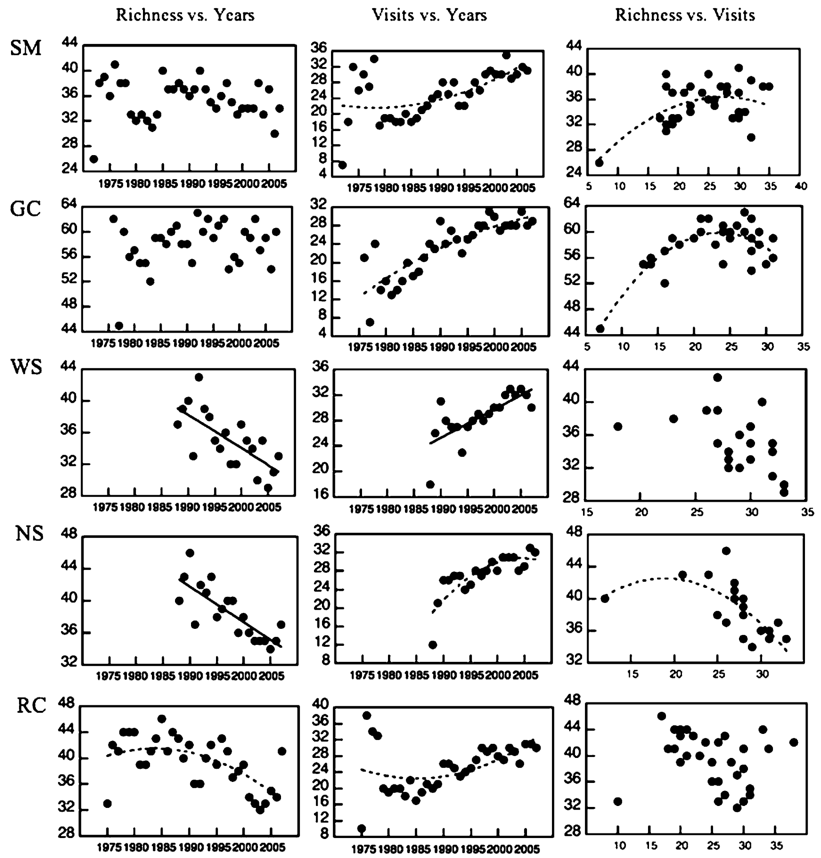

Fig. S2. Bivariate relationships among raw data for 5 of 10 sites. For each site, three relationships are shown: richness versus years (*Left*), number of visits versus years (*Center*), and richness versus number of visits (*Right*). Lines are only shown for relationships significant at $P < 0.05$, following multiple, table-wide correction for false discovery rate. Quadratic lines (dotted) are drawn if the adjusted R^2 was higher for the polynomial than for the linear fit.

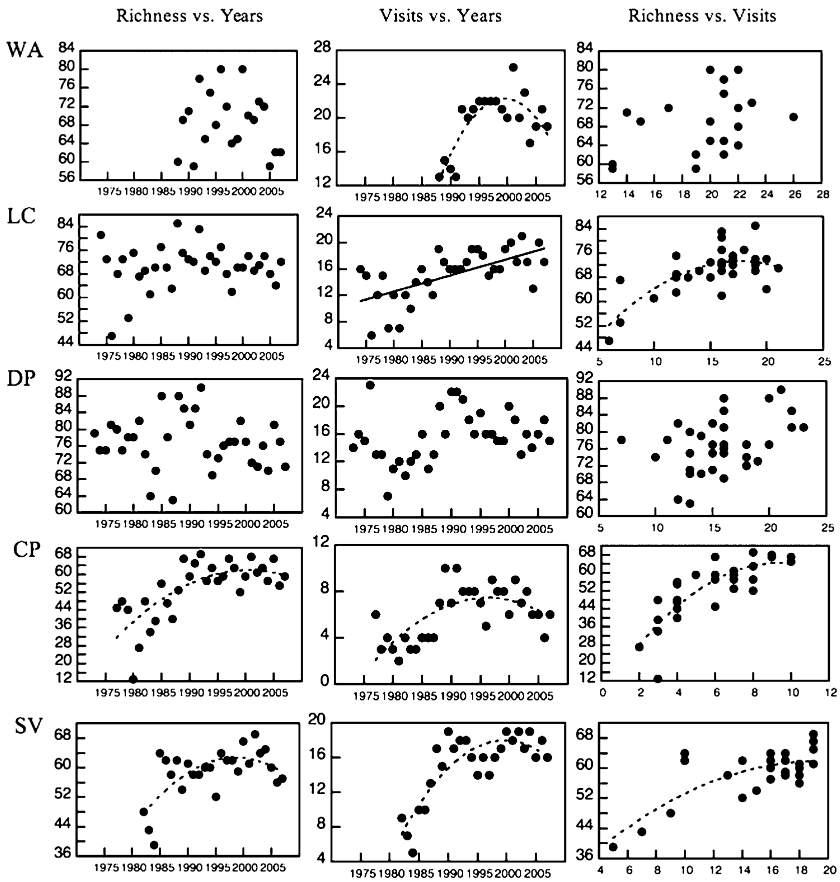

Fig. S3. Bivariate relationships among raw data for 5 of 10 sites. For each site, three relationships are shown: richness versus years (*Left*), number of visits versus years (*Center*), and richness versus number of visits (*Right*). Lines are only shown for relationships significant at $P < 0.05$, following multiple, table-wide correction for false discovery rate. Quadratic lines (dotted) are drawn if the adjusted R2 was higher for the polynomial than for the linear fit.

Table S1. Site characteristics and names of weather stations from which data were taken (associated codes refer to the National Weather Service's Cooperative Observer Program; http://www.nws.noaa.gov/om/coop)

Site	Elevation, m	Site characteristics	Weather station
Suisun Marsh (SM)	0–1	Tidally influenced complex of brackish and freshwater marsh. Plants include: halophytes, sedges, rushes, cattails, reeds, and herbaceous perennial composites.	Fairfield, 042934
Gates Canyon (GC)	190–600	Inner Coast Range foothill canyon. Vegetation includes: interior live oak woodland, blue oak woodland, chaparral, gray pine, and riparian forest of cottonwood, big leaf maple, and alder.	Vacaville, 049200
West Sacramento (WS)	9	Central Valley floor. Dense riparian cottonwood and willow forest with valley oak and ash; annual grassland.	Sac. 5 ESE, 047633
North Sacramento (NS)	8	Central Valley floor. Valley oak woodland; riparian cottonwood and willow; annual grassland.	Sac. FAA Airport, 047630
Rancho Cordova (RC)	18	Eastern edge of Central Valley. Interior live oak–gray pine woodland, valley oak-dominated riparian forest, and annual grassland.	PRISM (38.6241, 121.2777)
Washington (WA)	850–1,200	Sierra Foothills. Deep canyon with mixed serpentine and metasedimentary geology. Canyon live oak woodland with mesic mixed lower-montane forest including Douglas fir, incense cedar, and Ponderosa pine.	PRISM (39.3166, 120.8099)
Lang Crossing (LC)	1,500–1,700	West-slope Sierra Nevada. Mosaic of xerophytic vegetation (goldencup oak and manzanita) and moist slopes with mixed mesic forest (including Douglas fir and Ponderosa and sugar pines); site also includes a large wet meadow with boggy areas.	Blue Canyon, 04897
Donner Pass (DP)	2,000–2,200	High Sierra. Montane communities with local subalpine elements; granite balds with herbs and low shrubs; mature red fir forest; large wet and dry meadow complex with a few boggy spots, fringing willows, and mountain alders.	Sierra Snow Lab, 049998
Castle Peak (CP)	2,400–2,775	High Sierra. Subalpine and alpine vegetation; tree line of mountain hemlock, lodgepole pine, western white pine; alpine fell-fields of perennial herbs; persistent snow fields, boggy seeps, and wet meadows.	PRISM (39.3395, 120.3474)
Sierra Valley (SV)	1,500	East side of Sierra: Wet and dry meadows with juniper-shrub steppe and irrigated alfalfa fields.	Sierraville Ranger Station, 048218

For three sites, as indicated, climate data came from the PRISM model (*SI Text*) for the listed coordinates of latitude and longitude.

Table S2. Patterns of richness associated with sampling effort and years

Site	N	R^2	F	P	Years	P	Visits	P	Visits^2	P
SM	36	0.46	9.18	0.0002	−0.49	0.0036	0.49	0.0053	−0.45	0.0031
GC	32	0.60	13.74	<0.0001	−0.14	0.55	0.19	0.50	−0.70	0.0002
WS	20	0.48	8.00	0.0036	−0.73	0.011	0.050	0.85		
NS	20	0.64	15.19	0.0002	−0.96	0.0007	0.22	0.35		
RC	33	0.44	7.72	0.0006	−0.85	<0.0001	0.11	0.46	−0.47	0.0086
WA	20	0.24	2.71	0.095	−0.37	0.15	0.56	0.035		
LC	34	0.62	16.24	<0.0001	−0.41	0.010	0.69	0.0005	−0.36	0.014
DP	35	0.21	4.32	0.022	−0.25	0.13	0.46	0.0079		
CP	31	0.72	35.22	<0.0001	0.35	0.0051	0.61	<0.0001		
SV	26	0.52	12.69	0.0002	0.0050	0.98	0.72	0.0026		

For each site, a multiple regression model was analyzed with Years and Visits as continuous independent variables, and species richness as the dependent variable. A polynomial term for visits (Visits^2) was included for all sites, and was retained when significant at $P < 0.05$. Reported here are summary statistics for each model, as well as standardized β coefficients and associated P values for Years, Visits, and Visits^2. The table-wide false discovery rate (FDR) was investigated at the level of $P < 0.05$; FDR correction for these analyses was not different from uncorrected significance at $P < 0.05$.

Table S3. Results from models testing the interaction between type (ruderal or not) and years

Site	N	R^2	F	Years	Visits	Visits^2	Type	Type × years
SM	72	0.71	31.98***	−0.27**	0.27**	−0.25**	−0.75***	−0.0043
GC	64	0.97	357.12***	−0.023	0.030	−0.11***	0.97***	0.10***
WS	40	0.83	44.12***	−0.30**	0.020		−0.85***	−0.16*
NS	40	0.78	31.11***	−0.48***	0.11		−0.73***	−0.30***
RC	66	0.46	10.03***	−0.60***	0.081	−0.33**	0.45***	−0.17
WA	40	0.96	193.61***	−0.056	0.085		0.97***	0.072
LC	68	0.97	435.13***	−0.064*	0.11**	−0.057	0.97***	0.091***
DP	70	0.98	779.95***	−0.032	0.058**		0.99***	0.0093
CP	62	0.95	248.38***	0.10**	0.18***		0.93***	0.14***
SV	52	0.94	184.23***	0.0013	0.18***		0.94***	0.14**

Significance for linear regression models is as follows: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; only tests significant after correction for table-wide false discovery rate are marked with asterisks.

Table S4. Analyses of temporal trends for ruderal and nonruderal species separately

Site		*N*	R^2	*F*	Years	Visits	Visits^2
SM	Rud.	36	0.26	5.95**	−0.40*	0.61**	
	Non	36	0.46	9.13***	−0.46**	0.45**	−0.49**
GC	Rud.	32	0.32	6.94**	−0.96**	0.61	
	Non	32	0.54	10.82***	0.20	0.093	−0.56**
WS	Rud.	20	0.34	4.38*	−0.70*	0.18	
	Non	20	0.40	5.59*	−0.63	0.0029	
NS	Rud.	20	0.20	2.13	−0.56	0.16	
	Non	20	0.56	10.64**	−0.89**	0.20	
RC	Rud.	33	0.38	5.84**	−0.76***	0.077	−0.50**
	Non	33	0.44	7.72***	−0.85***	0.11	−0.47**
WA	Rud.	20	0.66	16.51***	−0.73***	−0.15	
	Non	20	0.31	3.75	−0.11	0.60*	
LC	Rud.	34	0.41	10.80***	−0.83***	0.45*	
	Non	34	0.61	15.73***	−0.071	0.55**	−0.37*
DP	Rud.	35	0.24	5.19*	−0.46**	0.35	
	Non	35	0.18	3.58	−0.16	0.44*	
CP	Rud.	31	0.45	11.28***	0.21	0.53**	
	Non	31	0.70	31.90***	0.36**	0.59***	
SV	Rud.	26	0.10	1.33	−0.36	0.45	
	Non	26	0.57	15.40***	0.097	0.69**	

Significance for linear regression models is as follows: *$P < 0.05$, **$P < 0.01$, *** $P < 0.001$; only tests significant after correction for table-wide false discovery rate are marked with asterisks.

Table S5. Turnover at each site, comparing the first half of available years with the second half (see Fig. 1 for the year in which continuous visits began at each site)

	Ruderal	Nonruderal
SM	0.064	0.167
GC	0.023	0.077
WS	0.064	0.158
NS	0.04	0.213
RC	0.047	0.057
WA	0.073	0.086
LC	0.073	0.081
DP	0.043	0.073
CP	0.231	0.074
SV	0.048	0.108
Mean	0.071	0.11

Calculations were performed separately for ruderal and nonruderal species. Average values are shown below each category.

Table S6. Simple linear regressions for weather variables versus years from fall of 1970 through summer of 2007

Site	Average daily max. temp.			Average daily min. temp.			Average daily precip.		
	R^2	F	Slope	R^2	F	Slope	R^2	F	Slope
SM	0.18	7.63**	0.050	0.29	14.61***	0.053	0.038	1.36	1.21
GC	0.25	11.73**	0.046	0.46	30.18***	0.061	0.024	0.84	1.12
WS	0.20	8.67**	0.033	0.018	0.64	0.0074	0.0018	0.063	0.20
NS	0.021	0.75	0.013	0.044	1.61	0.012	0.0034	0.12	0.26
RC	0.14	5.91	0.027	0.39	22.12***	0.035	0.0014	0.049	−0.16
WA	0.033	1.18	0.016	0.41	24.64***	0.049	0.0017	0.060	0.646
LC	0.018	0.56	−0.012	0.44	24.13***	0.058	0.000029	0.0009	0.086
DP	0.39	21.92***	0.10	0.29	14.04***	0.053	0.0037	0.13	0.83
CP	0.051	1.89	0.020	0.63	60.19***	0.076	0.00012	0.004	0.14
SV	0.33	17.39***	−0.10	0.26	12.40**	−0.056	0.0011	0.038	−0.24

All comparisons are for 37 years. Significance for linear regression models is as follows: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; only tests significant after correction for table-wide false discovery rate are marked with asterisks.

Table S7. Results from multiple regression models with yearly averaged weather variables

Site	N	R^2	F	Visits	Visits^2	Max. T	Min. T	Precip.
SM	36	0.38	3.65*	0.29	−0.45**	−0.13	−0.14	−0.16
GC	32	0.68	10.98***	−0.10	−0.78***	0.29	−0.0094	−0.08
WS	20	0.55	3.56	−0.82**	−0.58	0.60	−0.34	0.19
NS	21	0.67	5.72**	−0.91**	−0.61	0.80	−0.62	0.48
RC	33	0.08	0.62	−0.077		0.33	−0.42	0.21
WA	20	0.46	3.13	0.47		0.69	−0.10	0.15
LC	28	0.68	9.56***	0.64**	−0.38	0.60**	−0.21	0.19
DP	35	0.19	2.37	0.34			0.025	−0.18
	35	0.19	2.48	0.39		−0.11		−0.23
CP	31	0.71	16.29***	0.77***		−0.11	0.33**	−0.059
SV	26	0.57	6.81**	0.63**		0.19	−0.24	−0.05

The same model was run across all sites: (# visits to the site in a year) + (average daily max temp values for the whole year) + (average daily min temp values for the whole year) + (average daily precip values for the whole year) = (# sp observed in the year). A quadratic term for visits (Visits^2) was included for all sites, and was retained when significant at $P < 0.05$. Reported here are overall model stats (N, R^2, F), and then standardized β coefficients for the four predictors. Significance is as follows: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; only tests significant after correction for table-wide false discovery rate are marked with asterisks. Models were run twice at DP due to variance inflation factors > 5.0.

Table S8. Interactions from multiple regression models similar to those reported in Table S7, but including type (ruderal or nonruderal) as a factor

Site	N	R^2	F	Max. T * type	Min. T × type	Precip. × type
SM	72	0.69	15.18***	−0.048	−0.054	0.030
GC	64	0.96	165.17***	0.079	−0.0068	0.055
WS	40	0.83	16.86***	0.15	−0.12	0.045
NS	40	0.77	11.28***	0.49**	−0.36	0.22
RC	66	0.25	2.43	0.06	−0.13	0.10
WA	40	0.96	99.30***	0.092	0.0078	0.060
LC	56	0.98	224.97***	−0.045	0.14***	0.061
DP	70	0.98	398.93***	−0.072	0.061	−0.045
CP	62	0.93	93.1***	−0.018	0.089	−0.055
SV	52	0.94	82.61***	0.037	−0.11	−0.053

Significance is as follows: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; only tests significant after correction for table-wide false discovery rate are marked with asterisks.

Table S9. Results from analyses of land-use trends

County	Sites	N	R^2	F	P	Slope
Solano	SM, GC	12	0.98	503.69	<0.0001	360.24
Yolo	WS	12	0.98	560.53	<0.0001	159.02
Sacramento	NS, RC	10	0.97	265.70	<0.0001	887.07
Nevada	WA, LC, DP, CP	12	0.85	58.24	<0.0001	71.24
Sierra Valley	SV	12	0.71	24.08	0.0006	3.91

Slopes reflect the number of hectares per year converted to urban areas and other uses. Data are from the California Department of Conservation; see *SI Text* for details.

Table S10. Spearman's rank correlations between the amount of developed land and butterfly richness (residuals having removed the effect of sampling)

Site	N	Spearman's ρ	P
SM	12	−0.42	0.17
GC	12	−0.028	0.93
WS	9	−0.73	0.025
NS	9	−0.63	0.067
RC	10	−0.78	0.0072
WA	9	−0.50	0.17
LC	12	−0.48	0.11
DP	12	−0.077	0.81
CP	12	0.23	0.47
SV	12	0.032	0.92

Land-use data were in 2-year increments, and richness was similarly analyzed here in 2-year increments (see *SI Text* for full details).