BIOCLIMATIC INDICES TRENDS IN CALIFORNIA (U.S.) FROM 1980 TO 2019

Alejandro GONZÁLEZ-PÉREZ[1], Ramón ÁLVAREZ-ESTEBAN[2], Ángel PENAS[3], Sara DEL RÍO[3]
[1]Department of Biodiversity and Environmental Management (Botany Area). Faculty of Biological and Environmental Science. University of Leon. Campus de Vegazana s/n. 24071. León (Spain).
[2]Department of Economics and Statistics (Statistics and Operations Research Area). Faculty of Economics and Business. University of Leon. Campus de Vegazana s/n. 24071. León (Spain).
[3]Department of Biodiversity and Environmental Management (Botany Area). Faculty of Biological and Environmental Science. University of Leon. Mountain Livestock Institute CSIC-UNILEON. Campus de Vegazana s/n. 24071. León (Spain).
agonp@unileon.es, **ramon.alvarez@unileon.es**, **sriog@unileon.es**, **apenm@unileon.es**

Resumen
La Bioclimatología es una ciencia interdisciplinar que estudia las relaciones entre las condiciones climáticas y la distribución de los seres vivos y sus comunidades en el planeta (Rivas-Martínez et al., 2011). En este sentido, los valores de los parámetros e índices climáticos y bioclimáticos en lugares concretos se utilizan para la toma de decisiones. El objetivo de esta investigación es mostrar resultados actualizados de los índices bioclimáticos y a su vez señalar la importancia de conocer la evolución espacial y temporal de estos índices y cómo puede afectar a la biodiversidad de la flora de California. Para ello, a partir de los datos originales de las estaciones meteorológicas (350) este estudio se centra en las 172 finalmente seleccionadas. De cada una de ellas se calcularon los parámetros e índices bioclimáticos siguiendo a Rivas-Martínez et al. (2011). Se aplicó el método de la pendiente de Sen y el test de Mann-Kendall para estimar las tendencias y la significación estadística. Los resultados se muestran en mapas de contornos en los que se observó que en los índices ombrotérmicos (Io, Ios1, Ios2, Ios3, Ios4) se presentan marcadas tendencias negativas en el sur y centro de California de -3 mm/año, a -0,028 unidades/año, -0,02 unidades/año, -0,025 unidades/año, -0,03 unidades/año, respectivamente. Las temperaturas positivas en el desierto de Mojave y sus alrededores son las que muestran los mayores incrementos con una tendencia de +6 unidades/año.

Palabras clave: Bioclimatología, California, Tendencias, Mann-Kendall, Sen slope, Mapas de contorno

Abstract
Bioclimatology is an interdisciplinary science that studies the relationships between climate conditions and the distribution of living beings and their communities on the Globe (Rivas-Martínez et al., 2011). In this regard, values of climate and bioclimate

parameters and indices in specifically locations are used for decision making. The aim of this research is to show updated results of the bioclimatic indices and to point out the importance of knowing the spatial and temporal evolution of these indices and how it can affect the biodiversity of the flora of California. To achieve this, from the original meteorological station data (350) this study is focused on the 172 finally selected. From each one of them, bioclimatic parameters and indices were calculated according Rivas-Martínez et al. (2011). It was applied Sen´s slope method and Mann-Kendall test to estimate trends and the statistical significance. Results are shown in contour maps in which the ombrothermic indices (Io, Ios_1, Ios_2, Ios_3, Ios_4) marked negative trends are shown in southern and central of California from -3 units/year, to -0.028 units/year, -0.02 units/year, -0.025 units/year, -0.03 units/year, respectively. Positive temperature has shown the highest increases in Mojave Desert and surrounding areas with a trend of +6 units/year.

Keywords: Bioclimatology, California, Trends, Mann-Kendall, Sen slope, Contour Maps**.**

1. INTRODUCCIÓN

A great number of species have been being affected by climate change. Comprehend how species will respond is vital for effectiveness in management and conservation biodiversity. In addition, natural resources managers will need tools to assess potential impacts of global warming throughout their local area of influence (Torregrosa et al., 2013). In this regard, Bioclimatology is an ecological science that studies the relationships between climate conditions and distribution of living beings and their communities all over the world (Rivas-Martínez et al., 2011). According to Worldwide Bioclimatic Classification System (WBCS from now on) by Rivas-Martínez et al. (2011), the bioclimatic units are precisely correlated to vegetation models and climate values. The increase in comprehensive knowledge of the distribution of vegetation on Earth, as well as changes in form and composition of potential vegetation, have allowed scientists to recognise bioclimatic threshold to define them. The limits of bioclimatic units (macrobioclimates, bioclimates, thermotypes and ombrotypes) have been progressively redefined. In fact, bioclimatic models can predict the responses of living organisms to climate change focusing on climatic thresholds of species distribution (Canu et al., 2015). For this reason, amongst others, it is important to measure bioclimatic trends in order to reduce variability in future uncertainty. In climatic studies both the physical aspects and those of statistical significance are fundamental to trend prediction. Indeed, such is the importance of bioclimatic trends that new methodologies and research have focused on the distribution of plants that provide a basis for regional economic production (del Río et al., 2021; Gopar-Merino et al., 2015). Previous research has shown that climate trends in the United States present both regional and seasonal variations (Wang et al., 2009), particularly over winter period (Burakowski et al., 2008). The expected values of climate and bioclimate parameters and indices in specifically locations are used for decision making such as plant hardiness zones by the U.S. Department of Agriculture (Krakauer, 2012).

Authors considered that this research might deepen in the knowledge of the bioclimatic indices trend due to the fact that shows up-to-date results. This research could support decision-making for environmental managers. On this matter, is also worth noting the importance of knowing the spatial and temporal evolution of the bioclimatic indices and how this may affect California´s flora biodiversity.

2. METHOD AND MATERIALS.

2.1 Survey area.

In this research, the area established for its study is the State of California that covers 423,955 km2. This State is one of the largest states in the U.S. and presents two leading mountain ranges named Sierra Nevada and the Coast Range. The Coast Range runs through the northwest of the State to the Mexican boundary. Moreover, Sierra Nevada is the largest range with Mount Whitney as the highest peak (4421 m). In addition, this State shows a wide variety of landscapes. From Mediterranean climate, spreads all over State, to Temperate one in Klamath mountain, the climate is highly variable (Rivas-Martínez et al., 2011). This wide variety of climates is possible, thanks to its intricate topography and latitudinal extension (Pathak et al., 2018). This is the case of the differences observed on the southern and northern hills, since they have microclimates that affect the length of the growing season, particularly in years with little rainfall (Liu et al., 2021). In addition, the proximity to the Pacific coast is another determining factor of climate variability in this State.

Fig. 1: Meteorological stations used in this study.

2.2 Data.

Climatic data values of precipitation and average temperature were obtained from the climatic database WRCC (Center, 2000). Initially, monthly time series of average temperature (ºC) and accumulated rainfall (mm) were included in our database. From the 350 meteorological stations available, this study is focused on the 172 finally selected (Fig. 1). Analysis of the homogeneity of the data was performed (Blöschl et al., 2019; Gocic & Trajkovic, 2013; Karmeshu, 2015; Song et al., 2019). In this research was determined by the run test (Thom, 1966), recommended by the World Meteorological Organization. To represent this data in maps, altitude values and geographic coordinates were added. For each one of those meteorological stations bioclimatic indices were calculated following Rivas-Martínez et al. (2011) (Table 1).

Index name	Definition
Positive Precipitation (Pp)	Sum of the average precipitation in millimetres of the months whose average temperature is greater than 0ºC.
Positive Temperature (Tp)	Sum of the temperatures of the months whose average temperature is greater than 0ºC. It is expressed in tenths of a degree.
Maximun Temperature (Tmax)	Average temperature of the hottest month of the year
Minimun Temperature (Tmin)	Average temperature of the coldest month of the year
Simple Continentality Index (Ic)	It expresses the difference or oscillation between the mean temperature of the warmest month (Tmax) and that of the coldest month of the year (Tmin). Ic = Tmax - Tmin.
Thermicity Index (It)	It can be calculated as the average annual temperature plus twice the temperature of the coldest month and all this multiplied by ten. It is, therefore, an index that weights the intensity of the cold.
Compensated Thermicity Index (Itc)	Index that tries to weight the value of the termicity index (It), due to the "excess" of cold or temperance that occurs during the cold season in the territories of marked continental or hyperoceanic climate on Earth. In addition, this Index provides Termotipes characterisation.
Annual Ombrothermic Index (Io)	This index is the quotient between the positive precipitation (Pp) and the positive temperature (Tp) multiplied by ten.
Summer Ombrothermic Indices (Ios_i)	Ios_1 (ombrothermic index of the warmest month of the summer quarter); Ios_2 (ombrothermic index of the hottest two months of the summer quarter); Ios_3 (ombrothermic index of the summer quarter) and Ios_4 (calculated with the months of the summer quarter and the previous month).

Table 1. Parameters and Bioclimatic indices from Rivas-Martínez et al. (2011)

2.3 Trend analysis.

In first place, we applied Sen´s slope method and Mann-Kendall test to estimate trends and the statistical significance for each one of meteorological stations established. For this accomplishment we applied the Sen slope estimator, a non-parametric technique that estimates variations per unit of time in a series when there is a linear trend (Q. Liu et al., 2020). The non-parametric Mann-Kendall test most commonly used for predicting trends in environmental time series data (Ahmad et al., 2015; He & Gautam, 2016a; Kukal & Irmak, 2016; Peña-Angulo et al., 2021; Sarricolea et al., 2019). It is noteworthy that in so many territories the number of weather stations are scarce, and climatic studies are truly challenging (Abatzoglou et al., 2018; Díaz-Padilla et al., 2011; Marchi et al., 2017). For that reason, interpolation of data is necessary for a specific location. Aiming to carry out the slope calculations the Empirical Bayesian Kriging geoprocessing tool was applied. This tool is implemented in ArcGis software 10.8 (Environmental Systems Research Institute (ESRI), 2019). The semivariogram estimated in this kriging method is obtain using the restricted maximum likelihood method (Krivoruchko, 2012). Finally, the results obtained from the analysis of each one of the bioclimatic indices selected are shown in contour maps. Those are the overlaid slope interpolations for each year of the study period with statistical significance when it exists at 95% confidence level. This slope value is heterogeneously distributed over the study area.

3. RESULTS AND DISCUSSION.

According to WBCS, the annual rhythm of precipitation is more important than quantity, for plant communities. In this regard, annual Ombrothermic Index (Io) express the quotient between the average precipitation in millimetres and the sum in degrees of those months whose average temperature is above zero degrees, since below this temperature the water absorbed functions of the plant´s root, are inhibited. In addition, Summer Ombrothermic Indices (Ios_1, Ios_2, Ios_3 and Ios_4) are very important, since they measure summer aridity and its possible compensation: they are essential to differentiate the Mediterranean Macrobioclimate from the Temperate Macrobioclimate. In relation to our Io results, it is important to mention that negative trends are found over Central and North Sierra Nevada (-0.036 Units/year) (Fig. 2). This implies that the precipitation available for the vegetation communities in those mountains is going to be scarce, turning into a drier territory which could lead to a loss of the suitable area of plants found today in that locations. These results but with a less negative trend are shown in South California, in particular, at zones such as San Gabriel and San Bernardino Mountains. Opposing to that, positive trends of this index are found in the North of the State closer to the coast in Eureka and West of Coast Ranges.

Similar outcomes are found for the summer Ombrothermic Indices. It is noteworthy the negative trends (-0.04/year) found for Ios_2. This result is found in the surroundings of Lake Tahoe. Those areas of Temperate Macrobioclimate have shown an increasing summer drought. That could be related to an increase of temperature as it can be verified in Positive Temperature Map (Fig. 2). The map highlights that Southern California warms up faster, as well as the North does but to a lesser extent. In this regard, Mojave Desert and surrounding areas are shown the highest increases with a trend of +6 units/year.

Moving to our results of the Tmax a quite similar pattern to Tp is found. In this case Tmax increases in a rate of +0.072ºC/year in Mojave Desert neighbouring. In this case the slightest increases are found in the Pacific coast of this State (+0.32ºC in the period studied). According to our result of Tmin the highest increases are found in Sacramento and San Joaquin Valley which it could affect crops and plant distribution (Kerr et al., 2018; Liu, 2016). It is remarkable negative trends existing in Klamath Mountains Region that spread to the coast from Eureka to Crescent City.

For Positive Annual Precipitation (Pp), negative trends are found (-1.5 mm/year) in foremost parts of the State. Particularly, in the South of the State where large-scale plant mortality has been documented during recent drought (Hantson et al., 2021). As it was mentioned before this index is important due to fact that considers only precipitation that

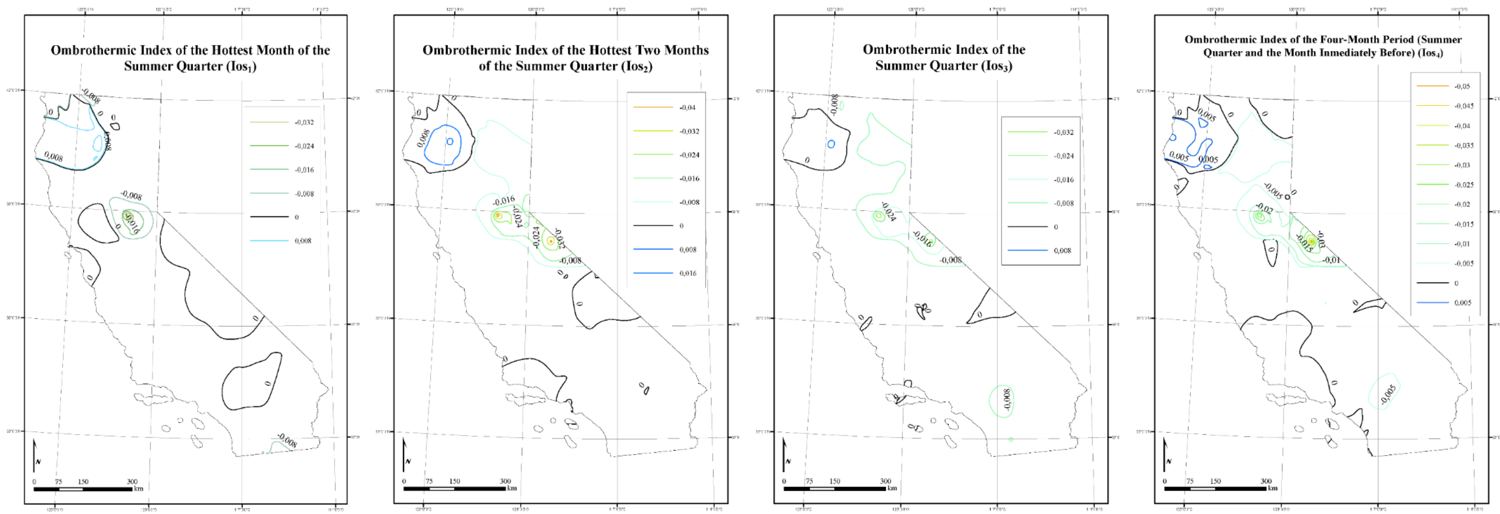

Fig. 2: Annual Trend results per year of the time-space analysis for each one of the bioclimatic indices considered for this research.

is useful and available for plant growth. Positive trends were found in both Shasta mountain vicinities and Lake Tahoe (+1.5 mm/year). Increases in temperatures dropped the number of days below zero degrees. The snow melting processes have advanced in California`s Ranges (Guan et al., 2013; He & Gautam, 2016b). In those areas, plants might have more water accessible. Simple continentality index is related to the range of temperature of the most extreme months of the year (a value expressed in degrees). This index has a great influence on the distribution of vegetation, and as a result the boundaries amongst bioclimates zones (Rivas-Martínez et al., 2011). Our outcomes show positive trends in the Sierra Nevada Ranges and the Mojave and Sonoran Deserts, from +0.05 ºC/year to +0.07 ºC/year respectively. It is important to outline negative trends (-0.04 ºC/year) in San Francisco Bay, Salinas, San Jose, Monterey and South Gabriel Mountains an increase of oceanity is expected to be found. Finally, and related to Thermicity index (It), which considers the intensity of the cold, a limiting factor for most of the plants and plant communities. There is a high correlation between this index and vegetation in warm and temperate climates (Rivas-Martínez et al., 2011), while in cold climates and extratropical zones the Itc takes the leading role. In our results both indices seem to show analogous trends. In particular, the highest trends for It are found in Sacramento and San Joaquin valleys (+1.2 units/year) while for Itc +1.5 units/year are found in Mojave

Desert and Death Valley. Opposite to this, happens in the North of the State where negative trends are found in Shasta mountain vicinities for It (-0.4 units/year) and in the Pacific coast of California for Itc (-0.5 units/year).

These results are consistent with the increases found in average temperature and the general decreases in precipitation. The teleconnections patterns could influence temperature

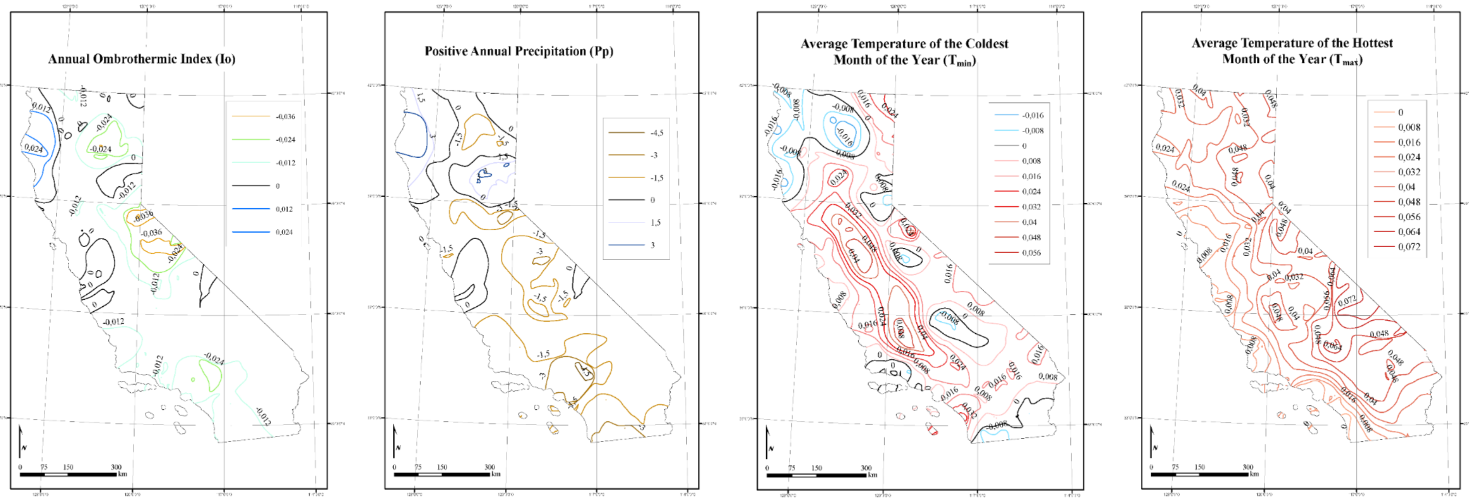

Fig. 2: Continue.

and precipitation regimes. Particularly, in González-Pérez et al, (2022), was found that temperatures in February, March, April and May are highly correlated with most of the teleconnection patterns studied in the State of California. Taking all this into consideration, we could display that the State of California shows an increase in territories with positive trends in some of the indices studied. On the one hand the territory of California is instead towards more Mediterranean, more continental and territories showed drier ombrotypes. This is consistent with previous research highlighting the frequent of droughts in the State (Mann & Gleick, 2015). On the other hand, and in relation to the vegetation, this implies a possible change in the conditions for the development of the vegetation in California. In this way, if these conditions are maintained in the future, it will be challenging for environmental managers (Abatzoglou & Williams, 2016; Miller et al., 2012; Williams et al., 2019). For example redwood ecosystems being more stressed under a summer climate of reduced fog frequency (Johnstone & Dawson, 2010).

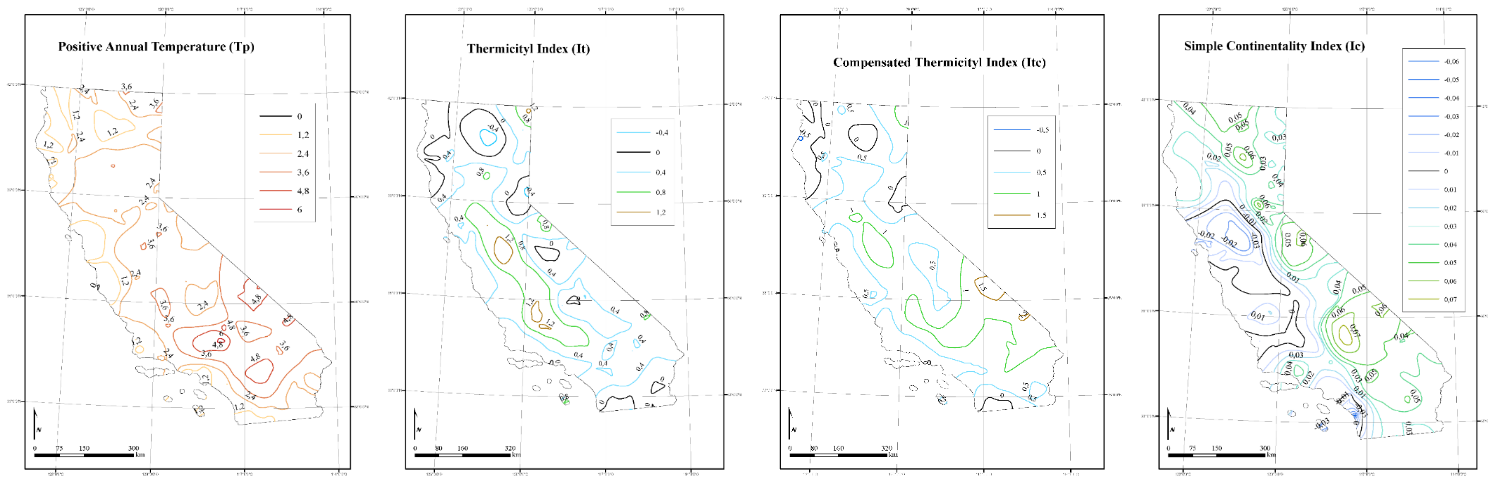

Fig. 2: Continue.

4. CONCLUSIONS.

The aim of this research was to determine bioclimatic trends in California from 1980 to 2019. For this achievement a wide range of bioclimatic indices were chosen following WBCS methodology (Rivas-Martínez et al., 2011). In accordance with the results some of the significant conclusions are stated in the following lines.

- Related to those indices more related with a thermic component, Positive Annual Temperature (Tp), Temperature of the hottest month of the year (T_{max}), Temperature of the coldest month of the year (T_{min}) and Simple continentality index (Ic) positive trends are found, +3.6 units/year, +0.04 ºC/year, +0.03 ºC/year and +0.04 units/year respectively. Both thermicity index (It) and compensated thermicity index (Itc) show positive trends in the centre and South of the State up to 1.5 units/year.

The indices studied related to the ombric component such as Positive precipitation (Pp) and Ombrothermic indices (Io, Ios_1, Ios_2, Ios_3, Ios_4) marked negative trends are shown in the South and centre of California particularly in places like Auburn, Lake Tahoe and Placerville from -3 mm/year, to -0.028 units/year, -0.02 units/year, -0.025 units/year, -0.03 units/year, respectively.

Finally, authors consider that these outcomes provide awareness for future research related to the use of bioclimatic indices as indicators of vegetation development in regional studies. In this way, the possible evolution of the vegetation within the context of climate change can be known and managers and politicians are helped to make decisions regarding the care of the environment.

REFERENCES.

Abatzoglou, J. T., Dobrowski, S. Z., Parks, S. A., & Hegewisch, K. C. (2018). TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015. Scientific Data, 5. https://doi.org/10.1038/sdata.2017.191

Abatzoglou, J. T., & Williams, A. P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences, 113(42), 11770–11775. https://doi.org/10.1073/PNAS.1607171113

Ahmad, I., Tang, D., Wang, T., Wang, M., & Wagan, B. (2015). Precipitation Trends over Time Using Mann-Kendall and Spearman's rho Tests in Swat River Basin, Pakistan. https://doi.org/10.1155/2015/431860

Blöschl, G., Hall, J., Viglione, A., Perdigão, R. A. P., Parajka, J., Merz, B., Lun, D., Arheimer, B., Aronica, G. T., Bilibashi, A., Boháč, M., Bonacci, O., Borga, M., Čanjevac, I., Castellarin, A., Chirico, G. B., Claps, P., Frolova, N., Ganora, D., … Živković, N. (2019). Changing climate both increases and decreases European river floods. Nature 2019 573:7772, 573(7772), 108–111. https://doi.org/10.1038/s41586-019-1495-6

Burakowski, E. A., Wake, C. P., Braswell, B., Brown, D. P., Burakowski, C.: Wake, C. P., Braswell, B., & Brown, D. P. (2008). Trends in wintertime climate in the northeastern United States: 1965–2005. Journal of Geophysical Research: Atmospheres, 113(D20), 20114. https://doi.org/10.1029/2008JD009870

Canu, S., Rosati, L., Fiori, M., Motroni, A., Filigheddu, R., & Farris, E. (2015). Bioclimate map of Sardinia (Italy). Journal of Maps, 11(5), 711–718. https://doi.org/10.1080/17445647.2014.988187/SUPPL_FILE/TJOM_A_988187_SM2357.PDF

Center, W. R. C. (2000). Western regional climate center. Tuweep, Arizona Station Report, Reno, Nevada, USA.

del Río, S., Álvarez-Esteban, R., Alonso-Redondo, R., Hidalgo, C., & Penas, Á. (2021). A new integrated methodology for characterizing and assessing suitable areas for viticulture: A case study in Northwest Spain. European Journal of Agronomy, 131, 126391. https://doi.org/10.1016/J.EJA.2021.126391

Díaz-Padilla, G., Sánchez-Cohen, I., Guajardo-Panes, R. A., del Ángel-Pérez, A. L., Ruíz-Corral, A., Medina-García, G., & Ibarra-Castillo, D. (2011). Mapeo del Índice de Aridez y su Distribución Poblacional en México. Revista Chapingo Serie Ciencias Forestales y Del Ambiente, XVII(Especial), 267–275. https://doi.org/10.5154/r.rchscfa.2010.09.069

Environmental Systems Research Institute (ESRI). (2019). ARCGIS (10.7).

Gocic, M., & Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Global and Planetary Change, 100, 172–182. https://doi.org/10.1016/j.gloplacha.2012.10.014

González-Pérez A, Álvarez-Esteban R, Penas Á, del Río S. Analysis of Recent Mean Temperature Trends and Relationships with Teleconnection Patterns in California (U.S.). Applied Sciences. 2022; 12(12):5831. https://doi.org/10.3390/app12125831

Gopar-Merino, L. F., Velazquez, A., & de Azcarate, J. G. (2015). Bioclimatic mapping as a new method to assess effects of climatic change. Ecosphere, 6(1). https://doi.org/10.1890/ES14-00138.1

Guan, B., Molotch, N. P., Waliser, D. E., Fetzer, E. J., & Neiman, P. J. (2013). The 2010/2011 snow season in California's Sierra Nevada: Role of atmospheric rivers and modes of large-scale variability. Water Resources Research, 49(10). https://doi.org/10.1002/wrcr.20537

Hantson, S., Huxman, T. E., Kimball, S., Randerson, J. T., & Goulden, M. L. (2021). Warming as a Driver of Vegetation Loss in the Sonoran Desert of California. Journal of Geophysical Research: Biogeosciences, 126(6), e2020JG005942. https://doi.org/10.1029/2020JG005942

He, M., & Gautam, M. (2016a). Variability and Trends in Precipitation, Temperature and Drought Indices in the State of California. Hydrology. https://doi.org/10.3390/hydrology3020014

He, M., & Gautam, M. (2016b). Variability and Trends in Precipitation, Temperature and Drought Indices in the State of California. Hydrology. https://doi.org/10.3390/hydrology3020014

Johnstone, J. A., & Dawson, T. E. (2010). Climatic context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences of the United States of America, 107(10), 4533–4538. https://doi.org/10.1073/pnas.0915062107

Karmeshu, N. (2015). Trend Detection in Annual Temperature & Precipitation using the Mann Kendall Test – A Case Study to Assess Climate Change on Select States in the Northeastern United States. University of Pennsylvania.

Kerr, A., Dialesandro, J., Steenwerth, K., Lopez-Brody, N., & Elias, E. (2018). Vulnerability of California specialty crops to projected mid-century temperature changes. Climatic Change, 148(3), 419–436. https://doi.org/10.1007/S10584-017-2011-3/FIGURES/4

Krakauer, N. Y. (2012). Estimating climate trends: Application to united states plant hardiness zones. Advances in Meteorology, 2012. https://doi.org/10.1155/2012/404876

Krivoruchko, K. (2012). Empirical Bayesian Kriging. ESRI Press, Fall 2012, 6–10. http://www.esri.com/NEWS/ARCUSER/1012/files/ebk.pdf
Kukal, M., & Irmak, S. (2016). Long-term patterns of air temperatures, daily temperature range, precipitation, grass-reference evapotranspiration and aridity index in the USA Great Plains: Part I. Spatial trends. Journal of Hydrology. https://doi.org/10.1016/j.jhydrol.2016.06.006
Liu, H., Jin, Y., Roche, L. M., O'Geen, A. T., & Dahlgren, R. A. (2021). Understanding spatial variability of forage production in California grasslands: Delineating climate, topography and soil controls. Environmental Research Letters, 16(1). https://doi.org/10.1088/1748-9326/abc64d
Liu, Q. (2016). Interlinking climate change with water-energy-food nexus and related ecosystem processes in California case studies. Ecological Processes, 5(1), 1–14. https://doi.org/10.1186/S13717-016-0058-0/TABLES/4
Liu, Q., Shepherd, B., & Li, C. (2020). Presiduals: An R package for residual analysis using probability-scale residuals. Journal of Statistical Software, 94(12), 1–27. https://doi.org/10.18637/jss.v094.i12
Mann, M. E., & Gleick, P. H. (2015). Climate change and California drought in the 21st century. In Proceedings of the National Academy of Sciences of the United States of America (Vol. 112, Issue 13). https://doi.org/10.1073/pnas.1503667112
Marchi, M., Chiavetta, U., Castaldi, C., & Ducci, F. (2017). Does complex always mean powerful? A comparison of eight methods for interpolation of climatic data in Mediterranean area. Italian Journal of Agrometeorology, 2017(1). https://doi.org/10.19199/2017.1.2038-5625.059
Miller, J. D., Skinner, C. N., Safford, H. D., Knapp, E. E., & Ramirez, C. M. (2012). Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications, 22(1), 184–203. https://doi.org/10.1890/10-2108.1
Pathak, T., Maskey, M., Dahlberg, J., Kearns, F., Bali, K., & Zaccaria, D. (2018). Climate Change Trends and Impacts on California Agriculture: A Detailed Review. Agronomy. https://doi.org/10.3390/agronomy8030025
Peña-Angulo, D., Gonzalez-Hidalgo, J. C., Sandonís, L., Beguería, S., Tomas-Burguera, M., López-Bustins, J. A., Lemus-Canovas, M., & Martin-Vide, J. (2021). Seasonal temperature trends on the Spanish mainland: A secular study (1916–2015). International Journal of Climatology, 41(5). https://doi.org/10.1002/joc.7006
Rivas-Martínez, S., Rivas-Sáenz, S., & Penas, Á. (2011). Worldwide bioclimatic classification system. Global Geobotany. https://doi.org/10.5616/gg110001
Sarricolea, P., Meseguer-Ruiz, Ó., Serrano-Notivoli, R., Soto, M. V., & Martin-Vide, J. (2019). Trends of daily precipitation concentration in Central-Southern Chile. Atmospheric Research, 215, 85–98. https://doi.org/10.1016/j.atmosres.2018.09.005
Song, X., Zhang, J., Zou, X., Zhang, C., AghaKouchak, A., & Kong, F. (2019). Changes in precipitation extremes in the Beijing metropolitan area during 1960–2012. Atmospheric Research. https://doi.org/10.1016/j.atmosres.2019.02.006
Thom, H. C. S. (1966). Some methods of climatological analysis: Vol. 551.5 T4.
Torregrosa, A., Taylor, M. D., Flint, L. E., & Flint, A. L. (2013). Present, Future, and Novel Bioclimates of the San Francisco, California Region. PLOS ONE, 8(3), e58450. https://doi.org/10.1371/JOURNAL.PONE.0058450
Wang, H., Schubert, S., Suarez, M., Chen, J., Hoerling, M., Kumar, A., & Pegion, P. (2009). Attribution of the Seasonality and Regionality in Climate Trends over the United States during 1950–2000. Journal of Climate, 22(10), 2571–2590. https://doi.org/10.1175/2008JCLI2359.1
Williams, A. P., Abatzoglou, J. T., Gershunov, A., Guzman-Morales, J., Bishop, D. A., Balch, J. K., & Lettenmaier, D. P. (2019). Observed Impacts of Anthropogenic Climate Change on Wildfire in California. Earth's Future, 7(8), 892–910. https://doi.org/10.1029/2019EF001210