Left Out in Drought: California Fish

Impacts of the California Drought on Freshwater Ecosystems

Morgan Shimabuku and Cora Kammeyer

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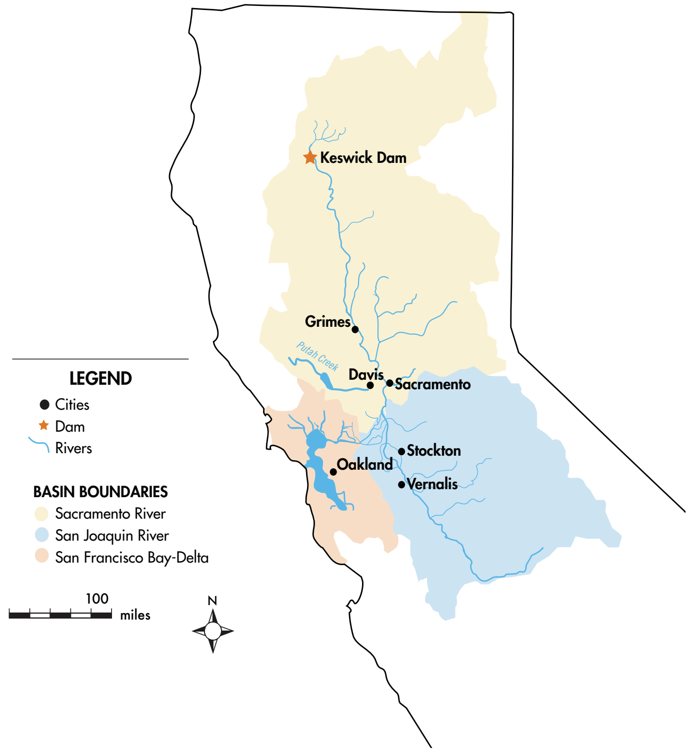
California is deep into the third year of another major drought. Rural and urban areas again face water use restrictions and financial losses. Less water and hotter temperatures also stress ecosystems, increasing the prevalence of wildfires, air pollution, dry streambeds, and loss of wildlife. Impacts to rural and urban areas frequently mask the disproportionate ecological impacts of the drought and the related policy and management responses that have exacerbated those impacts. The lack of acknowledgement and de-prioritization of ecosystem water needs during drought has led to insufficient actions taken to protect the natural systems on which we all depend.

This report highlights the significant and persistent threats of the current drought—and the associated policy and management responses—to fish and to freshwater ecosystems more broadly. Our goal is to expedite improved management responses by informing communities and policymakers of the severity of the drought's impact on aquatic ecosystems, and by recommending strategies and solutions that build drought-resilient water systems now and for generations to come.

In this report, we focus on drought impacts on fish in the Sacramento River, San Joaquin River, and San Francisco Bay-Delta (Figure ES1) during the current drought. This report builds on the extensive expertise and experience of many who have documented these impacts for decades.

Figure ES1. Sacramento River, San Joaquin River, and San Francisco Bay-Delta with Select Cities and Dams



Data sources: State of California n.d.; USGS n.d.; Zarate 2012

THE DROUGHT'S IMPACTS ON FISH IN CALIFORNIA

Freshwater species in California are adapted to periodic droughts and floods, but human alterations to freshwater ecosystems combined with de-prioritization of these ecosystems during droughts reduce species' ability to withstand them. During droughts in California, freshwater ecosystems experience low water flows generally, but also lower and shorter peak flows, warmer temperatures, and reduced water quality. For multiple days and even months in 2020 and in 2021, temperatures in the Sacramento and San Joaquin rivers exceeded the lethal limit for salmon. The diminished freshwater flows in 2020 and 2021 also resulted in exceedances of salinity thresholds at multiple monitoring locations in the San Francisco Bay-Delta. Due to stagnant water, high temperatures, and high nutrient loadings, harmful algal blooms in the Delta were nearly twice as extensive in 2021 as they were in 2020, reducing oxygen levels and threatening fish, animals, and people.

Low water flow, warmer temperatures, and poor water quality in many freshwater ecosystems across the state have resulted in deadly conditions for fish in the past two years. One of the best-known examples of impacts to fish species was on the endangered winter-run Chinook from the Sacramento River. In 2021, when river flows reached an 11-year low of 6,400,000 acre-feet, the egg-to-fry survival for winter-run Chinook reached a historic low of 2.6%, largely due to high stream temperatures.

The drought also affects the communities, economies, and ecosystems that depend on fish. As the numbers of salmon and other ocean and freshwater species decline, commercial and recreational fisheries' earnings decline. For commercial salmon fishing, a decline in fish harvest over time ripples through supporting industries, multiplying the impacts. The drought also adversely affects Native communities, exacerbating existing scarcity of their food, economic opportunities, and material bases for their cultural and spiritual practices.

CONCLUSION AND RECOMMENDATIONS

We offer six recommendations to ensure California fish build resilience to droughts: three for decisions made during droughts and three for ongoing ecosystem management.

1. **Make water management institutions nimbler during drought.**
   Remove roadblocks, reduce redundancy, and expedite decisions to protect ecosystems during drought.
2. **Create drought plans for freshwater ecosystems.**
   Drought plans and advanced negotiations should allow water and wildlife managers to act proactively and at scale.
3. **Emergency drought declarations should not forgo minimum flow requirements for the environment.**
   A variety of approaches should be explored to ensure regulatory requirements for fish and other species are met, especially during drought.
4. **Prioritize freshwater ecosystem protection.**
   Wildlife managers should work with local, state, and federal water management agencies to ensure the existing protections of water flows critical to fish survival are being maintained and enforced by regulators, and expanded where they do not exist.
5. **Expedite projects to restore connectivity with and health of floodplains.**
   Direct physical connection of floodplains and other habitats adjacent to streams must be maintained and expanded to sustain fish populations.
6. **Standardize and coordinate research and data collection, and improve information on lesser-known species.**
   State and federal data are not well coordinated or integrated, limiting the data's utility for making timely and effective management decisions for much of the state.

Droughts of increasing frequency and intensity threaten water needs for California's communities, economies, and ecosystems, and new approaches are needed. California's fish populations are in long-term decline, with several species and taxa facing extinction. Drought exacerbates that decline, as ecosystem water needs go unmet due to policy and management decisions that de-prioritize freshwater ecosystem health. As this report shows, the current drought is no exception. However, policymakers and water managers can make changes to improve freshwater ecosystem management—such as those recommended above—and help ensure better outcomes for California's streams, fish, and all who rely on and benefit from them.

INTRODUCTION

Drought has returned to California. In the summer of 2022, 97.5% of the state is in a severe drought (National Oceanic and Atmospheric Administration n.d.). Rural and urban areas again face curtailments in water use and financial losses. Less water and hotter temperatures also stress ecosystems, increasing the prevalence of catastrophic wildfires, polluted air, desiccated streams, and widespread loss of invertebrates, amphibians, fish, and birds dependent on flowing rivers and abundant wetlands. Impacts to rural and urban areas frequently mask the disproportionate ecological impacts of the drought and the related policy and management responses that have exacerbated those impacts.

Human-caused changes to rivers and riparian corridors have significantly altered and degraded much of California's 190,000 miles of rivers and streams, threatening native plants and animals with extinction. Some 1,500 dams control and store water across the state, regulating flow of snowmelt-fed rivers, limiting variability, and increasing reliability and predictability where there was once tremendous difference in flows from season to season and from year to year. Dams also block migration routes and access to food sources (Minckley et al. 1991). Native fish species adapted to seasonal flooding have seen their populations decimated by the elimination of floods and the destruction of habitat. Native fish populations have also suffered from the introduction of non-native species such as bass, sunfish, and carp, which can thrive in the regulated flows of the contemporary river and compete with and prey upon native species. This is especially true of native coldwater fish species; as rivers and streams receive less snowmelt, the warmer waters favor non-native and mostly warmwater species.

The 2020 California Water Resilience Portfolio notes:

> Reduced stream flows, increased temperatures, lack of habitat, and proliferation of invasive species have impacted many fish species across the state. Native fish and wildlife evolved to cope with drought, but dry periods are increasingly stressful given reduced habitat and river flow in recent decades. During extended drought, many streams already diminished by diversions warm, lessen, or dry up completely. Pollution compounds the stress. Many species are declining, and the number of fish species considered highly vulnerable to extinction rose from nine in 1975 to 31 species today. (California Department of Water Resources 2020a, p. 12).

As of January 2022, California had 38 state and/or federally endangered, threatened, and species of concern fish taxa[1] of a total of 123 native and 43 non-native taxa (Quiñones et al. 2015). A few of these endangered species and taxa, such as the delta smelt and various species of salmon-like chubs, suckers, and pupfish tend to be overlooked. Also overlooked are declining numbers of invertebrates and microorganisms, most of which have not been identified and whose decline could pose an even greater obstacle to the recovery of aquatic ecosystems because they represent the base of fragile food chains upon which native aquatic species depend (Howard et al. 2015).

As fish populations decline—especially when these populations become isolated—they become more vulnerable to extirpation from habitat alteration, non-native species, drought, disease, and fire (Mount et

1 "Taxa" is a broad term including both species, subspecies, and different runs of anadromous fish. Anadromy is an evolutionary adaptation. Fish spawn and reproduce in freshwater streams but spend much of their lives in the ocean, dispersing populations across different habitat types to increase resilience in the face of variable conditions (Mount et al. 2017).

al. 2017). The resistance of a population to extinction varies based on a number of factors, including the demographic structure of the population, its reproductive strategy and success, its genetic diversity, its access to resources, the population's life-history (Gilpin et al. 1986), and increasingly on its geographic range (Quiñones et al. 2015).

Many California native fish demonstrate remarkable resilience in the face of highly variable streamflow and temperatures. These adaptations have enabled populations to survive shocks in one location and eventually migrate and replenish populations in other areas (Quiñones et al. 2015). One of the few conservation tools left for imperiled native fish species is to create habitat refuges in lakes, reservoirs, or streams outside their native ranges (Sedell et al. 1990; Morelli et al. 2016; Martinez 2022).

The current and recent droughts, combined with significant water depletions in non-drought periods, have exacerbated population declines (California Department of Water Resources 2020a) and threaten the continued survival of many aquatic species (Lennox et al. 2019). Although the late fall storms in 2021 prompted the return of coho salmon to some coastal streams (Reuters 2022), the cumulative impact of drought, dams, disease, insufficient or lack of management, disconnected populations, warmer temperatures, depleted instream flows, invasive species, and pollution appears likely to drive many of California's freshwater fish species to extinction (Moyle et al. 2017).

ABOUT THIS REPORT

This report highlights the significant and persistent threats of the current drought—and the associated policy and management responses—to fish and freshwater ecosystems more broadly, to call attention to these challenges and the urgent need to address them. We should care about native fish for many reasons, including our stewardship responsibilities to current and future generations, and because fish are a major indicator of watershed health (Lennox et al. 2019) upon which all of us depend. Our goal is to expedite improved management responses by informing communities and policymakers of the severity of the drought's impacts on aquatic ecosystems, and demonstrating strategies and solutions that build drought-resilient water systems now and for generations to come.

We describe how the current drought is impacting freshwater fish in California, elevating the plight of these species to bring attention and resources to address their survival, as well as the survival of the ecosystems we all depend upon. We build on a rich literature assessing impacts of the 2012–2016 drought on aquatic ecosystems (see for example Durand et al. 2020; Feinstein et al. 2017; Hanak et al. 2015; Lund et al. 2018; Mahardja et al. 2021; Mount et al. 2017; Moyle et al. 2017). The focus on the current drought attempts to broaden the conversation about impacts beyond those affecting important human water demands.

In the following pages, we describe our methods and research findings, highlight the impacts of the current drought in two different streams, and offer conclusions and recommendations for policy and management actions that address the ongoing decline in freshwater and anadromous fish in California. This high-level overview summarizes recent impacts to fish, building upon extensive academic literature and the expertise and experience of many who have documented these impacts for decades.

METHODS

We compiled data and information for this report through desktop research using publicly available datasets including USGS flow data and state and federal fish counts, reports by state and federal agencies, and peer-reviewed literature. We also used newspaper and online media outlets to gather qualitative information and stories from drought-impacted communities to augment the quantitative data. See Appendix 1 for a complete list of data and data sources used.

To augment the desktop research, we interviewed five experts in early 2022 to gather input on drought impacts on freshwater fish species, information to support the development of case studies, and recommendations for addressing the challenges faced by these species.

Inadequate and outdated streamflow monitoring and reporting limits our ability to manage our resources adequately. The contemporary nature of this report and the lag time between monitoring and releasing data and reports limited data availability.

Scope

We mainly focused our evaluation of drought impacts on fish in the Sacramento River, San Joaquin River, and San Francisco Bay-Delta (Figure 1) during the current, ongoing drought (from 2020 to the present). In the two river basins, we selected locations where data and information were available to evaluate drought impacts. Data selected from the Bay-Delta are not comprehensive, but offer a current and geographically broad snapshot of species abundance for some native and non-native fish. This focus is not meant to imply that these species, specific locations, or river systems are more important than others, or more impacted by drought. Rather, it reflects government agency resources and priorities for water resource and fisheries monitoring and management in the state and at the federal level. Notably, these resources and priorities are focused on the state's major water infrastructure projects that deliver water to agricultural and municipal users from northern California to the Bay Area, Central Valley, and southern California.

Figure 1. Sacramento River, San Joaquin River, and San Francisco Bay-Delta with Select Cities and Dams

Data sources: State of California n.d.; USGS n.d.; Zarate 2012

The Sacramento River flows generally from north to south, from the McCloud and Pit Rivers in the southern Cascade Range around Mount Shasta to the northeastern edge of the San Francisco Bay-Delta. Heavily altered by diversions to satisfy agricultural, industrial, and municipal water demands, dams for energy generation and water storage, and a large levee system that works with the dams to provide flood management, the Sacramento River's flow is carefully regulated in an attempt to balance competing priorities between people (mostly agriculture) and ecosystems. The volume of water, timing of flows, and temperature of the river are measured, monitored, and managed by multiple federal and state agencies, and the laws under which they operate.

The San Joaquin River flows generally from south to north through the Central Valley, with its largest tributaries flowing from the western slope of the central Sierra Nevada, terminating in the southeastern portion of the San Francisco Bay-Delta (Figure 1).

Similar to the Sacramento River Basin, the San Joaquin River Basin has an extensive network of dams, levees, diversion canals, and other flood control, water supply, and energy infrastructure. Straightening and dredging the river to maintain Stockton's viability as a port has greatly impacted the lower reaches of the river with deleterious outcomes for fish and other wildlife due to high water temperatures and low dissolved oxygen levels (Schladow et al. 2009). Additionally, due to storage of rain and snowmelt in tributary reservoirs along the Central Valley's rim, extraction by individual water users along the main stem, and intensive pumping operations in the Bay-Delta to meet municipal and agricultural demands in the Bay Area and further south, the lower San Joaquin River in the Delta has been known to run in reverse and has had sections that go completely dry, especially in past summers prior to the San Joaquin River Restoration Settlement that instated minimum instream flows to protect and revive spring-run Chinook salmon (The Bay Institute 2012; San Joaquin River Program 2022).

These two rivers meet in the San Francisco Bay-Delta (Bay-Delta), a major hydrologic system supporting species from both rivers, anadromous fish, and saltwater-adapted species. Like the rivers, human activity has transformed the Bay-Delta, including reclamation of islands and conversion of marshland to farmland, as well diversions for irrigators, industries, and communities. The State Water Project and the Central Valley Project are state and federally operated pump and water transfer systems that remove millions of acre-feet of fresh water from the Bay-Delta every year (Delta Stewardship Council 2021).[2]

The Bay-Delta is also heavily monitored and managed for water quality, with a focus on preserving low salinity near the State Water Project and Central Valley Project pumps in the South Delta. The location where freshwater transitions to brackish water, along with the salinity and rate of change in salinity, are important determinants of ecosystem health in the Bay-Delta.

2 Fresh water removed from the Bay-Delta is primarily derived from Sacramento River flows.

THE DROUGHT'S IMPACTS ON FISH IN CALIFORNIA

Freshwater species in California have adapted to periodic droughts and floods. Climate change has exacerbated this variability—a "weather whiplash" with remarkable and hard-to-predict impacts to California's water resources (Swain et al. 2018). During droughts in California, freshwater ecosystems experience low water flows generally, but also lower and often shorter peak flows, warmer temperatures, and reduced water quality. Unfortunately, climate is no longer the only driver of water shortages for ecosystems. Human water use now has a far greater impact on water availability in the environment, especially in drier years.

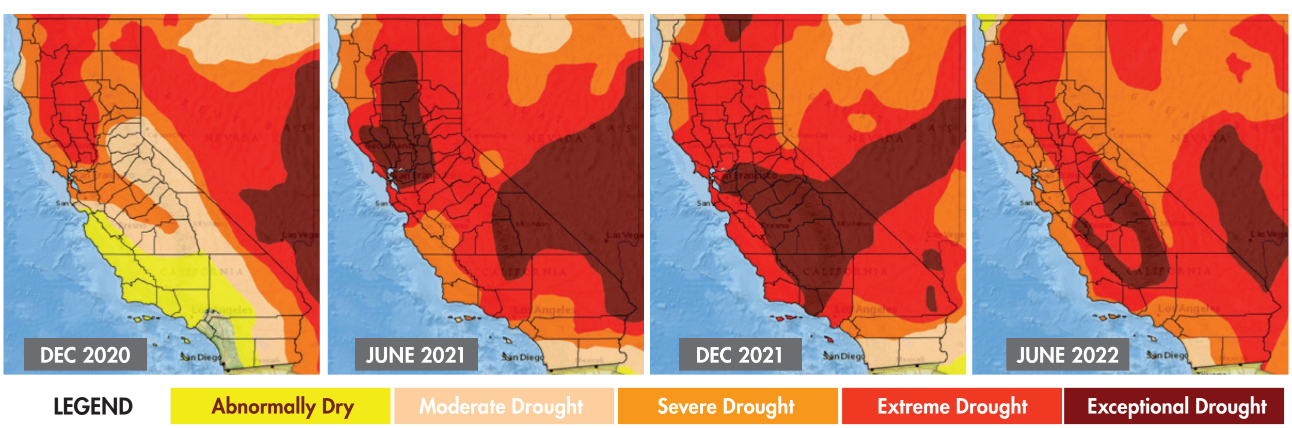
As an example, according to California Department of Water Resources data,[3] total state precipitation in 2000 was roughly the same as in 2018, yet the volume of dedicated and incidental "environmental water" declined by about 20% between those years for instream flows, Delta outflows, and Wild and Scenic River flows.[4] The difference is even more stark between wet and dry years. In 2011, statewide precipitation was about 135% of average, while in 2014 it was only 56% of average. Not surprisingly, people diverted and applied more water in dry years than in wet years. Urban water use was 5% higher and agricultural water use was 21% higher in the drier 2014 relative to the wetter 2011. However, dedicated and incidental environmental water *decreased* by almost 60% from the wet to the dry year.

In this section we examine the current California drought, especially for freshwater ecosystems, and highlight the intensity of drought impacts on those systems. Then we show how freshwater and anadromous fish species have generally responded to the drought and provide an overview of impacts from fish decline to California's economy, communities, and the ecosystem more broadly.

DROUGHT CONDITIONS

The National Oceanic and Atmospheric Administration (NOAA) data show that the current drought began in 2020 (Figure 2) (NOAA 2022). By the end of 2020, a majority of the state was classified as experiencing Moderate to Extreme drought.[5] By early 2021, the drought intensified, with parts of the state experiencing Exceptional Drought. As of early June 2022, most of the state remains classified under Severe, Extreme, or Exceptional Drought.

Figure 2. NOAA Drought Classifications for California, December 2020 to June 2022



Data Source: National Oceanic and Atmospheric Administration n.d.

3 California Department of Water Resources Estimated Agricultural Land and Water Use data through 2015 are posted at https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates; provisional 2016 and 2018 data provided by Department of Water Resources staff.

4 Wild and Scenic is a federal protective designation for a river based on its outstanding natural, cultural, and recreation values, and free-flowing condition.

5 Drought classifications and descriptions from NOAA's Drought Severity Classification list https://www.weather.gov/riw/drought_index/.

The state's policy responses to the drought thus far have been mixed for freshwater ecosystems. California Governor Gavin Newsom announced an emergency drought declaration in April 2021 focused on a small portion of northern California in Mendocino and Sonoma counties (Newsom 2021a) (Figure 3). The emergency proclamation called for resources for ecosystem and water management to support wildlife, but it also suspended requirements under the California Environmental Quality Act (CEQA), one of the state's primary policy mechanisms for environmental protection. In May and July 2021, Governor Newsom further extended the state of emergency to additional parts of the state and encouraged state agencies to start taking action on behalf of public health, safety, and the environment (Newsom 2021b; 2021c). In June 2021, the California State Water Resources Control Board (State Water Board) reduced minimum instream flow requirements for the Russian River to allow the local water agency to hold more water behind their dam (State Water Board Order WR 2021-0056-Exec). In October 2021, Governor Newsom extended the emergency to the entire state and further suspended public participation laws for water management decisions by state agencies (Newsom 2021d).

In late March 2022, the governor issued an executive order directing additional action by Californians and state agencies, which was recently followed in May when the State Water Board voted to ban watering "non-functional turf" on commercial, industrial, and institutional properties (Newsom 2022; State Water Board 2022). While many of these actions encourage or direct action to be taken on behalf of the environment, it is unclear if there are mechanisms in place for enforcement and whether or not action will be sufficient to protect already struggling native fish and other species.

Figure 3. Timeline of Drought Emergency Declarations and Responses from California State Government

Data sources: Newsom 2021a–d; Newsom 2022; State Water Resources Control Board 2022

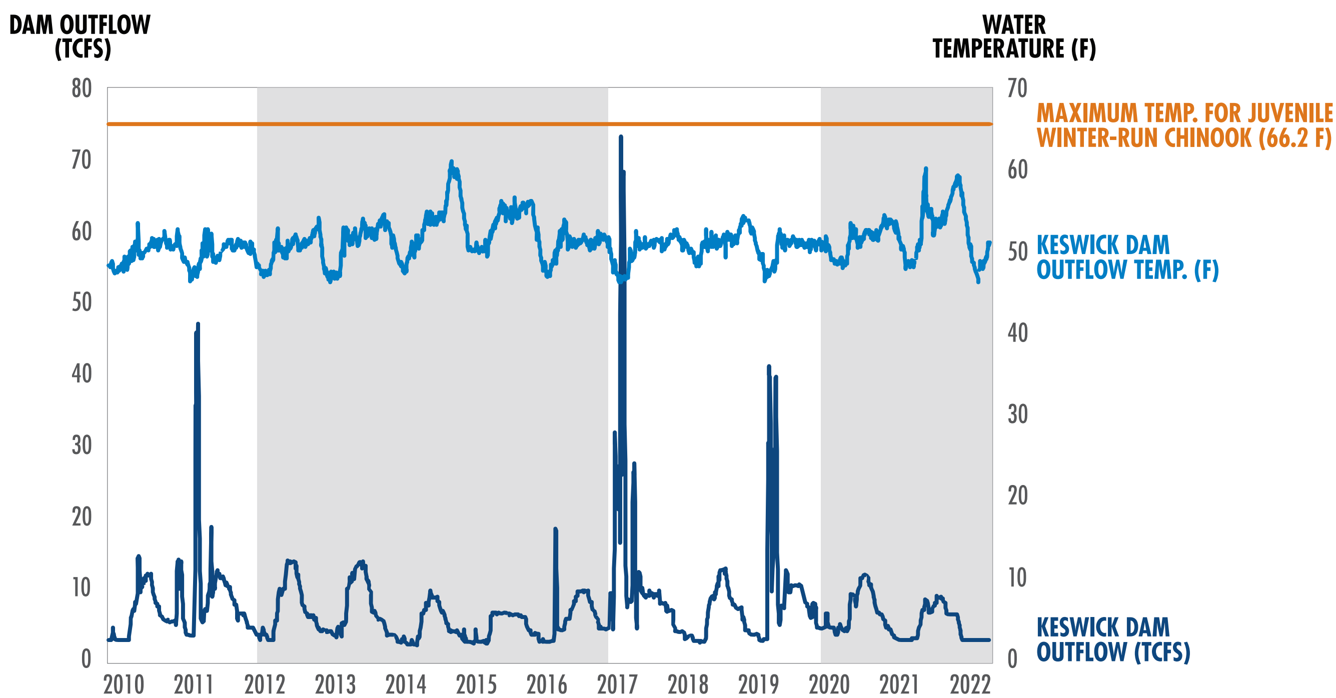
FRESHWATER CONDITIONS

River flows and water temperatures are key indicators of drought impacts on freshwater fish. During drought, flows are reduced due to decreased rain and snow, impacting both peak flows and base flows. Water temperatures in rivers, streams, and lakes are often higher as well, especially in places where snowmelt typically makes up a significant portion of the flow. High air temperatures, also often experienced during times of drought, can contribute to increased water temperatures in places where water is shallow and stagnant.

Sacramento River

In 2020 and 2021 there were clear signs of drought with low flows and high water temperatures, both on upper and lower portions of the Sacramento River. During the spring when snow melt and spring rains historically contribute to larger outflow, the 2021 peak flows on the upper Sacramento were low relative to the previous 11 years (Figure 4). According to flow data from Keswick Dam, a major flow-regulating and energy-generating dam on the upper portion of the river, in 2021 the river reached its second-lowest maximum outflow since 2010, eclipsed only by the low peak flow in 2015 during the last major drought (Figure 4). Mean water temperatures immediately below the dam in in 2020 reached 55° Fahrenheit (F) in October and 60° F in May and October of 2021. These temperatures had not been measured at this point in the river since the previous drought, in 2014 and 2015.

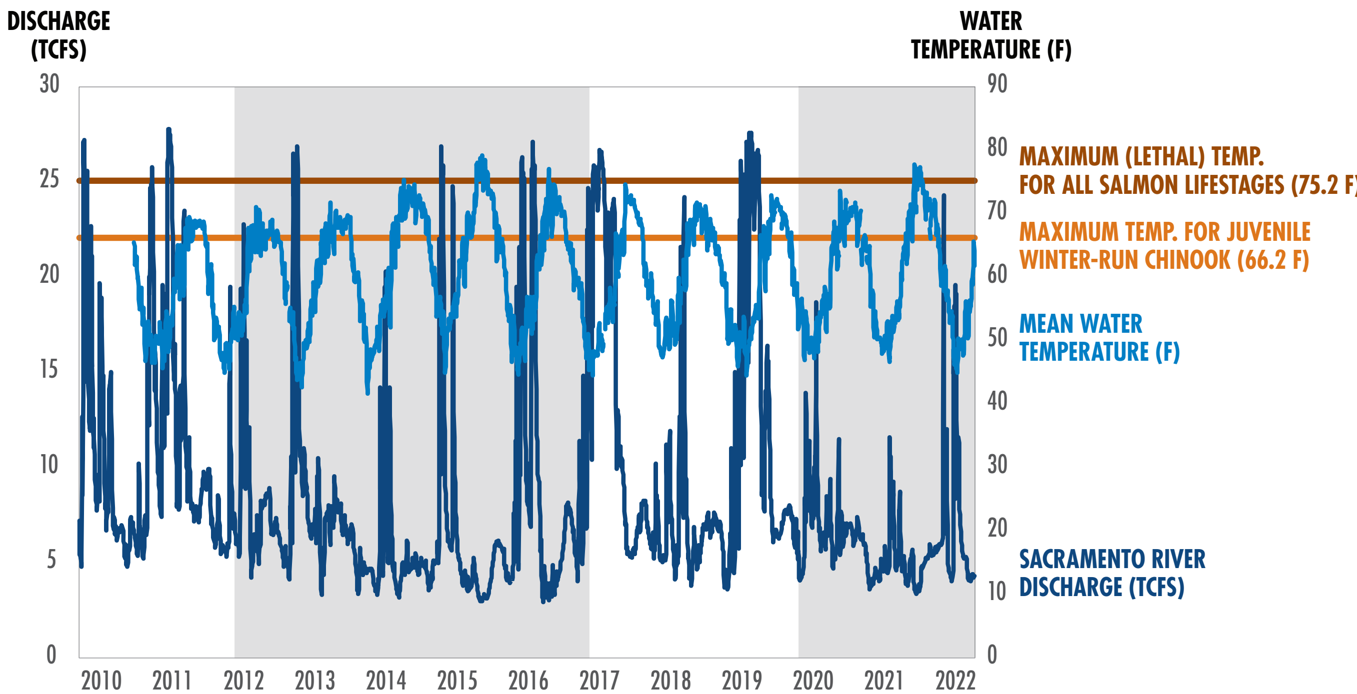
Figure 4. Sacramento River Outflow at Keswick Dam, January 2010 to March 2022



Notes: Drought periods shown in gray. A cubic foot of water is equivalent to 7.48 gallons. A flow rate of 1 TCFS is equivalent to 1,980 acre-feet per day, or 646,000,000 gallons per day.
Data Sources: University of Washington 2022; California Department of Water Resources 2020b; UC Davis 2022

Downstream reaches of the Sacramento River, closer to the Delta, also experienced lower flows and warmer conditions over the past two years (Figure 5). In fact, for every year since 2011, the water temperature in the Sacramento River about 40 miles north of Sacramento (Figure 1) peaked above 66.2° F, the maximum temperature tolerated by healthy juvenile Chinook salmon (UC Davis 2022). In 2021 (as well as in 2014, 2015, and 2016), minimum and mean water temperature exceeded 75.2° F, lethal for salmon across all life stages (UC Davis 2022). It is notable that in 2021 the mean and minimum water temperature exceeded 75.2° F on 13 days in June, and July—two weeks of fatal conditions for all four runs of salmon in the Sacramento River. 2015 is the only year in the recent past that had more days (29) when mean and minimum water temperature exceeded 75.2° F. While salmon can typically avoid the mainstem of the river during these peak temperature events in summertime, there are reduced options due to dams on many tributaries. Furthermore, climate change will exacerbate and extend the duration of these lethal events.

Figure 5. Sacramento River Discharge Near Grimes, January 2010 to March 2022

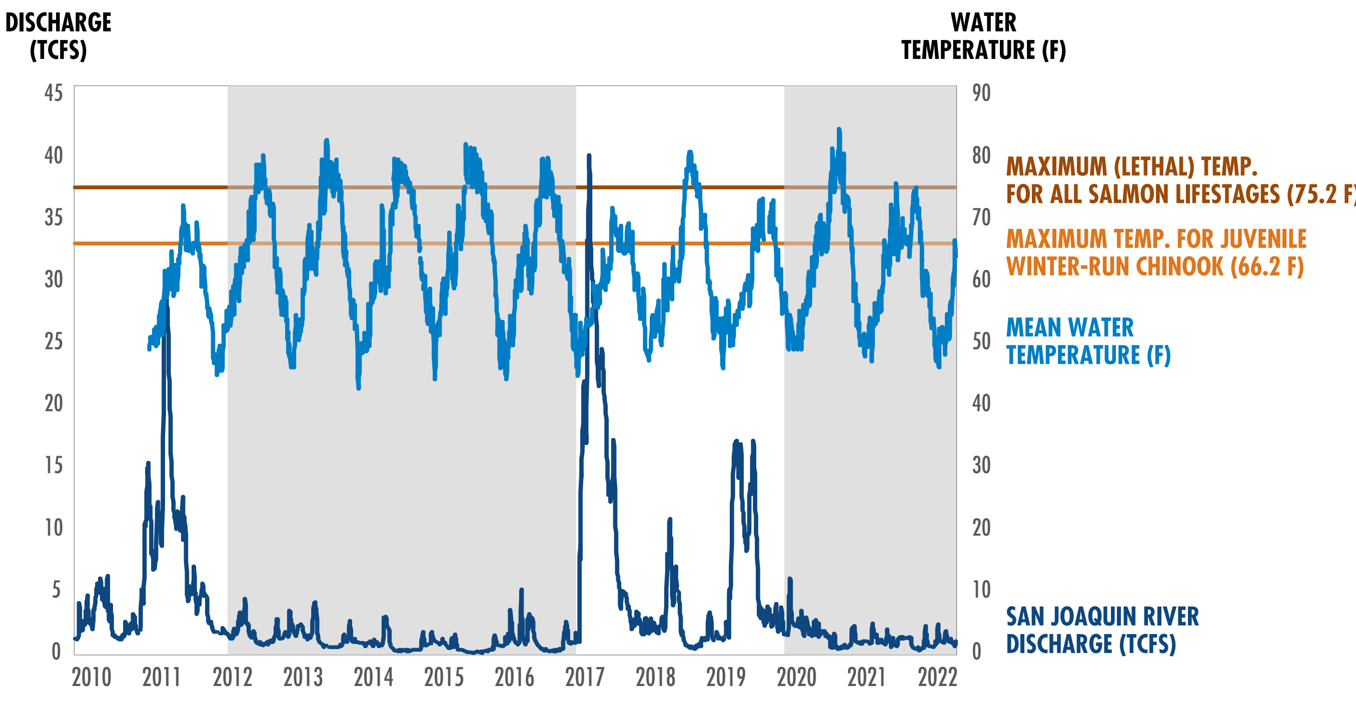


Notes: Drought periods shown in gray.
Data sources: Gage data from USGS monitoring location 11390500 (USGS 2022a); University of Washington 2022; California Department of Water Resources 2020b; UC Davis 2022

San Joaquin River

Similar low flows and higher temperatures occurred on the San Joaquin River over the past two years (Figure 6). While the natural flow of the San Joaquin River is typically less than the Sacramento River, it was especially low in 2020 and 2021. In 2020, the lowest flows occurred in August, dipping to around 500 cubic feet per second (CFS). In 2021, the lowest flows occurred in September and October, with several days below 300 CFS. Mean water temperatures exceeded 75.2° F continuously for nearly two months from July into September in 2020 and for multiple days in 2021. While these conditions on the San Joaquin River are slightly better than what was experienced at the height of the 2012–2016 drought, the cumulative impact from repeated low flow and high temperature is not sustainable for many native fish populations.

Figure 6. San Joaquin River Discharge Near Vernalis, January 2010 to March 2022



Notes: Drought periods shown in gray.
Data Sources: Gage data from USGS monitoring location 11303500 (USGS 2022b); University of Washington 2022; California Department of Water Resources 2020b; UC Davis 2022

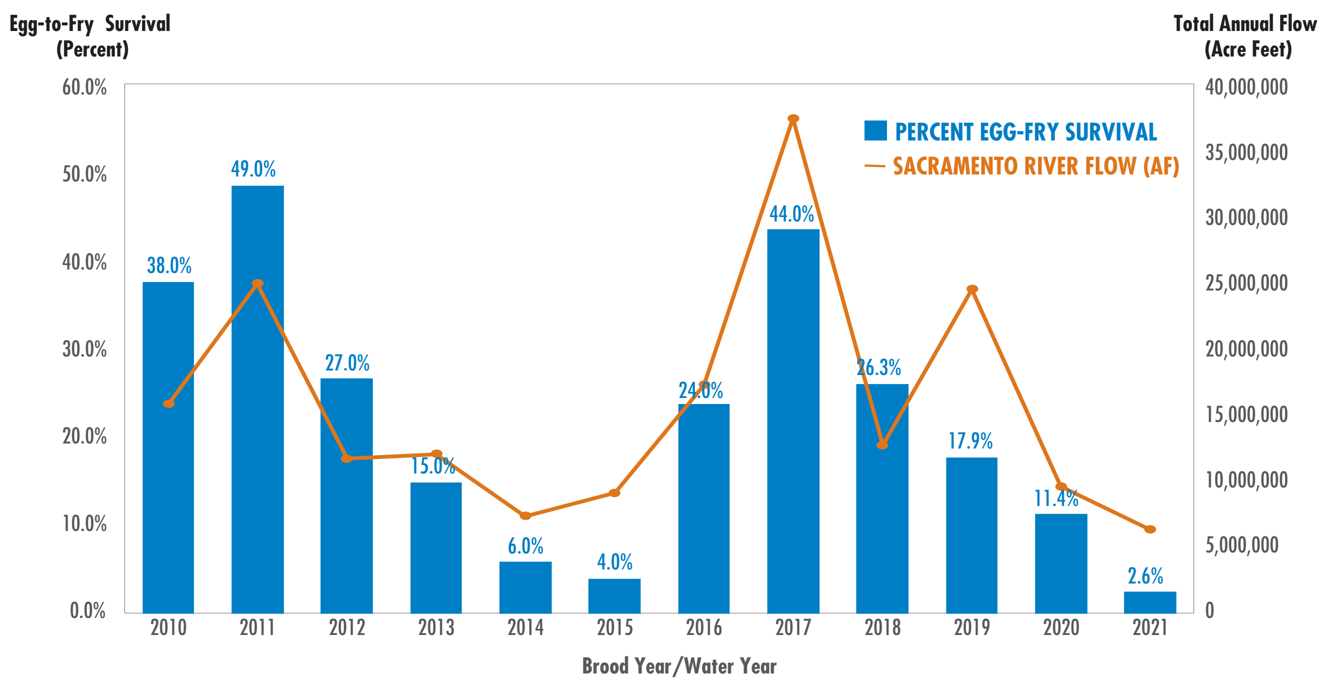
Bay-Delta

During drought years, reduced freshwater inflows from the Sacramento and San Joaquin rivers contribute to greater intrusion of high salinity water from the Pacific Ocean to the Delta via the San Francisco Bay, as well as from agricultural return water from the San Joaquin River. In 2021, salinity of the Bay-Delta exceeded water quality thresholds for human-related water uses at multiple monitoring locations (Delta Stewardship Council 2022). Specifically, high salinity, particularly in locations where it is typically low, can stress aquatic species, including fish and their prey (e.g., Jassby et al. 1995). Non-native species and algal blooms also contribute to Bay-Delta ecosystem distress (Delta Stewardship Council 2022). Due to stagnant water, high temperatures, and high nutrient loadings, algal blooms were nearly twice as extensive in 2021 as they were in 2020 (Delta Stewardship Council 2022). Algal blooms harm fish by reducing oxygen content in the water, and some forms, such as cyanobacteria, can be toxic to fish, animals, and people (Peacock et al. 2018).

FISH CONDITIONS

Low water flows, combined with warmer air temperatures, resulted in higher water temperatures and poor water quality in many freshwater ecosystems across the state, resulting in deadly conditions for fish in 2020 and 2021. One of the best-known examples of impacts to fish species was on the Sacramento River's endangered winter-run Chinook. Figure 7 shows the survival rate of the youngest winter-run Chinook, after they hatch from their eggs (i.e., egg-to-fry) along with total annual flow of the Sacramento River. In 2021, when river flows reached an 11-year low of 6,400,000 acre-feet, the egg-to-fry survival for winter-run Chinook also reached a historic low of 2.6%—only 6% of the 2017 survival rate and dramatically lower than the 84% survival rate reported in other locations (Stark et al. 2018). High stream temperatures were a major contributor (Marcinkevage 2022). Notably, this egg-to-fry survival rate was even worse than in the 2012–2016 drought when the lowest recorded survival was 4.0% in 2015 (Figure 7). Similar poor survival rates were found on the Klamath River in 2021, where record-high die-offs of juvenile salmon were caused by a disease, *C. shasta*, which was exacerbated by drought conditions (Smith 2021).

Figure 7. Egg-to-Fry Survival Rate for Winter-Run Chinook and Flow for the Sacramento River, 2010 to 2021

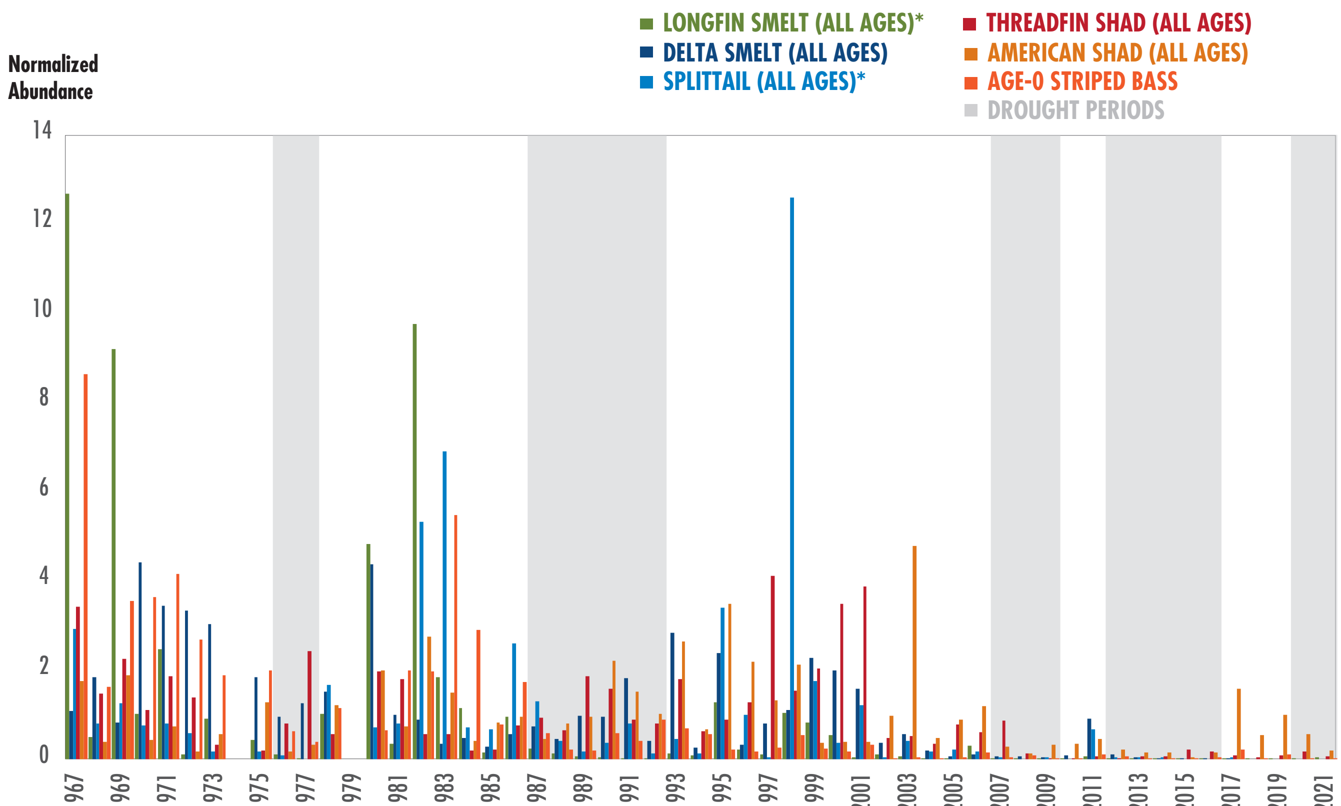


Notes: Brood Year runs July 1–June 30 and is named for the year in which it begins. Water Year runs October 1–September 30 and is named for the year in which it ends. However, because total annual flow is measured at the end of each Water Year (in September) and winter-run Chinook fry emerge in the beginning of the Brood Year (typically July–October), the above plotted values align sufficiently for comparison.
Data Sources: Voss et al. 2020; Poytress et al. 2014; Marcinkevage 2022; California Department of Water Resources 2021

California's increasingly severe and frequent droughts affect many other native and non-native species. Figure 8 shows annual species abundance indices (normalized to allow for direct comparison) for six fish species in the Bay-Delta. These six species, three native (blue bars) and three non-native (red and orange bars), have been monitored regularly by California Department of Fish and Wildlife's Fall Midwater Trawl since 1967.[6,7] The data show that the abundance of all six species shown has been in decline for several decades, accelerating in the early 2000s.

The abundance of the native species measured by this survey, two species of smelt and a splittail, reflect drought conditions, with lower abundance correlated with lower flows and typically some recovery when flows increase.[8] This is similar to findings from Mahardja et al. (2021), which found that Delta smelt, Longfin smelt, and Sacramento splittail show low resistance, yet medium to high resilience, to droughts.[9] However, the higher frequency and intensity of droughts in the past two decades have left these species with insufficient recovery time (Mahardja et al. 2021).

Figure 8. Normalized Species Abundance Index from Fall Midwater Trawl, 1967 to 2021



Notes: Grey indicates drought periods. Blue and green indicate native species. Red and orange indicate non-native species. Umbrella species denoted with *.

Data Sources: White 2021; Interagency Ecological Program (IEP) 2022; California Department of Water Resources 2020b

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6 The annual abundance index is calculated as the sum of monthly abundance indices from the California Department of Fish and Wildlife's Fall Midwater Trawls, in which a boat towing a net catches fish and other aquatic species found in the water column. Monthly abundance indices are calculated by averaging catch per tow for index stations in each region, multiplying each regional average by its respective weighting factor (based on water volume) for each region, and summing those products for all 14 regions (White 2021). The values were normalized within each species type by dividing each year's total abundance index by the mean of total abundance indices for 1967–2021.

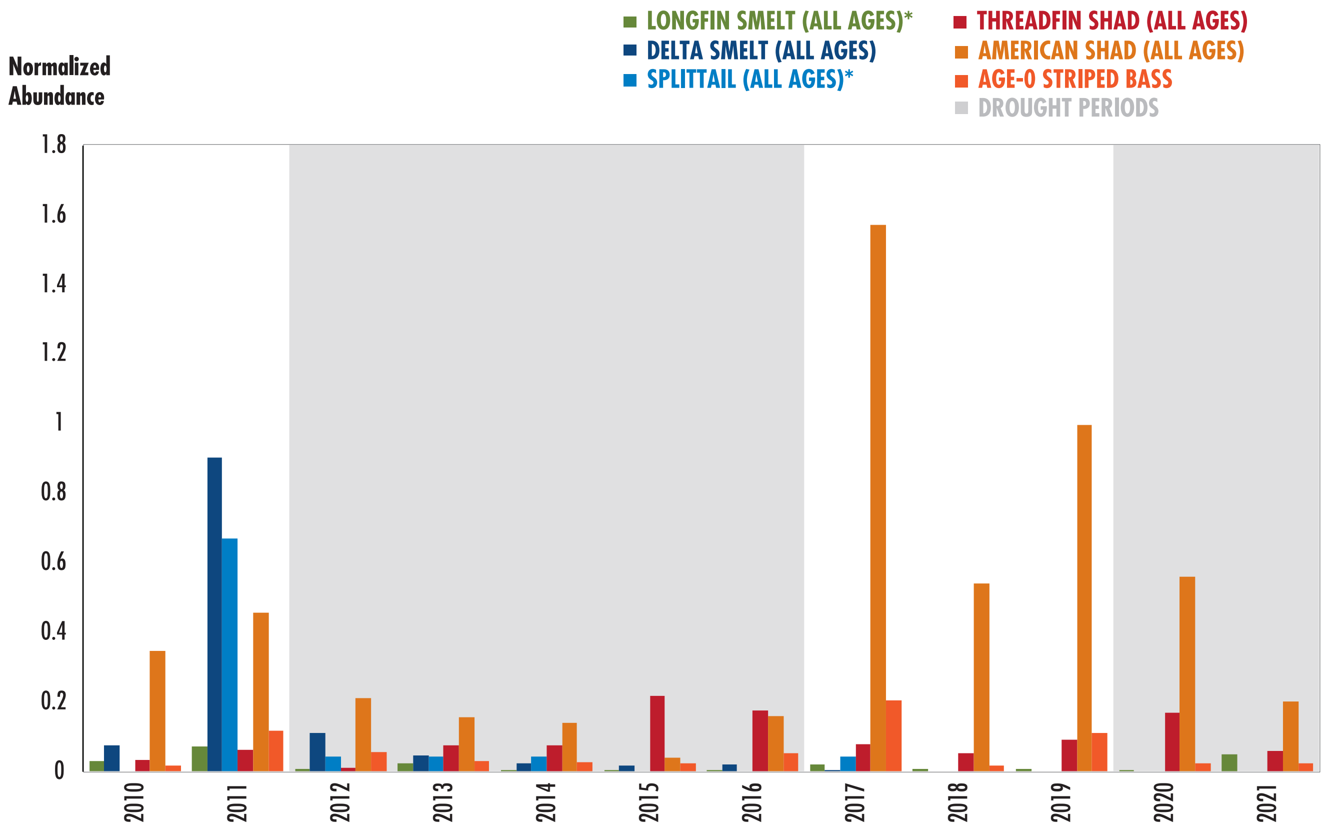
7 The Fall Midwater Trawl works mainly for pelagic species and does not reflect overall conditions for all fish nor for the entire Bay-Delta. The trends in splittail numbers, for example, have been shown by others (e.g., Stompe et al. 2020) to be increasing.

8 Low river flows along the Sacramento and San Joaquin Rivers, the two main freshwater tributaries to the Bay-Delta, were measured 2001–2004 even though this timeframe was not recognized as a statewide drought (California Department of Water Resources 2021).

9 Here, the definition of resistance is related to a species' persistence despite a disturbance, while resilience is defined relative to a species' ability to recover after a disturbance (Mahardja et al. 2021).

The decline, and even disappearance, of resilient freshwater and anadromous species over the past two decades highlights the plight of California fish (Figure 9). While scientists do not believe that these species are completely extinct, they are considered functionally extinct and incapable of natural recovery (e.g., Bork et al. 2020; Moyle 2015; Moyle et al. 2021). The abundance of Longfin Smelt, Threadfin Shad, American Shad, and Striped Bass has also declined precipitously since 2018.

Figure 9. Normalized Species Abundance Index from Fall Midwater Trawl, 2010 to 2021



Notes: Gray indicates drought periods. Blue and green indicate native species. Red and orange indicate non-native species. Umbrella species denoted with *.

Data Sources: White 2021; Interagency Ecological Program (IEP) 2022; California Department of Water Resources 2020b

The abundance of other California fish has also plummeted. For example, in the remote northeastern corner of the state, Tule Lake is expected to dry up in summer 2022. This could drive the Lost River sucker and the shortnose sucker, two endangered species, to extinction (Alexander 2022). Tule Lake is part of a protected National Wildlife Refuge and typically covers 13,000 acres but is expected to disappear due to drought and pumping for irrigation (US Fish & Wildlife Service n.d.). Wildlife managers from state and federal agencies, along with tribal groups, are working to save as many individual fish as they can until the lake returns (Alexander 2022).

Popular native inland cold-water species are also showing signs of distress and decline from drought and other factors. In a report by California Trout, a conservation and public policy nonprofit organization, 31 native salmon, steelhead, and trout species declined in abundance from 2008 to 2017 due to multiple factors causing reductions in suitable habitat and accelerated by drought (Moyle et al. 2017). The report concludes that if present trends continue, 14 of these remaining 31 freshwater species are likely to be extinct within 50 years, and 23 are likely to be extinct in 100 years. The decline of these native coldwater fish is an indicator that the conditions to which they adapted is disappearing in California, driven and exacerbated by drought and inadequate management.

IMPACTS TO COMMUNITIES, ECONOMIES, AND THE REST OF THE ECOSYSTEM

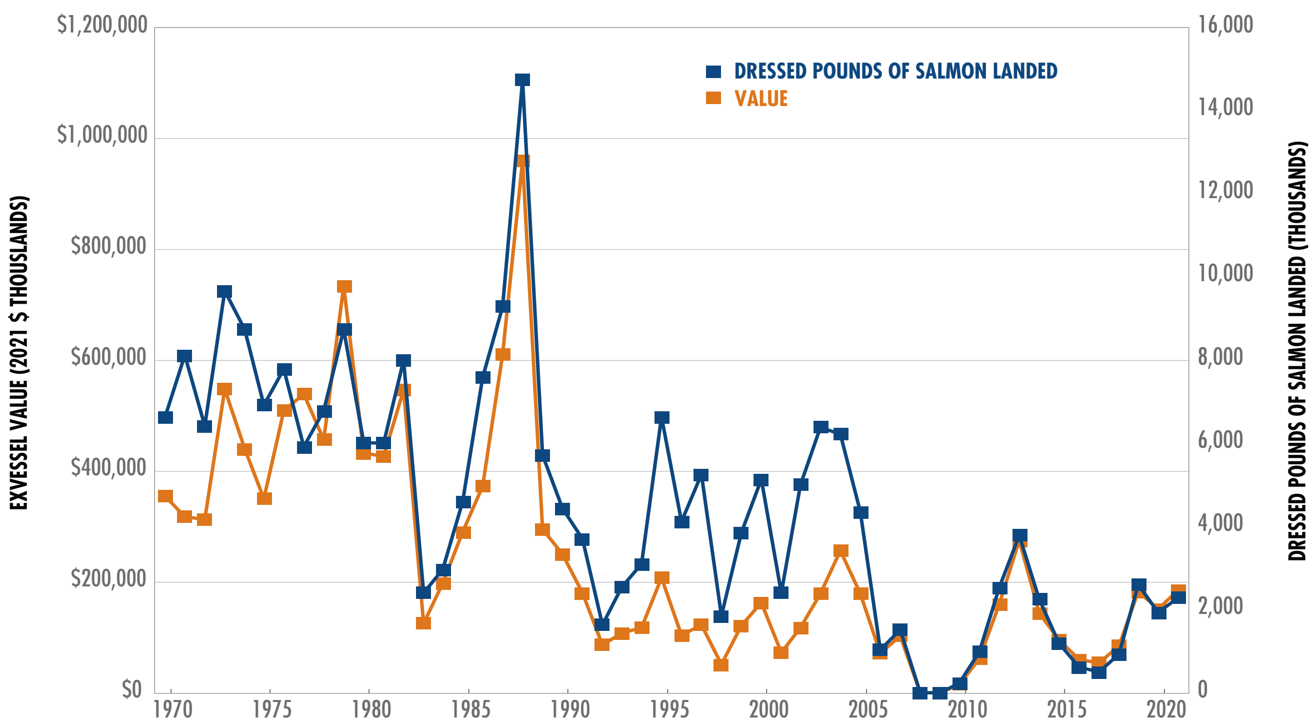
The drought's imperilment of freshwater fish species also affects the communities, economies, and ecosystems that depend on them.

Fishing Industry Impacts

Commercial and recreational fisheries for anadromous fish provide measurable economic benefits to Californians, visitors, and Native communities. In the Pacific Ocean off the coast of California, commercial and recreational Chinook fisheries contribute hundreds of millions of dollars per year to the regional economy (National Oceanic and Atmospheric Administration 2018). As the numbers of salmon and other ocean and freshwater species decline, commercial and recreational fisheries' earnings decline.[10] Figure 10 shows a multi-decadal decline in economic value of California's commercial salmon fishery. Although the price of salmon has increased over this period, that increased price is driven by scarcity; the rise has been insufficient to counteract the reduction in pounds of fish caught for the commercial fishing industry.

Drought can have immediate and long-term impacts on the fishing industry. In drought years, the California Department of Fish and Wildlife may impose "low-flow" restrictions on recreational trout and salmon fishing. In the 2021–22 season, low-flow restrictions reduced the number of days per week when fishing is legal on specific streams and rivers in northern California, the San Francisco Bay Area, the Sierra Nevada, and the Central Coast (Fish and Game Commission of the Department of Fish and Wildlife 2022). These necessary reductions harm local economies that depend on recreational fishing and tourism, as well as the larger recreational economy that supports outdoor activities. This economy represents more than two million anglers who spent more than $3 billion and contributed to $5.6 billion in total economic output in 2018, supporting almost 40,000 jobs (Southwick Associates 2020).

Figure 10. Dollar Value and Total Weight of Commercially Harvested Chinook and Coho Salmon in California, 1960 to 2021



Notes: Coho salmon is now listed as an endangered species. Commercial fishing of Coho salmon has been prohibited since 1992. The value of salmon at the point of landing is termed exvessel value. It is expressed in 2021 dollars (inflation adjusted) (U.S. Bureau of Labor Statistics 2022).
Data source: Pacific Fishery Management Council n.d.

10 For information on marine species decline see the IUCN Red List of Threatened Species (www.iucnredlist.org).

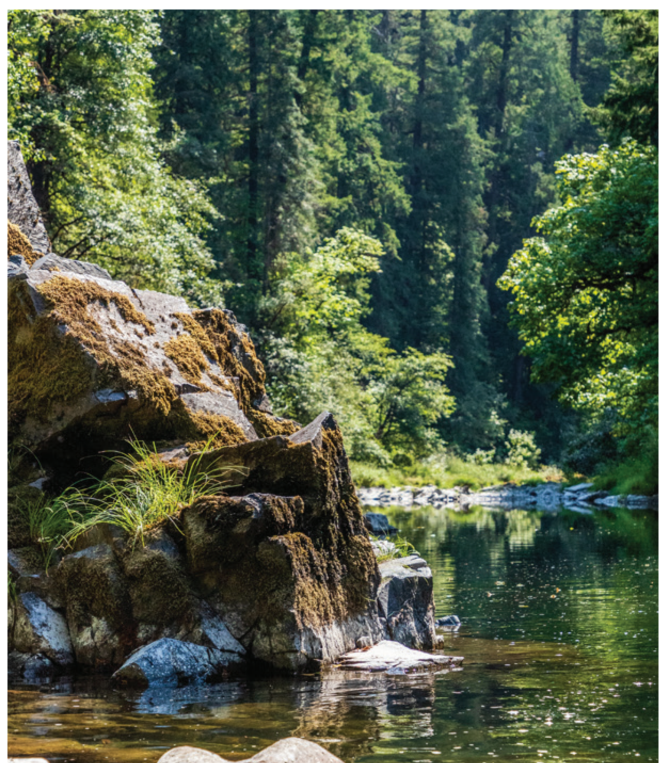
In the future, we can expect reduced activity and earnings for recreational and commercial fishing, respectively, as lower fish survival and reproduction during the drought lead to reduced abundance of fish large enough to keep once caught. For commercial salmon fishing, a decline in fish harvest over time ripples through the industry, as supporting goods and services, such as ice stores and dock crews, go unused (Feinstein et al. 2017). When this happens season after season, it can lead to permanent closures of supporting businesses, making future recovery more challenging. Similarly, many commercial fishers rely upon Dungeness crab to supplement their income; these species have also been negatively affected by drought, with fishery closures due to cyanobacteria in crab that results from warm nearshore ocean waters associated with hot droughts (National Oceanic and Atmospheric Administration 2022).

Native Community Impacts

Native communities are adversely impacted by the drought's added toll to fish and aquatic ecosystems. A collaborative study between University of California, Davis researchers and members of 40 California tribes and tribal groups found that the rate of fish use, both for consumption and cultural practices, has been greatly reduced for many tribes relative to traditional rates (Shilling et al. 2014). Tribes attributed this change primarily to aquatic ecosystem conditions, such as declining fish populations, concerns about water quality and associated safety risks of consuming fish products, dry streams, extinction of local fish species, and land and water development (Shilling et al. 2014). Droughts exacerbate these conditions, reducing the ability of Native communities to use fish for numerous purposes. Reduction in fish consumption, for example, can directly impact the health of tribal members (Norgaard 2005). In California, the Yurok and Hoopa Valley tribes have federally-reserved fishing rights to Klamath River fish, but many other recognized and un-recognized tribes do not have secured rights. In a world with dwindling fish populations, even those with secured rights are harmed.

Ecosystem Impacts

When one part of an ecosystem is lost, other parts will be impacted. In some instances, loss or reduction in certain fish species will be an opportunity for their prey to proliferate, which can further impact the ecosystem. In other cases, loss of certain native species can provide a niche for establishment of non-native species with similar habitat and prey preferences. For animals and organisms that rely on fish as a food source, declining fish abundance can diminish their own populations. For example, reduced abundance of Chinook salmon has contributed to the decline in Orca populations (Hanson et al. 2021). Salmon and other anadromous fish also convey nutrients from the ocean to inland aquatic and terrestrial ecosystems (Naiman et al. 2002). The ongoing drought is a major added stressor for already degraded and impaired ecosystems. Loss of fish and other species, many of which are naturally resilient to droughts and other extreme hydrologic variation, could prove to push these systems beyond their ability to recover in the future.



CONCLUSION AND RECOMMENDATIONS

California's native fish species historically demonstrated remarkable resilience in the face of climatic and hydrologic variability, but suffer from rising temperatures, depleted instream flows, loss of habitat connectivity, declining water quality, and proliferation of non-native species. Each drought takes an increasing toll on these fish, reducing their reproductive success and decreasing their populations to a point where they may no longer be able to recover, as shown by the loss of the Delta smelt and the abysmal egg-to-fry survival rate of winter-run Chinook. The increasing frequency and intensity of California's recurrent droughts test the resilience of the state's fish and threaten the economies and cultures of people who depend on these fish.

Climate change increases California's hydrologic variability, with atmospheric rivers creating intense storm events coupled with extended hotter and drier droughts. With sufficient management in place—such as dedicated instream flows and increased connectivity to headwaters and floodplains—native fish populations can recover and contribute to California's freshwater ecosystems, communities, and economies. For example, October 2021 storms generating high flows in Marin County (north of San Francisco) prompted the return of Coho salmon to streams where they had been absent for more than two decades (Reuters 2022).

To ensure California fishes' resilience to—and recovery from—droughts, water policy and management decisions must protect and prioritize freshwater ecosystem health. Here we offer six recommended policy and management changes to better protect fish from drought in California: three for changing decisions made during droughts, and three for changes to ongoing ecosystem management more broadly. We also provide a case study of a qualified management success from Putah Creek as a potential model for better drought management and ongoing ecosystem health.

Putah Creek Case Study: Restoring Flows and Fish

Putah Creek demonstrates the importance of dedicated instream flows, research, monitoring, and management for the protection and recovery of native fish species. Putah Creek flowed about 110 miles southeast from its headwaters on Cobb Mountain, north of Santa Rosa in the Coast Range of Northern California, to discharge into the Sacramento River (see Figure 1), historically supporting steelhead and other anadromous fish and an assemblage of resident species including Sacramento pikeminnow and prickly sculpin. Two dams – Monticello Dam and Putah Diversion Dam – disconnected the lower 22 miles of Putah Creek from its upper reach and tributaries. About six miles downstream from Monticello Dam, the Putah Diversion Dam regulates streamflow and diverts about 80% of that flow during normal and dry years to irrigate about 95,000 acres in Solano County and provide water to Benicia, Fairfield, Suisun, Vacaville, and Vallejo. At its downstream end, Putah Creek now discharges periodically into the Yolo Bypass through the Los Rios Check Dam (Rabidoux et al. 2022).

In 1989, in the middle of a five-year drought, more than 19 miles of lower Putah Creek dried completely, killing fish and other aquatic and riparian organisms. In 1991, the Putah Creek Council, later joined by UC Davis and the City of Davis, sued the Solano Irrigation District and the Solano County Water Agency, which eventually led to the May 2000 Putah Creek Accord, requiring dam releases to ensure minimum instream seasonal flows. The Accord includes three operational requirements targeted to benefit fish and other organisms adapted to the natural flow regime: a Spring pulse flow to reduce water temperature and benefit fish spawning, a Fall pulse flow to facilitate salmon migration, and an annual minimum instream flow to provide suitable habitat for native fish. These operational requirements mimic the timing but not the volume of Putah Creek's natural flows (Kiernan, Moyle, and Crain 2012).

Restoration of Putah Creek has also included channel realignment, reconnection with the floodplain, intensive monitoring, and periodic removal of obstacles that impede streamflow and reduce connectivity. These efforts have encouraged the return of native fish, including limited numbers of anadromous fish.

The Fall 2020 Fish Survey report notes that native fish dominate about the first half of Putah Creek below the diversion dam (Salamunovich and TRPA Fish Biologists 2021). Farther downstream, where the pulse flows have less impact, slower and warmer water temperatures favor non-native species such as bluegill sunfish, largemouth bass, and Mississippi silverside. The most recent fish survey also noted a much lower abundance of native Sacramento suckers than observed in prior years, possibly due to poor recruitment in 2019. Prior fish surveys noted low numbers of spawning Chinook salmon but some successful juvenile production.

The re-emergence of a resilient community of native fishes in the upper half of Putah Creek below the diversion dam, coupled with the return of anadromous fish, suggests that other disturbed California streams can also regain some semblance of natural function despite recurring and intensifying droughts if streamflow regimes mimic historical hydrographs and habitat restoration is undertaken to allow access to high quality habitat upstream.

Putah Creek represents a qualified restoration success, demonstrating the value of appropriately timed instream flows, cooperation and partnerships among multiple stakeholders (including water agencies, irrigators and property owners, environmental and recreational organizations, academics, the City of Davis, and wildlife agencies), the removal of barriers to fish passage, and the importance of on-going monitoring (Rabidoux et al. 2022).

IMPROVE ECOSYSTEM MANAGEMENT IN TIMES OF DROUGHT

1. Make water management institutions nimbler during drought

Cooperation and coordination between federal, state, tribal, and other actors is necessary when managing California's water resources, especially during drought. In the 2012–2016 drought, up until last year, many of the processes and regulations created to enhance this coordination were burdensome to the point of rendering them ineffective. However, beginning in the spring of 2022, the State Water Board as well as the Department of Water Resources have worked to remove roadblocks, reduce redundancy, and expedite decisions that are time-limited (Mount 2022). More effort is needed to ensure these process changes are made permanent and to evaluate the effectiveness of the actions that were taken. Work should be done to ensure water managers act quickly on behalf of ecosystems when necessary. Putah Creek, as explored in the case study here and supported by analysis from Mount et al. (2017), offers one example where coordination and planning have built effective response strategies during times of drought.

2. Create drought plans for freshwater ecosystems

Drought management planning and innovations have allowed industry, agriculture, and communities to weather droughts—the same could be true for ecosystems. Rather than simply reacting to drought-related mandates or waiting until emergency declarations force action, drought plans and advanced negotiations could allow water and wildlife managers to act proactively and at scale (Mount et al. 2017). In 2012–2016 drought, for example, wildlife managers, in partnership with private landowners, were able to strategically allocate the environment's small allotments of water to reduce the drought's impact on wetland habitat critical to migratory birds (Hanak et al. 2015). Actions taken by water users on the Yuba River under the Yuba River Accord during the last drought offer additional examples of the benefits of drought contingency planning (Mount et al. 2017).

3. Emergency drought declarations should not forgo minimum flow requirements for the environment

Tensions between sustaining instream flows and diversions for agricultural and municipal uses rise during drought, when people's livelihoods and public health and safety are at risk. As described previously, diminished instream flows—often a small fraction of the pre-development volume—increase water temperatures, decrease dissolved oxygen concentrations, diminish reproductive success, and can desiccate streams entirely. Waiving required instream flows might provide short-term benefits for diverters at the expense of aquatic species already on the threshold of catastrophic loss. It can also sow mistrust of those responsible for water management, which can reduce collaboration on other efforts in the future. Limited volumes of water can and should be dedicated to meet minimum flow requirements, through mechanisms such as market-based acquisitions, cooperative forbearance agreements with downstream diverters, regulatory requirements, or by granting water rights to the environment (Mount et al. 2019).

IMPROVE ONGOING ECOSYSTEM MANAGEMENT

4. Prioritize freshwater ecosystem protection

If fish and other aquatic species are to persist, water for the environment must become a higher priority for local, state, and federal agencies that allocate the state's water resources. The tools and regulations needed to do this are already in place. For example, Fish and Game Code Section 5937 indicates that it is the responsibility of a dam owner to maintain fish populations in "good condition" below a dam (F. E. Smith 2014). Other critical laws include the California Porter-Cologne Act, federal Clean Water Act, the public trust doctrine, and both the California and federal Endangered Species Acts (Mount et al. 2017). Wildlife managers should work with local, state, and federal water management agencies to ensure that existing protections of water flows critical to fish survival are being maintained and enforced by regulators, expanded where they do not exist, and maintained and strengthened in the few instances where they do currently exist—like on Putah Creek.

A narrow focus on providing instream flows can mask the importance water quality considerations such as temperature and dissolved oxygen concentrations, as well as the seasonal variations in flow. Additionally, simple volumetric requirements can ignore the importance of the timing of instream flows; poor timing can favor non-native species, which can exacerbate changes to the physical habitat and make native species recovery harder. A broader ecosystem perspective, especially one that restores natural flow, function, and connectivity along streams as well as lateral connections to backwaters and floodplains, can be more effective and provide greater resilience for the system and should not be waived during emergencies. For example, rearing and releasing hatchery fish to increase a species' abundance without improving the conditions that caused population declines will not promote species recovery, much less the recovery of the system as a whole. Creating freshwater protected areas in several locations could provide refugia for aquatic species, enabling the re-establishment of populations in connected streams (Moyle et al. 2017).

5. Expedite projects to restore connectivity with and health of floodplains

Direct physical connection of floodplains and other habitats adjacent to streams is important to sustaining fish populations in California and worldwide (Opperman et al. 2017). During drought, these connections are even more critical. Most notably, these landscape features help to recharge groundwater during wet times, which can then slowly release into rivers and other water bodies during dryer times. Many floodplains are now used for growing crops, meaning solutions will need include work with the agricultural community to reconnect and repurpose these lands, at least temporarily. This can be done in ways that are safe for crops and beneficial to groundwater recharge that enhances streamflow (Sankovitz 2021; California Department of Water Resources 2022). Efforts to reconnect floodplains were underway in 2008, establishing a program for improving flood management, including for the benefit of native fishes and ecosystems (California Department of Water Resources 2012). This effort must be expanded to include other parts of the state, and to include headwater catchments as well as the mainstems of the state's rivers.

6. Standardize and coordinate research and data collection, and improve information on lesser-known species

The state's management focus on a limited number of species extends to monitoring and reporting. While there is extensive information on fall-run Chinook, for example, data on other native coldwater fish species such as mountain whitefish are very limited (Moyle et al. 2017). Monitoring and reporting also tend to focus on economically valuable fish like salmon, while much less is known about smaller and non-commercial fish like sculpins, dace, and splittail. But these species are also critical for the ecosystems in which they exist. California also needs to standardize and coordinate data management and storage across different reporting platforms and between various reporting entities. Furthermore, current data are not being used to make effective water management decisions for fish. In 2021, water managers had sufficient data to recognize the severity of the drought and need for proactive efforts to ensure instream flows, but institutional challenges delayed or prevented needed actions.

California's fish populations are in long-term decline, with many facing extinction. Droughts of increasing frequency and intensity exacerbate this decline, as ecosystem water needs go unmet due to policy and management decisions that de-prioritize freshwater ecosystem health. As this report shows, the current drought is no exception. Fortunately, policymakers and water managers can make changes to improve freshwater ecosystem management and help ensure better outcomes California's streams, fish, and all who rely on and benefit from them.

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APPENDIX 1. DATA AND DATA SOURCES

Table A1. identifies the complete list of data gathered and presented in the report, with complete citations listed in the References section.

Table A1. List of data type, source, and date range included.

DATA TYPE	SOURCE	DATE RANGE
River flow and temperature	University of Washington 2022; USGS 2022a; 2022b; Department of Water Resources 2021	2010-2021
Historical drought periods	California Department of Water Resources 2020	1967-2018
California drought classifications	National Oceanic and Atmospheric Administration (NOAA) 2022	January 1, 2016-May 31, 2022
Percent Egg-Fry Survival	Poytress et al. 2014; Voss and Poytress 2020; Marcinkevage 2022	2006-2021
CDFW Fall Midwater Trawl	Interagency Ecological Program (IEP) 2022	1967-2021
Economic value of CA commercial salmon fisheries, pounds of salmon caught	Pacific Fishery Management Council n.d.	1960-2021
Inflation index	U.S. Bureau of Labor Statistics 2022	1947-2021

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