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Visitation to national parks in California shows annual and seasonal change during extreme drought and wet years

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Abstract

This study examines the influence of drought indicators on recreational visitation patterns to National Park Service units in California (USA) from 1980 to 2019. We considered mountain, arid, and coastal park types across a climate gradient where seasonal recreational opportunities are directly or indirectly dependent on water resources. Significant departures from the normal hydroclimate, reflected by drought or unusually wet conditions, can lead visitors to change their behavior, including recreating at a different time or place. Drought conditions can facilitate earlier seasonal access at higher elevation parks, but displace visitors in other seasons and parks. Wetter-than-average conditions can displace visitors due to snowpack or flooding, but also facilitate other activities. We found a decrease in annual visitation at popular mountain parks including Yosemite (-8.6%) and Sequoia and Kings Canyon (-8.2%) during extreme drought years due to lower-than-average attendance in peak summer and fall months. Extreme wet years also had significantly reduced annual visitation in Sequoia and Kings (-8.5%) and Lassen Volcanic (-13.9%) due to declines in spring and summer use as snowpack restricts road access. For arid parks, drought status did not have a statistically significant effect on annual visitation, although extreme drought led to less use during the hottest months of summer at Death Valley, and extreme wet conditions at Pinnacles led to less visitation throughout the year (-16.6%), possibly from impacts to infrastructure associated with flooding. For coastal park units, extreme drought led to year-round higher levels of use at Redwood (+27.7%), which is typically wet, and less year-round use at Channel Islands (-23.6%), which is relatively dry, while extreme wet years led to higher levels of annual use at Channel Islands (+29.4%). Collectively, these results indicate the effect of extreme drought or wet years on park visitation varies by park depending on geography and recreational activities offered.

1. Introduction

Outdoor recreation and visits to national parks in mid-to-high latitudes tend to be linked to seasonal variability, which differs by regional climate and geographic factors and their collective influence on touristic activities and the nature-based amenities that support them [1, 2]. Visitors often consider recent climatic conditions when selecting a destination, formulating their plans on when and where to travel for different activities from various data inputs that influence their expectations, including official channels like park websites and marketing materials, as well as through social media [3, 4]. Additionally, weather remains one of the most consumed topics in the media by winter recreationists, largely sourced through the Internet or mobile devices [5]. Tourists plan their trips around forecasts of local and regional weather, and sometimes adjust their trip timing, trip length, or activities based on the weather [6]. Similarly, those with a greater sense of place attachment, who are generally more familiar with an area, are more willing to tolerate inclement weather at a park or seek a nearby comparable alternative [7]. Studies tend to focus on a comparison between past visitation levels and a set of climatic variables, including temperature and temperature-based indices [8–11]. We expand on this knowledge by focusing on the role that drought–which reflects sustained departures from hydroclimatic averages–plays in the volume and timing of use levels across three types of parks spanning climate gradients in California: mountain, arid, and coastal (Fig 1).

1.1 Climate and recreation

Drought is a complex phenomenon that has assumed numerous definitions and indicators [12], but is most parsimoniously described by Redmond [13] as insufficient water to meet needs. Drought is most often associated with shortfalls in water supply with precipitation and snowpack, but research has highlighted the increasingly important role of the demand side of the water balance on drought [14]. The demand side has become increasingly important particularly in recent decades, with increased evaporative demand associated with a warming climate [15]. California and the broader southwestern United States are prone to significant interannual variability in precipitation, with many ecosystems therefore considered drought adapted. Nonetheless, since 2000, much of the region is in the most extreme drought in the past thousand years [16], including the most extreme multi-year drought in California (2012–2015) [17]. These droughts have resulted in numerous effects, including contributing to widespread drought-induced tree mortality and historic wildfire seasons. Numerous studies have highlighted the role that anthropogenic climate change has had on current droughts in the region (e.g., [18, 19]) and are projected to have in the coming decades [20].

Studies generally agree that warmer temperatures expand the seasonal range for warm-weather recreation opportunities in cooler climates; increase demand for water-based recreation, particularly on hot days; and shorten the season and geographic extent of areas that support snow-based recreation [21–23]. However, days with extreme heat tend to be less tolerable and usually lead to a decrease in visitation and shift in visitation timing [8, 24, 25] with maximum daily temperature being most impactful to recreationists in the afternoon [2, 26]. Previous studies also have found that daily or monthly precipitation affects patterns of visitation, with visitation generally declining with more precipitation [27, 28]. Although visitation is reduced on days with precipitation, many outdoor recreation activities are directly or indirectly water dependent (e.g., boating, fishing, wildlife viewing).

Distinct from the direct role that daily temperatures and precipitation play on park visitation, protracted departures in hydroclimatic conditions, as realized through drought, can also affect outdoor recreation in variable ways by season and activity and may cause visitors to mitigate or adapt their recreation in response [29–31]. Drought causes direct effects, including

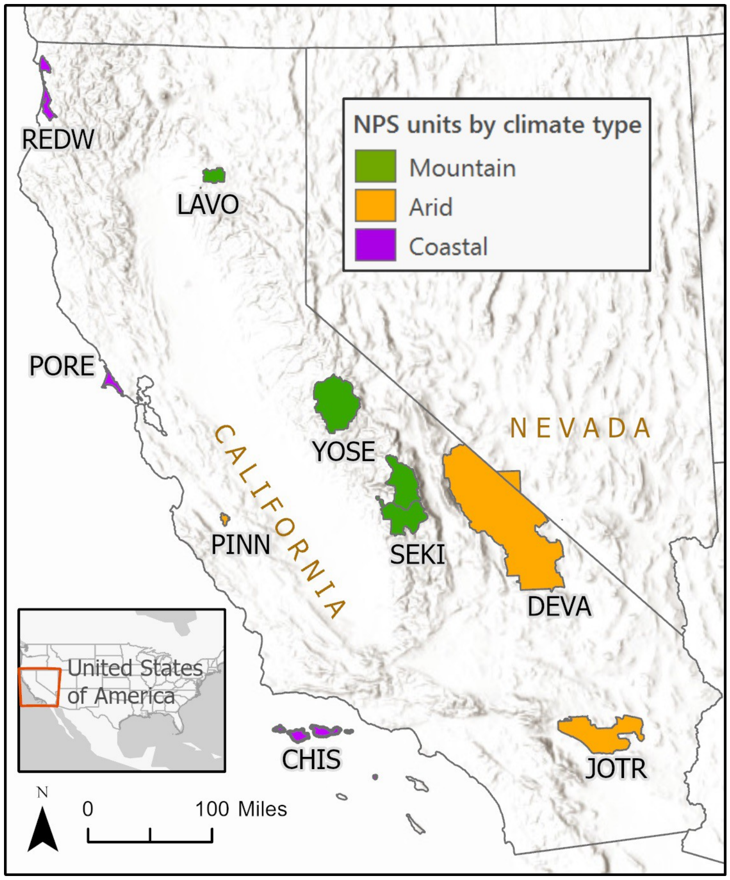

Fig 1. Locations of selected National Park Service (NPS) units in the State of California include mountain, arid, and coastal climate types (from top, clockwise): Redwood National Park (REDW), Lassen Volcanic National Park (LAVO), Yosemite National Park (YOSE), Sequoia & Kings Canyon National Parks (SEKI), Death Valley National Park (DEVA), Joshua Tree National Park (JOTR), Channel Islands National Park (CHIS), Pinnacles National Park (PINN), and Point Reyes National Seashore (PORE). Base layers source: Esri. "Light Gray Canvas Base" [vector]. Scale Not Given. "World_Basemap_v2". Oct 26, 2017. https://www.arcgis.com/home/item.html?id=291da5eab3a0412593b66d384379f89f. (August 4, 2022).

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reduced snowpack, earlier peak runoff, and lower streamflow, lake, and reservoir levels–all of which can alter the availability of outdoor recreation activities [32–34]. Winter drought can reduce opportunities for snow-based activities, such as cross-country skiing and snowshoeing, but less snowpack also affects streamflow and lake levels into the spring and summer, all of which affect outdoor recreation [35]. For instance, shifting peak runoff and reduced streamflow impact the timing and quality of fishing [36], and lower reservoir levels can reduce visitation numbers [37]. At both Glen Canyon and Lake Mead National Recreation Areas, for example, research has clarified the links among drought, lower lake water levels, fewer access points for lake-based recreation, decreases in day and overnight visitation numbers, and less tourism contribution to the local economy [38]. Drought conditions can also affect the number of people who participate in river-based recreation, such as rafting [39]. Recreationists participating in water-based activities such as rafting, boating, or fishing generally prefer moderate streamflow and lake levels, with exceptionally low water levels often reducing access or enjoyment, and exceptionally high water levels potentially making activities dangerous [35]. Drought may also affect the timing or prevalence of scenic resources in parks where visitation is dependent on seasonal water availability and runoff [40, 41]. Quality waterfall viewing, for example, depends on a combination of snowpack and spring melt timing. Though some recreationists will continue to engage in water-dependent activities regardless of the water conditions, others will be displaced spatially to an area of more resource abundance, temporally to a different time period when the resource may be more bountiful, topically to a different activity not requiring such resources, or totally displaced [7, 42, 43].

Drought also indirectly affects outdoor recreation by impacting the vegetation, wildlife habitats, and scenic resources, and the likelihood of disturbances (e.g., wildfire) that may result in restrictions in certain activities, impacts to infrastructure, park closures, or degraded air quality [32, 33, 44–46]. For instance, earlier snowmelt associated with relatively warmer temperatures can often cooccur with drought conditions to affect the timing of wildflower blooms in parks and associated visitor levels [47], sometimes causing blooms before the peak visitation season begins, and conferring potential for an earlier ending to the peak growth season, especially if drought conditions persist. Recreationists expecting blooms at a certain time may not have the quality experience they were expecting during their visit. For those able to visit at an earlier time, these visits in quantity can stress managerial resources (e.g., staffing capacity) that are not prepared for high levels of early season visitation. High rates of tree mortality are also correlated with prolonged periods of drought [48], especially in the context of historically fire-suppressed and overly dense forest landscapes that are already vulnerable to insects and disease [49]. The collective effects to scenery from ecological disturbance have been shown to interfere with visitor experience and influence intended displacement [50].

It is important to assess how visitation to U.S. national parks responds to drought conditions across a hydroclimatic continuum, given the breadth of drought's impacts to landscapes and the recreational activities that rely on these places. The need for such multi-scalar information–on parks across a region and across multiple time periods–has been emphasized as a need for visitor use management research [42, 51]. The pressing issue of climate change, and its manifestation of drought conditions across California, provide an urgent and meaningful context to synthesize such information. In this study, we examine relationships between drought and visitation dynamics across three types of national parks in California that span diverse climates within the state. We specifically seek to understand how drought inhibits or enables access for recreational use seasonally. Relative differences in seasonal visitation by drought or wet year category allow us to anticipate future shifts in level and timing of recreational use, to assess the impact these changes may have on demand and access to water or snow-dependent activities, and to propose and coordinate adaptation strategies suited to the needs and context of each park.

1.2 Climate and California parks

California and its diverse parks exemplify a number of climatic conditions that influence visitation seasons, including mountain, arid, and coastal types (Fig 2). For mountain parks, visitation typically increases in the spring towards the peak summer months, when temperatures are most ideal and precipitation is limited. Heavy snowfall and icy roads may limit vehicle access to mountain areas during the peak of winter, and snowpack can limit access to many trails and popular sites well into the spring [52]. Temperatures are routinely coldest in the winter, but in mountain parks, cold temperatures beyond what is comfortable for the average park visitor can persist into the late spring. Likewise, visitation to coastal locations peaks in the late summer months as precipitation decreases and temperature increases, while visitation is lowest when the conditions are typically the wettest from late fall to early spring. An inverse visitation pattern typifies arid locations. Peak visitation in these arid parks generally occurs in the late winter and early spring months, typically declines with the onset of summer's high

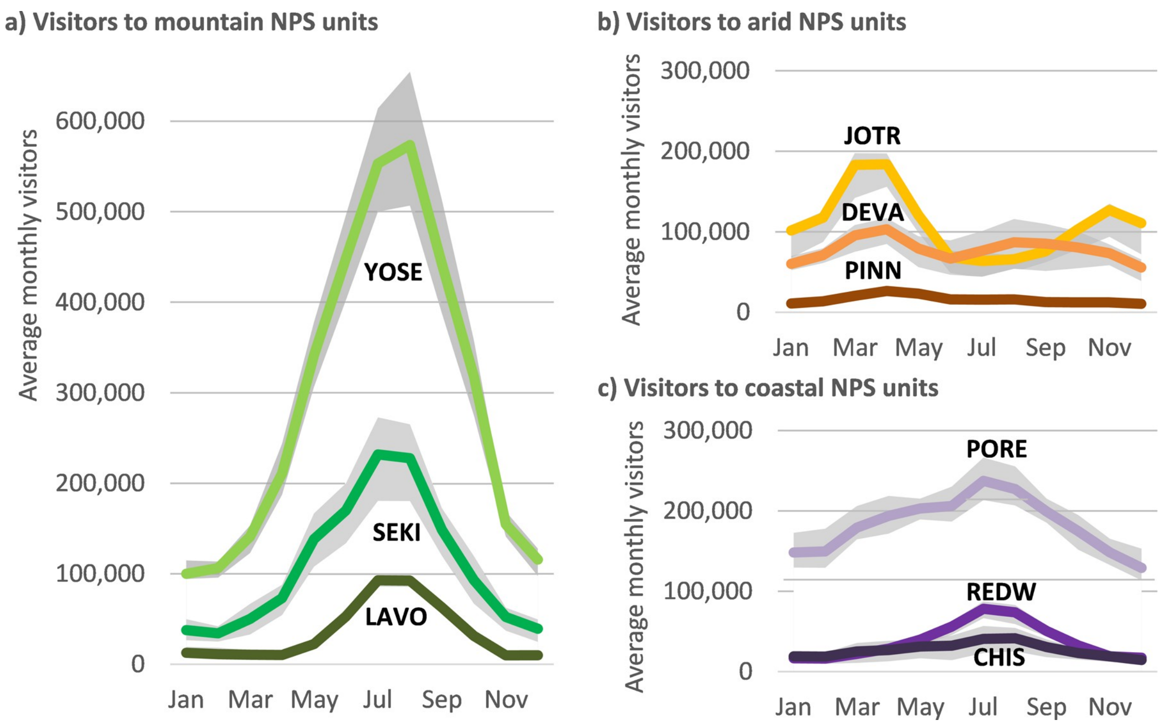

Fig 2. Mean visitation and 50% variance (+/-25% of raw visitation data closest to the mean, 1980–2019) for each National Park Service (NPS) unit in California by seasonal climate type: a) mountain, b) arid, and c) coastal. Note: Lassen Volcanic and Pinnacles both have a window of variance that is too narrow to be visible. Visitor data source: Integrated Resource Management Applications (IRMA), National Park Service, 2022.

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temperatures, and increases in a second, smaller peak in fall before declining with the onset of cold winter temperatures. We do not apply monthly start and end dates for visitation seasons, as these vary by unit type and are specific to the infrastructural, climatic, and administrative access considerations of each. Moreover, we avoid *a priori* assumptions of normalcy that could influence the interpretation of our results given the hydroclimatic variability from one year to the next. Park managers in California realize that while there may be average conditions over time (e.g., snowpack, precipitation), there are no normal years [33]. Rather, we demonstrate how hydroclimatic variability leads to different trends in the timing and number of visitors between wetter or drier years.

2. Methods

2.1 Park visitation

We assess the impact of drought conditions on the demand for recreational park visitation across a total of nine units administered by the National Park Service (NPS) from 1980–2019. To do so, we collected monthly park visitation data from the NPS Integrated Resource Management Applications [53] portal for eight national parks (two of which are jointly administered–Sequoia and Kings Canyon National Parks and Redwood National and State Parks) and one national seashore in California. This study focuses on park units that each have a large land area, a variety of day and overnight outdoor recreational opportunities, and recreational access through entrances and trailheads where vehicle and trail counters are routinely deployed to measure use. NPS units with narrow seasonal access windows (e.g., Devils Postpile National Monument), day use reservation limits (e.g., Muir Woods National Monument), and/or bisected by highways with thru traffic (e.g., Whiskeytown National Recreation Area) were excluded from the study because estimates of use at these locations are likely not a true reflection of seasonal demand.

Together, the selected NPS units are broadly representative of the geographic and climatic diversity of the State of California. For this study, mountain units include Yosemite National Park, Sequoia and Kings Canyon National Parks, and Lassen Volcanic National Park. Arid units include Joshua Tree National Park, Death Valley National Park, and Pinnacles National Park. Coastal units include Point Reyes National Seashore, Redwood National and State Parks, and Channel Islands National Park. These nine NPS units in three climatic regions constitute a diversity of total annual use, peak visitation seasons, and water-dependent recreational activities offered (Table 1). Other studies (e.g., [42]) have also grouped diverse protected areas by geographic criteria to assess climate impacts to recreation.

2.2 Park drought

We examined several potential measures of drought given the diversity of existing metrics and definitions. Within these, we focused on metrics directly calculated from climate variables rather than relying on hydrologic data or remotely sensed data that can be influenced by management and land-use factors. Drought remains challenging to quantify given the varied influences of precipitation amount, phase, timing, and evaporative demand as well as the varied means through which these climatic factors influence resources [12]. There are numerous drought indicators including those that focus exclusively on precipitation (SPI, standardized precipitation index), exclusively on evapotranspiration (EDDI, evaporative drought demand index), and metrics that combine supply and demand (SPEI, standardized precipitation-evapotranspiration index and PDSI, Palmer Drought Severity Index). Some of these metrics (e.g., SPI/SPEI) are multi-scalar in that they require identification of an appropriate duration (e.g., 1-month, 10-month), which adds both flexibility but also complexity in drought monitoring efforts.

We constrained the bulk of our analysis to summer (June-August) Palmer Drought Severity Index (PDSI), given its widespread usage in the drought literature, ability to incorporate both supply and demand aspects of drought, lack of multi-scalar nature that lends to ease in use, and its operational use in drought monitoring for longer duration droughts. The PDSI is a standardized index based on water balance models of supply and demand that represents the severity of

Table 1. National Park Service (NPS) units by climatic type, average annual visitors, and freshwater-dependent activities. Visitor data were collected from the Integrated Resource Management Applications interface (National Park Service 2022) and water-dependent recreational activities were synthesized from each park's official website.

	NPS unit	Average annual visitors, 1980–2019 (+/-25% variance)	Peak Visitation Season	Freshwater-dependent recreational activities offered
Mountain	Yosemite	3,505,943 (3,118,275–3,936,664)	Summer	• Directly water-based: Boating/rafting, swimming, fishing, waterfall viewing • Indirectly water-dependent: Wildflower viewing, wildlife viewing • Snow-based: Cross-country skiing, downhill skiing (Yosemite), snowshoeing, snow camping, and front country snow play.
	Sequoia & Kings Canyon	1,296,385 (990,268–1,555,080)		
	Lassen Volcanic	419,222 (358,727–475,928)		
Arid	Joshua Tree	1,320,996 (999,032–1,416,262)	Spring	• Directly water-based: None • Indirectly water-dependent: Wildflower viewing, wildlife viewing • Snow-based: None
	Death Valley	934,184 (677,634–1,135,322)		
	Pinnacles	189,913 (159,327–211,026)		
Coastal	Point Reyes	2,196,013 (1,973,738–2,471,441)	Summer	• Directly water-based: River rafting, waterfall viewing, freshwater fishing • Indirectly water-dependent: Wildflower viewing, wildlife viewing and birding at lagoons and marshes • Snow-based: None
	Redwood	450,226 (373,571–508,700)		
	Channel Islands	321,998 (180,030–422,625)		

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departure from normal soil moisture conditions. Negative values indicate dry conditions and positive values represent wet conditions. Furthermore, many recent analyses of drought in California have focused on summer PDSI as a proxy for capturing overall annual drought intensity in California, as PDSI contains both information about precipitation supply over the previous 9–12 months (encapsulating the wet season) while also incorporating evaporative demand during the warm season [19, 54]. PDSI for each NPS unit was obtained from gridded climate data calculated from gridMET [55] on a 4-km horizontal resolution grid. Drought indices available at the native 4-km horizontal grid were averaged across all pixels within the boundary of each NPS unit. We further decomposed years into drought classes grouped by standard PDSI classification categories as follows: (i) extreme drought: PDSI $\leq$ -3, (ii) moderate drought: -3 $<$ PDSI $\leq$ -1, (iii) normal: -1 $<$ PDSI $<$ 1, (iv) moderate wet: 1 $\leq$ PDSI $<$ 3, and (v) extreme wet: PDSI $\geq$ 3. We use a composite analysis of monthly park visitation among the five drought categories to identify differences that reflect the resource conditions and managerial decisions across the geographies and structures of these nine park units.

To complement our primary analyses of drought using summer PDSI, we additionally considered other drought metrics. The metrics considered include snow water equivalent and soil moisture in the top 200-m of the soil column as simulated by the Variable Infiltration Capacity Model [56], as well as shorter-term drought indices realized through the 3-month SPI, 3-month SPEI, and 3-month EDDI from gridMET. The supplemental analysis considered contemporaneous relationships between metrics averaged over a 3-month period and visitation totals over the same 3-month period. While an exhaustive review of the relationships among all potential drought indicators and park visitation is beyond the scope of this project, drought-visitation relationships among the national park units viewed through the lens of these shorter-lived drought indicators may provide insight into seasonal influences of drought on visitation.

2.3 Park visitation and drought

Prior to analysis of visitation data by PDSI, monthly use levels were detrended to account for the incremental growth in visitation across the national park system over the four decades of available data analyzed here (1980–2019). Visitation to national parks has been steadily growing over the tenure of the NPS, albeit with intermittent recessionary periods, and may be driven by a variety of factors, including marketing campaigns, low gas prices, rising international visitation, favorable weather patterns, and new recreational preferences [57, 58]. Though tempered by recent global events limiting international visitors (e.g., the COVID-19 pandemic) and with increases in gas prices, high levels of visitation are likely to remain [59]. This continued demand presents challenges for visitor use management when visitation levels already exceed the resource budget and conditions of use for which they were designed [58].

Detrended monthly park visitation data was calculated using a three-step process. First, we calculated the proportion of annual visitation that took place in each month, for all months and years in this study. Second we calculated a detrended annual time series by removing the linear least-squares fit of annual visitation totals during 1980–2019 and adding back in the 2000–2019 annual mean value. Finally, to reconstruct monthly detrended data we took the detrended annual time series and multiplied it by the original monthly proportion. Detrending attempts to remove longer-term drivers of park visitation that have not been associated with climatic factors–for example the increase in park visitation nationally. After detrending visitation estimates for each park, monthly visitation numbers were averaged for years based on the five drought categories during 1980–2019 (see S1 Table for dataset underlying Figs 2–5). We examine both monthly visitation totals and percent departure from average monthly visitation totals. To complement the seasonal differences by drought category, we additionally examined departures from average annual visitation totals for each park. We used Student's t-tests to evaluate whether average visitation for a given drought category was significantly different ($p < 0.05$) than all other years.

Finally, a supplemental correlation analysis between the more comprehensive set of drought metrics (PDSI, EDDI, SPI, SPEI, soil moisture, and snow water equivalent) and seasonal visitation was performed to contextualize the primary analysis using summer PDSI. This supplemental analysis examined Pearson's correlations between detrended seasonal visitation and seasonal drought indices during 1980–2019 (see S2 Table for dataset underlying Fig 6). We used 3-month climatological seasons of winter (December-February), spring (March-May), summer (June-August), and fall (September-November). Correlations were deemed significant based on p-values < 0.05.

3. Results

The average annual visitation for the different drought categories are summarized for each park in Fig 3. Results indicate that annual visitation decreased for some of the mountain parks (Yosemite: -8.6%, Sequoia and Kings: -8.2%) during extreme drought years, although these declines are not statistically significant. Extreme wet years resulted in significantly lower-than-average annual visitors in mountain parks (Sequoia and Kings: -8.5%, Lassen Volcanic: -13.9%), particularly during springtime and peak summer months when snowpack typically restricts road access. There were not statistically significant differences in annual visitation at any of the arid parks based on drought status, but there were some differences by month. For instance, Pinnacles experiences a decline in March and December visitation in extreme wet years, but a decline in January visitation in extreme drought years. At coastal park units, extreme drought led to significantly higher levels of annual visitation at Redwood (+27.7%), which is typically wet, and less annual visitation at Channel Islands (-23.6%), which is typically dry. Years that were extremely wet resulted in significantly higher annual visitation at Channel Islands (+29.4).

3.1 Mountain parks

Visitation to mountain parks is seasonally dependent because snowpack restricts access to higher elevations during the winter months, typically November through April. The peak months of visitation are June, July, and August, when higher elevations are accessible (Fig 4). The timing of plowing and access to higher elevation roads that are closed due to snowpack in the winter is typically earlier in extreme drought years (late-April to mid-May) and later in extreme wet years (late-May to late-June or in some cases July).

Visitation to mountain parks shows relative differences between extreme drought and wet years that vary by the magnitude of overall average monthly visitors, with the more visited parks (i.e., Yosemite and Sequoia and Kings Canyon) having less variability from month-to-month (Figs 5 and 6). While Yosemite National Park and Sequoia and Kings Canyon have more average visitation during extreme years, there are still seasonal differences. Sequoia and Kings Canyon see a significant decline in visitation during extreme wet years during the entire spring (March–May), while Yosemite only sees a significant decline in May during extreme wet years. Lassen Volcanic also sees a significant decline in visitation in late spring and early summer (May–July) during extreme wet years. Lassen Volcanic incurs the bulk of the difference in visitation levels during spring and early summer months due to annual variability in snowpack and timing of spring snowmelt that dictates seasonal closures and openings of the

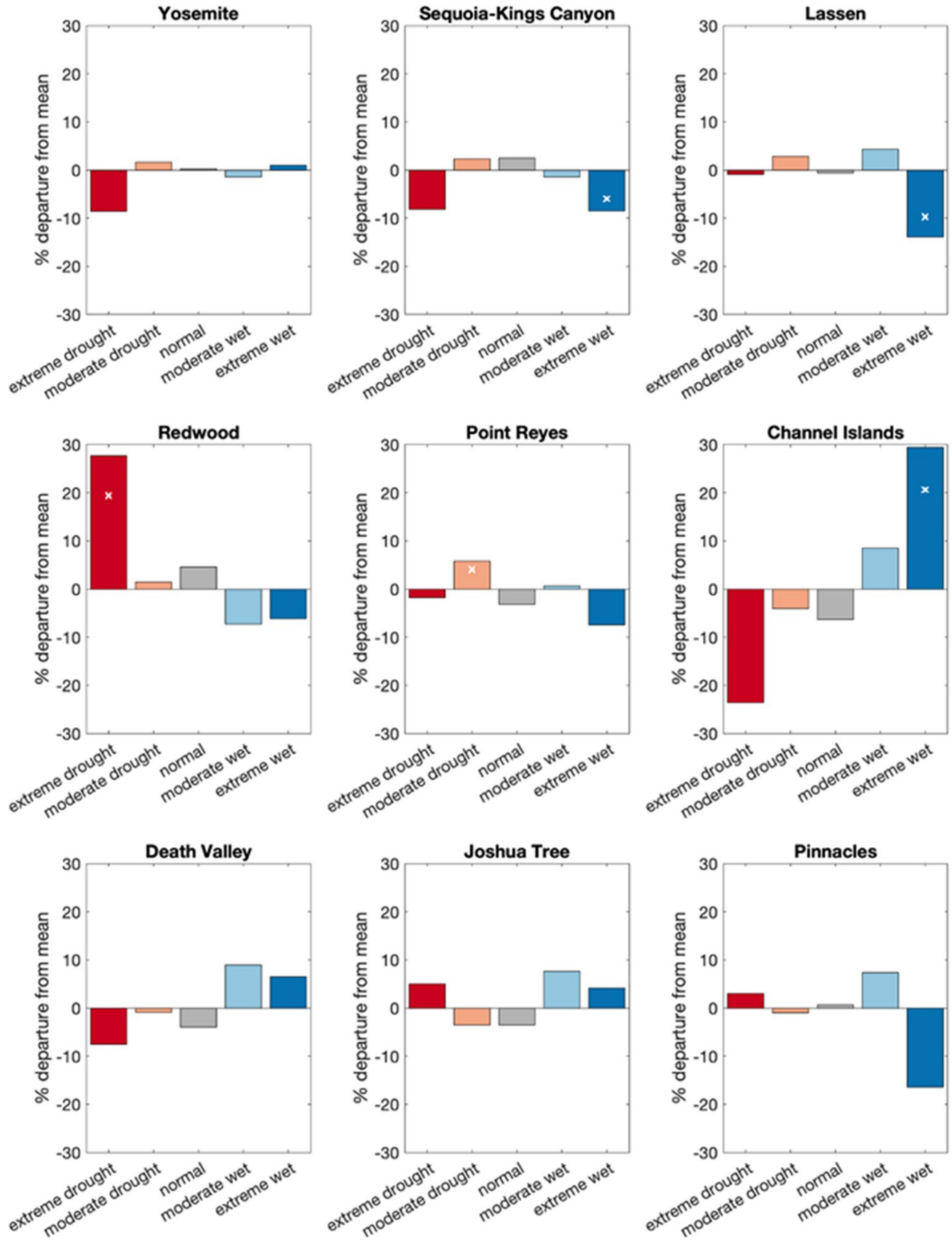

Fig 3. Departures in annual visitation totals for the nine different National Park Service (NPS) units by drought status reflected by summer Palmer Drought Severity Index (PDSI) during 1980–2019. Statistically significant ($p < 0.05$) differences are denoted by white x symbols.

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higher elevation thoroughfare that connects the entrances. The effects of extreme drought were not statistically significant in any month for mountain parks.

Similarly, additional analyses show significant negative linear correlations between spring visitation at these mountain parks and spring drought indices including PDSI as well as spring SPI, SPEI, EDDI, and snow water equivalent (Fig 6). It is likely that for Yosemite and Sequoia and Kings Canyon the effect of drought or wet conditions may be mediated by the large number of international and domestic visitors that require booking travel and lodging well in

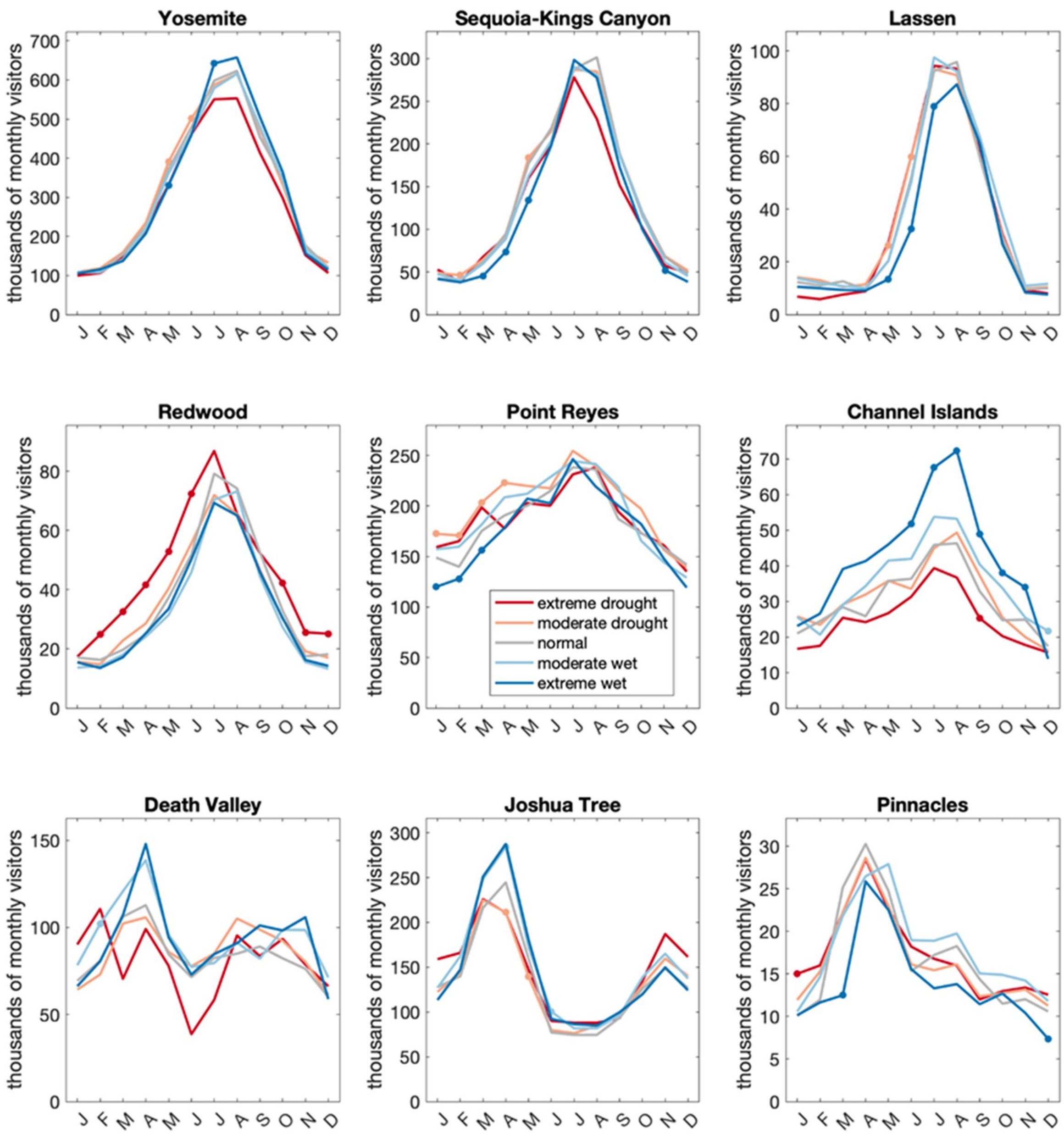

Fig 4. Average monthly visitation by drought category at nine National Park Service (NPS) units in California. Months where average visitation was significantly ($p < 0.05$) different for a given drought category than all other years are denoted by a colored dot.

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advance, which limits the flexibility visitors have to adjust their travel plans. The bulk of international visitors tend to make plans to visit during peak and late summer when road tends to be more reliably open, therefore springtime visitation to these parks may be more responsive to drought status given greater flexibility in planning for more localized visitors.

3.2 Arid parks

Visitation to arid parks reaches a peak in the spring months of March, April, and May when temperatures are most suitable between the cold winter months and hot and dry summer months (Fig 4). Additionally, springtime in the desert is when wildflowers are most abundant,

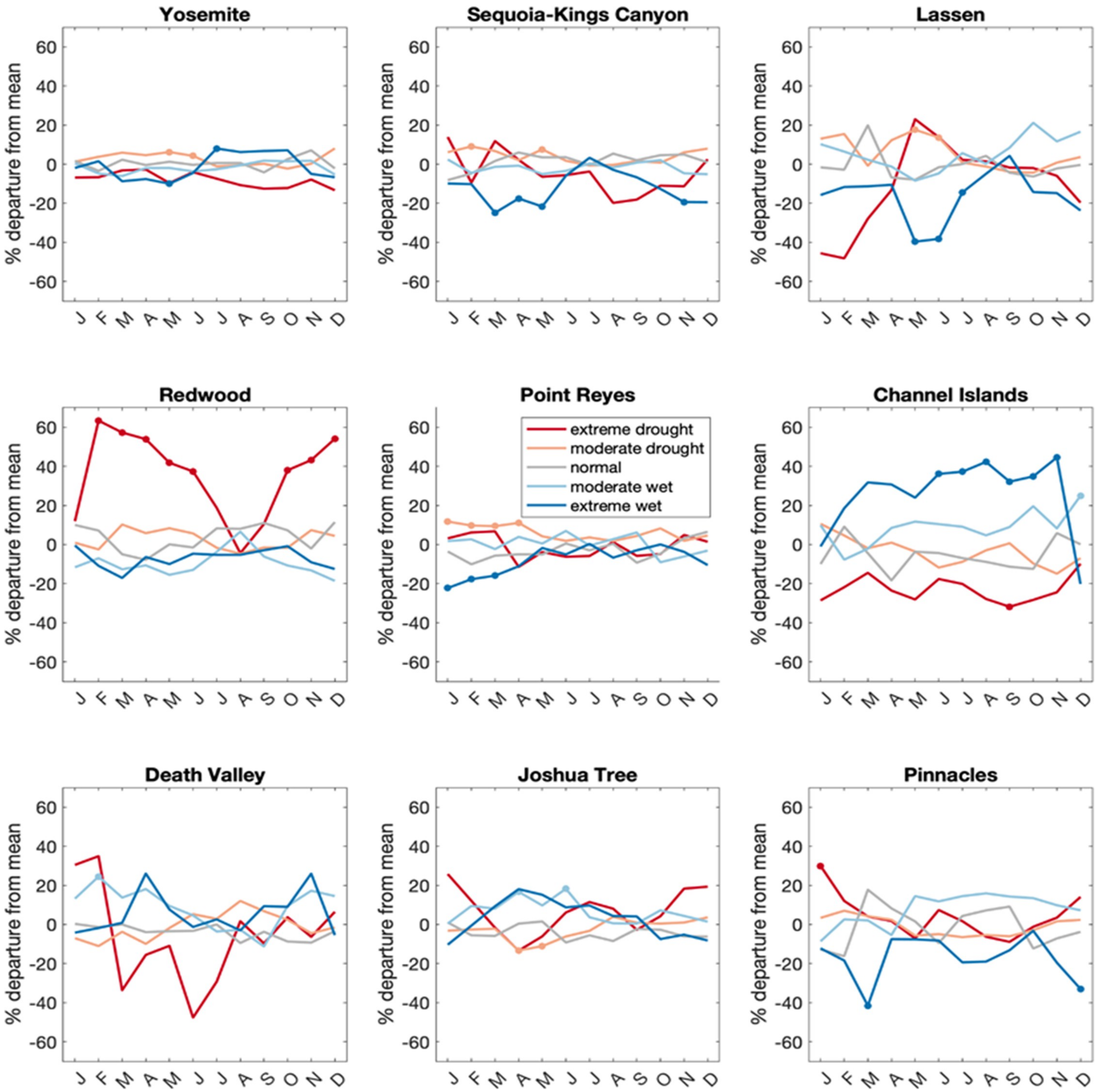

Fig 5. Average monthly visitation expressed as a departure from 1980–2019 average by drought category at nine National Park Service (NPS) units in California. Months where average visitation was significantly ($p< 0.05$) different for a given drought category than all other years are denoted by a colored dot.

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and animals are most visible. These parks have a secondary, minor peak in visitation during the late-fall at Joshua Tree National Park, and less pronounced at Death Valley and Pinnacles National Parks in late summer.

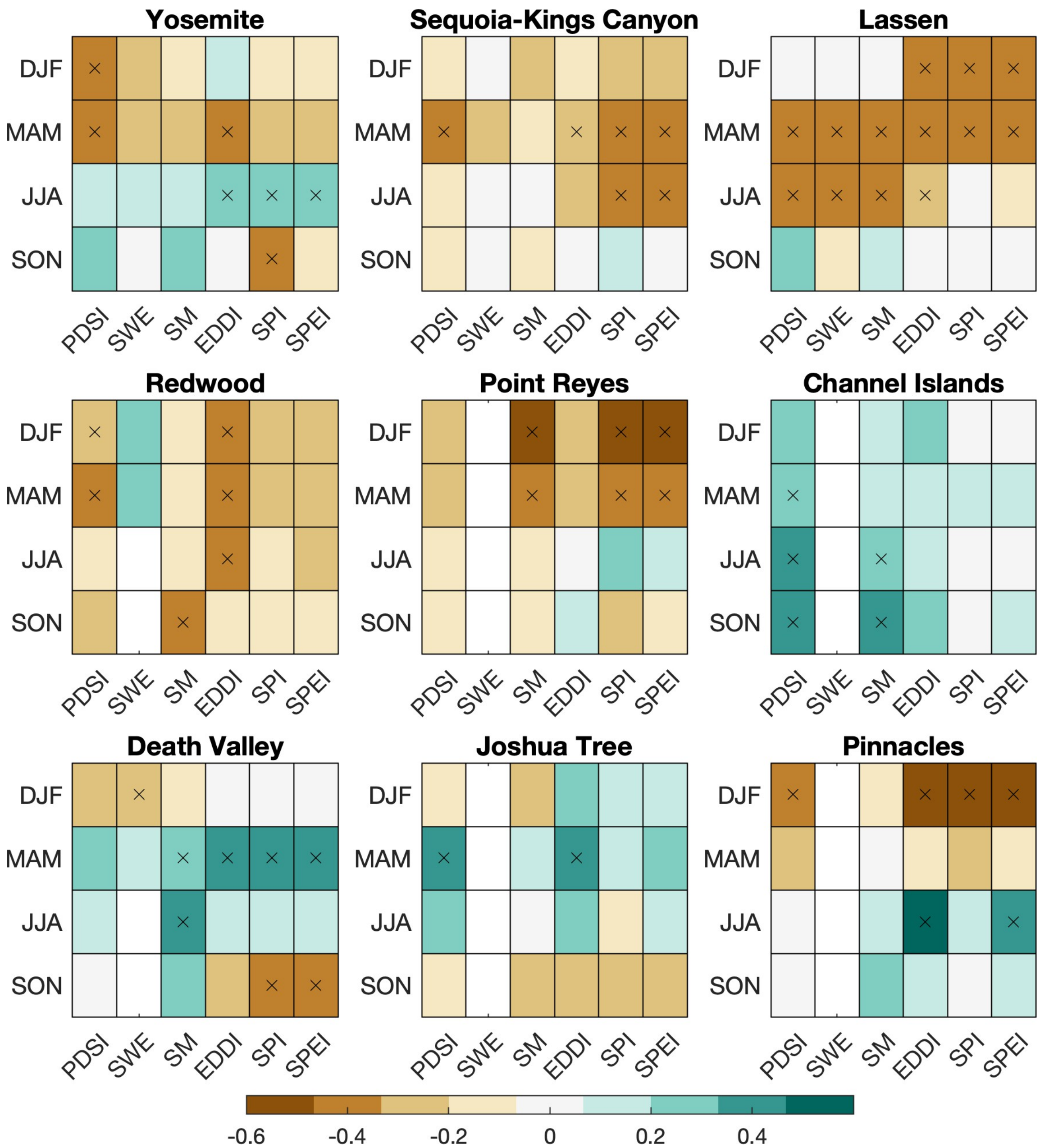

Fig 6. Matrix of Pearson's correlations between detrended seasonal park visitation and seasonal drought indicators during 1980–2019 across the nine national parks in California. The correlation considers the Palmer Drought Severity Index (PDSI), snow water equivalent (SWE), soil moisture (SM), evaporative demand drought index (EDDI), Standardized Precipitation Index (SPI), and Standardized Precipitation Evapotranspiration Index (SPEI). Correlations that are statistically significant ($p< 0.05$) are denoted by an x. For aid in visualization, the sign of the correlation for EDDI is reversed. DJF, MAM, JJA, and SON refer to combinations of months, beginning with December, January, and February, and continuing with March and so on in successive monthly order.

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At the arid parks, extreme drought decreased visitation at Death Valley in the spring and summer (although this difference is not statistically significant); conversely, extreme drought increased visitation significantly in Pinnacles in January only (Figs 5 and 6). Extreme wet years decreased visitation in Pinnacles in March and December but did not have a statistically significant impact on visitation in Death Valley or Joshua Tree. These differences may be attributable to the local context of each park. Extreme drought years in desert ecosystems generally impact the abundance and diversity of desert flora and fauna that are already narrowly adapted to scarce water resources. Further water deficit in these ecosystems can therefore impact visitation associated with wildflower and wildlife viewing. Additional analyses show a positive correlation between spring drought indices and spring visitation at Joshua Tree and Death Valley, with stronger linear correlations for shorter-term seasonal drought indices in Death Valley (Fig 6). When considering all the drought indices in Fig 6, this indicates visitation is higher in wetter springs in Death Valley and Joshua Tree. Pinnacles has negative correlations between visitation and drought status in the winter, indicating visitation declines in wet winters, possibly due to the impacts to road and trail infrastructure in its flood-prone geography.

3.3 Coastal parks

Visitation to coastal parks reaches a peak during the summer months of June, July, and August as visitors seek out cooler coastal conditions (Fig 4). The average annual visitation curve is similar to that of mountain parks, though less steep, highlighting that access continues through winter when there tends to be cool temperatures and high precipitation levels. These park units are in a climatologically wet location and experience relatively cooler summer conditions. As such, they offer respite for those living inland during extreme drought or heat conditions.

Visitation is relatively less variable overall based on drought status at Point Reyes National Seashore, reflecting consistent high levels of demand from the nearby urban population center of the San Francisco Bay Area and the associated local recreation in addition to destination tourism (Fig 5). Redwood experienced statistically significant increased visitation during extreme drought years in February–June and October–December. The increases in visitation in Redwood were substantial, for instance, over 60% in February during drought years. Visitation to Channel Islands consistently decreased in all months of extreme drought years, although this decrease was only statistically significant in September. In extreme wet years, visitation significantly decreased between January–March at Point Reyes National Seashore, but significantly increased visitation at Channel Islands between June—November. Additional analyses across other drought indices indicate that wetter years are correlated with increased visitation at Channel Islands in the spring, summer, and fall, but that wetter years are correlated with decreased visitation in the winter and spring for Redwood and Point Reyes (Fig 6). These differences could be attributable to the fact that Channel Islands is the only island park in this study, so drought may have different effects compared to Redwood and Point Reyes. Extremely dry years generally impact island flora and fauna that have adapted to water sensitive ecosystems, and which therefore exhibit strong responses to water limitation. Thus, the potential for wildflower and wildlife viewing is usually diminished in drought years on Channel Islands, and increased in wetter years, and these conditions likely affect visitors.

4. Discussion and conclusions

This research shows that the effect of extreme drought on park visitation varies by park and season, even within mountain, arid, and coastal parks in California. Previous research also found that the impact of an exceptionally dry or wet year varies by park, even among only mountain parks [60]. Previous research on the current California drought corroborates this variability, noting that droughts have the potential to affect recreational values of landscapes year-round, but in context-specific ways that acknowledge the relative differences between drought and average years [61]. Yet, even among the context-specific differences of park prestige, geography, and climate, some patterns emerged from our investigation that are useful for further research and managerial consideration. These points are even more salient as more people access the national parks and the climate continues to fluctuate in ways further deviating from the current average, toward years of more extreme drought and years of more extreme wet conditions. Our analysis depicts the climatic influence–particularly of abnormally dry or wet years–on visitation. In this regard, it builds on other studies that have examined other climatic influences on visitation, particularly warming weather, and corresponding resource changes (e.g., [24, 25]). It also directly addressed a noted lack of information between drought conditions and quantifiable tourism data [34].

Related to people's expectations of conditions and access timing, the mountain parks are moderately sensitive to drought. This may be because for iconic parks like Yosemite, Sequoia and Kings Canyon, people book their trips farther in advance (more non-local visitors) and have less flexibility with lodging that is in high demand. Non-local visitors may also simply have limited knowledge of the existence of drought or how that translates into potential conditions, instead relying on seasonal temperature or precipitation averages that become misconstrued for norms with little variability. Indeed, the translation of drought to the scale of the visitor experience (e.g., less greenery, lower water levels, heightened fire risk) may be difficult to untangle within visitors' expectations about park conditions during their visit. While the likelihood and size of wildland fires have been shown to be associated with drought [62], the potential for fire to impact park-wide access and use levels exists from year-to-year so long as the extent of the fire poses risks to road corridors and infrastructure [33]. Fire response and subsequent clean up and mitigation efforts have led to park-wide and gate closures lasting multiple days, weeks, or months at Lassen Volcanic, Yosemite, and Sequoia and Kings Canyon, as well as some coastal units. However, for the Park Service, many wildland fires are left to burn for forest resource benefit so long as they remain in wilderness. Outside closures that result from fires which threaten property and life, visitation to parks remains generally persistent during the peak season, including during times of poor and unhealthy air quality from wildfire smoke [63]. Otherwise, mountain parks and the more visited arid and coastal parks appear to be the relatively most immune to visitation fluctuations throughout the year, while parks that are typically very dry (i.e., Channel Islands, Death Valley) or susceptible to seasonal precipitation and flooding (i.e., Redwood, Pinnacles) exhibit the greatest variability between extreme drought or wet conditions, among other categories. However, while the most popular units in many cases have a relatively smaller percent change between extreme wet and dry years, the differences at these park units represent a larger overall difference of people. Parks with moderate visitation levels and not in urban areas may be affected marginally more by extreme wet or drought conditions given that these units are more remote and already difficult to access, that resource and funding allocations can be more scarce, and that a small absolute change in the number of visitors equates to a relatively large departure from average. Future research might then focus on parks such as Lassen Volcanic, Pinnacles, and Redwood to assess how extreme drought and wet years affect visitation differently as it relates to infrastructure and site access (e.g., roads, buildings, trails, lakes, rivers), which could help managers deliver specific information in their messaging to visitors.

Given these patterns in the visitation fluctuations or consistency, we highlight the importance of drought affecting not only the resource conditions but also the particular recreational conditions in the parks. The majority of visitors to Yosemite book their trips over one month in advance, and although Yosemite does offer water-based activities, most visitors do not participate in activities that are directly water-dependent [64]. The little direct involvement in water-dependent activities is likely similar today between Yosemite and Sequoia and Kings Canyon, which have nearly the same range of recreational opportunities. In contrast, at a park like Joshua Tree, visitation is in part driven by media coverage on drought/wet status given its location in a desert and capacity for people to get to the park [65], which is equidistant from two metro areas (i.e., Las Vegas and Los Angeles) and where a small, but relatively large amount of precipitation in the typically arid environment can make conditions poor for recreational opportunities in the moment but unleash a flood of planning and reservation-making for wildflower viewing other recreational activities that are popular in the park during the spring months (e.g., camping, climbing). Finally, visitation patterns for each park and type of park in our dataset emphasized that infrastructure supporting recreational activities, namely open access points and roadways, is both critical to visitation numbers and influenced by drought and wet years. In all mountain parks studied, visitation declined in the spring during extreme wet years. Extreme wet years with higher levels of snowpack and precipitation can pose hazardous conditions or limit visitation altogether, as happened in 2023 for park units in California experiencing flooding and the other effects of successive atmospheric rivers upon the State. Infrastructural solutions have included moving roadways and buildings further from flood-prone areas or removing them altogether. Administrative fixes during wet years might include the creation of a reservation system during times when water-dependent winter visitation is anticipated to be at its peak (e.g., Yosemite put a day use reservation system in place for weekends in February, 2023, when waterfall viewing peaks), thereby attempting to reduce crowding near water features and fragile riparian and meadow systems, improving visitor experience and safety, and mitigating impacts to resource amid sensitive, erodible soil conditions.

Park visitors can adapt their behavior based on drought conditions with the most common being substituting locations, activities, or the timing of their trips, but to adapt, they must be aware of the drought, its implications, and alternative options (e.g., locations or activities), as well as have the ability to change their plans [31, 66, 67]. One suggested adaptation strategy is for parks to provide updated information to visitors on the impacts of drought at different sites within the park so visitors can adapt their activities or locations, if need be [32]. The effects of drought on park resources and visitation, including affected natural features and infrastructure, should be monitored, and incorporated into ongoing climate adaptation planning efforts. Parks could also work with other land managing agencies to include information about recreational opportunities on other nearby public lands outside of the park, especially when conditions inside the park are not ideal for some activities [21]. Parks can also embrace this opportunity to interact with visitors during droughts to educate them about droughts, their causes, and implications by providing information to these stewards to enhance the quality and safety of their visits. Additionally, park managers can adapt to changing drought conditions by carefully managing lake and river access and capacity, including increasing the length of some boat ramps to still provide access when water is lower (where appropriate) [21]. All of these contextualized suggestions based on our dataset align with previous work on an interdisciplinary drought-tourism/recreation framework by Thomas et al. [34], which centers on the multi-season vulnerability of recreation to drought and the necessity for multiple arenas of measures, mitigation, adaption, and preparedness.

This was the first effort to understand how drought may impact visitation to national parks in California. Future research could work to better understand how drought fits in to the larger suite of variables that impact visitation–including temperature, precipitation, and the state of the economy. Additionally, because we analyzed visitation numbers, we cannot draw conclusions about if people were changing their intended activities, or if the overall quality of their park experiences changed during drought years. We also do not know if potential visitors were displaced and went elsewhere for a certain activity, or just did not visit parks altogether. This shows the need for future research on this topic. It is possible that only a subset of visitors are impacted by drought (e.g., those participating in water-dependent activities), but more research is needed to determine which visitors pursuing what activities are the most affected by what type of short or long-term drought or wet conditions and how exactly they respond to these conditions among parks with different climate types. This research is useful for managers in that it can inform overall park staffing levels and allocation of resources given the different visitation timing and use levels between wet and dry years. Future research should build on this to consider the timing and volume for different types of recreational use, such as with front country camping, day use, and backcountry, as has recently been shown [52]. Visitor expectations and patterns of use between wet and dry years are particularly important to asses given the rapid transitions that can take place between drought and flooding [68]. A visitor survey across different recreational activities could complement an analysis and would be useful to see how people perceive drought, how it affects their ability to access or pursue a given recreational activity, and if it impacts their quality of experience. These surveys should include reference not only to water-dependent recreational activities, but also the transportation means and timing necessary to access these activities. Regional perspectives across protected areas are also needed, to contextualize relative increases/decreases in NPS visitation with data available for other sites in the region (e.g., U.S. Forest Service, California State Parks).

Supporting information

S1 Table. Monthly and annual visitation levels and drought classification for select mountain, arid, and coastal parks in California.
(XLSX)

S2 Table. Supplementary data for matrix of Pearson's correlations between detrended seasonal visitation and seasonal drought indices during 1980–2019.
(XLSX)

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