ENVIRONMENT AND DROUGHT IN CALIFORNIA 1987-1992

IMPACTS AND IMPLICATIONS FOR AQUATIC AND RIPARIAN RESOURCES

Linda Nash

Pacific Institute for Studies in
Development, Environment, and Security
July 1993

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EXECUTIVE SUMMARY

The years 1987 to 1992 comprised the second driest period in California's recorded climate history. For six years, precipitation in the state was only about three-quarters of the recorded average, while streamflow was a mere one-half of the average. Many of the most severe and long-lasting impacts of the recent drought fell on the state's natural environment. Moreover, future droughts are likely to cause still more severe impacts to California's environmental resources.

Drought is a natural phenomenon, which may potentially *contribute* to the stability of ecosystems over the long-term; however, the resistance of species and ecosystems to natural stresses is dependent upon the condition of ecosystems prior to the onset of drought. Highly modified ecosystems, such as those encountered throughout California, are much more likely to suffer permanent changes during extended dry periods. California's plant and animal populations have weathered droughts of comparable severity in the past; yet there are many factors today that prevent wild populations from rebounding from a drought as they once might have. Among the most important are the extremely small size of many populations and the fragmentation of habitats. Small populations are much more likely to become extinct as a result of droughts, while fragmented habitats make it impossible for species to migrate to seek better conditions during drought and also preclude the natural recolonization of areas following a severe drought.

Effects of the Drought on Aquatic and Riparian Resources in California

Overall, aquatic and riparian resources in California fared very poorly during the recent drought. Many species currently listed as threatened or endangered dwindled to perilously low numbers, while declines among several other species have caused them to be proposed for similar listing. The lack of ecological monitoring, however, makes it impossible to know what exactly has been lost during the drought. Although in most cases, the primary factor in the loss of California's native species is habitat destruction, the recent drought accelerated ongoing losses and highlighted how inadequate our past attempts at ecosystem protection and management have been.

<u>Impacts on Spawning Success of Anadromous Fish</u>

- Because most of the state's rivers are regulated by large dams, the drought has resulted in extremely high temperatures in some systems, which in turn have reduced the spawning success of many anadromous fish species. For instance, on the Klamath River, recorded temperatures were as high as 84°F during the fall salmon run, while salmon normally cannot tolerate temperatures above 75°F, and to avoid mortality of eggs they require temperatures of less than 57°F.

- Adverse temperatures were also a chronic problem throughout the Sacramento River system. One estimate places temperature-induced losses among spring-run chinook salmon eggs in the Upper Sacramento River at 50% during 1992.

- The fall run of salmon in the Sacramento-San Joaquin system declined by over 50% between 1989 and 1992. Among the most dramatic declines were seen in the San Joaquin River, where fall-run salmon returns fell from 15,800 fish in 1987 to 600 fish in 1991. Approximately 1,100 fish returned in 1992.

- The winter run of salmon in the Sacramento River reached an all-time low of only 127 adult fish in 1991.

<u>Drought-Induced Loss of Habitat</u>

- Almost all of the state's streams and lakes are subject to either water diversions or ground water pumping; thus, during periods of drought, water availability for plants and wildlife is much less than it would be under "natural" conditions. Several streams and lakes went completely dry during the recent drought.

- The Carmel River did not flow to the ocean for three successive years, making the survival of the river's steelhead trout population primarily dependent upon a captive breeding program.

- Goose Lake in northeastern California, home to four species of endemic fish, essentially dried up during the drought due to low streamflows and diversions of its tributary streams. Populations of lake-dwelling fish were eliminated, and thousands of fish died as they attempted to move up into the lake's tributary streams. As a result, the lake-dwelling form of redband trout and the Goose Lake sucker may both face extinction.

- Seasonal wetlands were reduced in both time and extent during the drought. In the northern part of the state, the Lower Klamath Lake National Wildlife refuge, which depends upon water from the federally operated Klamath River Project, received no water between December 1991 and September 1992; most of this refuge's managed wetlands remained dry throughout water-year 1992.

Success of Exotic Species

- The drought has contributed to long-term changes in the state's natural ecosystems by creating conditions that have allowed exotic species to expand their range. Although the extremely heavy rains that occurred during the winter of 1992-93 may reduce the overall success of these invaders, it is too early to discern what the long-term effects will be in most systems.

- During the drought, exotic benthic species in the Delta region expanded their range. In particular, the Asian clam, *Potamocorbula amurensis*, which established itself in the Delta following the floods of 1986, appears to have displaced the normal dry-period community due to this clam's tolerance for a wide range of salinities.

- In desert regions in the southern part of the state, tamarisk plants extended their range. In addition to displacing native riparian vegetation, these plants consume large amounts of water and contribute to the depletion of both surface and ground water resources in water-scarce areas.

Impacts on Vulnerable Wildlife Populations

- The drought has directly contributed to dramatic declines in several species causing them to be either listed or proposed for listing as threatened or endangered. According to one estimate, the number of native fish fauna in serious trouble increased from 6 (18%) to 28 (38%).

- The drought was a significant factor in the decline of the Delta smelt, recently listed as a federally threatened species.

- At least two populations of the tidewater goby, a fish currently proposed as an endangered species, disappeared during the recent drought.

- The southern steelhead may have been pushed to near-extinction. Current numbers are estimated to be less than 500 fish. Yet the lack of monitoring efforts makes it difficult to assess the strength the remaining population.

Impacts on Water Quality

- The drought, in combination with the operation of the state's water projects, had a significant adverse impact on water quality in the Sacramento-San Joaquin Delta. Water quality standards for salinity were violated in 1990, 1991, and 1992.

- Water temperatures in the Delta were high, frequently the highest ever measured, in late summer and fall. Dissolved oxygen concentrations fell below levels acceptable for anadromous fish on several occasions.

- Flows in Scott Creek (Santa Cruz County) disappeared, causing severe water quality problems in Scott Creek Lagoon, which supports juvenile steelhead, juvenile coho salmon, and the tidewater goby.

In general, our ability to assess the environmental impacts of drought quantitatively is limited by the lack of information. There have been very few efforts to monitor environmental conditions over the long term. Much of the information available on drought impacts is therefore anecdotal. Among the better proxy measures currently available for estimating the impacts of drought on anadromous fish are estimates of egg mortality, the frequency of occurrence of critical temperatures in rivers and streams, and changes in the availability of spawning habitat. There is also the potential to quantify changes in the availability of seasonal wetlands. All of these measures are hindered, however, by the lack of long-term monitoring data.

Environmental Mitigation Efforts

The environmental mitigation program implemented during the recent drought was largely ineffective in slowing the decline of species. The potential of the effort was limited by the fact that additional funds were not available to address drought-related problems until late 1990, nearly four years into the drought. In addition, the lack of drought-contingency plans and monitoring efforts made it difficult to determine which resources were in the most critical condition and what specific efforts should be undertaken.

Overall, the mitigation efforts were heavily focused on the Central Valley, primarily upon waterfowl habitat and anadromous fisheries. A significant portion of the mitigation fund went towards supporting the existing hatchery system, a questionable strategy. This may reflect the traditional bias of the Department of Fish and Game (CDFG) towards, as well as the focus of the public on, "game" species. Although serious impacts were occurring in other regions of the state (e.g., Northeastern California), these areas were bypassed by drought mitigation efforts.

Drought Planning and Policy

Efforts to plan for natural ecosystems in the face of increasing pressures have moved too slowly to avoid dramatic losses. Meanwhile, projected increases in the state's human population guarantee that the next drought will be still more severe. Conflicts over the uses to which limited water supplies should be put are likely to grow more intense. If we are concerned about the resiliency of ecosystems, however, the traditional response to water shortages -- additional storage capacity -- must be viewed more skeptically. Large reservoirs represent a costly investment with few direct benefits for natural ecosystems.

Despite our experience with the recent drought, little or no drought contingency planning is currently ongoing at the state level; thus future droughts, like past droughts, are likely to be viewed as emergencies. While overall improvements in water planning will improve the situation under drought as well as normal conditions, if we continue to consider droughts as emergencies, then existing rules are unlikely to be adhered to. If the risk of drought is to be allocated in a reasonable and fair manner, the procedures for making decisions during a drought must be agreed upon publicly and in advance, not on an emergency basis. This includes decisions about how to manage reservoir storage during periods of low inflow, what minimal environmental protections will be maintained under various conditions, and how and when activities that aggravate drought impacts on plant and wildlife populations (e.g., grazing, logging, ground water pumping) will be curtailed. Moreover, these agreements need to be aggressively enforced during drought.

The results of this work suggest several specific recommendations for drought planning:

- Environmental needs should be adequately represented in long-term drought and water planning, preferably at the administrative level. In particular, a conservation-oriented agency, such as CDFG, should have a lead role in drought and water planning.

- The state should develop an institutional definition of drought. This would allow all parties to agree on when the state, or regions of the state, are experiencing a drought, and would trigger previously identified responses. This is a critical policy need if mitigation measures are to be implemented in a timely manner and if emergency resources are to be tapped.

- Contingency plans for ecosystem protection should be adopted at the state and local levels. These plans should identify critical resources likely to be at risk during a severe drought, as well as a set of potential responses, both short- and long-term. At a minimum, these plans should encompass rules for the management of large reservoir systems and major ground water basins, as well as guidelines that proscribe those activities that significantly aggravate the effects of drought on sensitive populations.

- The state should develop greater flexibility in water management, including water banking and water-transfer options. This offers the best opportunity to reduce both socioeconomic and environmental vulnerability to drought in both the short- and the long-terms.

- The impacts of drought should be adequately assessed and incorporated into the planning process. An independent group should be designated at the state level to standardize methods of drought assessment, to establish priorities for data collection, and to assess the risk that drought poses to specific environmental resources as well as to economic activities.

- Environmental protection and water policy must recognize the need to protect and to restore ecosystems to healthy conditions so that they can withstand prolonged droughts and other natural stresses. In particular, states and localities must seize the opportunity afforded by wetter years to implement longer term management plans and to build up depleted species populations to sustainable levels.

- Finally, there is a need to put more effort into monitoring critical environmental resources and to integrate monitoring programs into long-term management plans as a means of testing and refining management goals. Although the dedication of funds to monitoring is difficult in a period of chronic budget shortfalls, monitoring and research should be viewed as important, long-term investments. Currently the lack of information is appalling, even for recreationally important species such as steelhead. Information for many less-glamorous species is almost non-existent. Many of these species could easily disappear unnoticed in the next dry year.

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INTRODUCTION

Background

The years 1987 to 1992 comprised the second driest period in California's recorded climate history. For six years, precipitation in the state was only about three-quarters of the average, while streamflow was a mere one-half of the recorded average. By 1990, most residents found themselves subject to mandatory reductions in water usage. Farmers saw their surface water supplies curtailed, while ground water aquifers dropped to record low levels. Lakes and streams around the state went dry, often for the first time in recent memory.

Considerable controversy has arisen throughout California over what the impacts of the drought have been. By reducing water availability, droughts may potentially affect many different aspects of the state including agricultural production, industrial output, quality of life, and natural ecosystems. However, the impacts of drought on any one sector are extremely difficult to differentiate from other non-drought-related changes. For instance, agricultural production in any given year is affected by trends in crop prices both nationally and internationally, by other climate variables (e.g., temperature), natural disturbances (e.g., agricultural pests), changing subsidy and incentive programs, decisions made in previous years, and longer term financial conditions in the farm sector.

Similar difficulties exist in trying to assess the impacts of the drought on the natural environment. Ecosystems are not static but dynamic, and over any period of years they are affected by many anthropogenic and natural forces, drought being but one of these. Among the natural forces that shape ecosystems are variations in climate, ecologic succession, natural catastrophes (e.g., volcanoes, avalanches, floods), while among the anthropogenic forces influencing ecosystems are changes in land use, pollution, the introduction of exotic species, and overharvesting.

Yet despite these difficulties, there is a growing need to understand the scope and magnitude of drought effects on natural ecosystems as well as on the state's economy. This is due, in part, to the continued growth of the state's population and the increasing pressure on water supplies, and also to the declining health of many populations of wild species. The purpose of this report is to identify and to document the principal impacts of drought on California's aquatic and riparian resources, to assess the efficacy of the state's efforts to mitigate environmental impacts, and to examine water and environmental conservation policy in the context of drought planning.

Climate and Drought in California

Drought eludes easy definition. In a meteorological sense, drought refers to low precipitation, often referred to as a "precipitation deficit." Often, however, it is streamflow and soil moisture that are of interest, rather than simply precipitation. Thus, drought is more commonly defined based on hydrologic parameters.

For most regions of the state, recorded streamflow data exist from the early 20th century, roughly 90 years. Statewide, both precipitation and runoff were below this recorded average from 1987 to 1992. Even though water-year[1] 1992 produced well above average precipitation across Southern California, amounts in the northern one-third of the state, and especially in the Sierra Nevada, were well below average. Throughout the drought, precipitation was about three-quarters of the average, while runoff was roughly one-half the average. This contrasts with the 1976-77 drought, which was more severe annually but lasted for only two years. In water-year 1977, the most severe on record, statewide precipitation was only 45% of the long-term mean, while runoff was a mere 20% of the mean (Roos, 1992) (Figure 1).

For the rivers flowing through the Central Valley, the recent drought was roughly equal in severity to the drought that gripped the state from 1929 to 1934. This comparison is based on actual streamflow measurements. In the northern region of the state average annual runoff, as represented by the Four-River Index[2], was 10.0 million acre-feet (maf) during the recent drought, compared to 9.8 maf from 1929 to 1934. (From 1976 to 1977 the mean annual value of the Four-River Index was only 6.6 maf.) In the San Joaquin Valley, however, average annual runoff during the recent drought was only 2.7 maf, compared to 3.3 maf during the 1929-34 period (Figure 2).

Longer term hydrologic records have been developed for the Sacramento River Basin based on tree-ring research. These data indicate that the period from 1929 to 1935 was the most severe period of low-flow in the entire reconstructed

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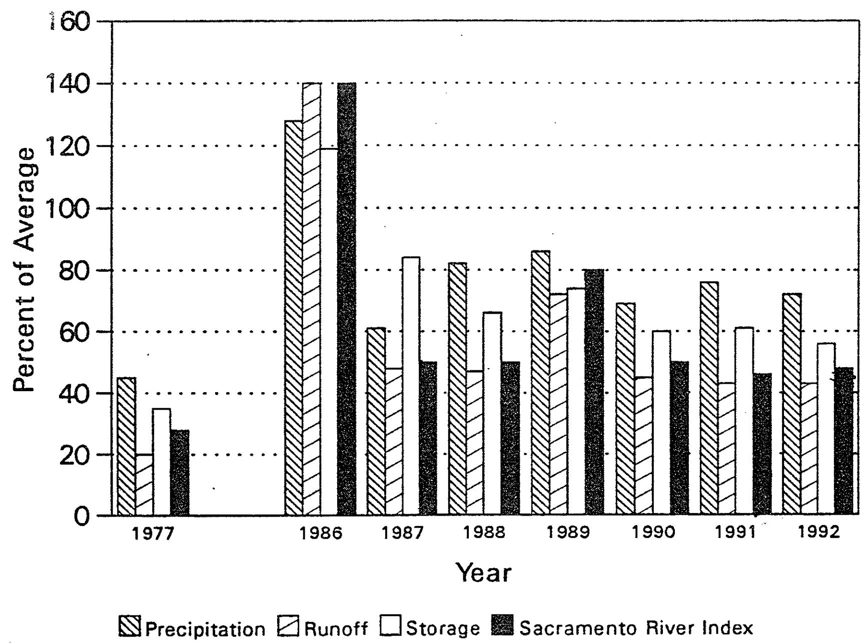
[1]The "water year" runs from October to September. Water-year 1992 begins on October 1, 1991.

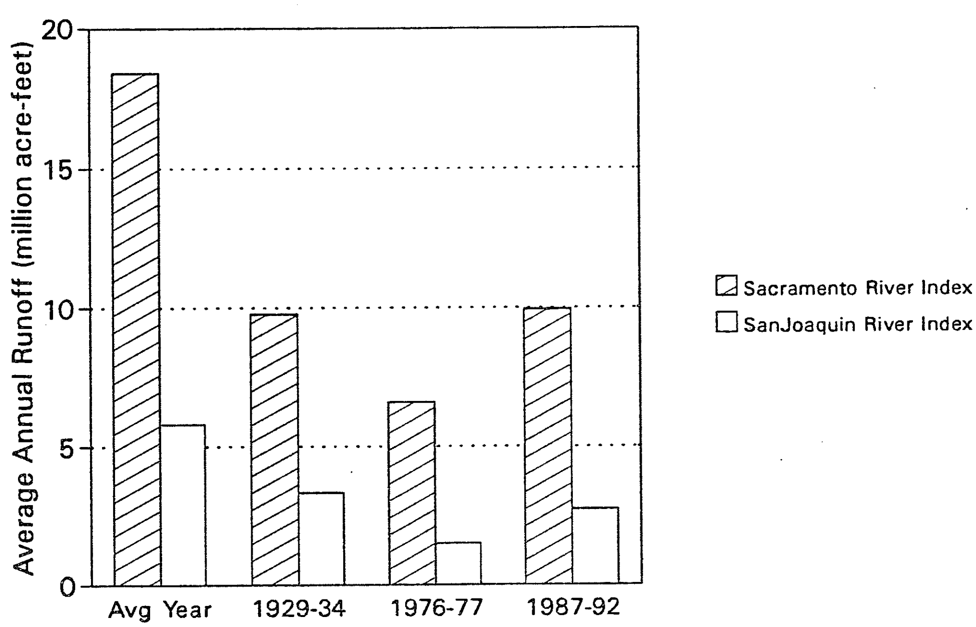
[2]The Sacramento Four-River Index is the summation of annual flows, corrected for diversions and impoundments (i.e., unimpaired flows), of the Upper Sacramento, Feather, Yuba, and American rivers.

Figure 1: Summary of Statewide Hydrologic Data on October 1



Source: CDWR

Figure 2: Comparison of Major California Droughts



Source: Roos, 1992

period, since 1560. However, several other periods of extended low-flow have occurred historically. For instance, the longest severe drought occurred during the period of the late 1830s and early 1840s, although individual years were not the most severe (Earle and Fritts, 1986). Moreover, the extremely severe 2-year drought of 1976-77 has no analogue in the tree-ring record. Using tree-ring data, Loaiciga, et al. (1992) estimated the "recurrence interval" of a 3-year period with below-median streamflow to be 15 years for the Sacramento River Basin. Also interesting is the fact that the last 150 years appear to have experienced more years of above-average runoff. Of course, this time period also corresponds with the historical settlement of California and may have conditioned perceptions of drought in the region (Stockton, et al., 1991).

Longer term precipitation (but not streamflow) records have been developed from tree-rings for the central coast of California by Michaelson et al. (1987). These records show that four of the five driest periods since 1600 occurred before streamflow measurements were initiated. Among other things, this record shows that the early 20th century was an anomalously wet period in the region, and that climatic variability in the mid-20th century has been relatively low compared to the long-term record. A long-term reconstruction of statewide precipitation similarly shows a relative increase in precipitation since 1900 (Fritts and Gordon, 1980).

In general, the climate of California is extremely variable and subject to wide variations in precipitation and streamflow. There are some indications that the middle of the 20th century has been somewhat less variable climatically than other periods. Moreover, droughts are a recurring feature of the regional climate, although the probability of experiencing a drought of a given severity is difficult to estimate given the existing data and our limited understanding of climatic processes and streamflow distributions.

Water Management During the Drought

In response to the variability of the region's streamflow, numerous dams and reservoirs have been constructed throughout the state to store water. Every major river in the state, with the sole exception of the Smith, holds a large dam. The state has 155 major reservoirs that have a combined capacity of over 37 maf. In addition, Southern California receives stored water from the Colorado River system.

The principal in-state reservoir systems are the State Water Project (SWP) and the federal Central Valley Project (CVP). These projects store water from the northern half of the state and deliver it to the southern half, via the Sacramento-San Joaquin Delta. The SWP, operated by the California Department of Water Resources (CDWR), has its principal reservoir (Lake Oroville) on the Feather River, which supplies water to both agricultural and urban users in the southern half of the state. The principal reservoirs of the CVP, operated by the U.S. Bureau of Reclamation (USBR), are the Shasta-Trinity reservoir complex, a massive system that bridges two basins and has a combined storage of more than 7 maf, and Folsom Lake, with a capacity of 1.1 maf on the American River. Other large reservoirs in the CVP system include New Melones and Friant Dam/Millerton Lake, both located in the San Joaquin Valley.

The North Coast rivers are regulated by the federal Klamath River Project, which operates seven reservoirs in northern California and southern Oregon to supply water to roughly 240,000 acres of irrigated agriculture. In comparison to the Central Valley projects, the Klamath project contains relatively small amounts of storage, approximately 1.2 maf.

In addition to state- and federally-operated projects, several water projects have been built by localities. These include the Hetch-Hetchy system on the Tuolomne River (San Francisco), Camanche and Pardee reservoirs on the Mokelumne River (East Bay Municipal Utility District), and the Los Angeles Aqueduct system, which transports water from the Eastern Sierra and the Owens Valley to Los Angeles. Many regions of the state also rely heavily on ground water, including the central coast and the southern San Joaquin Valley.

During the recent drought, the management of reservoirs became a highly contested issue, as decisions about deliveries to users (agricultural and urban contractors) had potentially severe ramifications for wildlife, principally fisheries and other aquatic resources in the Sacramento-San Joaquin system. Water management decisions have several implications for environmental resources:

- Wildlife refuges and private wetlands in the Central Valley are almost wholly dependent upon surface water delivered through the water projects.

- The management of reservoirs determines the extent to which cold water, necessary for successful spawning, will be available for migrating fish.

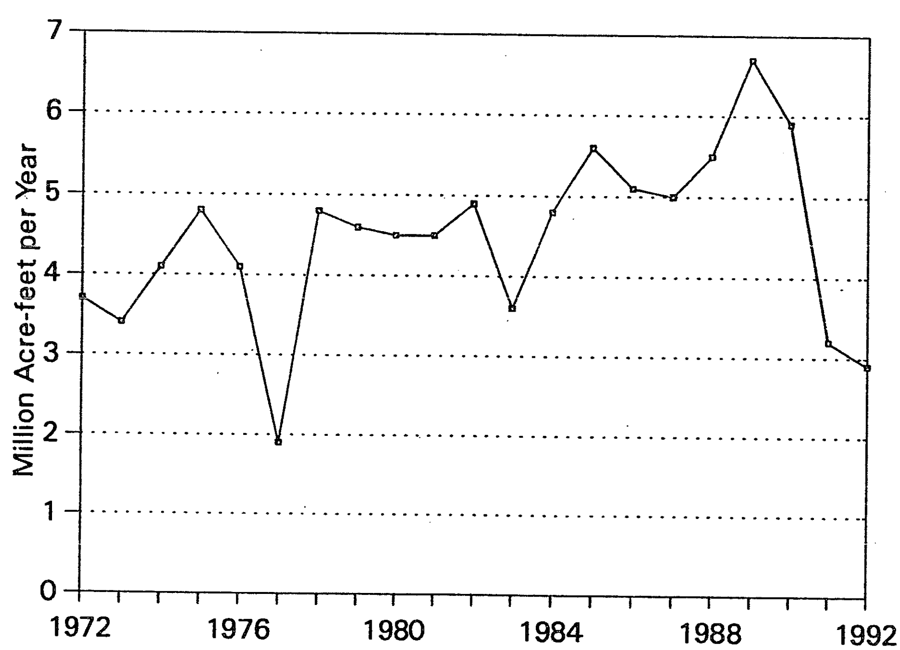
- Sudden and extreme fluctuations in flow are extremely detrimental to fish and other aquatic life.

- In the Sacramento-San Joaquin Delta, the amount of freshwater that is allowed to flow through the Delta and out to sea affects estuarine water quality and productivity and is linked with the success of several fish species. The pumping of water out of the Delta region ("exports") for delivery south may reverse flows in the region, increase salinity, and entrain juvenile fish, particularly when inflows into the Delta are low.

At the beginning of the drought, storage in major reservoirs was approximately 28.2 maf. By November of 1992, storage had declined by almost 60%, reaching a nadir of 11.8 maf. In the early years of the drought, water deliveries by the SWP and CVP were not reduced or curtailed, and reservoirs were drawn down under the assumption that storage would be adequate to meet existing needs. Overall exports out of the Delta had increased substantially during the 1980s and continued to do so until 1990 (Figure 3).

The first cutbacks to water-project contractors were implemented in 1990, at which time CVP storage was roughly 50% of the desired carryover and SWP storage was 50% of its historic average. In 1990, the CVP cut deliveries to urban and agricultural users by 25% and 50%, respectively; the SWP cut deliveries to agriculture by 50%, but maintained full deliveries to urban areas. In 1991, reductions were more severe. The CVP cut deliveries to urban areas by 50% and to most agricultural contractors by 75%; the SWP cut urban deliveries by 70% and made no deliveries to agriculture. In 1992, deliveries were increased somewhat.

Figure 3: SWP and CVP Delta Exports, 1972-1992



Source: CDWR

The CVP provided urban areas with 75% of their historic use, but retained 75% cutbacks to most agricultural users; the SWP eased its reductions to 55% for both urban and agricultural contractors. The Klamath River Project imposed the first cutbacks to users in 1992.

During the drought, requirements for carryover storage -- that is, the amount of water that is retained in reservoirs for use in following years -- were reduced by both the CVP and the SWP in order to allow greater deliveries to users and to reduce the potential economic impacts of the drought. The continued drawdown of project reservoirs ultimately resulted in less cold water being available for anadromous fish, with the resulting temperatures on some rivers being too high for successful spawning.

Given the large amount of reservoir storage that exists in California, moderate droughts of short duration pose little threat to most agricultural and urban water users. One critically dry year, such as 1987, creates little measurable hardship. Thus, from the perspective of planners and policymakers, what is of concern is when decreases in water supply (i.e., streamflow) begin to impose significant social and environmental costs. This is one definition of "socioeconomic" or "societal" drought (USACOE, 1991). As population and water demand increase, however, our vulnerability to meteorological drought also increases, particularly if we do nothing to increase our flexibility.

Organization of This Report

This report is organized into five sections. In the following section, general information on the impacts of drought is presented and questions about the role of disturbance and ecosystem resiliency are addressed based on the existing scientific literature; subsequently, factors that potentially decrease the resiliency of ecosystems in California to drought are presented. In Chapter 3, examples of resources at risk during the recent drought are presented and quantitative measures of drought impacts are presented and discussed. Chapter 4 describes and assesses the state's environmental mitigation program undertaken during the drought. The final chapter discusses drought planning from an environmental perspective and describes what needs to be done to ensure the protection of ecosystems in a future drought.

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ENVIRONMENTAL IMPACTS OF DROUGHT: GENERAL OVERVIEW

Background

The existing literature that directly addresses the impacts of drought on aquatic and riparian ecosystems is sparse. In part, this reflects the difficulty of studying impacts that occur gradually, over relatively long periods of time. Most research programs are designed to be of relatively short duration, usually less than three years, which is partially due to the constraints of funding (Resh, et al., 1990). Similarly the emphasis of governmental wildlife programs has traditionally been on the management of fish and game resources rather than on longer term monitoring of ecological conditions. In addition, it is extremely difficult to disaggregate the impacts of drought from other significant factors that affect natural communities. The continued growth in human population and rapidly expanding urban development during the last decade have put natural ecosystems in a continual state of flux as they respond to numerous external threats, making it impossible to delineate a quantitative and consistent baseline from which to measure drought impacts.

Ecologic theory suggests that environmental variability may be a positive force in maintaining the stability and diversity of natural ecosystems. In particular, community ecology now recognizes the importance of "disturbance" in ecosystem functioning. Disturbance may be generally defined as "any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett, 1985).

Earlier theoretical work in ecology presupposed that ecosystems existed in an equilibrium state, with a constant or near-constant environment. Yet more recent ecological models have recognized the importance of environmental variability to ecosystem stability. For example, the "intermediate disturbance hypothesis" suggests that it is important that disturbances occur at a high enough frequency and intensity to keep competitively dominant species from eliminating competitively inferior ones, yet low enough to prevent the elimination of species through environmental stress. Thus, this hypothesis predicts that intermediate levels of disturbance lead to maximum species richness (Connell, 1978). A related model proposed by Huston (1979), the "dynamic equilibrium model," describes community structure as a tradeoff between growth rates, rates of competitive exclusion, and the frequency of population reductions. This model assumes that diversity is determined not as much by the relative competitive abilities of the competing species as by the influence of the environment on the outcome of species interactions.

Because they occur over relatively long periods of time, droughts differ from more discrete disturbances such as floods or logging. Yet much like floods, droughts represent natural environmental variability and may play an important role in promoting ecosystem stability and diversity. At the least, droughts are not necessarily harmful to natural communities although they have the potential to alter relationships among species over both the short- and long-term.

Impacts Identified in the Literature

Among the better studied aspects of drought is the impact of persistent low flows and drying on aquatic insect communities. The effects of drought on aquatic insects have been studied in conditions ranging from reduced discharge (Iversen, et al., 1978; Pearson, 1984) to intermittent flows (Hynes, 1958; Larimore, et al, 1959) to complete loss of aquatic habitat (Resh, 1982). Overall, these studies have shown that when flow is reduced, densities of some taxa decrease (e.g., rheophilic forms, passive filter feeders) while others increase (e.g., detritivores, silt-tolerant forms).

Invertebrate species may survive droughts through a variety of mechanisms including migration, delayed hatching, and burrowing into the substrate. However, even species that disappear during a drought may recolonize a stream rapidly through drift, upstream migration, or aerial recolonization. In general, the resumption of flow is usually accompanied by a rapid recolonization of biota, usually in less than one year (Niemi, et al., 1990). Yet although pre-disturbance organisms may reappear relatively quickly, more detailed investigations have suggested that complete recovery is more gradual. For instance, Resh (1990) observed that the macroinvertebrate community in a California stream required nearly 10 years to reestablish its pre-drought population-age structure.

One permanent change often facilitated by drought is the appearance of new species. For instance, several investigators have noted the appearance or an increase in abundance of *Asellus aquaticus* during drought conditions. This species is well-adapted to intermittent streams. It is able to survive in water-saturated air for long periods and moves into the substrate to avoid dessication. Similarly, the leech *Helobdella stagnalis* may expand its range during drought conditions because of its ability to produce two generations per breeding season under favorable conditions, such as reduced competition during drought periods (Extence, 1981).

General impacts of drought on fish include loss of stream habitat, adverse effects of increased stream temperatures and decreased dissolved oxygen concentrations on growth and survival, impacts on food supply, and increased competition, particularly from introduced species. The literature, however, is extremely limited. Most impacts must be inferred from modeling and laboratory studies that are based on limited field measurements.

One potential impact is permanent changes in fish assemblage (i.e., the composition and relative abundance of species in the fish community), as noted by Grossman, et al. (1982) for Otter Creek in Indiana. They concluded that environmental fluctuations could cause unpredictable changes in stream-fish assemblage. However, these conclusions have been challenged by other investigators. For instance, Erman (1986), studying the long-term structure of fish populations in the Sierra Nevada, found that over most of the stream course, fish populations had been stable or resilient, in spite of years with both extremely high and extremely low runoff. Although a sequence of drought years appeared to have eliminated brook trout (*Salvelinus fontinalis*), these fish had recolonized the area within 4 years. Depressed year classes were observed after drought and floods but with no major shifts in species abundance. The only departure from long-term stability of fish populations in Sagehen Creek occurred at the lower two sections, which were influenced by a reservoir. The presence and fluctuating level of the reservoir seems to have created conditions that favor some species in the stream but gradually lead to extinction of others in the reach above the reservoir. Speckled dace, mountain whitefish, and brook trout have all become very rare in the reservoir-influenced section, while Tahoe sucker populations have expanded dramatically. More recently, a 10-year study of the fish in Martis Creek, in the Sierra Nevada found that fish community structure did change in response to flood disturbance; however, these authors concluded that the fish community was moving between different equilibrium points (dynamic equilibrium) rather than in a purely random manner (Strange, et al., 1992).

Another potential impact of drought on ecosystems noted in the literature is the reduction of nutrient loads to aquatic ecosystems. Hough, et al. (1991) studied the macrophyte community in a chain of lakes in southeastern Michigan and found that the submersed aquatic plant community of eutrophic Shoe Lake changed qualitatively and quantitatively to one more similar to that of the less productive East Graham Lake, downstream in the chain. In Shoe Lake, the previously dominant non-rooted species declined along with phytoplankton biomass, and the abundance and diversity of submersed rooted plants increased. During the drought, the concentration of total phosphorus in these waters remained at eutrophic levels; however, the limited availability of total inorganic nitrogen became more critical, causing nutrients to become limited, decreased phytoplankton growth, and greater light availability. Yet other work has shown that nutrient concentrations increased as the result of reduced lake outflow (Schindler, et al., 1990). Thus, the impact of drought on lake systems is variable and highly dependent upon geomorphological features.

Regionally, several investigators have focused on the impact of low-flow years on the ecology of San Francisco Bay and the Sacramento-San Joaquin Estuary. In northern San Francisco Bay, drought conditions during 1976 and 1977 caused dramatic changes in both the phytoplankton and benthic (bottom-dwelling) communities. Recent dry years (1977 to 1981) caused a decline in the density and diversity of the phytoplankton community in Suisun Bay and the Delta, although extremely high rainfall in 1982 temporarily shifted the phytoplankton community back to a more diverse population. Reduced river flow has resulted in increased sea-water intrusion and the upstream movement of marine centric diatoms, and the upstream movement of the entrapment, or mixing, zone. The mixing zone is a region of high concentrations of both nutrients and suspended particulates; it forms where the upstream marine currents are balanced by the downstream freshwater currents. Large phytoplankton species such as *Skeletonmea costatum* are more common when the mixing zone is located in Suisun Bay rather than in the upstream river channels. During low-flow years, blooms in the central Delta have been dominated by *Melosira granulata*.

The possible mechanisms for reduced phytoplankton biomass include the limited light available to phytoplankton in deeper (upstream) water. In addition, Nichols (1985) proposed that the migration of suspension-feeding estuarine benthos, such as *Mya arenaria*, provided the potential for the removal of large amounts of particulate material, including phytoplankton cells, from the shallow water column. Moreover, the disappearance of phytoplankton from Suisun Bay may have affected higher trophic levels by reducing food supply for striped bass (*Morone saxatilis*). The implication is that any prolonged period of low river flow in the estuary will lead to a shift from a pelagic (water-column) to a benthic (bottom-dwelling) food web in which energy is passed directly from the primary producers in the water column to the benthos. During such periods the abundance of pelagic consumers (e.g., fish, shrimp) might be expected to decline.

Potentially permanent changes in the benthic community of San Francisco Bay have been documented by Nichols, et al. (1990). Normally the benthic community oscillates between wet- and dry-period communities, with the latter actually being more diverse as species that favor higher salinity water migrate further up the estuary. However, the drought has aided the establishment of an exotic Asian clam, *Potamocorbula amurensis*. This species was able to establish itself following dramatic flooding in 1986 which depopulated the benthic community. This species is also tolerant of a wide range of sediment types and salinities ($<1\%$ to $>30\%$). Thus far, the normal dry-period community has not reestablished itself, and the clam's ability to tolerate low-salinity water as well suggests that the benthic community may be permanently altered.

The drought has also been a significant contributing factor to the decline of the Delta smelt, recently listed as a federally threatened species. The smelt is adapted to living in association with the mixing zone of the Sacramento-San Joaquin estuary, where it feeds on copepods and other zooplankton concentrated there. Because it has a limited range, a one-year life cycle, low fecundity, and planktonic (floating) larvae, the species is unusually sensitive to estuarine conditions. The combination of reduced freshwater inflows (drought) and increased water exports has shifted the location of the mixing zone from Suisun Bay to the river channels. This shift of the mixing zone not only decreases the amount of suitable habitat for Delta smelt but also results in decreased phytoplankton and zooplankton abundance (Moyle, et al., 1992, Arthur and Ball, 1979).

Limited information exists on the impact of drought on riparian plant species, although several investigators have examined the impact of river regulation and water diversions. Pelzman (1973) studied the causes of riparian plant encroachment into streambeds below dams in northern California. He demonstrated the significance of fluctuations in stream height to the successful establishment of riparian species and concluded that establishment was limited by declining spring and summer flows under natural streamflow regimes.

McBride and Strahan (1984), in a study of seedling survival on gravel bars, observed drought-induced mortality of seedlings, particularly in areas more elevated from the streambed and presumably further from underground water sources. More generally, seedling establishment of Fremont cottonwoods (*Populus fremontii*) and willows (*Salix* spp.) in the Sacramento River region is restricted almost entirely to gravel bars because establishment patterns have been altered by flood control and water-resource development.

In riparian communities, drought resistance is species dependent, but generally drought stress works selectively against young and old trees. Rood and Mahoney (1990) studied the impacts of flow regulation and drought on riparian poplar forests in western prairie regions. They noted that earlier investigators had documented widespread mortality of poplars during the severe drought of the 1930s. More generally, they found that natural variations in flow provide poplars with an interval for hardening during which their drought tolerance gradually increases. An abrupt shutoff of water or severe drought may eliminate this hardening. Moreover, the regulation of rivers and streams has contributed to a general decline in forest replenishment, making the loss of trees during drought a more serious concern. The elimination of spring floods through river regulation leads to the downgrading and channelization of the river bed, and the steeper embankments that result are less suitable for poplar establishment. The authors noted that there was no evidence of forest recovery within 40 km of two dams in the Rocky Mountain foothills of Alberta. Similarly Rood and Heinze-Milne (1989) used aerial photography to document a 23-48% reduction in riparian forest cover over a 20-year period in response to the damming of several rivers in southern Alberta.

Smith, et al. (1991) examined the impact of streamflow diversions on riparian vegetation on Bishop Creek in the eastern Sierra Nevada. At low flow sites, they found that leaf size and leaf area were reduced while leaf thickness increased in all studied species (water birch, *Betula occidentalis*; black cottonwood, *Populus trichocarpa*; Fremont cottonwood, *P. fremontii*). Changes in physiological behavior were generally more pronounced for juvenile trees of each species, indicating that early life stages are particularly vulnerable to low-flow conditions. A probable consequence of this would be senescence of the community over the short term followed by changes in community structure and/or shrinkage of the riparian corridor over the long term. Several other studies have shown a shift in the age structures of riparian populations as a result of the inhibition of seedling establishment. For example, Schlesinger and Jones (1984) showed Mohave Desert shrub vegetation to exhibit reduced density and increased aggregation as a function of long-term diversion of surface runoff.

Fenner, et al. (1985) studied Fremont cottonwoods on the Salt River in Arizona, and also found that river regulation had inhibited cottonwood regeneration. The flows expected in the absence of dams would be of higher volume, reduced duration, and earlier in the season than would flows observed with dams in place. The result is less flood plain inundation. In addition, summer flows are maintained at fairly high levels until the fall, when Fremont cottonwoods enter dormancy. Thus, under the regulated flow regime, a large winter/spring flood does not normally occur. No alluvial seedbeds are created as a result of reduced sediment availability and the smaller magnitude of river flow. In addition, water levels do not gradually recede to leave a moist substrate for seed germination.

Thus, changes associated with stream diversion are likely to result in reduced leaf areas of riparian communities, a shift toward aging populations with little successful recruitment of juveniles, increased invasion by particular riparian taxa (such as *Artemisia tridentata* and *Rosa woodsii* along Bishop Creek) and, in the longer term, a possible loss of riparian species from diverted streamside environments (Smith, et al., 1991)

In summary, drought can be viewed as a "disturbance," which may potentially *contribute* to the long-term stability of ecologic communities, based on the predictions of ecologic theory. Natural systems generally recover quite quickly to pre-drought conditions, although there exists some potential for long-term changes. However, the resistance of species and communities to adverse conditions is dependent upon the conditions that exist prior to the onset of the drought. The question of what makes certain communities more robust remains unanswered, although several investigators have noted that highly modified habitats are more likely to experience permanent changes as a result of drought. Furthermore, droughts may encourage the invasion of exotic species, which may permanently alter the abundance and diversity of species in some systems. Ultimately the ability of species to recover to pre-drought abundance levels may be adversely affected by several factors, including the ability of species to regenerate/reproduce in modified habitat conditions, the ability of small populations to survive the disturbance, and the ability of a given population to remain genetically viable.

Managed Ecosystems

Managers need to consider the resiliency of individual systems to unpredictable disturbances such as severe drought, rather than assuming that natural communities in arid regions are necessarily "adapted" to climatic fluctuations. While natural communities may be expected to recover from drought in most cases, the rate and the extent of that recovery will depend upon pre-drought conditions.

Unlike agricultural and urban water uses in California, most environmental needs for water are not buffered against drought through the presence of large reservoir storage systems. Although in some cases environmental water needs are met primarily through storage (e.g., the Central Valley seasonal wetland habitats), many other environmental resources remain vulnerable to year-to-year variations in climate. In the most narrow sense, droughts are not a threat to California's ecosystems but are a natural phenomenon to which most of the state's plants and animals are well adapted. Yet California's ecosystems are far from existing in a natural state.

In addition to natural variations in climate, environmental resources have been subject to many other threats. Among these are changes in land-use and habitat degradation, water-project development and water diversions, overharvesting (hunting, commercial and recreational fishing, logging), water pollution (including municipal and industrial effluents, non-point water pollution, sedimentation from logging and land development, agricultural drainage), air pollution (tropospheric ozone, acid deposition), and global atmospheric change (ozone depletion, global warming).

Aquatic and riparian resources in the state have been tremendously altered by the construction and operation of the water-supply and distribution systems on which we have become so dependent. As a consequence, aquatic and riparian ecosystems are no longer "natural" but exist only in a highly managed and perturbed state. For instance, the annual distribution of streamflow on most regulated rivers, including the Sacramento, has become much flatter: high spring runoff is captured in reservoirs and low fall runoff is augmented with stored water. River regulation not only affects the migration and spawning success of anadromous fish, but also affects riparian vegetation and riparian-dependent species. For instance, the lack of spring floods prevents plant species such as the Fremont cottonwood from germinating. Few of the once abundant natural seasonal wetlands remain in the state; instead, wetland areas are intensively managed public and private refuges that depend upon water delivered through the state and federal water projects. Native fish populations have been affected not only by the construction of dams, but also by the introduction of hatchery fish, which may interbreed with wild fish and compete for spawning space and food.

Past decisions have thus rendered California's ecosystems highly managed and, in many cases, distinctly "unnatural." But such altered systems require management not only during periods of average rainfall, but more particularly during drought. There are many factors today that prevent wild populations from rebounding from a drought as they once might have.

Habitat Fragmentation and Isolation: Historically, if populations were locally eliminated by an extreme event in one area, that particular area could be repopulated through the migration of individuals from adjoining areas. Today, in the most extreme cases, once widely distributed species are confined to a few highly localized areas, such as the unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*), a small fish that is now found only in an 8-mile section of the Santa Clara River. In many other cases related populations are completely isolated from one another, thus the potential for natural recolonization following a drought or other extreme event has been eliminated. In addition, where habitats remain intact, populations are able to migrate to seek adequate food supplies or better circumstances when environmental conditions become critical. For instance, the fish in Goose Lake, in northeastern California, have survived previous droughts by moving up into the streams which feed the lake; today, fish passage into these streams is blocked by numerous small diversion dams.

Small Population Numbers: At least 75 species of plants and animals have become extinct in California (Jensen, et al., 1990; Moyle and Yoshiyama, 1992). An additional 328 species are recognized by either the state or the federal government as being threatened or endangered (CDFG, 1991). Dozens of other species are recognized as being in danger, and numerous petitions for federal listing under the federal Endangered Species Act are pending. Many of the species now recognized as being in trouble were once among the most-abundant species in the state, e.g., the spring-run chinook salmon. Small, restricted populations may become extremely sensitive to environmental variability and highly vulnerable to extinction (Pimm, et al., 1988).

Decreased Genetic Diversity: Once populations become small, the species may also suffer from the adverse effects of limited genetic diversity. In addition, commercial and recreational fish species are susceptible to the dilution and loss of specific traits that adapt them to the local environment as a result in interbreeding with hatchery fish. Decreases in the genetic diversity of wild species may ultimately make them less well-adapted to natural variations in the regional climate and thus more vulnerable during periods of extended drought.

Introduced Species: In some systems, introduced species have proven adept at exploiting ecological conditions during drought events. For instance, certain exotic species may be particularly well-suited to warmer water temperatures or higher salinities that may accompany droughts in specific systems, while other exotics may simply be more tolerant of stressful conditions. In some cases, these exotics become so well-established that their populations decline only marginally once dry conditions abate. Thus, they may cause permanent changes in aquatic and riparian communities. Moreover, many introduced fish species in California are predators of native fish as well as native amphibians.

In addition to the concerns noted above, the obvious impacts of drought on natural resources in California today are more severe than they were previously. With the exception of very high elevation regions, no watershed in California is free from water diversions or ground water pumping. Streams and lakes that would have dried up naturally now dry up sooner and stay dry longer. Similarly, large reservoirs aggravate the temperature problems that most anadromous fish species would face under natural conditions by blocking access to cooler upstream waters and by delaying the natural cooling of river temperatures.

Given this situation, we first need to recognize the problems created by heavy intervention in natural systems. These disturbed systems will ultimately require more complicated and more intensive management, particularly during periods of stress. Secondly, we can no longer rely confidently on the "resiliency" of native species and ecosystems. Native species are highly adapted to drought and most have presumably survived a drought of equal severity that occurred only about 65 years ago; but most of the complicating threats that species now face have appeared in the interim since 1930. Drought underscores the value of protecting the integrity of the region's natural ecosystems, so that we are not forced to manage individual species and systems so intensively.

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EFFECTS OF DROUGHT ON AQUATIC AND RIPARIAN RESOURCES IN CALIFORNIA

Background

Little information that illustrates the impacts of the recent drought in California has yet appeared in published scientific literature. This is a function not only of the length of time required for most research to reach print, but also the more general problem of differentiating drought impacts from other, ongoing effects. More generally, most field research in ecology and biology is necessarily of limited duration and frequently not enough data exist to differentiate dry-year patterns of change and the extent of post-drought recovery (Resh, et al., 1990). Drought has rarely been the subject of field-research projects, and, consequently, drought impacts are often cited only indirectly.

This report relies heavily on the observations made by wildlife resource managers. In many instances, managers have been collecting data locally that can be used to assess, or at least to suggest, the impacts of drought on particular resources. In other instances, field biologists have made long-term observations of the condition of resources, although their observations may be qualitative rather than quantitative. While there are problems associated with relying on this type of information, it nonetheless provides useful insights into the types and magnitude of drought impacts that have occurred. Moreover, the inadequacies of the existing data point out the areas in which we need to improve our monitoring and evaluation efforts if we are to truly understand how drought affects the region's natural environment.

Despite these limitations, it is imperative that we begin to identify critical drought impacts so that we can make decisions about risk allocation and plan for future mitigation efforts. The fact that little information was collected on the environmental impacts of the 1976-77 drought has led, on occasion, to the erroneous conclusion that no serious impacts occurred.

In putting together this report, an effort was made to contact people throughout the state to identify impacts across regions and type of resources. Yet the information presented here is necessarily incomplete. Some regions of the state are much more thoroughly covered than others, which reflects the greater availability and accessibility of information for those areas. Some areas that experienced severe impacts are undoubtedly under-reported here. The intent is to provide representative information, both anecdotal and quantitative, in order to document the principal impacts on aquatic and riparian ecosystems and to identify regions and resources potentially at risk from drought.

In the sections that follow, the basic categories of drought-related impacts observed in California are described. Subsequently, examples of observed impacts are provided with available data, organized by region. For the purposes of this report, the state has been divided into six regions: Central California, the North Coast, Northeastern California, the Central Coast, Southeastern California, and the South Coast. The state's principal rivers and lakes are shown in Figure 4.

Categories of Drought Impacts

The impacts that have been observed during the recent drought may be roughly divided into four categories.

> *Complete Loss of Habitat:* In localized regions, aquatic habitats were completely lost during the drought, if only temporarily. This was true for mountain streams in Southern California, vernal pools throughout the state, and for terminal lakes, such as Goose Lake in the northeastern corner of the state. In many cases, the infrequent drying of aquatic habitats is to be expected. However, in most cases, water diversions combined with decreases in streamflow to eradicate habitats that otherwise would have persisted in a partial state throughout the drought.
>
> *Decrease in Habitat Availability:* Diminished flows reduced the quantity of available habitat in every stream and river throughout the state. Habitats were decreased in time as well as space, as annual springs and streams dried sooner and favorable spawning/nesting conditions were available only for much shorter periods. For instance, the quantity of seasonal wetlands decreased dramatically in certain regions, restricting avian populations to smaller areas for reduced periods of time. In streams and rivers, spawning habitats were dramatically reduced, so that in some instances fish were observed laying eggs on top of existing redds (nests).
>
> *Degradation of Habitat Conditions:* Drought adversely affected habitats in numerous ways. Perhaps most obvious was the decreased

Figure 4: Map of California Showing Principal Rivers and Lakes

water quality in aquatic systems. This includes increases in stream temperatures, decreases in dissolved oxygen, increases in pH, as well as increases in salinity in the Delta and other coastal estuaries and lagoons. Similarly, the quality of wetland habitats decreased, as less water was used to flood areas and less water-intensive grasses were planted. The water quality in wetland areas was also decreased, particularly towards the end of the season as the concentration of salts and other minerals increased. Throughout the state, drought-induced degradation combined with other adverse impacts (e.g., logging, grazing) to accelerate declines in the population of many species.

Interference by Exotic Species: Evidence of the relative success of introduced species during the drought has been noted in several regions of the state. Examples range from riparian plants (tamarisk) to benthic invertebrates (Potamocorbula amurensis) to fish (green sunfish). Although the extremely heavy rains that occurred during the winter of 1992-93 may reduce the overall success of these invaders, it is too early to discern what the long-term effects will be in most systems.

Miscellaneous Impacts: Drought made certain species more vulnerable to poaching, notably summer steelhead. In addition, predation on aquatic species by reptiles, birds, and mammals became a major problems in local areas, particularly in areas were fish were restricted to small pools or drying lakebeds.

This report focuses on native species. Although introduced species are numerous, and often important recreationally (e.g., striped bass, brown trout), native species are likely to be better indicators of the overall state of California's ecosystems. Native species are genetically adapted to the variability of California's climate, as well as to the unique riparian and aquatic communities that exist in the state. Recently, several investigators have suggested that California's ecosystems should be managed to promote native species (e.g., Moyle and Ellison, 1992; Swift et al., 1993).

Most of the impacts described here relate to fisheries simply because information on fisheries is the most readily available. In addition, the state of fisheries may be considered an indication of the condition of the entire aquatic ecosystem. Several fisheries fared extremely poorly during the drought. Two species of fish were declared threatened under the federal Endangered Species Act (winter-run chinook and Delta smelt), while petitions for two additional estuarine species were submitted (longfin smelt, Sacramento splittail), with the request that the entire Delta be considered an "endangered ecosystem." Other species are likely to follow (e.g., southern steelhead). Salmonid numbers declined dramatically, particularly in the later years of the drought. Impacts on other fisheries (e.g., golden trout, Lahontan cutthroat trout, Clear Lake hitch) were observed throughout the state. Several local fish populations are likely to have been eradicated during the recent drought (e.g., the tidewater goby in Redwood Creek).

Although information is much sparser than for fish, native amphibians have also suffered during the drought, principally through the elimination of ephemeral breeding sites. The Santa Cruz long-toed salamander suffered dramatic declines in recruitment, which were attributed to the loss of its freshwater habitat in coastal woodland and chaparral. In the Eel River system, the introduced bullfrog (*Rana catesbiana*) has expanded its range, and apparently has displaced native species including the yellow-legged frog and the red-legged frog.

Impacts on birds are much more difficult to assess because these species are so wide-ranging. While the drought did affect the quantity and quality of available waterfowl habitat, the links to impacts on species are much more difficult to draw. But drought impacts on birds are not limited to waterfowl. The bank swallow, a threatened species that breeds in California primarily along the upper Sacramento River, is believed to have been severely affected by the drought (CDFG, 1991a).

Native plant populations have also declined. This has been a particular concern because of the number of plants that are near extinction in California and their limited range. Most vulnerable are those plants that occur in marshes, wetlands, and vernal pools. Many of these habitats were either severely restricted or temporarily erased during the drought. In addition, many riparian plant populations were further affected by increased grazing pressure and increased water diversions.

Effects on Aquatic Resources

Central California

Central California is defined by the Sacramento and San Joaquin Rivers, which together drain an area of over 40,000 square miles. The aquatic and riparian resources of this region are both highly varied and unique. This area encompasses the west side of the Sierra Nevada mountains, with its numerous streams, the wetland regions of the San Joaquin Valley, the watershed of Clear Lake in Lake County, the Sacramento-San Joaquin Delta, and San Francisco Bay. With the exception of the southern California coast, this region is also the most highly modified. Both of the major rivers are completely controlled by dams and waterworks, as are many of the principal tributaries. The centerpiece of this massive water-supply system is the Sacramento-San Joaquin Delta, in which environmental conditions are determined as much by water demands to the south as they are by seasonal precipitation.

Given this situation, drought affects the aquatic and riparian resources of the lowlands of Central California indirectly, through its effect on water-project operations. Frequently when we speak about the "environmental impacts of drought," what we are actually addressing is reservoir management under the constraints of drought.

Chinook Salmon: Salmon runs in the Central Valley declined dramatically during the drought years, causing one run -- the winter-run chinook -- to be listed as a federally threatened species. Central Valley salmon are differentiated into four distinct races by the time of year in which they migrate upriver to spawn. The majority of fall-run fish migrate upstream between August and November. Late fall-run fish migrate between October and February. The winter-run occurs primarily between January and April. Spring-run fish enter the rivers from March through June, while still immature; they then hold in pools in their spawning streams and spawn in the fall.

Large dams have severely limited the life-history strategies of salmonids (salmon and trout) in the Central Valley and elsewhere in California. These strategies would otherwise increase the resiliency of these fish to a severe and sustained drought. The most obvious impact has been the blocking of fish from their upstream spawning range, which is typically cooler, particularly under conditions of low flow. If water is too warm for successful spawning, fish will continue moving upstream in search of cooler regions in which to lay their eggs. In addition, large reservoirs exacerbate temperature problems through the thermal mass that they hold. Even under normal flow conditions, rivers with large dams experience delayed cooling because it takes much longer for cooler air temperatures to affect reservoir temperatures than corresponding stream temperatures.

In addition, reservoir management practices influence the life-history of fishes. In California, the reservoir system is managed primarily for fall-run fish. This has resulted in the near-extinction of other runs, including the spring-run, which was once the largest run in the Sacramento-San Joaquin system. Thus, if in any given year a catastrophic event should affect the fall-run, nearly the entire salmonid population would be destroyed for that year. More specifically, the system is usually managed for the peak spawning season and for a variety of reasons (temperature, flow level, flow fluctuations) both early and late spawners are disfavored by operational decisions. Under extreme environmental conditions, however, it is these early and late spawners that might have had an advantage under unregulated conditions. For instance, under drought conditions, the eggs of fall-run fish that spawned early would hatch and mature earlier, and thus juveniles would be more likely to move downstream before temperatures reached lethal levels.

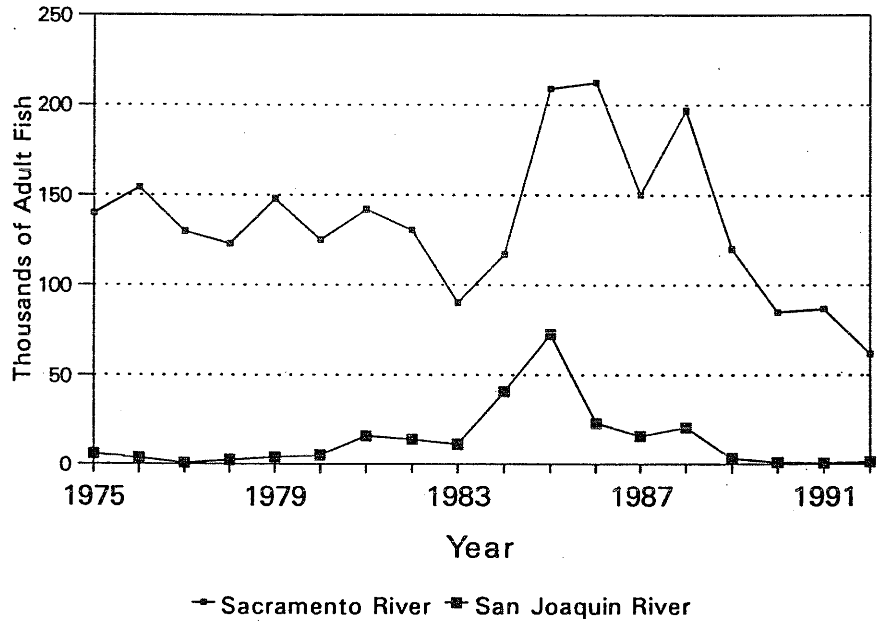
Finally, dams and reservoirs have contributed to cross-breeding among different runs of salmon, which were formerly more segregated spatially. Now spring- and fall-run fish spawn in the same sections of river. In addition, hatchery fish have cross-bred with wild fish and may have diluted important genetic traits in the population. Certainly the native fish of California are well-adapted to periods of extreme drought; however, hatchery stocks have frequently come from outside the region (e.g., Washington and Oregon) and are likely to be poorly adapted to the California environment.

As a result of river management practices, fall-run salmon now comprise the major run in the Central Valley. Natural (as opposed to hatchery) returns of fall-run fish declined during the drought, from 236,000 adult fish in 1986 to 62,000 in 1992. As Figure 5 shows, there is considerable variation in returns from year to year; yet the extremely low numbers counted in 1990, 1991, and 1992 stand out. Among the most dramatic declines that occurred during the drought were on the mainstem of the San Joaquin River, where fall-run fish fell from 15,800 fish in 1987 to 600 fish in 1991. This run recovered slightly in 1992, to 1100 fish. In general, fall run sizes on most rivers in the Sacramento-San Joaquin system declined by over 50% between 1989 and 1992 (Figure 6).

The winter-run reached an all time low in 1991 of only 127 adult fish. In 1992, the winter-run spawning escapement increased to approximately 1100 adults, which reflected the slightly better water-year in 1989 as well as modifications to water-project operations that helped to increase escapement.

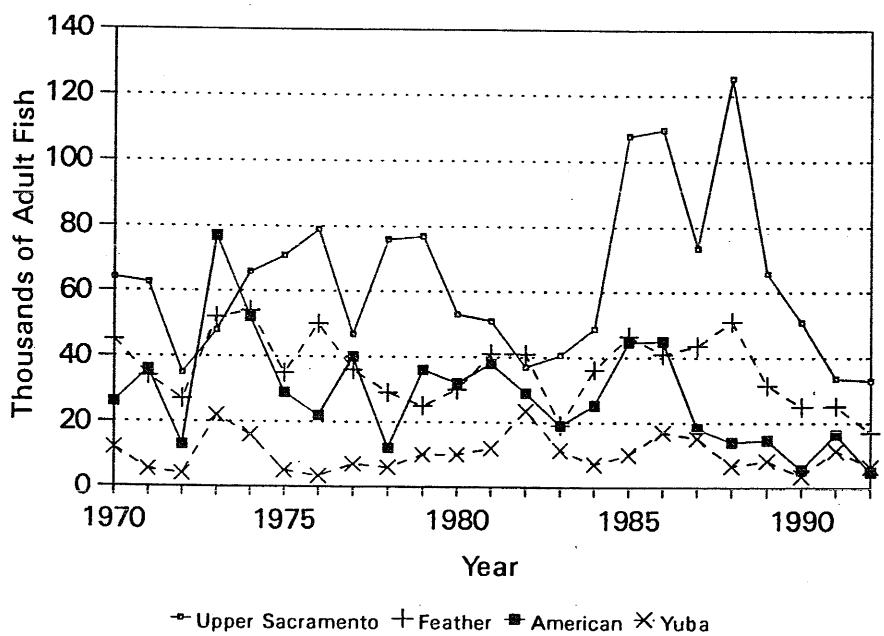
Although historically spring-run were the most abundant salmon in California, natural spring-run fish in the Central Valley are now limited to two very small runs on Deer and Mill Creeks. Combined, these runs are usually less than 1000 fish. In addition, Butte Creek contains a highly variable population of 100 to 1500 fish (Moyle and Yoshiyama, 1992). Fish counts conducted by the California Department of Fish and Game (CDFG) for Deer and Mill Creeks show considerable variability, but overall numbers have declined during the drought. Combined 1992 estimates for both creeks were less than 600 fish (CDFG, unpublished data). Moyle and Yoshiyama (1992) have proposed that the spring-run chinook be classified as threatened/endangered. Low flows probably exacerbated the condition of the runs on Mill and Deer Creeks. Both streams temporarily dried out along sections of their reach during the drought. Water temperatures were also very high at times, with spring-run salmon holding upstream in pools as hot as 68°F. In addition, CDFG personnel suspect that low flows and high water temperatures have delayed the outmigration of spring-run salmon, although they lack data to show this. Spring-run

Figure 5: Central Valley Natural Fall-Run Chinook Salmon Spawning Escapement, 1975-1992



Source: PFMC, 1993

Figure 6: Spawning Escapement for Fall-Run Chinook on the Upper Sacramento, Feather, American, and Yuba Rivers



Source: PFMC, 1993

fry probably emerge in February-March, but in dry years, they may face thermal/water barriers by April, forcing fish to wait until October or the following year to migrate (C. Harvey, CDFG, pers. comm.).

On both Mill and Deer Creeks, nearly the entire average flow is allocated to local landowners. CDFG was successful in negotiating some additional water for Mill Creek during the drought, as part of a long-term mitigation plan. In addition, CDFG leased additional water for one year. No additional water was obtained for Deer Creek (C. Harvey, CDFG, pers. comm.; S. Cepello, CDWR, pers. comm.).

Extremes in temperature occurred throughout the Sacramento-San Joaquin system, limiting the success of salmon spawning. Cool temperatures are essential to the development of chinook salmon eggs. At 56°F, no mortality occurs; however, at a temperature of 62°F, all eggs are lost. Partial mortality occurs for temperatures falling in between these extremes. In addition, higher temperatures make salmon eggs susceptible to a lethal fungus, *Saprolegnia*. During the drought, temperature problems became critical on several occasions.

Winter-run salmon are particularly likely to encounter lethal temperatures because they spawn in the summer, generally beginning in mid-April. Prior to the construction of Shasta Dam, winter-run salmon spawned in the tributaries of the McCloud River. Now most of these fish spawn in the area between Red Bluff and Shasta Dam. The temperatures in the spawning reach are influenced primarily by the quantity and temperature of water releases from the Shasta-Trinity reservoir system, as well as by ambient air temperatures. Temperature problems were noted in the Upper Sacramento River in 1987, the first drought year, when temperatures exceeding 59°F were measured at Bend Bridge, 45 miles downstream of Shasta Dam, during the early summer.[3] In September of 1987, the maximum temperature at Bend Bridge was 61.5°F (USBR, 1987). High temperatures remained a problem on the Upper Sacramento throughout the drought. Yet temperatures on the McCloud River, the historic spawning area of the winter-run, remained suitable throughout the dry years (CDFG, unpublished data). This is an obvious example of how changes in river systems have made wildlife more susceptible to drought.

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[3]Concern over temperature during winter-run spawning was largely spurred by the petition to list the species under the federal Endangered Species Act. The first petition, brought by the American Fisheries Society in 1985, was denied; however, an ensuing legal challenge resulted in the listing of the species in 1989. As a result of the increasing concern over the winter-run, the Bureau of Reclamation initiated a temperature monitoring program in the Upper Sacramento River in the latter half of 1990. Prior to this time, only limited temperature monitoring was conducted in the River and data were not available on a "real-time" (i.e., immediate) basis. Temperature requirements for the Upper Sacramento River were not adopted by the State Water Resources Control Board until the beginning of 1990.

In order to prevent temperature-induced mortality to any of the salmon runs, temperatures in the Upper Sacramento would have to remain below 57° from early summer through the following January. Low-water reserves in the system, combined with water-contractor deliveries, made this impossible. In general, three responses to the temperature problem were adopted:

(1) the distance over which the temperature objective was maintained was reduced. Throughout the drought years, the Bureau of Reclamation most frequently operated the CVP to meet temperature objectives at Balls Ferry (26 miles downstream of Shasta) rather than at Red Bluff (59 miles downstream of Shasta). This reduced the suitable spawning habitat for winter-run chinook by more than one-half.

(2) The time period during which temperature objectives were met were reduced, i.e., temperature objectives for September were raised, with the realization that this would increase mortality among the late spawning winter-run and particularly among the spring-run fish.

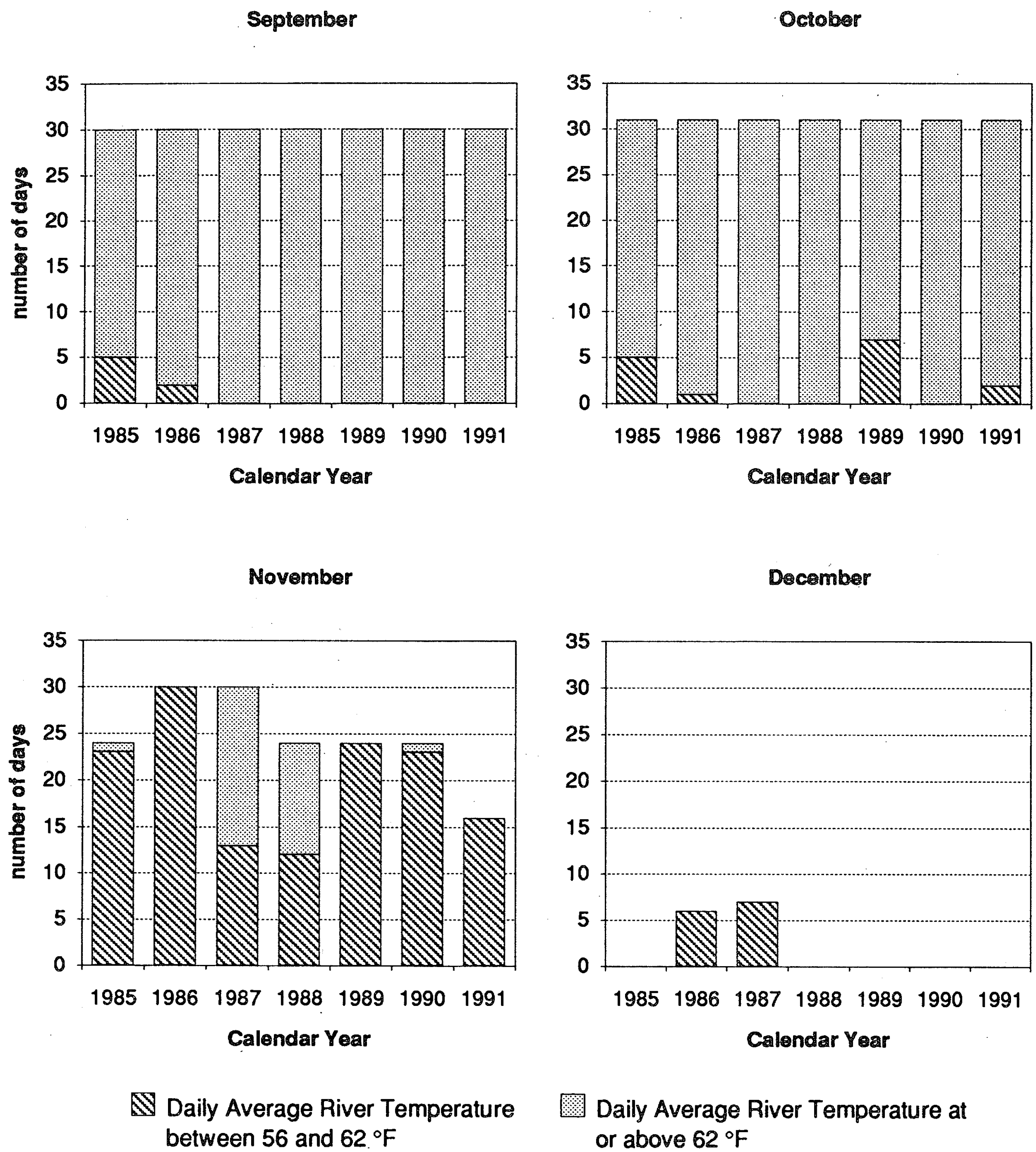
(3) The temperature objective was raised. Throughout the drought years, agencies frequently agreed on a temperature objective of 57°F during spawning, even though some mortality would result.

In the later years of the drought, temperature management for the winter-run, a threatened species under the Endangered Species Act, resulted in inadequate cold-water reserves for the fall- and particularly spring-run fish. As a result, mortalities for these runs were estimated to be quite high (H. Rectenwald, CDFG, pers. comm.). According to one estimate, in 1992 high temperatures destroyed 18% of the winter-run spawn, 21% of the fall-run spawn, and 52% of the spring-run spawn (T. Sletteland, Sacramento River Council, pers. comm.)

Overall, the Upper Sacramento received the best temperature protection in the system, largely as a result of the threatened status of the winter-run chinook. Yet in order to maintain better conditions on the Upper Sacramento, higher temperatures were allowed on other systems, particularly the American River. Temperatures on the American River are frequently too high for successful spawning of salmonids. This problem continued during the drought, although it is not clear that temperatures were actually any worse than they were in the period immediately preceding the drought (Figure 7).

Sacramento-San Joaquin Delta/San Francisco Bay: The drought, in combination with the operation of the state's water projects, had a significant impact on water quality in the Sacramento-San Joaquin Delta. Water quality standards for salinity

Figure 7: Occurrence of Adverse Spawning Temperatures on the American River during Fall Months, 1985 - 1991



Source: CDFG.

Notes: Data converted from °C to °F. Daily average is midpoint of maxima and minima (in °F). American River at Nimbus Fish Hatchery, CA.

(conductance) were violated in 1990, 1991, and 1992 (Table 1). This was a function of decreased inflows into the Delta and increased exports. Figure 8 shows long-term trends in conductance at several stations throughout the Delta and San Francisco Bay. Long-term salinity data show that conditions in the Delta during 1990-92 were worse than they had been since the 1976-77 drought. Between 1980 and 1986, salinities in the South Bay were generally above 20 ug/l except during high outflow periods. During the drought, salinity in this region remained above 25 ug/l and fluctuated around 30 ug/l. Salinities in San Pablo Bay normally fluctuate between 0 and 28 ug/l, but during the 1987-1991 period they remained consistently above 20 ug/l except for brief periods in 1989 and 1991. In Suisun Bay salinities fluctuate between 0 and 15 ug/l, while during the drought they remained above 10 ug/ except for brief periods in early 1987, 1989, and 1991 (CDFG, 1992b).

Although there were no consistent increases in temperature during the drought, water temperatures in the Delta were high, frequently the highest ever measured, in late summer and fall. Dissolved oxygen concentrations also fell below levels acceptable for anadromous fish on several occasions; in August of 1990, minimum concentrations were below 5.0 mg/l.

Water quality extremes were accompanied by extremes in the phytoplankton community. In 1990, chlorophyll concentrations in the southern Delta were the highest measured since 1980 (80 ug/l), while concentrations in the central Delta and Suisun Bay were among the lowest measured (<8 ug/l and <3 ug/l, respectively) (Figure 9).

The abundance of estuarine fish species declined during the drought; however, only a few marine species actually increased in abundance in response to the higher salinity levels. Overall there was a decrease in the abundance of the estuary's major prey species, incluidng *Crangon franciscorum*, northern anchovy, Pacific herring, and longfin smelt (CDFG, 1992b).

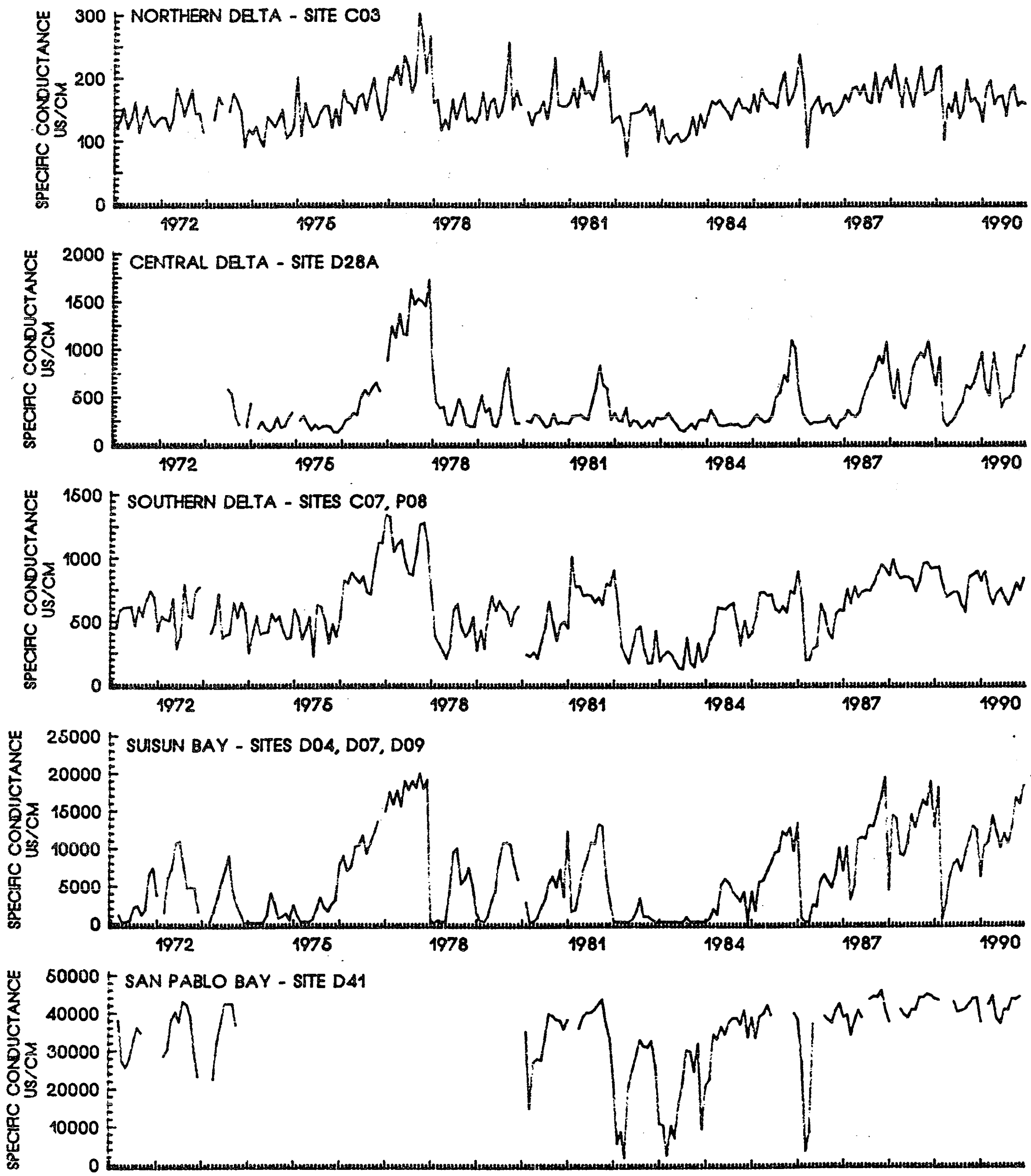
In March of 1993, the USFWS formally listed the Delta smelt as a federally threatened species. Delta smelt are confined to the Sacramento-San Joaquin estuary, and live mainly in Suisun Bay and the Delta. The smelt is adapted to living in association with the mixing zone, where it feeds on copepods and other zooplankton concentrated there. When the mixing zone is located in Suisun Bay, optimal conditions for smelt occupy a much larger total area that includes extensive shoal areas compared to when the mixing zone is located upstream in the Delta. Increasing diversions of freshwater have altered the locations of the mixing zone, as well as flow patterns of the Delta during much of the year. During months when the smelt are spawning, the changed flow patterns presumably draw larvae from the Sacramento River into the San Joaquin River, where they can be exported through the pumps. According to Herbold, et al., (1992), "entrainment or dislocation of

Table 1: Violations of Water Quality Standards in the Sacramento–San Joaquin Delta

Year	Location	Beneficial Use Affected	Dates of Violation
1992	Emmaton	Agriculture	May 27–Aug 15
1991	Rock Slough	Municipal	Feb 20–Mar 12
1991	National Steel	Wildlife	Feb 1–Feb 28
1991	Collinsville	Wildlife	Feb 1–Feb 28
1991	Beldons Landing	Wildlife	Jan 1–Feb 28
1991	Chipps Island	Wildlife	Jan 1–Mar 8
1990	Rock Slough	Municipal	Dec 18–Dec 29
1990	Beldons Landing	Wildlife	Nov 1–Nov 30
1990	Emmaton	Agriculture	May 14–May 20
1989	Rock Slough	Municipal	Feb 9–Feb 13
1989	Emmaton	Agriculture	Jun 7–Jun 9
1989	Jersey Point	Agriculture	Jul 17–Jul 29

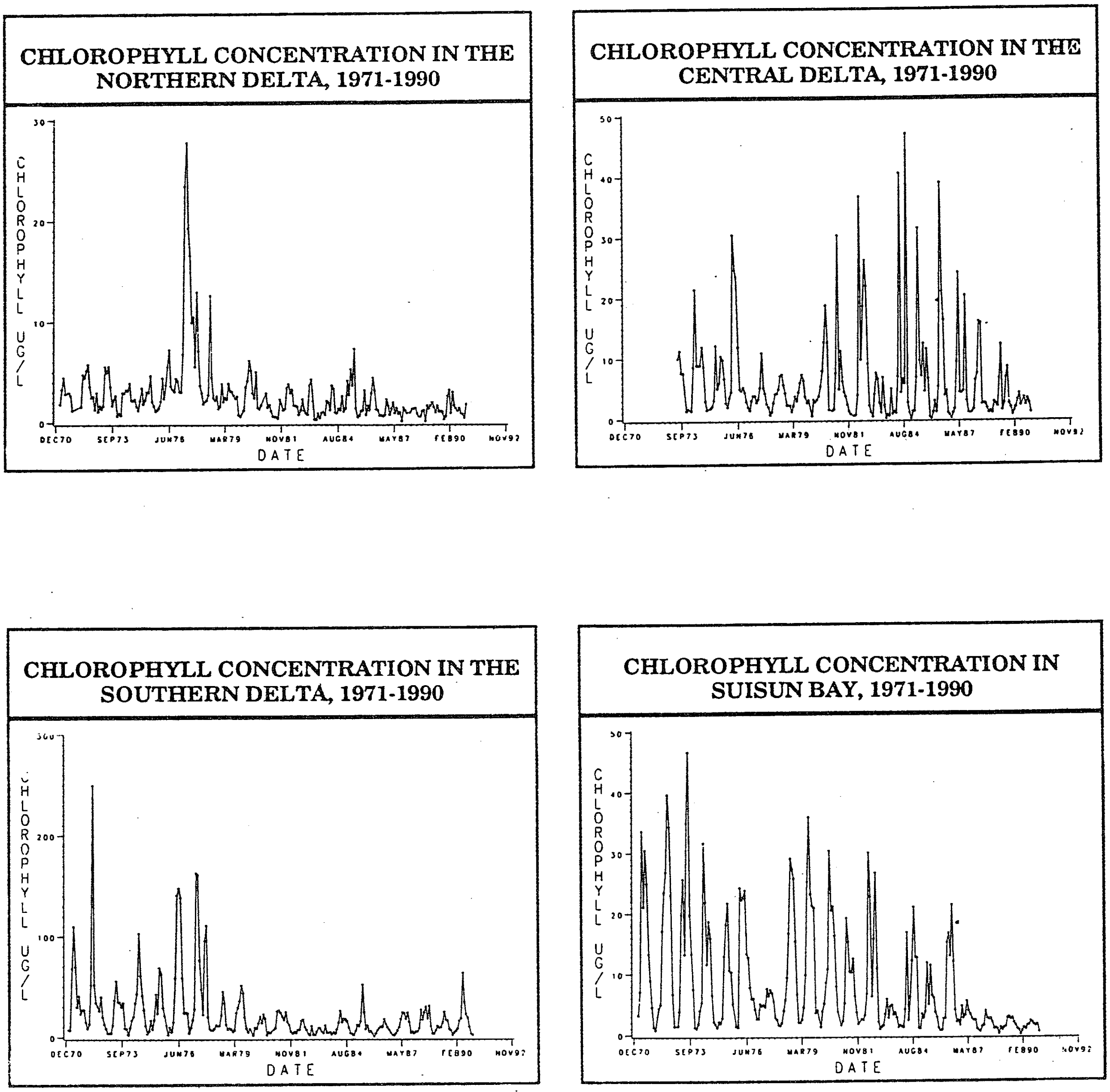
Source: SWRCB

Figure 8: Long-term Trends in Specific Conductance in the Delta, 1971-1990



Source: CDWR, 1992

Figure 9: Long-term Trends in Chlorophyll Concentration in the Delta



Source: CDWR, 1992

larvae by exportation of water has no doubt been exacerbated by the near-drought conditions that have existed in the drainage since 1987...." Because it has a limited range, essentially a 1-year life cycle, low fecundity, and planktonic (floating) larvae, the species is highly sensitive to changes in estuarine conditions (Moyle, et al., 1992). Since 1984, the percentage of inflow diverted has been higher and stayed higher for longer periods of time than during any previous period, including the 1976-77 drought. Smelt abundance has declined accordingly. CDFG's index of smelt abundance peaked in 1978 at 62.5, and declined to a record low of 0.8 in 1985 Moyle et al, 1992). The index has remained below 3.0 throughout the recent drought and was 2.4 in 1992.

Recently, two new Delta species came under consideration for listing as threatened or endangered: the longfin smelt and the Sacramento splittail. The longfin smelt is a euryhaline, anadromous fish that resides in the Sacramento-San Joaquin estuary. Once one of the most abundant fish caught in the estuary, longfin smelt numbers have declined dramatically since 1983. Although longfin smelt numbers have always been adversely affected by drought, their persistently low populations in recent years have resulted in a petition to list them as a federally threatened species. Since 1986 the total catch of longfin smelt at 27 stations in the CDFG trawl survey has been less than 300 fish, and has declined steadily to 67 fish in 1990. The factor that is most strongly associated with their recent demise is the increased proportion of freshwater that is being exported out of the Delta by the Central Valley Project and State Water Project (Moyle and Yoshiyama, 1992). This is an effect of increased exports (project water deliveries) as well as decreased inflows (drought).

Sacramento splittail are large cyprinids endemic to the Central Valley. Although once widely distributed, they are now confined to the Sacramento-San Joaquin estuary, primarily due to loss of their lowland habitat. CDFG (1992a) estimates that splittail are now 35 to 60% as abundant as they were in 1940, although this may be an underestimate of their losses. Currently their abundance in the estuary is strongly tied to outflows, presumably because spawning occurs over flooded vegetation in both the lower reaches of rivers and the Delta. Low outflows may consequently lead to reproductive failure. Thus drought probably has a substantial effect on population size. According to Moyle and Yoshiyama (1992), splittails in the Delta have declined steadily since 1980 and are now (1992) probably the lowest on record.

During the drought, the benthic community of the Delta has undergone substantial changes, resulting in the dominance of several introduced species including *Potamocorbula amurensis*, *Hemileucon hinumensis*, and *Gammarus* sp. Between 1987 and 1990, one or more exotic species have been among the four numerically dominant organisms at each of the benthic monitoring sites. These changes in the benthic community are associated with increased salinity and an increased percentage of fine sediments, which is a result of decreased river inflow (CDWR, 1992). *P. amurensis* was first detected in Suisun Bay in 1986; it now occurs throughout San Pablo and Suisun bays and in Suisun Marsh, and has replaced the historic dry-period community in these areas. *H. hinumensis* is a small crustacean native to Asia that was first detected in 1986 and has since spread into Suisun Marsh and the western Delta. *Gammarus* sp. is a highly mobile epibenthic amphipod that was first detected in the Delta in 1983, but did not reach appreciable concentrations until 1986. It now occurs throughout much of the Delta.

Western Sierra Nevada: Headwater streams dried up throughout the western Sierra, eliminating local populations of golden and rainbow trout. In most cases, it is believed that these streams have dried out before, and that they will be recolonized by neighboring populations. The drought, however, has affected CDFG's reintroduction program for golden trout in the Kern River drainage by reducing the success of reintroduced fish (probably due to a combination of high temperatures, low dissolved oxygen, and increased algae growth in target reaches), but these impacts are most likely temporary (D. Christenson, CDFG, pers. comm.). In other areas, however, anthropogenic impacts have probably exacerbated drought impacts. For instance, Fish Creek, a stream on the Kern Plateau, probably would not have gone dry except for the increased erosion in the watershed due to logging and cattle grazing (D. Christenson, CDFG, pers. comm.).

Clear Lake Hitch: Clear Lake, in Lake County is the largest freshwater lake wholly within California, with an average surface area of nearly 44,000 acres. It is a low-elevation, eutrophic lake that supports an endemic native fish, the Clear Lake hitch, a Class 3 species of special concern.[4] During the drought, the hitch had difficulty moving up the tributary streams where they normally spawn, and the population appears to have been reduced substantially, although no quantitative surveys have been done. The area surrounding Clear Lake is subject to significant agricultural diversions and ground water pumping, which has reduced streamflows. Although the lower reaches of their spawning streams probably dried up naturally, they now do so earlier in the year. In addition, upstream spawning areas are blocked by roads

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[4]"Species of special concern" are those species that identified by the State of California as warranting special attention although they are not formally listed as threatened or endangered. Class 1 species are those taxa that may already conform to the state definition of threatened or endangered. Class 2 species have populations that are low, scattered, or highly localized and that require active management to prevent them from becoming threatened. Class 3 species are uncommon taxa occupying much of their natural range that were formally much more abundant. Class 4 species have declined in abundance within their native range but have been introduced and established in greater numbers outside their native range; yet special management is required to prevent loss of native populations. Class 5 species are common or widespread taxa whose populations appear stable or increasing despite alterations in their habitats (Moyle, et. al., 1989).

and other obstacles. Thus, spawning habitat has been severely limited during recent years, and late spawners were observed laying their eggs on top of an earlier spawn (R. Macedo, CDFG, pers. comm.; Moyle, et al., 1989).

North Coast

The major drainages of California's North Coast include the Lower Klamath River, the Trinity River, the Eel River, and the Russian River. Over most of the coast, rainfall is normally abundant. The major water projects in this region are the Klamath system, which regulates flow through the upper Klamath into the mainstem, and Clair Engle Lake on the Trinity River. The latter project stores water in the Trinity Basin so that it can be exported to the Sacramento system. The Klamath River system serves agricultural users in southern Oregon and northern California. Poor water quality is a chronic problem in the region, due principally to agricultural return flows. In addition, reservoirs on the Klamath system have delayed the cooling of stream temperatures during the fall months.

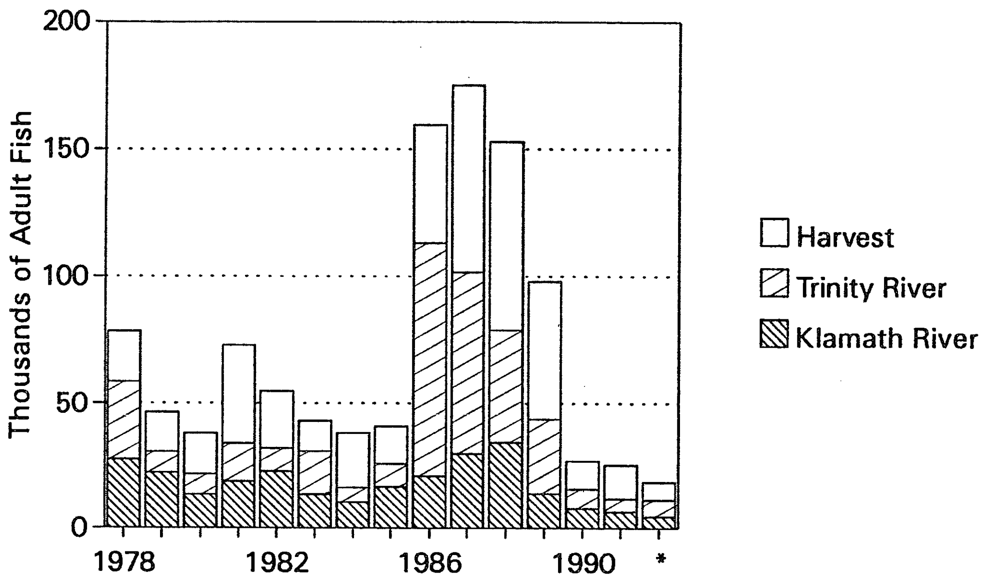
Salmon and Steelhead: The 1992 run-size estimate (harvest + escapement) for fall-run chinook salmon in the Klamath River Basin is 25,500 adults, the lowest since comprehensive in-river monitoring began in 1978. The spawning escapement of 18,400 adults was virtually the same as the 1991 escapement of 18,000 fish and was the second lowest since 1978 (Figures 10-11). These declines appear to be at least partially drought-related, given the high temperatures and low-water conditions that have occurred in the region.

The Salmon River and its tributary Wooley Creek support the only wild run of spring-run fish in the Klamath Basin, with the exception of a few fish on the South Fork of the Trinity River (three adults in 1991 and 1992). Salmon River escapement to summer holding areas has fluctuated from an estimated 1200 to fewer than 200 adult fish during the period 1980-92. The years 1989-92 have had very low numbers, less than 250 fish (USFS, 1992).

Coho salmon in California are maintained principally by hatchery stocks. Hatchery returns since 1988 have declined by 45% from previous levels (letter from B. Curtis, CDFG to B. Kor, NCRWQCB, 10/22/92) The South Fork of the Eel River supports the only remaining wild, big-river coho run in California. While recent runs were estimated to be as high as 1300 fish, the 1990 survey indicated a population one-half to one-third that size (Moyle and Yoshiyama, 1992).

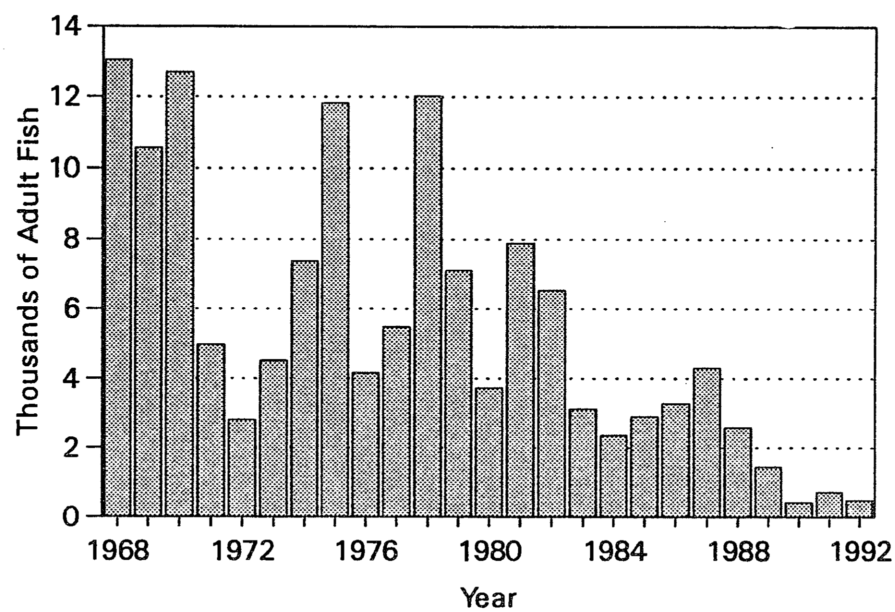
Summer steelhead are a variety of anadromous rainbow trout that migrate upstream while still immature and spend the summer in deep pools in remote canyons of coastal streams. The only systems with populations above 500 fish are the Middle Fork Eel River, North Fork Trinity River, and New River. The most

Figure 10: Klamath River Fall-Run Chinook Spawning Escapement and in-River Harvest, 1978-1992



*1992 data preliminary
Source: PFMC, 1993

Figure 11: Shasta River Fall-Run Chinook Spawning Escapement, 1968-1992



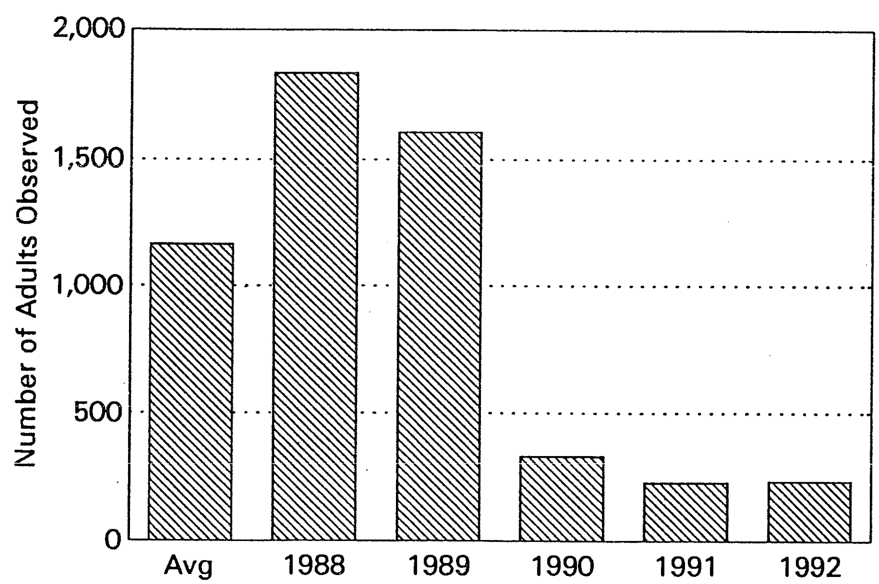
Source: PFMC, 1993

severe threat to steelhead is poaching while they hold in pools. Most likely this threat was exacerbated during low-flow years, which made the fish even more vulnerable. In addition, during low-flow years, outmigrating juveniles may suffer heavy mortality when moving downstream, especially if trapped in pools that become too warm for them in summer. Surveys of summer steelhead on the Klamath River show dramatic declines in the population since 1988, from 1834 fish to 234 fish (KNF, 1992a) (Figure 12).

Surveys of available salmonid spawning habitat in the Salmon, Scott, and mid-Klamath sub-basin indicate that available spawning habitat between 1989 and 1991 was only 74% (535,000 square feet) of that available under average flow conditions (721,000 square feet). Spawning habitat in several creeks was not readily accessible to chinook salmon because of low fall flows. The number of redds observed also dropped dramatically between 1988 and 1990 in all streams surveyed (KNF, 1992).

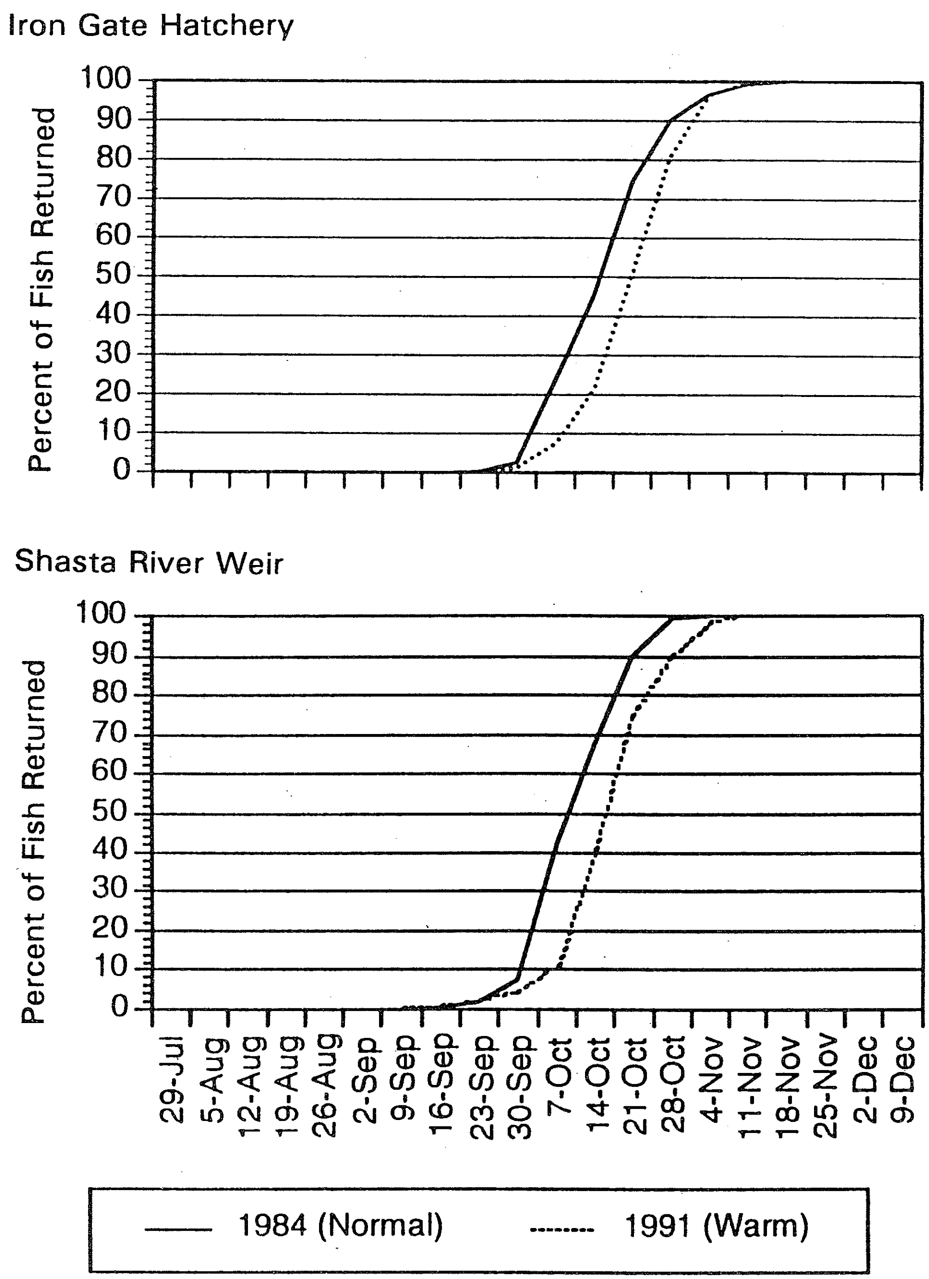
High temperatures, while always a problem in the Klamath, were particularly acute during the drought. The occurrence of high temperatures during late summer and early fall has compressed and delayed the migration and spawning seasons of chinook and coho salmon, particularly in low-water years. Figure 13 shows that while in 1984 60% of the fall-run chinook had reached Iron Gate Hatchery by mid-October, only 40% had returned by that time in 1991.

Figure 12: Summer Steelhead Holding Escapments on the Klamath River



Source: Klamath National Forest, 1992
Note: Average is from 1977-87

Figure 13: Effect of Increased Stream Temperature on the Timing of Spawning of Fall-Run Chinook Salmon in the Klamath River Basin



Source: CDFG, unpub. data

Temperature became a severe problem in the mainstem Klamath River during 1992. Water temperatures were extremely high in the summer and fall, with the maximum measured temperature rising to 84.0°F upstream of Cade Creek in August of 1992. The mean daily temperature in August of 1992 was 73.9°F; the mean in September was 66.6°F (Reichert and Olson, 1993). These temperatures would have caused 100% mortality of salmonid eggs.

In the Shasta River between September 1988 and June 1992, daily water temperatures of 68°F and higher occurred on 101 of 289 sampling days, or 35% of the time. Temperatures of 77°F or higher were reached at least 18 times. Two die-offs of juvenile chinook were observed in the Shasta River during the spring of 1992. Continuous temperature monitoring in the Scott river below Scott Bar during the summer of 1992 revealed maximum temperatures of 77°F or higher on 42 of 122 days monitored from June through September. This represents a substantial increase in the frequency of lethal temperatures compared to the period 1962-1985, although data for the earlier period are much more limited (letter from D. Koch, CDFG to B. Kor, NCRWQCB, 12/9/92).

Northeastern California

The principal drainages in Northeastern California are the Pit River and the Upper Klamath River, which straddles the Oregon-California border. The upper Klamath system has been operated as a federal water project since the 1930s, with the major reservoirs being Upper Klamath Lake (Oregon), Clear Lake, Copco, Gerber, and Iron Gate (Oregon). In addition to these river systems, Northeastern California also contains several shallow, alkaline lakes with endemic fish populations.

Goose Lake: Goose lake is an immense, shallow, terminal alkaline lake that is situated on the Oregon-California border, covering nearly 96,000 acres. It is home to four species of endemic fish including the Goose Lake redband trout, Goose Lake sucker, Goose Lake tui chub, and Goose Lake lamprey. The first three of these species are candidates for federal listing as threatened or endangered species, while the lamprey is a California species of special concern (Moyle and Yoshiyama, 1992). In 1992, as a result of the drought and diversions of its tributary streams, the lake went essentially dry; this was the first time the lake had dried since the 1930s. Lake populations were essentially eliminated, and thousands of fish died as they attempted to move up into the lake's tributary streams (K. Stubbs, USFWS, pers. comm.).

The redband trout and Goose Lake sucker may both face extinction as no populations are known to occur outside of the lake. Presumably after the drought of the 1930s, the lake was repopulated by stream-dwelling fish, although not enough is known about the life-history and taxonomy of these fishes to be certain. In addition, the access of fish to tributary streams has been severely reduced by blockages and the poor condition of the tributary streams. In response to the drought, wildlife agencies initiated a fish salvage operation and attempted to develop refugia at various local sites (Moyle and Yoshiyama, 1992; G. Sato, BLM, pers. comm.).

Cowhead Lake Slough: Cowhead Lake Slough is a small, muddy creek in Modoc County, which is the sole habitat for the Cowhead Lake tui chub (a Class 1 species of special concern, proposed for listing as threatened or endangered) (N. Kanim, USFWS, pers. comm.). The slough went dry in the summer of 1992, with the exception of the very upper end and one pool in the middle of the slough. This was the first year in which the slough was known to have dried completely. Although the fish in the upper part of the slough, which receives irrigation drainage, probably made it through the summer, there have been no population surveys. The Bureau of Land Management owns some of the land on which the slough flows, but there is no water associated with the publicly owned lands, which has prevented direct efforts to help the fish during the recent drought (G. Sato, BLM, pers. comm.). Previously the tui chub probably moved into Cowhead Lake during dry years; however, the lake has long since been drained and converted to pasture. The limited habitat of the tui chub has also been adversely affected by cattle grazing (Moyle and Yoshiyama, 1992).

Modoc Sucker: In the upper Pit River drainage, the endangered Modoc sucker has been severely affected by drought conditions. For three years, 1990-1992, fish were salvaged from drying pools and moved upstream. It is believed that drought conditions have reduced the reproductive success and may have increased the susceptibility of Modoc suckers to predation by exotic fish species. Modoc sucker habitat has also been significantly degraded by grazing (CDFG, 1991a). However, preliminary survey results suggest that suckers in headwater regions have fared reasonably well, although populations in the lower watershed were severely reduced (G. Scoppettone, USFWS, pers. comm.).

Clear Lake: Clear Lake is a natural lake in the northeastern part of the state that was dammed to create a reservoir. The lake/reservoir now has a capacity of 527,000 af and a surface of 25,760 acres (USBR, 1992). It is home to two endangered fish, the Lost River sucker and the shortnose sucker. Although prior to the drought, Clear Lake was considered to be a fairly pristine environment, the combination of water-project operations and limited inflow reduced the lake to historic lows. The normal surface area was reduced by more than one-half; the east lobe of the lake was drained completely, and some suckers were salvaged (USFWS, 1992; N. Kanim, USFWS, pers. comm.). There was concern over the potential for winter fishkills, given the low water levels, but no kills occurred in Clear Lake during the winter of 1992-3. By the spring of 1993, reservoir levels were approaching normal, although the fish observed during this time appeared "thin." Other reservoirs in the Upper Klamath system were also affected. Both Gerber and Malone reservoirs developed water quality problems, and suckers observed in these reservoirs during the spring of 1993 also appeared very thin (K. Stubbs, USFWS, pers. comm.).

Central Coast

The central coast of California was particularly hard hit by the recent drought. Much of the Central Coast is agricultural, and both surface and ground water supplies are heavily, and frequently over, utilized. Water supply is inadequate to meet current demands in many areas; thus, the impacts of drought on aquatic and riparian resources were particularly severe, and certainly exceeded the impacts that might be expected under "natural" conditions.

Carmel River: The most obvious impact of the drought on the central coast was the complete drying of several streams, including the Carmel River, which supports an important population of self-sustaining steelhead trout. The Carmel River drains a 255 square mile watershed, in which both surface and ground water resources are heavily utilized. Steelhead counts at San Clemente Dam, which do not include in-river harvest or downstream spawners, ranged up to 1300 fish in the late 1960s and early 1970s. During the recent drought, the Carmel River failed to reach the ocean in 1988, 1989, and 1990, and consequently no steelhead were able to spawn. Flow was extremely limited in 1987 and 1991 as well, resulting in only one spawner in the latter year. Although steelhead can survive droughts by remaining in the headwaters of their spawning streams, juvenile production also decreased during the drought. The Carmel River dried during the 1976-77 drought as well, and it seems likely that the run did not completely recover prior to the onset of the recent drought, although the data are incomplete. At this point, the population has been reduced to a remnant run (MPWMD, 1993; MPWMD, unpub. data). In response to the drought, CDFG initiated a captive broodstock program, in which they captured returning fish at the mouth of the river and transported them to a hatchery. The captive breeding program has proven relatively successful, with 281 fish returning to spawn in the river in 1993 (K. Anderson, CDFG, pers. comm.).

The eradication of flows was common throughout the Central Coast. For instance, the upper headwaters of the Nacimiento River went dry for the first time in memory, extirpating local populations of wild trout; it is expected, however, that these fish will recolonize from other tributaries (K. Anderson, CDFG, pers. comm.)

Scott Creek Lagoon: Flows in Scott Creek also disappeared, causing severe water quality problems in Scott Creek Lagoon, which supports juvenile steelhead, juvenile coho salmon, and the tidewater goby. In response to the conditions in Scott Creek Lagoon, CDFG identified and shut down an illegal agricultural diversion in order to provide minimum instream flows of 2 cfs. Similar actions might have been taken on other streams had personnel and time been available (K. Anderson, CDFG, pers. comm.).

Tidewater Goby: This species, currently being proposed for listing as an endangered species, occurs all along the California coast. Its habitat consists of lagoons and stream mouths where the water is brackish (Swift et al., 1989). The goby is believed to have a one-year life-cycle and to be extremely susceptible to drought coupled with habitat degradation. Moyle et al. (1989) reported that 6 of 20 populations were extirpated in San Luis Obispo county between 1984 and 1989 due to the combined effects of water diversions and drought. During the recent drought, at least one population was rescued and placed in aquaria. A population in Redwood Creek (Mendocino County) has not been observed for the last five years (C. Swift, Los Angeles Museum of Natural History, pers. comm.). The effect of the drought on tidewater gobies is of great concern because these fish rarely recolonize once a population has disappeared (Swift et al., 1993)

Southeastern California

The southeastern section of the state is comprised of three main drainage systems: the southern Lahontan, Death Valley, and the Colorado River. These are all desert areas, which receive little rainfall even in normal years. Streams and lakes are fed either by runoff from the Sierra or by underground springs. During the drought, many springs and creeks have gone dry. Several regions are subject to intensive water development, most notably the Owens River Valley, from which the city of Los Angeles derives a large portion of its water supply.

Owens River Valley: In the Owens River Valley, several tributary streams were reduced to low or non-existent flows, threatening the fishery resources. The vast majority of the fish in this area are introduced species (notably brown, rainbow, and golden trout) that support a very large recreational fishery. The natural drought conditions were exacerbated by diversions and ground water pumping in the area by lessees of the Los Angeles Department of Water and Power. For instance, Mammoth Creek, a premier trout-fishing stream, was nearly entirely diverted to irrigate pasture. Similarly, the lower Owens River was dewatered (D. Wong, CDFG, pers. comm.).

Native species were also affected. The Owens tui chub is restricted to three small areas, all of which were threatened by low flows. One of the largest populations occurs in Hot Creek Springs. Whereas normal flows in the springs are 10-11 cfs, measured flows had dropped to less than 3 cfs in 1990, causing a dramatic reduction in available tui chub habitat. In the spring of 1993, CDFG will undertake a mitigation effort to restore chub habitat in Hot Creek Springs (D. Wong, CDFG, pers. comm., CDFG, 1991a).

ByDay Creek: In addition, a refugial/broodstock effort in ByDay Creek on behalf of the endangered Lahontan cutthroat trout was severely threatened by low flows. ByDay Creek is one of the few streams in California with native cutthroat trout. On several occasions, beginning in 1988, cutthroat trout were salvaged and moved to other streams. The cutthroat population in this stream survived the 1976-77 drought as a result of beaver dams which created habitat in spite of nearly non-existent flows; however, those dams have been abandoned. Flows in 1990 were so low they could be measured in gallons/minute (D. Wong, CDFG, pers. comm.).

Heenan Lake: Actually located in the northern Lahontan Basin, near the border of Alpine and Mono Counties, Heenan Lake is an artificial lake that was created by damming Heenan Creek in the 1920s. CDFG purchased the lake about 10 years ago and now uses it as a refuge for the endangered Lahontan cutthroat trout. Although CDFG owns the lake, the department holds water rights to only about 20% of the lake's capacity. During 1992, almost all inflow into the lake was diverted by local water-rights' holders. During the summer of 1992, there was a limited die-off of trout due to low water levels. Moreover, catch-per-unit-effort data suggest that trout populations have decreased throughout the drought (E. Gerstung, CDFG, pers. comm.; CDFG, unpubl. data).

South Coast

The South Coast of California is characterized by warm streams with variable flows. The entire region has been extensively altered, so that few rivers or streams even approximate natural conditions. Most rivers have been lined with concrete in all or part of their length and have frequently been altered from their original course. Urbanization has destroyed most of the riparian habitat and vegetation, except in the more mountainous regions. Nevertheless, a few native, endemic fish species survive, all of which persist in very small, isolated populations.

Southern Steelhead: The southern steelhead species has fared very poorly during the recent drought, and may have been pushed to near-extinction. Southern steelhead are ecologically and physiologically adapted to the seasonally warm and intermittent streams of Southern California. Moyle and Yoshiyama (1992) estimate current numbers to be less than 500 fish, with the largest run in Ventura River (approximately 200 fish). Other runs occur in Malibu Creek (60), the Santa Clara River drainage (Sespe Creek), and the Santa Ynez River. None of the rivers in which southern steelhead are found went dry, but the low flows made many obstacles (diversion dams, roads) impassable to migrating fish. As of the spring of 1993, several migrating steelhead were seen in the Ventura River, a few sightings were noted in the Ventura, and none were seen in the Santa Clara (D. McEwan, CDFG, pers. comm.). Despite the precarious state of the southern steelhead, there are currently no population monitoring efforts, which makes it difficult to assess the strength of the population.

Unarmored Threespine Stickleback: The unarmored threespine stickleback is a small fish confined to an 8-mile stretch of the Santa Clara River in the Santa Clarita Valley. This region has recently undergone relatively rapid development, and continued pressure on ground water resources has threatened surface water supplies in the Santa Clara River. During the drought, pressure on local ground water increased tremendously, and several new wells were drilled, further decreasing river flows. Moreover, the dry conditions in the river canyon spurred residents to pond water for fire suppression, and subsequently green sunfish, a predatory exotic, was stocked in several ponds. Recent surveys indicate that some reproduction of stickleback has occurred in the last year, although the winter floods appear to have reduced the number of adults (CDFG, 1991a; C. Swift, Los Angeles Museum of Natural History, pers. comm.).

Shay Creek Stickleback: During the drought, the habitat of the Shay Creek stickleback[5] was severely restricted, largely as a result of increased ground water pumping and consequent dewatering of the creek. During wet years, this fish occupies both Shay Creek and Baldwin Lake in the San Bernadino Mountains. During the drought, Shay Creek has not flowed and Baldwin Lake dried completely; the only remaining habitat for the fish was a small, warm, shallow pond, which was artificially maintained in Shay Creek. As an emergency measure, some fish were transplanted to a refugial area. However, drought also threatened the viability of the relocation site. CDFG funded a feasibility study to determine whether a wastewater reclamation project might be used to create additional stickleback habitat; however, this project has been unsuccessful thus far (see following section) (D. Maxwell, CDFG, pers. comm.). The total population of Shay Creek stickleback is probably less than 10,000 individuals, with 5,000-6,000 in the original habitat (Moyle and Yoshiyama, 1992).

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[5]The Shay Creek stickleback was originally treated as a population of the federally endangered unarmored threespine stickleback (*Gasterosteus aculeatus williamsoni*). It is now recognized as a distinct species and has been proposed for a separate listing under the federal Endangered Species Act (Swift et al, 1993; C. Swift, LA County Museum of Natural History, pers. comm.).

Santa Ana Speckled Dace: The Santa Ana speckled dace, another native fish of Southern California, is also likely to have been severely affected by drought conditions. The fish is confined to remnants of its former range, in nine non-contiguous populations, although two of these populations (in Big Tujunga and Santiago creeks) could not be found in 1990-92 despite a thorough search (Swift et al, 1993). Moyle and Yoshiyama (1992) conclude that only two of these populations are large enough not to be faced with imminent extinction. While habitat destruction is clearly the principal cause of the dace's decline, drought has exacerbated this trend.

Santa Ana Sucker: A state species of special concern, Santa Ana sucker populations have been severely reduced during the drought. Populations existed recently in the San Gabriel River system and in the lower Santa Ana River. Fish became very rare in the Big Tujunga drainage in 1990-92, and the species may soon be completely extirpated from the Los Angeles River drainage (Swift et al., 1993).

Effects on Riparian Resources

Amphibians

Very little information is available on the status of amphibians during the drought, despite the fact that amphibian populations are vulnerable to droughts and appear to be declining in many regions. Some information suggests that amphibian populations may be decreasing worldwide and that the causes may be global, such as increasing UV radiation or acid precipitation (Blaustern and Wake, 1990). Drought, however, is one possible cause of amphibian declines regionally. Amphibians rely on seasonal wetland areas for breeding, and, as is well-known, these types of habitat have disappeared rapidly over the last several decades. Drought further reduces both the number and the duration of ephemeral breeding sites.

Along the central coast, the principal breeding habitat of the Santa Cruz long-toed salamander, an endangered species, went dry for several years during the recent drought. No recruitment for this species is believed to have occurred between 1987 and 1992. To enhance habitat conditions for this species, CDFG drilled a ground water well (J. Brode, CDFG, pers. comm.). Salamanders, however, are long-lived species that recruit very successfully during wet years; thus, their populations are likely to rebound. Nonetheless, no data are available on population trends for the salamander, making it difficult to assess the overall condition of the species.

More generally, the adverse impacts of grazing on amphibians were noted during the drought, as the both cattle and amphibians concentrated around fewer water sources (J. Brode, CDFG, pers. comm.).

There is also evidence to suggest that the presence of exotic species may inhibit the recovery of native amphibians following the drought. For instance, on the Eel River, introduced bullfrogs (*Rana catesbiana*) have expanded their range during the recent drought (T. Dudley, Pacific Institute, pers. comm.). Bullfrogs favor laying eggs on aquatic vegetation and survive well in slow, silty pools. Thus, they are more successful in dry years when the absence of high winter and spring floods increases the growth of aquatic vegetation and creates a siltier substrate. Moreover, their ability to leave the water reduces their susceptibility to drought. Bullfrogs do compete with native frogs such as yellow-legged frogs, red-legged frogs, as well as with arroyo toads (Hayes and Jennings, 1986). Low water levels have also allowed bullfrogs to prey on native stickleback (Swift et al., 1993).

Birds

Most of the concern about the impact of the drought on bird populations has focused on waterfowl. The refuges of the Central Valley, which provide wintering habitat on the Pacific Flyway, were faced with uncertain water supplies during the latter years of the drought.

The only attempt to quantify water needs for wildlife refuges is a 1989 study by the Bureau of Reclamation. This study defined four levels of water supply for all Central Valley refuges, as shown in Table 2. In general, most refuge water supplies are not "firm", but are garnered from a variety of sources in any given year, including water-project deliveries, agricultural drainwater, carriage losses, and other sources. Since the mid-1980s, water supplies in the northern San Joaquin Valley have dwindled following the discovery of toxic levels of selenium and other elements in agricultural return flows.

During the drought, extraordinary efforts were made to secure additional water supplies for refuges. These included purchases from the Drought Water Bank, water trades with local irrigation districts, and the development of ground water on several refuges. Overall, the Central Valley refuges appear to have done fairly well in terms of water supply. Most areas were able to flood most if not all of their area, although the flooding season was shorter and overall water quality was probably somewhat lower (Gleick and Nash, 1991; D. Marciochi, Grasslands Water District, pers. comm.; J. Beam, Los Banos Wildlife Area, pers. comm.). For instance, the Grasslands Area received no water prior to October in 1991 and 1992, nor did they receive additional water deliveries after mid-November. This contrasts with their

Table 2: Water Supply Needs (in acre-feet) for Wildlife Refuges in the Central Valley.

Refuge	Level 1		Level 2	Level 3	Level 4
Modoc NWR	18,500		18,550	19,500	20,550
Sacramento NWR	0		46,400	50,000	50,000
Delevan NWR	0		20,950	25,000	30,000
Colusa NWR	0		25,000	25,000	25,000
Sutter NWR	0		23,500	30,000	30,000
Gray Lodge WMA	8,000		35,400	41,000	44,000
Total Sacramento Valley	26,550		169,800	190,500	199,550
Grassland RCD (a)	50,000		125,000	180,000	180,000
Volta WMA	10,000		10,000	13,000	16,000
Los Banos WMA	6,200		16,670	22,500	25,000
Kesterson NWR	35,000		3,500	10,000	10,000
San Luis NWR	0		13,350	19,000	19,000
Merced NWR	0		13,500	16,000	16,000
Mendota NWR	25,463	(b)	18,500	24,000	29,650
Pixley NWR	0		1,280	3,000	6,000
Kern NWR	0		9,950	15,050	25,000
Total San Joaquin Valley	95,163		211,750	302,550	326,650
TOTAL	121,713		381,550	493,050	526,200

Level 1: Existing firm water supply.
Level 2: Current average annual water deliveries.
Level 3: Full use of existing development
Level 4: Optimum management if refuge were fully developed.

(a) As of 1985, Grassland RCD no longer recives agricultural drainage flows due to water-quality concerns.

(b) Only 18,500 acre-feet can be delivered to the Mendota WMA without modifications of existing facilities..

Source: USBR, 1989

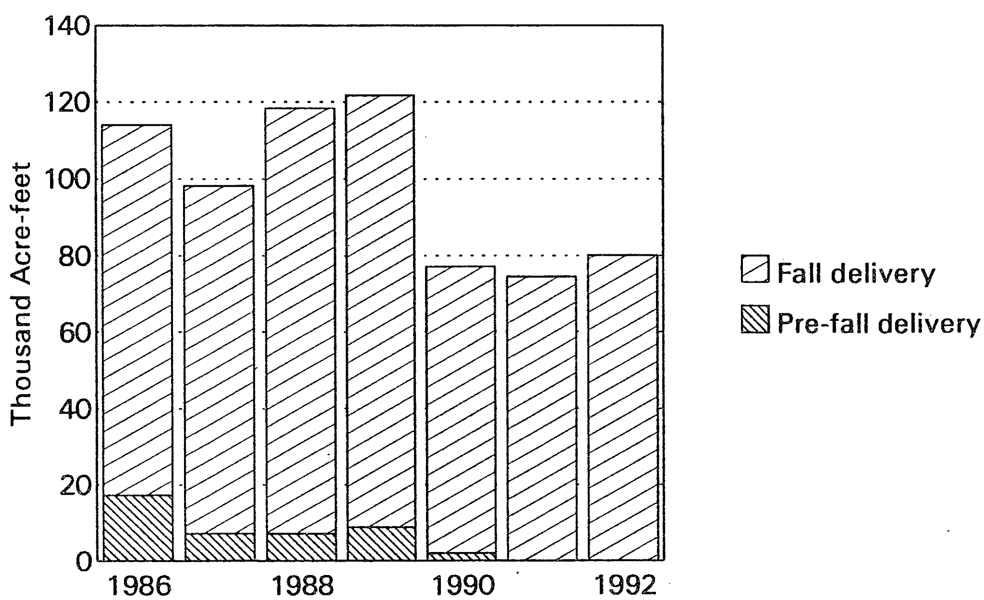
usual, non-drought operations (Figure 14).

It is not particularly meaningful to examine waterfowl numbers as an indicator of drought impacts, given the wide variety of factors that affect waterfowl in any given time. In fact, some managers reported that waterfowl numbers on refuges increased during the drought years, simply because little other water was available in the area. Yet some species did appear to be affected by the drought. For instance, in both 1990 and 1991 wintering sandhill cranes on the Carrizo Plains Reserve (San Joaquin Valley) arrived very late in the season and remained for a much shorter time than usual (J. Lidberg, CDFG, pers. comm.).

An attempt to quantify the loss of food supply to waterfowl in Yolo and Solano counties as a result of land fallowing (due to purchases by the Emergency Water Bank) concluded that between 18% and 42% of wintering waterfowl in the region were affected by the loss of feeding opportunity. However, the investigators indicated that considerable uncertainty surrounded this estimate (Coppock and Kreith, 1992).

More severe habitat losses occurred in the northern area of the state, in the Klamath National Wildlife Refuges. This complex contains 6 refuges, 5 of which are managed wetland areas. All of the wetland areas depend entirely on agricultural

Figure 14: Annual Water Deliveries to Grasslands Water District



Source: Grasslands Water District

drain water; none have any firm water rights or contracts. While most of the refuges received adequate supplies, Lower Klamath Lake Refuge received no water from December 1991 to September 1992. However, lands that dried out during the drought have proven to be among the most productive following the wet winter of 1992-93 (R. Johnson, Klamath NWR, pers. comm.).

Also of concern in the Klamath region was the drying of the east lobe of Clear Lake Reservoir, which exposed pelicans nesting on an island to potential predators. In response, wildlife managers fenced the nesting area (K. Stubbs, USFWS, pers. comm.).

In addition to waterfowl, other riparian birds are also potentially affected by the drought. Among the riparian-dependent birds in California are many that are classified as threatened or endangered, such as the California black rail and the California clapper rail. Recently CDFG has noted the precipitous decline of bank swallows, which nest along the Upper Sacramento River. Nesting pairs have declined from over 12,000 in 1986 to 7525 in 1991. In addition, the range of the species has declined by over 50% since 1990. While the principal threat is the loss of habitat through channel stabilization and rip-rapping activities, the decline may have been exacerbated by drought conditions (CDFG, 1991a).

Riparian Plants

The State of California recognizes 142 plants as officially threatened or endangered and another 68 species as rare (CDFG, 1991a). Jensen, et al. (1990) estimate that 663 plants, comprising 10% of the state's natives, are seriously at risk. Among these are numerous riparian plants, including several vernal pool species. California's vernal pool habitats are estimated to have declined by more than 90% (Jensen, et al., 1990). Many rare and endangered species now exist in only a few, limited populations.

The principal concern with native plants during the drought has been their extremely limited populations, the complicating effects of grazing and off-road vehicle use, and the establishment of drought-tolerant and competitive exotic plants. As part of the drought-mitigation program, CDFG identified 38 rare and endangered plants for which the drought posed a significant threat (Table 3). Most of the mitigation proposals focused on fencing (to limit disturbance by cattle and ORVs), exotic plant abatement, and habitat restoration (particularly for vernal pools).

Owens Valley chickerbloom occurs in meadows and seeps in the Owens Valley. Its habitat is lost through ground water pumping and meadow draining, which have accelerated dramatically during the drought. Drought tolerant species

Table 3: Drought Mitigation Requests for Rare and Endangered Plants

Species	Location	County
Alameda manzanita	East Bay Regional Parks	Alameda, Contra Costa
Antioch Dunes evening primrose	Brannan Island	Sacramento
Bakersfield atriplex	Kern Lake Preserve	Kern
Baker's manzanita	Harrison Grade Ecological Reserve	Sonoma
Pennell's bird's-beak	" "	" "
beach layia	Pt. Reyes National Seashore	Marin
	Samoa Peninsula	Humboldt
beach spectacle pod	Guadalupe dunes	San Luis Obispo, Santa Barbara
Surf thistle	" "	" "
black jewelflower	Tiburon Peninsula	Marin
Burke's goldfields	Laguna de Santa Rosa	Sonoma
California dandelion	San Bernadino National Forest	San Bernadino
California jewelflower	various sites	San Luis Obispo, Fresno
Crampton's tuctoria	Jepson Prairie	Solano
Cuyamaca Lake downingia	Cuyamaca Lake	San Diego
Parish's meadowfoam	" "	" "
delta button celery	Los Banos Wildlife Area	Merced
dwarf alkaki grass	Whiskeytown	Shasta
Eldorado morning-glory	Pine Hill Ecological Reserve	El Dorado
Pine Hill flannel bush	" "	" "
fountain thistle	San Francisco watershed	San Mateo
Gambel's watercress	Nipomo Dunes	San Luis Obispo
hairy Orcutt grass	Vina Plains Preserve	Tehama
Greene's tuctoria	" "	" "
Howell's spineflower	MacKerricher State Park	Mendocino
Menzies' wallflower	MacKerricher SP, Samoa Peninsula	Mendocino, Humboldt

Table 3: Drought Mitigation Requests for Rare and Endangered Plants (continued)

Species	Location	County
Ione buckwheat	Apricum Hill Ecological Reserve	Amador
Kaweah brodiaea	Blue Ridge/Kaweah Brodiaea Ecological Reserves	Tulare
Kellogg's buckwheat	Little Red Mtn. Ecological Reserve	Mendocino
La Graciosa thistle	Santa Maria River	San Luis Obispo, Santa Barbara
large-flowered fiddleneck	various sites	Contra Costa, Alameda, San Joaquin
Loch Lomond button celery	Loch Lomond Ecological Reserve	Lake
Orcutt's spineflower	Oak Crest Park	San Diego
Otay Mesa mint	Otay Mesa	San Diego
palmate-bracted bird's beak	Alkaki Sink Ecological Reserve	Fresno
	Colusa NWR	Colusa
Presidio clarkia	San Francisco Presidio	San Francisco
Sacramento Orcutt grass	Phoenix Field Ecological reserve	Sacramento
San Mateo thorn mint	various sites	San Mateo
Santa Cruz cypress	Bonny Doon Ecological Reserve	Santa Cruz
Santa Cruz wallflower	Quail Hollow Ecological Reserve	Santa Cruz
Santa Cruz Island bush mallow	Santa Cruz Island	Santa Barbara
slender-horned spineflower	San Jacinto River, San Bautista Canyon	San Bernadino
slender Orcutt grass	various sites	Shasta, Tehama
slender-petalled mustard	Baldwin Lake Ecological Reserve	San Bernadino
Sonoma spineflower	Pt. Reyes National Seashore	Marin
Springville clarkia	Springville Clarkia Ecological Reserve	Tulare

subsequently invade the meadows. The impacts on this species have also been aggravated by cattle grazing. However, no consistent monitoring has been undertaken for this species (CDFG, 1991a).

Bird-footed checkerbloom and slender-petaled thelypodium are two endangered plants that inhabit the Baldwin Lake Area of the San Bernadino Mountains, also the home of the Shay Creek stickleback (CDFG, 1991a). This area was almost completely dewatered during the recent drought (D. Maxwell, CDFG, pers. comm.). Both plants depend on seeps and springs, which have virtually disappeared for the last several years.

Many plant populations disappeared during the drought, although these disappearances are likely to be temporary. For instance, Crampton's tuctoria, located in a limited area of Solano County, has not been seen since 1987 (CDFG, 1991a). Boggs Lake hedge-hyssop, which occurs on a Nature Conservancy preserve, also has not been seen for several years. Water levels became extremely low and exotic grassland species were invading the plant's habitat (CDFG, 1991a).

Mason's lilaeopsis is a small, semi-aquatic plant of the carrot family that inhabits the Sacramento-San Joaquin Delta. Currently about 50 occurrences of the plant are known, although all are threatened by proposed modifications in the region (CDFG, 1991a). Although the plant can survive in saline environments, it requires freshwater to reproduce; thus, its reproduction has been limited by high Delta salinity associated with the drought.

The drought also appears to have hastened the invasion of tamarisk (*Tamarix* spp.), an exotic, riparian plant that is common in all desert areas in California. Tamarisk has successfully replaced gallery forests in many desert areas, particularly in regulated river basins. It is of particular concern because it is highly water consumptive; thus large populations may significantly lower the water table and dewater seeps and springs, causing adverse effects on local wildlife, particularly in water-scarce desert areas. Recent research in Anza-Borrego State Park suggests that high winter flooding decreased tamarisk densities more than those of native vegetation, suggesting that flood disturbance is important to controlling tamarisk expansion (T. Dudley, Pacific Institute, pers. comm.).

Quantitative Assessments of Drought Impacts

One objective of this effort was to identify quantitative data that might be used to assess drought impacts on environmental resources. In general terms, the absence of quantitative data has made it more likely that policymakers will overlook environmental effects and that environmental concerns will be viewed as constraints on policy rather than as the focus of planning efforts. In this section, several types of available quantitative data are presented as well as examples of how this information might be used to assess the impacts of the recent drought.

The most basic measure of drought impacts is the decline in populations of important species, usually fish. While it is obvious that many factors other than drought affect fish populations -- and, in fact, the main factor in their decline regionally is habitat destruction -- fish populations are nonetheless affected by drought. Longer term records indicate drought-related trends. For instance, chinook salmon populations in some systems declined noticeably after the 1976-77 drought. This is not surprising, because spawners generally faced very high temperatures which undoubtedly reduced the viability of eggs. The impact of drought on salmon populations, however, shows up in the year-class produced during the drought, i.e., three years later. Thus, dramatic drops in Central Valley salmon runs became evident three years into the current drought, in 1990.

The greatest problem with population numbers for anadromous fish is their inaccuracy. Spawning escapement, the number most widely available, does not reflect ocean and in-river harvest, and thus does not reflect true population numbers. It is possible to model river populations by using data available on harvests and making assumptions about what proportion of a given harvest reflects fish from the river of interest; however, assumptions about the distribution of harvest tend to be highly subjective.

A better measure of the impact on anadromous fisheries is egg mortality, which can be estimated using data on in-river temperatures and spawning distribution. This assumes that temperature is drought-related and that temperature is the primary variable affecting egg survival. In most cases, these are probably good assumptions. Spawning distribution, however, may be affected by both drought and non-drought factors. For instance, low flows and high temperatures (drought) may limit the access of fish to suitable habitats. Yet spawners are also limited by the availability of suitable substrate, which is not necessarily drought-related. Although egg mortality does not necessarily correlate with the number of returning adults, estimates of temperature-induced egg mortality nevertheless reflect the effects of drought and can be easily compared with similar estimates for higher flow years.

More generally, temperature alone is an indicator of drought impacts in many systems, particularly those managed by large reservoirs. Although reservoir systems alter natural temperature regimes in all years, heating becomes a particular problem in low-flow years, as cold-water reserves become exhausted. During the recent drought, the impact of high temperatures on anadromous fisheries became one of the principal concerns. The frequency with which adverse temperatures occur is thus an indirect measure of impact. Data from the Feather River (Figure 15) show that adverse temperatures during the spawning period of fall-run chinook (October-January) began to develop in 1990, as reservoirs were drawn down. For instance, October 1990 had 25 days in which temperatures were above 57°F, whereas in previous years, no October temperatures had been that high. In contrast, data from the American River (Figure 6) does not show a drought-related increase in adverse temperatures; instead, adverse temperatures are a chronic problem, even in the high runoff year of 1986.

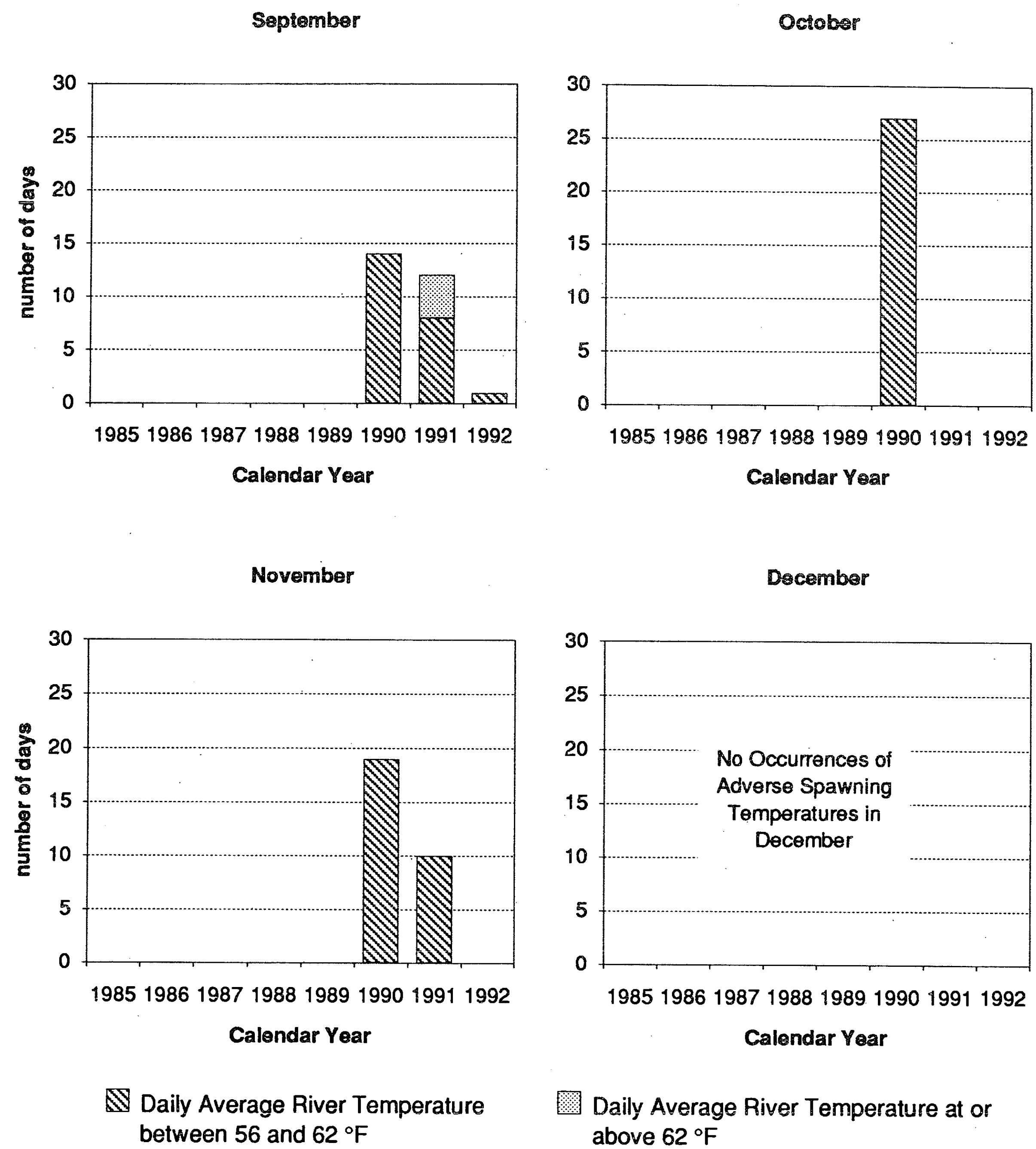
Temperature is a good proxy for drought-related impacts; however, it is not available on most systems for more than a few years. Even on the Upper Sacramento River efforts to monitor temperature on a continuous basis only began in 1990 (J. Smith, USFWS, pers. comm.). Similarly, a comprehensive temperature monitoring program in the Klamath River Basin was not initiated until 1992 (A. Olson, Klamath National Forest, pers. comm.).

Another potential tool for developing quantitative measures of drought impacts on fisheries is to use relationships between incremental streamflows and available fishery habitat. These relationships, termed "weighted usable area" (WUA) relationships, have been developed on many streams as a means of determining appropriate minimum flow requirements. Biological preferences of fish for various stream characteristics (velocity, depth, substrate, etc.) are documented empirically; then stream transects are surveyed to determine the extent to which preference criteria are met at various discharges. These relationships, however, indicate how available habitat for particular life stages changes with streamflow on a given river.

Looking at WUA relationships for the Mokelumne River in the San Joaquin Valley suggests that water-year 1990 did decrease available spawning habitat for fall-run chinook salmon. Compared to mean monthly flow from 1964-89, low streamflows in water-year 1990 resulted in a 53% decrease in available spawning habitat during October and November, a 66% decrease in December, and a 28% decrease in January (Figure 16). When flows in 1990 are compared with the long-term unimpaired flow (1924-83), available habitat increased in October (+18%). This is because river regulation has increased fall flows above natural levels, which benefits early spawning fish (Figure 17).

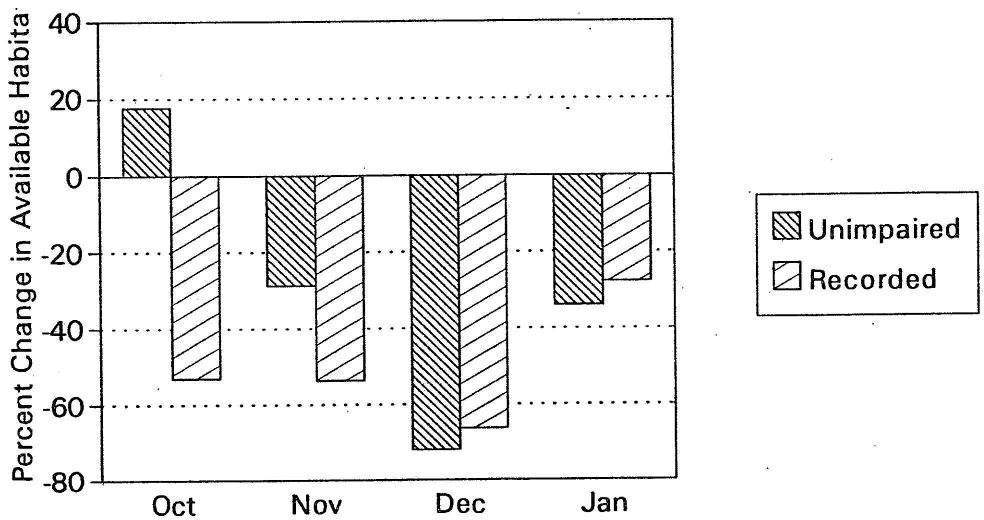
A similar calculation for water-year 1991 for the Yuba River is shown in Figure 18. In this case, the existing WUA relationships have only been developed for flows up to 2500 cfs, whereas mean flows in December and January exceed this value; consequently percent changes in WUA are shown only for October and November. In this system, low water actually increases spawning habitat over the average from 1969-88. On the lower Yuba River, peak spawning habitat occurs at

Figure 15: Occurrence of Adverse Spawning Temperatures on the Feather River during Fall Months, 1985 - 1992



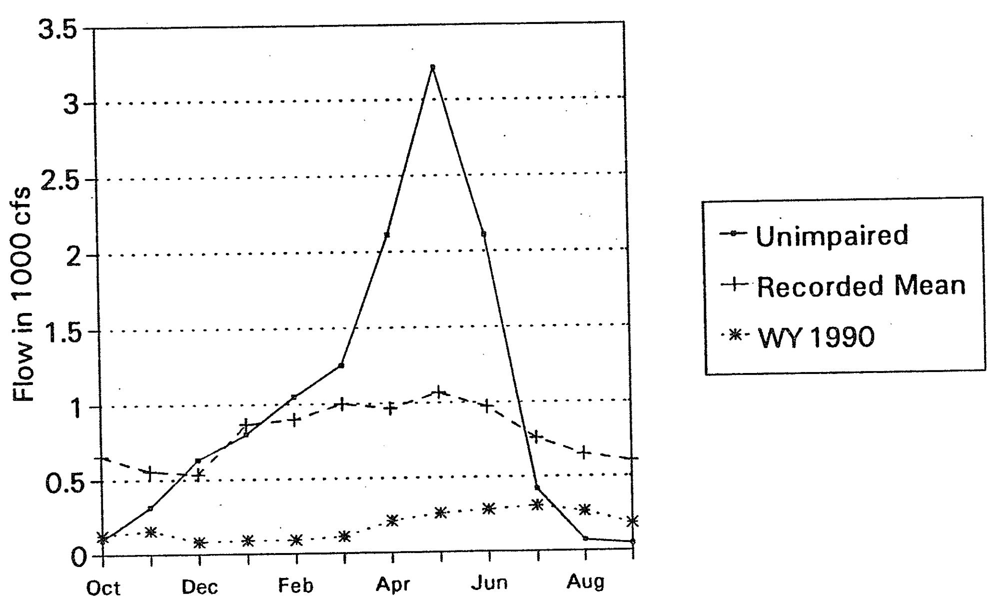
Source: USGS. DWR for 1991 and 1992 data.
Notes: Data converted from °C to °F. Daily average is midpoint of maxima and minima (in °F). Feather River at Oroville, CA.

Figure 16: Percent Change in Available Spawning Habitat on the Lower Mokelumne River in Water Year 1990 Compared to Mean Recorded and Mean Unimpaired Conditions



Source: CDFG, 1991c
Notes: Mean unimpaired flow @ Pardee Reservoir, 1921-83
Mean recorded flow below Camanche Reservoir, 1964-89

Figure 17: Monthly Flow on the Lower Mokelumne River



Source: USGS for recorded flow, DWR (1987) for unimpaired
Notes: Mean unimpaired flow @ Pardee Reservoir, 1921-83
Mean recorded flow below Camanche Reservoir, 1964-89

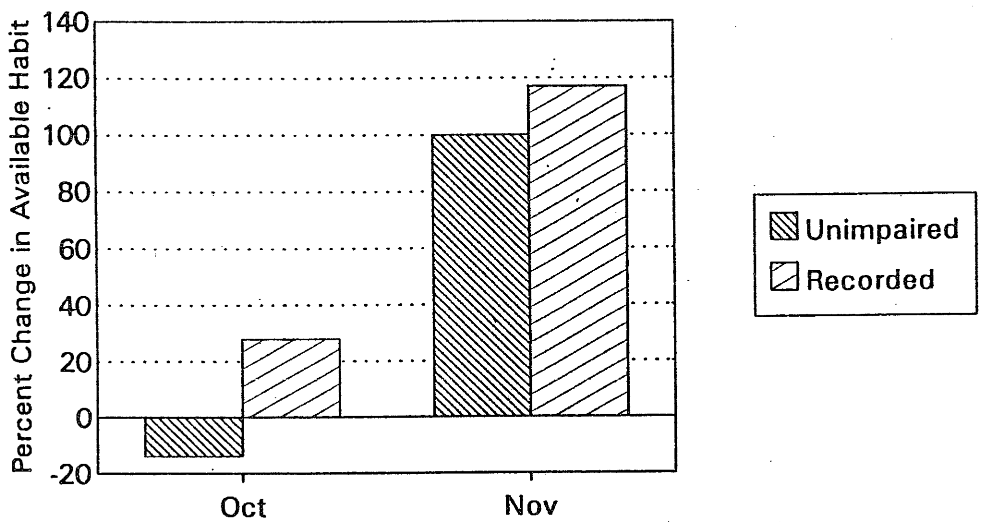
a flow of roughly 400 cfs, which is well below the 1969-88 October mean of 1251 cfs (Figure 19).

Recent studies of habitat availability and instream flows have been much more sophisticated than earlier work. The relationships between habitat and streamflow have been developed based on surveys of important stream reaches in particular streams, which suggests that the relationships better describe actual conditions. There are, however, problems with using WUA relationships to estimate drought-related losses, beyond questions about the accuracy of the relationships themselves. First, available spawning habitat may not be a limiting factor, particularly when high temperatures are an issue. This is probably the case on the Mokelumne, which has a history of temperature problems (CDFG, 1991c). Second, the WUA relationships are designed to establish minimum streamflow requirements, and may not accurately reflect the availability of habitat at higher flows. In the Yuba River study, for instance, WUA relationships cover only a small range of the flows that actually occur on the river. This becomes more of an issue for large rivers with large fluctuations in streamflow.

While the impacts of the recent drought on migratory bird species cannot be quantified, changes in habitat and/or food supply can provide some indication of drought impacts on avian populations. Seasonal wetland habitat in the Central Valley is comprised of state and federal wildlife refuges, private duck clubs, and rice fields. During the drought, most of the focus fell upon water supplies for refuges. As discussed above, it is difficult even to determine actual water supplies to refuges, because water comes from so many different sources. Limited information exists, however, on flooded area, which is gathered every two to four weeks through aerial observations. This information is unreliable, however, because the flooded area is a rough estimate based on individual observations, the individual observer may change frequently, and data are often not recorded accurately or completely.

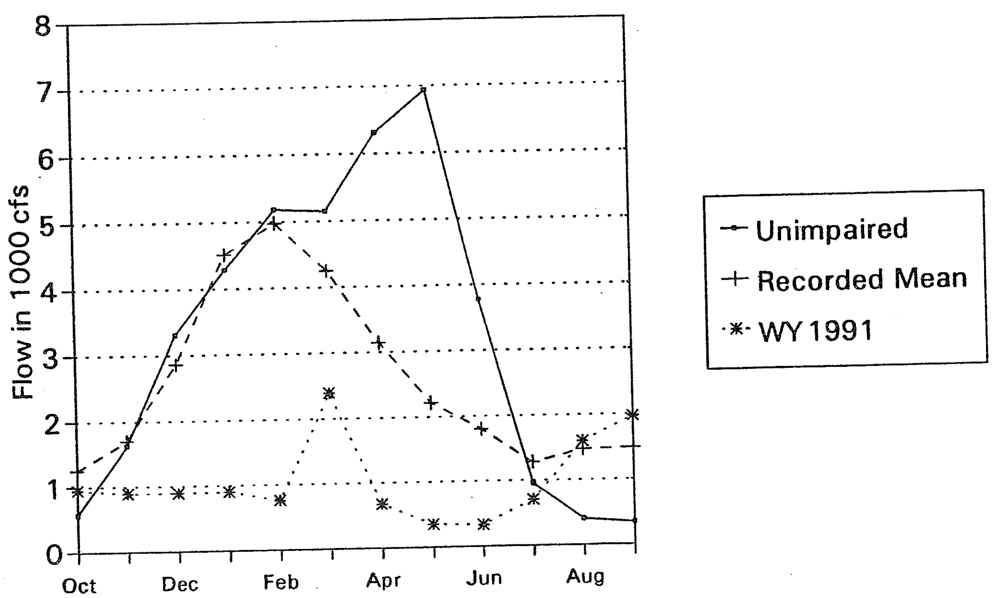
Flooding normally commences in early September, and full flooding is maintained through January, water supplies permitting. Flooded area observations for the northern San Joaquin Valley were compiled to see whether flooding occurred significantly later in the season during drought years. The information, however, suggests otherwise. In fact, overall, areas in the northern San Joaquin Valley appear to have had more area flooded in October than they have had in previous years (Figure 20). The inaccuracy of the data, however, prevent any real quantitative estimate of impact (or benefit). Yet the potential for collecting accurate information on available wetland habitat exists through satellite imagery and other advanced techniques. If collected on a regular basis, satellite data could provide information on long-term trends in habitat availability as well as on the effects of drought.

Figure 18: Percent Change in Available Spawning Habitat on the Lower Yuba River in Water Year 1991 Compared to Mean Recorded and Mean Unimpaired Conditions



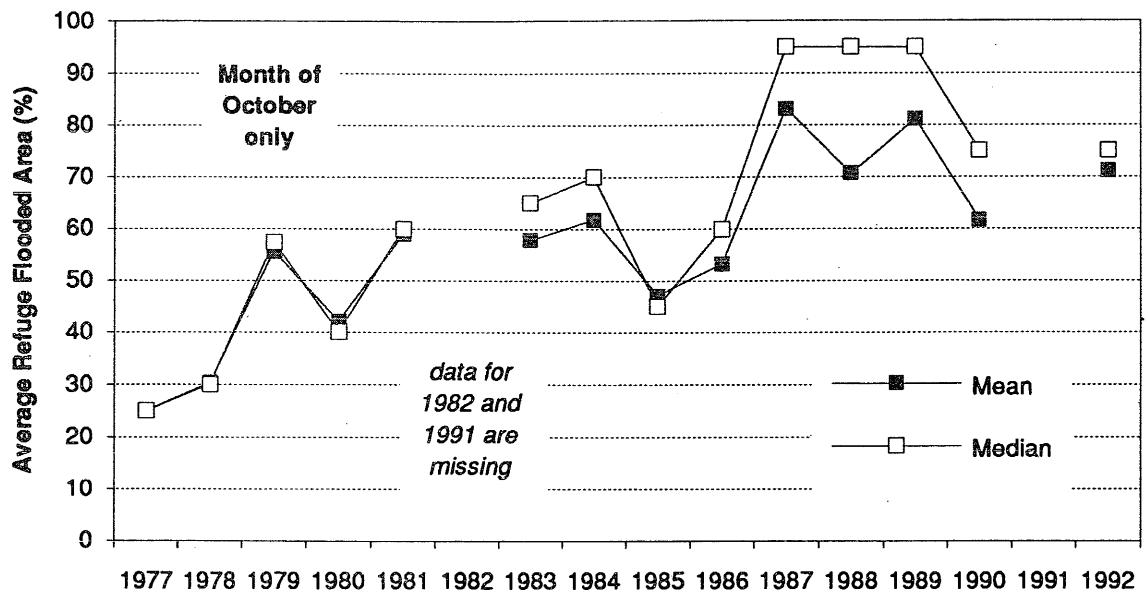
Source: CDFG, 1991b
Notes: Mean unimpaired flow @ Smartville, 1921-83
Mean recorded flow near Marysville, 1969-88

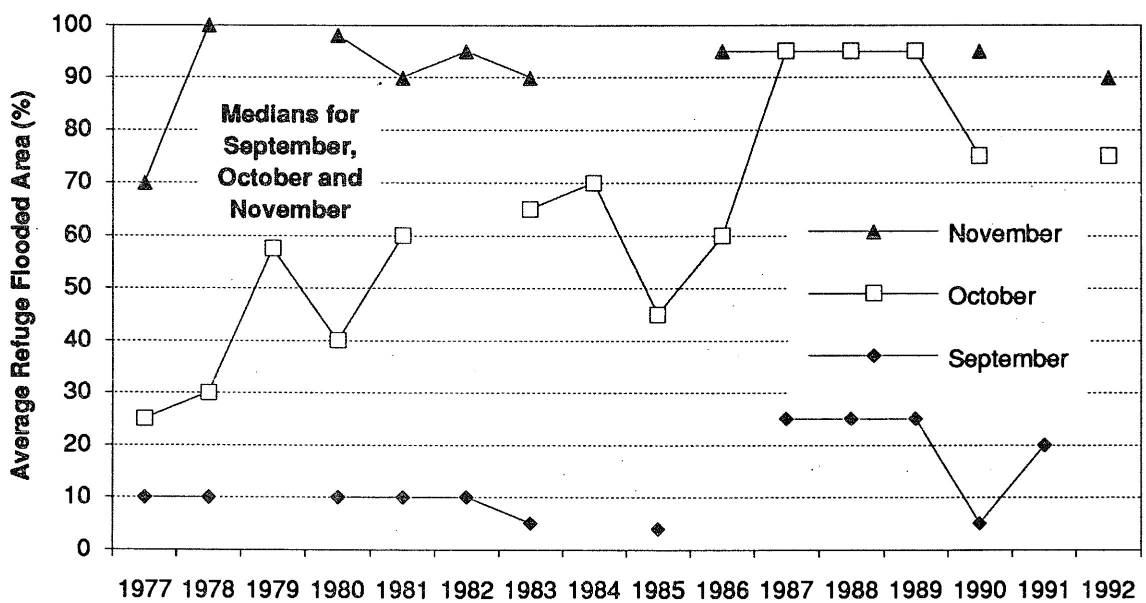
Figure 19: Monthly Flow on the Lower Yuba River



Source: USGS for recorded flow, DWR (1987) for unimpaired
Notes: Mean unimpaired flow @ Smartville, 1921-83
Mean recorded flow near Marysville, 1969-88

Figure 20: Seasonal Wetland Habitat in Northern San Joaquin Valley Fall Months, 1977 - 1992





Source: CDFG, unpublished data.
Data plotted are averages of observed flooded area in the Mendota, Volta, Los Banos, San Luis, Merced, So. Grass, No. Grass, Eastside and Kesterson wildlife refuges. The time series is missing a significant amount of data.

In addition, to flooded area, drought might be expected to alter habitat quality, which might be equally as significant as gross estimates of flooded area. Again this is an impact often cited by wildlife managers and others. Yet no efforts are made to assess habitat quality (i.e., depth of flooding, quality and quantity of food supplies, water quality) in any systematic manner.

In summary, we cannot expect to measure the impacts of drought on ecosystems quantitatively if we do not monitor ecosystems quantitatively. In many cases, we now have the knowledge and the technology to gather data on species, habitat extent, and habitat quality. While monitoring programs are frequently dismissed as a poor use of funds, they provide the only basis for understanding how different factors affect species and communities. Drought impacts can frequently be inferred from long-term data. One of the few systems for which longer term monitoring data exist is the Sacramento-San Joaquin Delta. Station data for several parameters exist from the early 1970s (see figures 8 and 9). This long-term data have made it possible to distinguish drought-related trends in water quality, including phytoplankton composition, and benthic community structure. These data have been used by Nichols, et al. (1990) to show the combined effects of reduced freshwater inflows (i.e., drought) and exotic clams on trends in phytoplankton production in the estuary.

Equally important, monitoring programs provide the basis for setting management goals and refining management programs. Currently conservation management goals are too frequently set legislatively, i.e. through the Endangered Species Act or through legislation such as the Central Valley Improvement Act. Ideally, management goals should be designed for individual systems, taking into account their degree of alteration and their relative importance, and such goals should be refined as our understanding of these systems increases.

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DROUGHT MITIGATION EFFORTS

Background

Contingency planning and mitigation are the cornerstones of drought planning, which has been far too infrequently applied to environmental resources. Drought mitigation represents a short-term response to periods of extreme environmental stress. Underlying the adoption of such emergency measures is the idea that weakened species and systems may need to be shepherded in order to survive and to be able to recover following a drought.

In the recent drought, responses to minimize environmental impacts took three principal forms: (1) the attempt to influence water-project operations in order to benefit aquatic species, principally anadromous fish; (2) the enforcement of water-rights claims to curtail illegal diversions on streams and rivers; and (3) the inititation of drought-mitigation projects to reduce impacts to specific species or ecosystems and to maintain baseline populations. This section deals only with the latter of these categories, and more specifically addresses the use of emergency funds by the Department of Fish and Game to address particular threats to ecosystems or species. Of course, many other "unofficial" mitigation measures were also undertaken locally, such as emergency fish salvage operations. Only the official mitigation program is analyzed here, in part because it is representative of the state-level response to the environmental impacts of the drought.

By their very nature, drought mitigation measures are emergency responses that are implemented quickly and that are intended to be in place for only a limited time. Thus, they cannot address long-term problems or chronic resource mismanagement. They can, however, recognize the exacerbating effects of drought and other anthropogenic impacts and attempt to reduce the latter to survivable levels until environmental conditions improve.

Mitigation projects implicitly recognize the fact that ecosystems and environmental resources are under intensive human management. While this may not be an ideal situation, it is the situation that exists in much, if not most, of California. Given the precarious state of many California species and ecosystems, there is an important role for mitigation efforts to play in preserving biodiversity during severe drought.

The Drought Mitigation Program in California

On October 5, 1991, the governor signed Assembly Bill 12X, which authorized the California Department of Fish and Game (CDFG) to take necessary actions to "minimize the effects of the five-year drought on ecological systems and to maintain and protect threatened and endangered species". The bill provided CDFG with $15.3 million in drought-relief funds.

This bill was initially proposed in April of 1991, amid rising concerns that the drought would pose an imminent disaster for California, and, among other things, would result in a permanent impact on the state's fish and wildlife. That spring a few high profile species had dropped to precariously low levels. The winter-run chinook spawning escapement dropped to 191 fish. The striped bass index fell to the lowest level ever recorded. The Bureau of Reclamation had announced 75% cutbacks to all parties, including the Central Valley wildlife refuges.

The mitigation program's principal goal was to maintain baseline populations in order to facilitate recovery following the end of the drought. The priorities, as set out by the Director of the Department of Fish and Game, were:

(1) Critical habitat for species designated endangered, threatened, or of special concern;

(2) Anadromous fish with special emphasis on stocks which have exhibited a lack of resiliency to the effects of drought or other environmental impacts;

(3) Managed natural wetlands and wetland dependent species;

(4) Anadromous fish production facilities which can support baseline populations;

(5) Wild streams which support native nongame and game species;

(6) Trout and warm-water fish production facilities which will provide fish for restocking;

(7) Reservoir fisheries, with priority based on recreation use and diversity;

(8) The provision of artificial or augmented drinking water for wildlife.

Direct mitigation efforts may be divided into three categories: (1) those efforts that attempt to reduce the severity of the drought, primarily through obtaining additional water for environmental resources; (2) those efforts that attempt to reduce other impacts that aggravate the effect of the drought on sensitive species or ecosystems (e.g., cattle grazing, overharvesting, etc.) through the improvement of habitat conditions; and (3) those efforts that artificially attempt to ensure the survival of depleted populations (e.g., captive breeding, salvage, and relocation). All three types of effort were undertaken in California during the recent drought.

The actual project-specific appropriations are given in Table 4. Roughly 55% of the funds went towards general program funding, including water purchases, administration, and additional enforcement. Sixteen percent (16%) went towards procuring supplemental water for seasonal wetlands used by waterfowl, including water purchases and the development of ground water supplies. Four percent (4%) went towards supplemental water for habitats serving species other than waterfowl. Hatchery programs received 14% of the funds. Actual mitigation projects for fish and wildlife received 7%. The endangered plant program received 4% of the appropriated funds. Actual projects undertaken varied somewhat from those which initially received funding, reflecting changed conditions, newly identified needs, and the department's inability to carry out some of the original proposals.

Overall, the most successful aspect of the mitigation program was the purchase of water to maintain seasonal wetlands and aquatic habitats. In total, $5.7 million was spent to purchase water during the drought; this included the purchase of two permanent water rights. Most of the one-time purchases served seasonal wetlands in the Central Valley. Although surface water supplies were extremely short in 1991 and 1992, most wetland areas (refuges and duck clubs) received fairly adequate water supplies. Purchases were made from individual water districts or farmers (78,000 acre-feet), as well as from the Drought Water Bank (20,000 acre-feet) (Table 5). Most water purchases made during the drought were made on an ad hoc basis as water became available. In one case, DFG personnel managed to trade 20,000 acre-feet of water-bank water with a local water district during the summer months in return for 25,000 acre-feet of additional water during the fall (J. Beam, CDFG, pers. comm.). Actual supplies to refuges were always in question, and most refuge managers managed to acquire small amounts of water from a variety of sources. Actual supplies to the refuges during drought years are thus extremely difficult to determine.

Considerable effort was also devoted to drilling wells to develop ground water supplies for wildlife refuges. In most cases, the time to develop wells was

Table 4: CDFG Drought Mitigation Program

General Program Funding

$7,917,000		Studies, documentation; water market purchases; creative solutions
$160,000		Additional enforcement for illegal diversions, streambed modification, etc.
$25,000		Manpower for waterfowl disease control, equipment.
$120,000		Increase enforcement capabilities
$253,000		Administrative personnel and expenses
$8,475,000	(55%)	

Augmentation of Hatchery System

$350,000		Iron Gate Hatchery--improvement of fish waste disposal
$100,000		Pipeline at Nimbus hatchery.
$100,000		LaGrange Canal facility for rearing fall-run chinook*
$85,000		Drilling of well to supply Silverado Fisheries Operation Base (fish stocking)
$150,000		Multi-level intake for Trinity River hatchery
$575,000		Pipeline to supply additional water to Nimbus hatchery
$600,000		Hatchery production of striped bass*
$15,000		Trucks and trailers for Trinity River, Iron Gate and Coleman hatcheries
$37,000		Monies for hatchery system.
$60,000		Water supply for Kern River hatchery (golden trout)
$1,044,000	(7%)	

Water/Habitat Development — Non-Waterfowl Species

$4,000		Development of wetland habitat: Pismo Lake Ecological Reserve
$25,000		Development of habitat for sandhill cranes (Carrizo Plains)
$3,000		Tule elk, pronghorn antelope and non-game species
$25,000		Panorama Unit, Carrizo Plain (tule elk)
$10,000		Development of habitat for Santa Cruz long-toed salamander
$200,000		Water purchase for spring-run chinook (Deer Creek)*
$250,000		Water purchase for spring-run chinook (Mill Creek)
$40,000		Water purchase for brown and rainbow trout (Lower Owens River)*
$45,000		Forage for Tule Elk (Camp Roberts)
$8,000		Irrigated pasture for tule elk, et al. (Cache Creek, Lake County)
$610,000	(4%)	

Endangered Plant Program

$685,000	(4%)	Endangered plant program.

Table 4: CDFG Drought Mitigation Program (continued)

Water Purchases/Water Development for Wildlife Areas

$150,000	Ash Creek WA
$65,000	Ash Creek WA
$50,000	Butte Valley WA
$4,000	Big Sandy WA
$16,000	Gray Lodge WA (portable pump)
$100,000	Gray Lodge WA
$160,000	Gray Lodge WA
$88,000	Honey Lake WA
$240,000	Salt Slough/China Island (N. Grasslands)
$120,000	Salt Slough/China Island (N. Grasslands)
$196,000	Salt Slough/China Island (N. Grasslands)
$150,000	Grasslands Area
$2,000	Napa-Sonoma Marsh WA
$200,000	Los Banos WA
$125,000	Los Banos WA
$150,000	Los Banos WA
$125,000	Volta WA
$150,000	Volta WA
$300,000	Mendota WA
$2,391,000 (16%)	

Efforts to Mitigate Impacts on Specific Species

$102,000	Barrier modification; improvement of fish passage
$189,000	Rescue and mitigation of SC,T&E species
$31,000	General Fish rescue efforts
$30,000	Equipment for fish rescue effots
$21,000	Habitat improvement for Lahontan cutthroat trout in ByDay Creek reserve
$10,000	Egg-taking program for Lahontan cutthroat trout for restocking of Mill Creek
$25,000	Rescue of salmon from channels in Sacramento River
$50,000	Improve screening at Glenn-Colusa ID intake (chinook)
$50,000	Barrier removal in Kelsey Creek (Clear Lake Hitch)
$150,000	Salmon trap on San Joaquin River
$30,000	Propagation on steelhead @ Fillmore hatchery, Ventura Co.*
$6,000	Spring boxes, water tanks, etc. for wildlife at San Luis Obispo WA
$50,000	Spring boxes, concrete troughs for deer, livestock
$300,000	Habitat development for Shay Creek stickleback*
$1,044,000 (7%)	
$15,277,000	**GRAND TOTAL**

*Not implemented

Table 5: CDFG Water Purchases for Wetlands

Destination	Quantity (acre-feet)	Cost	Source
1991			
Gray Lodge WA San Joaquin Valley WAs	28,000	$1,400,000	Yuba County Water Agency
San Joaquin Valley WAs	13,375	$40,250	Western Canal Water District
San Joaquin Valley WAs	6,000	$90,000	East Bay MUD
San Joaquin Valley WAs	5,920	$177,600	Placer County Water Agency
1992			
Upper Butte WA Mendota WA Volta WA	20,000	$1,800,000	Drought Water Bank
Gray Lodge WA	5,000	$250,000	Browns Valley Water District
Gray Lodge WA	4,000	$200,000	Sydenstricker Ranch
Gray Lodge WA	900	$45,000	Loring Ranch
Gray Lodge WA	5,100	$255,000	Justenson Ranch
Gray Lodge WA	5,000	$250,000	Joint Water Board
Los Banos WA	1,500	$75,000	San Luis Canal Company
Fall River Valley	1,400	$70,000	McArthur Ranch
Llano Seco Loma	2,000	$100,000	Dayton Partners
TOTAL	**98,195**	**$4,752,850**	

Source: CDFG

over one year, and thus most were not needed by the time they were operational. The existence of wells, of course, will help to mitigate against future droughts, although in some areas in which wells were drilled, ground water levels dropped dramatically during the drought (e.g., Kern County, Central Coast).

In addition to efforts on the behalf of seasonal wetlands, a few attempts were made to obtain additional instream water for fisheries. For example, DFG used drought funds to purchase permanent water rights on two systems: Butte Creek, which supports a variable run of spring-run chinook, and Red Lake, which the department plans to use in the future for Lahontan cutthroat trout broodstock. On Mill Creek, which supports one of the two consistent spring-run chinook salmon populations, DFG managed to negotiate with local landowners to obtain temporary water rights. This was possible largely because a long-term restoration plan exists for this creek that involves the leasing of water rights. As drought conditions became extreme, involved parties were willing and able to implement parts of the pre-existing plan. However, similar efforts to negotiate additional water for Deer Creek, which also supports spring-run chinook, were unsuccessful. Similarly, in the Owens Valley, DFG tried to lease water from the Los Angeles Department of Water and Power in order to reduce riparian diversions from Convict and McGee Creeks, spawning habitat for large populations of brown and rainbow trout. LADWP, however, turned down the offer and diversions continued throughout the drought, causing critically low water levels and the dewatering of several stream reaches.

Less successful generally than the water purchase and development efforts were attempts at the direct mitigation of impacts on particular species. Among the successful mitigation projects was the development of ground water to provide water for the coastal lagoon habitat of the Santa Cruz long-toed salamander, an endangered amphibian of the Central Coast. Ground water pumping allowed this species to reproduce successfully in 1992. In Lake County, drought-mitigation funds were used to remove barriers that blocked the access of Clear Lake hitch (a Class 3 species of special concern) to their spawning streams during low flows. Removing the barriers allowed the hitch to move further up the streams, providing them with additional spawning habitat.

Other species-specific efforts were less successful. In San Bernadino County, $300,000 was dedicated to the development of additional habitat for the Shay Creek stickleback, a state and federal endangered species. As planned, the project intended to use a dry lake bed as the site of a water-reclamation project; however, once the heavy rains came in late 1992, the site was under several feet of water. The project is currently on hold.

In Heenan Lake, a refuge for Lahontan cutthroat trout, DFG attempted to improve dissolved-oxygen levels through the use of aerators; however, the aerators sunk. Water quality remained a concern throughout the drought, although only limited information is currently available on how fish populations in the lake fared. At the Carrizo Plains Ecological Reserve, an attempt was made to develop ground water to benefit nesting sandhill cranes; however, the lag time involved prevented the project from getting underway before the cranes arrived to nest. By late 1992, the ground water wells were still not operational.

Throughout the state, several efforts were made to trap anadromous fish in late 1991 and 1992 in order to breed them in hatcheries and to help to preserve threatened runs. In most cases, these efforts were not highly successful because returns were so low that insufficient numbers of fish were trapped. For instance, on the Stanislaus River, an extreme case, only two female chinook were trapped (R. Ellis, CDFG, pers. comm.).

A notable exception to this general trend was the very successful trapping and breeding program for Carmel River steelhead. Following three years in which no flow reached the ocean, and consequently no fish were able to spawn, a captive broodstock program was initiated in 1991. The program is now in its third year and will be discontinued after 1994, at which time natural spawners should be adequate to support the fishery. Early returns to the river in the spring of 1993 indicate that the fishery is recovering (see preceding section).

Mitigation efforts for endangered plants focused primarily on fencing sensitive populations to protect them from other adverse impacts, notably grazing and off-road vehicles. In addition, some drought-mitigation funds are being directed to the restoration of endangered plant habitats (e.g., vernal pools) and to species reintroductions.

Overall, the mitigation efforts were heavily focused on the Central Valley, primarily upon waterfowl habitat and anadromous fisheries. This may reflect the attention given to this region by both media and policymakers, as much as its ecological value. It also reflects the traditional bias of the department towards "game" species. Although serious impacts were occurring in other regions of the state (e.g., Northeastern California), these areas were bypassed by drought mitigation efforts.

Given the variable success of rescue and species-specific mitigation, the most successful mitigation strategy appears to have been the purchase/securing of additional water for aquatic and riparian systems. This required far less direct human intervention in ecosystems. Yet the application of this strategy was limited by the lack of both time and preexisting agreements. Although the Drought Water Bank was able to provide water to Central Valley refuges, and could also have provided additional water for Central Valley fisheries, in other regions, the availability of water for environmental purposes depended upon the actions of local landowners. In most cases, agreements and/or relationships were not in place to allow such transfers to occur in a timely manner. Where an agreement was in place (i.e., Mill Creek), additional water was secured; in other instances where no agreement existed (i.e., the Owens Valley), water transfers could not be negotiated despite the availability of funds.

For areas that are highly modified yet contain threatened or endangered populations, it may be appropriate to enhance habitats during drought to aid the survival of limited populations. This is similar to what was undertaken at Ellicott Pond to benefit the Santa Cruz long-toed salamander. Similar measures were attempted (unsuccessfully) for the breeding habitat of sandhill cranes at the Carrizo Plains Ecological Area. Habitat enhancement may simply consist of the provision of additional water, but might also include other restoration activities (e.g., the removal of exotic species) as well as the stricter regulation of confounding impacts. Moreover, threatened and endangered species may need to be aided throughout their range during a drought in order to prevent the loss of genetic diversity represented in different populations. Ideally, threatened and endangered populations should be monitored, particularly during periods of drought, to assess the need for additional intervention. The lack of population monitoring during the recent drought has left a large gap in our knowledge of the condition of vulnerable species.

For species with small populations that face the risk of extinction during drought, captive breeding may also play a critical role. Clearly this was crucial to the survival of the Carmel River steelhead. But captive breeding of wild species should not be confused with increased reliance on the hatchery system, which also occurred during the drought. Hatchery-reared fish may only dilute limited stocks of wild fish during drought, and consequently may diminish the genetic integrity of the species and ultimately decrease the populations of truly wild fish following drought. Moreover, many hatchery fish are of mixed origin and are likely to be poorly adapted to California's dry environment over the long-run.

More generally, successful mitigation efforts cannot be effectively carried out without some advance planning. In the case of California's recent drought, not only did money for mitigation efforts become available after the drought was well-established, but the proposals for using the money were generated somewhat haphazardly, causing some questionable projects to be funded, while other needs went unaddressed. Based on our limited knowledge of the types and severity of impacts which occurred, as well as upon the experience of the drought-mitigation program, we can identify some necessary components of successful mitigation planning.

- Where possible, mitigation efforts should be system-based, rather than species-specific. For instance, $600,000 was spent to rear juvenile striped bass to augment declining populations in San Francisco Bay; however, concerns over the impact of the predatory bass on winter-run salmon juveniles ultimately caused this project to be abandoned. (The striped bass were stocked in reservoirs.) This failure illustrates the problem of considering only a single troubled species (in this case, a well-established and popular exotic) rather than threats to the ecosystem as a whole.

- Resources at particular risk during drought should be identified. These should include aquatic habitats subject to drying and/or severe water quality problems, aquatic and riparian-dependent species with small populations, species with short life-cycles, and unique assemblages of native species. Priorities should be developed based upon resource quality and uniqueness as well as the presence and number of native fauna. A recent proposal to catalog all aquatic habitats in California along similar lines as "aquatic diversity management areas" (Moyle and Yoshiyama, 1992) provides the logical starting point for this type of effort.

- For those systems designated as extremely sensitive to drought, anthropogenic factors that aggravate the impacts of drought should be identified, including: water diversions, grazing, logging, presence of exotics, etc. Alternatives for minimizing anthropogenic impacts should be identified, including dry-year options for water rights, ground water development opportunities, restrictions on grazing during drought years, and habitat enhancement opportunities.

- The securing of dry-year options on water in sensitive areas should be given high priority. CDFG should identify potential lessees and attempt to negotiate terms for water transfers in the event of a drought. Subsequently, drought-contingency funds could be used to activate these agreements in a timely manner.

- Plans for augmenting populations of particular species and fish stocks during severe drought should be developed, including the feasibility of captive broodstock programs. Although this is a last resort, as the example of the Carmel steelhead suggests, this level of intervention may be necessary to prevent the extinction of species during severe drought.

In summary, the environmental mitigation program implemented during the recent drought met with limited successes. The potential of the effort was constrained by the fact that additional funds were not available to address drought-related problems until late 1990, nearly four years into the drought. More importantly, however, the lack of drought-contingency plans and monitoring efforts made it difficult to determine which resources were in the most critical condition and what specific efforts should be undertaken. Without such planning, the focus of the program on traditional "game" species (e.g., commercial and sport fish and waterfowl) was predictable. The increased reliance on fish hatcheries during the drought is also questionable. While hatcheries may play a critical role in maintaining commercial fisheries during extended droughts, they may also contribute to the dilution of wild stocks. Other investigators have recently called for a more studied approach to the use of hatcheries; this is particularly true during drought periods, when populations of wild fish may drop to critically low levels.

Despite these concerns, however, mitigation efforts played an important role in several instances, particularly in securing additional water for environmental resources. The success of the program in securing water for certain seasonal wetlands and on a few stream systems suggests the long-term potential to mitigate the impacts of drought by securing dry-year options on water and through the development of more flexible water-management institutions.

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DROUGHT PLANNING AND POLICY

Background

Drought underscores unresolved questions about water and environmental management in California by intensifying the conflict over what priorities different water uses should have. The recent drought, for instance, brought increasing criticism of certain agricultural water uses, particularly the irrigation of highly water-intensive crops. The debate about what constitutes appropriate protection for environmental resources grew more heated as several fish species were proposed for listing under the federal Endangered Species Act. Similarly, the drought re-ignited longstanding debates about the need for additional reservoir and water-transfer facilities.

Not surprisingly, considerable conflict emerged over the proper response to the drought, particularly with respect to how quickly reservoir storage should be depleted during dry years. There exists a continual tradeoff between the benefits of carryover storage for a possible upcoming dry year versus the detrimental effects of imposing shortages and not making use of stored water. Both the SWP and the CVP opted to meet full, or nearly full, delivery schedules in the early years of the drought. Ultimately, as the drought continued, dramatic cutbacks became necessary in 1991 and 1992, and consequently anadromous fisheries suffered from severely reduced flows and higher water temperatures.

In retrospect, what is striking is the extent to which the drought was viewed as an unforseen emergency. By early 1991, the people of California were in a near-panic state. The Governor was considering whether to declare an official emergency across the state, which, among other things, would have allowed the reallocation of water without regard to established rights (Governor's Drought Action Team, 1991). Several counties had declared local emergencies and were pressing the Governor to make similar declarations. Yet the state had faced a similar water-supply situation only 15 years earlier. While droughts cannot be predicted with any accuracy, they are a known feature of California's climate, and the impacts of droughts and other natural hazards can be minimized through contingency planning. This section examines drought policy in California, focusing on: (1) how the state responded to the recent drought, (2) what recent policy changes will affect responses to a future drought, and (3) what issues remain to be addressed to ensure the protection of environmental resources during future droughts.

Responses to the California Drought

Prior to the recent drought, the state had few specific emergency drought plans. In general, water planners in California have focused on water-management planning more generally, rather than on drought contingency planning. As a result, responses to the recent drought were developed progressively to address particular situations. These extemporaneous responses were administrative and legislative as well as operational. One of the first actions was the development of the Drought Information Center, which served as a clearinghouse for information about both the drought and water conservation measures. In early 1988, the California Department of Water Resources (CDWR) began to survey water-supply agencies and to identify water-short communities as well as actions taken to address water-supply shortages (Findago, 1989). Yet for the most part, actions taken on the part of the state during the first three years of the drought were minimal.[6]

In February of 1991, with reservoir storage at a record low, the Governor announced a four-point drought plan. The most significant part of this plan was the establishment of the State Drought Water Bank to facilitate transfers of water to regions facing critical shortages. CDWR assumed sole responsibility for organizing and implementing the Bank. Sellers made water available by fallowing farmland and transferring conserved irrigation water to the Bank, substituting ground water for surface water, or transferring water stored in local reservoirs to the Bank. Most of the water sold came from the Sacramento Valley and the Delta, and in a few communities, large areas of farmland were not planted. During its two years of operation, the Bank delivered a total of 814,000 acre-feet, with 60% going to agricultural users, 25% to urban areas, and 15% to waterfowl habitat.

Most reviews of Bank operations have been fairly positive, given the short time in which it was set up and the state's lack of experience in water trading and marketing (e.g., Howitt, et al., 1992). The major criticisms have focused on the state's failure to consider adequately third-party impacts, that is, the ways in which the Bank affected parties other than the buyers and sellers. For example, in regions where large amounts of farmland were idled, jobs and income were adversely affected. Similarly, the environment may suffer impacts when water resources are transferred. In Yolo and Solano counties, the area of flooded wetlands was

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[6]In 1988 and 1989, however, DWR did augment SWP supplies through negotiations with a local water district.

substantially decreased as a result of sales to the Bank, potentially limiting available habitat for waterfowl (Coppock and Kreith, 1993). Environmentalists have also criticized the Bank for the inability of environmental interests to participate effectively in the Bank given the high price of Bank water, particularly in 1991 ($175/acre-foot). Overall, the Bank was established with urban and agricultural interests in mind, although emergency appropriations to the Department of Fish and Game allowed about 20,000 af of water to be purchased for Central Valley waterfowl refuges. The Bank also allowed additional water to be held in Shasta to benefit winter-run salmon, and attempted to minimize impacts on Delta fisheries by moving water across the Delta later in the year. Yet overall, the Bank did not serve critical environmental needs as well as it might have.

Aside from the Drought Water Bank, the other parts of the Governor's drought action plan included:

- Directions to communities that had not already done so to adopt rationing plans to achieve 50 percent cutbacks in water use;

- Direction to CDFG to work with the U.S. Fish and Wildlife Service to do everything "humanly possible" to protect habitats, and to prepare immediately for restoration of natural areas when the drought is over;

- A promise to sponsor legislation to establish a $100 million Drought Action Fund to provide technical and financial assistance to communities for conservation and new water supply projects, fund water reclamation and conservation projects, boost fire-fighting capabilities, and expand the California Conservation Corps.

Additional administrative actions taken during the drought focused on coordination and the distribution of information. To coordinate the state's response to the drought, the Governor formed the Drought Action Team, composed of top administrative appointees in various agencies. Among other things, the Drought Action Team played a major role in advising the Governor on the development of the Drought Water Bank. The Drought Information Center also coordinated the Interagency Drought Task Force, which served as a public information group that held meetings throughout the state to discuss the drought and conservation activities.

Among the major emergency legislative actions was AB-12X, which provided $15 million to the Department of Fish and Game to undertake the mitigation program described earlier. In addition, legislation was passed to require drought contingency plans for urban areas. These contingency plans must include the actions that would be adopted by urban water suppliers to respond to shortages of up to 50%. Specifically, the plans must specify mandatory prohibitions on wasteful practices, water-rationing limits that would be applied during severe shortages, penalties for excessive use, an analysis of the financial effect of the plan on the supplier, a draft resolution or ordinanace to implement the plan, and a mechanism to determine actual reduction in water use pursuant to the plan.

The major operational change that occurred during the drought was the passage of federal legislation that allowed federal projects, including the CVP, to deliver non-project water during a drought emergency. This action was critical to the functioning of the Drought Water Bank, because it provided access to additional buyers and sellers. Nonetheless, the Bureau of Reclamation did not allow CVP contract water to be sold to the Bank.[7]

Recent Developments in Water Policy

In the time during and since the drought, there have been several new developments in water policy that are likely to have a substantial effect on the management of water and natural resources during future droughts. While some developments are either a direct or indirect outgrowth of the recent drought, others are long-term changes that are not necessarily drought-related.

Undoubtedly the most significant recent development is the passage of P.L. 102-575, the Reclamation Projects Authorization and Adjustment Act of 1992, which included the Central Valley Project Improvement Act. This act not only expands the authorized purposes of the CVP to include benefits to fish and wildlife, but specifically dedicates up to 800,000 acre-feet per year of project water to fish and wildlife uses, and specifies that this amount may be reduced by no more than 25% during drought years. Additional water supplies are guaranteed to wildlife refuges through the requirement that the Bureau of Reclamation provide "Level 2" water supplies to wildlife refuges immediately and "Level 4" supplies within ten years. The act establishes a general goal of doubling natural anadromous fish populations (compared to average levels during 1967-91) and further requires a series of very specific habitat restoration and mitigation activities throughout the Central Valley, such as the installation of a temperature control device at Shasta Dam and the reduction of fish mortality at the Delta pumping plants. Most of these measures require a state-federal cost share, with the State of California responsible for roughly 25% of the costs in most cases. To fund the federal obligation, the bill establishes a "Restoration Fund." The revenue sources for this fund include surcharges for the

[7]CVP contractors with pre-project riparian rights did participate in the Bank, however.

non-renewal of contracts, revenues from tiered water pricing and the increase in water rates related to the transfer of water, the surcharge levied on entities who receive water from the Friant Division after September 30, 1997, and any mitigation or restoration payments. In effect, the bill requires users of project water (including power producers) to pay for the costs of mitigating project impacts.

The significance of this act for Central Valley fisheries and waterfowl is considerable. In essence, it makes the environment a contractor of the federal project, as well as laying out a specific set of goals and mitigation measures for restoring fish and wildlife resources. Within the state, some wildlife managers have expressed confidence that this measure will prove more than adequate in protecting environmental resources during future droughts. Yet there remains considerable uncertainty about the how the act will be implemented, particularly given the ongoing state budget crisis. Other promising environmental legislation has never been adequately implemented in the state, notably California Senate Bill 1086 (passed in 1988), which mandated the restoration of salmon and steelhead resources in the Central Valley.

A development of nearly equal significance was the announcement by the SWRCB in December of 1992 of Decision 1630, which established interim protections for San Francisco Bay and the Delta. This decision grew out of the water policy announced by Governor Wilson in April of 1992. The decision contained several important provisions that would have protected environmental resources; but, ultimately the plan was rejected by the Governor, who claimed that his own Water Policy Council (discussed below) and the recent decision by the federal government to list the Delta smelt as a threatened species made interim standards unnecessary. Among the most significant provisions of this decision were the establishment of an environmental mitigation fund (that, among other things, would have provided the state cost share required by P.L. 102-575), the adoption of seasonal pumping limits for the Delta, the requirement for real-time monitoring and management of water quantity and quality in the Delta, and the requirement that the state and federal projects develop and follow appropriate reservoir management policies.

The requirement for established reservoir management rules is particularly important from the perspective of drought management. This requirement would eliminate much of the uncertainty over when and how cutbacks to users would be implemented and would help to ensure that adequate water remained in storage to meet baseline environmental requirements. By contrast, the absence of enforced reservoir management rules can result in adverse impacts both to water users and to the environment. For example, management of the Sacramento system during the recent drought has resulted in a lawsuit that is being brought against the Bureau of

Reclamation by environmental interests (T. Sletteland, Sacramento River Trust, pers. comm.).

As part of his water policy announced in April of 1992, Governor Wilson established the Water Policy Council and the associated Bay-Delta Oversight Committee (BDOC), with the purpose of seeking a permanent solution to Delta issues. While the Water Policy Council was composed of agency leaders, BDOC brought together urban, agricultural, and environmental interests from different parts of the state. Potentially a useful forum for creating a long-term water policy for the state and forging a consensus on water management, this effort lost the critical participation of environmental interests when the Wilson administration backed away from the interim Delta standards proposed in Decision 1630.

The fourth major development since the onset of the drought has been the listing of threatened species, most notably the winter-run chinook and the Delta smelt. Because both of these species utilize the Delta, their threatened status has already begun to influence the operation of water projects. A biological opinion issued by the USFWS in February of 1993 has specified several operational changes that the water projects must implement to minimize impacts on the winter-run chinook. These include a more conservative method for forecasting deliveries, minimum storage requirements for most years (although requirements for dry and critically dry years are to be determined on a case-by-case basis), minimum flows in the Sacramento River between October and March, temperature objectives in the Sacramento River, and limits on the occurrence and duration on reverse flows in the Delta (NMFS, 1993). Similar recommendations to be issued on behalf of the smelt are expected to have a greater impact on Delta exports and pumping because the smelt spends its entire life-cycle in the Delta and is sensitive to both the location of the mixing zone and the rate at which water is exported (Moyle, et al., 1992). Two additional Delta species are currently under consideration for listing: the Sacramento splittail and the longfin smelt. The listing of so many species will undoubtedly reduce operational flexibility in the coming years. In one sense, this is the result of past failures to integrate water and environmental management more fully and to anticipate the impacts of drought on highly managed ecosystems.

Within the state, recently passed legislation, Section 1707 of the Water Code, provides for the dedication of existing water rights to instream uses. From an environmental perspective, the drought made obvious how little priority instream and environmental uses of water have in California. Little precedent exists for protecting instream flows during drought and several systems had minimal flows. In the most extreme cases, streams went dry for one or more seasons. The ability to negotiate for instream rights is critical to protecting environmental resources during drought years. Although this legislation takes a step towards providing a basis for the dedication of instream rights, there are many unresolved issues, and environmental interests fear that, as currently written, this legislation may not result in any firm water for the environment (C. Congdon, EDF, pers. comm.).

One direct outcome of the drought has been the attempt to establish a permanent Drought Water Bank. As currently proposed, the Bank would operate only on a year-to-year, emergency basis following a determination by the governor or CDWR that a critical water-shortage situation existed. Although, as the drought illustrated, water-banking has a tremendous potential to help alleviate water shortages and reallocate water, the current Bank proposal limits the potential to secure dry-year options on water for the environment. Moreover, CDFG would be the sole buyer of environmental water, which would unnecessarily limit the potential for local interests and non-profit groups to obtain water for ecosystems.

Drought Planning Needs

In a sense, all water planning in California can be considered drought planning, given that annual streamflow is frequently inadequate to meet demands. And, in fact, for the first time, CDWR will incorporate a drought scenario into its five-year water planning document (D. Priest, CDWR, pers. comm.). Drought contingency planning differs from established water planning, however, to the extent that it focuses on short-term responses and recognizes that all existing demands for water cannot be met.

Implicit in the idea of drought contingency planning is the recognition of risk. There always exists the possibility of extreme conditions in which demands cannot be met. One observation that emerges from the recent drought is the tendency of policymakers to underestimate the risk of drought. This is borne out by the willingness of water-project managers to continue full deliveries despite three years of very low streamflow. This observation, however, is not surprising. In fact, several studies of governmental response to natural hazards have pointed out that there exists a "bias towards optimism," as well as an expectation on the part of resource managers that natural processes will be uniform and that conditions will soon return to "normal" (Riebsame, et al., 1991; Holling, 1986). From the perspective of the policymaker, the central questions are: what level of risk is acceptable, how should that risk be allocated among different sectors; and to what extent should the state compensate those who bear the costs of drought?

Risk may be reduced by increasing flexibility and resiliency. For the human population, this means increasing the potential sources of available water and decreasing demands. For instance, farmers with access to ground water were able to rely increasingly on pumping as surface water supplies were cut back. Similarly, the availability of water through the Drought Water Bank reduced the costs incurred by urban water users. Moreover, many urban areas reduced their water usage by 15% to 20%, and more in some cases. For environmental resources, reducing risk requires that the overall condition of ecosystems and species be adequate to recover from drought-induced stress.

In order to allocate risk, it is necessary to have reliable information about the potential impacts of drought. While in many ways impact assessment may seem to be a second-order problem, it is critical to the equitable allocation of risk and/or scarce water supplies. As the drought moved into its fifth year in 1991, many parties offered highly biased assessments of the impacts they would suffer if forced to endure additional water shortages. Given that the crisis was already upon the state at that time, there was little or no opportunity for better assessments to be undertaken. More distressing, however, is the fact that little information was gathered during the drought that would make better assessments possible in the future.

The task of impact assessment has been given to the Department of Water Resources, which as an agency is traditionally more sensitive to its urban and agricultural clients than to environmental impacts. This is a natural reflection of that agency's mission, rather than an intentional bias. Yet even with respect to the estimation of urban and agricultural impacts, the methods used have generally been inaccurate and have often resulted in the overstatement of impacts in both the agricultural and industrial sectors (Gleick and Nash, 1991). Meanwhile, impact assessment has not been a function of environmentally oriented departments such as Fish and Game or Forestry, because these agencies are generally required to focus their efforts on management rather than on research or monitoring. As a result, the data gathered on plant and wildlife impacts has been disappointingly spotty.

Finally, the impact assessments that have been undertaken have frequently failed to ask the most important questions, particularly concerning the incremental costs of drought. With respect to agriculture, the important question from a planning perspective is not what were the *gross* impacts of drought on particular communities, but what are the marginal costs of reduced water supplies.

Environmental impacts have traditionally been ignored or downplayed in both contingency planning efforts and in impact assessments. Most frequently, environmental impacts are dismissed as being too difficult to quantify, resulting in an inordinate focus on impacts in other areas. Yet in California *all* impacts have proved extremely difficult to quantify accurately, although numbers have been produced. Again, agricultural impacts provide an interesting example. Agricultural profits are affected by numerous different factors, including prices and planting policies in other regions and countries, trade and tariff policies, extremely complicated farm subsidy and set-aside programs, existing debt in the farm sector, and land prices, to name but a few. Moreover, the fallowing of one crop may simply provide opportunities for the planting of another. Although impacts certainly occurred, it is not simple to single out the impacts of drought on profitability in the farm sector. Finally, it is not clear that our interest should be in the impacts of drought on annual profits in the local farm sector, rather than in the overall resiliency of the agriculture industry.

Conversely, the impacts of drought on particular environmental resources can be readily seen in many instances. The inability of reservoir systems to retain adequate cold water for anadromous fish spawning is one example. Decreases in water quality in the Delta are another. More accurate information about the impacts of drought on particular species and habitat types can be developed through research and monitoring. Yet to date, California's drought and water-management planning have largely ignored the need to plan for the protection of environmental resources.

While in many ways, changes in California water policy appear to be overtaking and overshadowing efforts to plan for drought, in fact, both water policy and drought planning lag far behind the state's continued growth in population and continuing pressures for development. The California Department of Finance estimates that the state's population will reach 63 million by 2040, compared to 30 million today (*San Francisco Chronicle*, 6/22/93). Much of this growth will undoubtedly reach into regions that have traditionally been sparsely populated, including the North Coast, the Central Coast, Northeastern California and the foothills of the Sierra Nevada. These regions contain many of the state's most intact ecosystems, as well as many endemic species. Yet little has been done to plan for both the growth of human population and the protection of environmental resources. Growth in human population and corresponding increases in water demands will intensify conflicts over water during droughts. Without policies that address baseline environmental needs throughout the state, species are certain to be lost even more rapidly.

The tendency of water planning in California has been to focus on investing in permanent drought protection (i.e., increases in water supply), primarily through increases in storage. Yet to eliminate any significant risk of drought would require extremely large investments that seem increasingly untenable. Moreover, what the recent experience in California suggests is that the risk of drought has been borne primarily by environmental resources. This is the natural outcome of traditional water planning, which focuses solely on meeting consumptive human demands. Increasing storage is unlikely to alleviate most of the environmental risks of drought, in part because the development of storage reservoirs inevitably entails adverse environmental effects. Instead, long-term efforts must focus first on increasing the viability of plant and wildlife populations and on maintaining the integrity of ecosystems.

Despite the state's failure to plan for ecosystem protection, there have been some important changes that will alter how the state responds to the next drought. First, The CVP Improvement Act will ensure adequate water deliveries to Central Valley wildlife during drought. Moreover, if any or all of the mitigation measures are successfully implemented in the near term, anadromous fisheries in the Central Valley should be in significantly better condition, and thus better able to recover following a drought.

In addition, the state's water system has become slightly more flexible, largely as a result of the experience with the Drought Water Bank. Provisions for the transfer of CVP water contained in the CVP Improvement Act, as well as a permanent water bank and the limited experience the state has gained in water trading should all help to reduce both the risks and losses incurred during a drought. Ultimately, however, the efficacy of water trades in reducing impacts will depend upon the extent to which they are encouraged, and how well they are managed, by the state.

Yet despite these improvements, many concerns remain. First, water policy in California remains unresolved and highly contentious. Perhaps above all else, the drought illustrated how ill-prepared the state was to deal with a major water shortage, particularly from the perspective of protecting critical environmental resources. Although admirable efforts were made to alleviate the impacts of the drought, these impacts still fell disproportionately upon the state's natural resources. In addition, many recent water-planning mechanisms have recently broken down, including those that were an indirect outgrowth of the drought. For instance, the Bay-Delta Oversight Committee has lost the support and critical participation of environmental interests. Interim water quality standards for the Bay and Delta have been abandoned. And separate attempts by agricultural, urban, and environmental interests to reach an accord have stalled. While many efforts to negotiate water policy reforms are ongoing, the absence of a comprehensive water policy for the state remains a constant, and without the immediate pressure of water shortages, progress seems likely to come even more slowly.

Secondly, the CVP Improvement Act promises significant restoration efforts in the Central Valley; however, it has also caused the focus of restoration to lie almost exclusively in that region of the state, and it addresses only those impacts attibutable to the federal project. Impacts associated with state and local projects, which are not insignificant in the region, are not addressed by this legislation. Many of the streams and rivers of the Central Valley are subject to diversions and river regulation by entities other than the CVP. In most cases, there are some instream flow requirements, but they are often inadequate. For instance, minimum flows on the Merced River are specified in a Federal Energy Regulatory Commission (FERC) permit for hydropower, and are inadequate to maintain the fishery in dry years.

Moreover, while the CVP Improvement Act sets aside water from the federal project for environmental use, the only environmental management goal that it establishes is a general one, i.e., the doubling of anadromous fish populations.

More generally, unique resources are threatened throughout the state by competition for water and ongoing habitat destruction. For instance, the Klamath River suffers from chronic temperature and water quality problems, and all anadromous fishes on the North Coast are in serious trouble (Moyle and Yoshiyama, 1992). The remaining native fish fauna of Southern California are all threatened with extinction (Swift, et al., *1993*).

Thirdly, little or no drought contingency planning is currently ongoing at the state level; thus future droughts, like past droughts, are likely to be viewed as emergencies. While overall improvements in water planning will necessarily improve the situation under drought as well as normal conditions, if we consider a drought as an emergency, then even more comprehensive water-management rules may be ignored or exempted in times of crisis. An example of this is the decision made by the SWRCB in both 1977 and 1992 to relax water quality protections for the Delta on an emergency basis, even though existing protections are scaled to reflect water conditions in the state. If the risk of drought is to be allocated in a reasonable and fair manner, the procedures for making decisions during drought must be agreed upon *publicly* and *in advance*, not on an emergency basis. This includes decisions about how to manage reservoir storage during periods of low inflow, what minimal environmental protections will be maintained under various conditions, and how and when activities that aggravate drought impacts on plant and wildlife populations (e.g., grazing, logging, ground water pumping) will be curtailed. Moreover, there should be a concerted effort to enforce these agreements during drought. One of the most obvious problems in California is the lack of a institutional definition of drought, which would allow all parties to agree on when the state, or regions of the state, are experiencing a drought, and which could be used to trigger previously agreed-upon responses. This is a critical policy need if mitigation measures are to be implemented in a timely manner and if emergency resources are to be tapped.

Arguably, regulations and plans are most important during an extreme period, such as the recent drought. While some resource managers may claim that the severity of the recent drought could not have been anticipated, a drought of equal magnitude was recorded in the first half of the century. Certainly we can plan for more severe situations, even if we do not actually anticipate them. Unusual events are precisely the phenomena for which institutions must plan the most carefully. Less severe, more frequent stresses can be managed by routine responses and flexibilities, but extreme events can lead to wholesale system failures (Riebsame et al., 1991).

In addition, ground water development and depletion are likely to emerge as major issues during the next severe drought. Ground water resources were severely overdrafted during the current drought in order to offset lost surface water supplies. Thousands of new wells were drilled throughout the state to supply farmers, wildlife refuges, municipal water suppliers, and private homeowners. From a water-supply perspective, this represents a significant loss of drought resiliency. These wells will be tapped in the next drought, and ground water reserves will be drawn down more quickly. In many cases, wells actually tap river underflow, as in the Carmel River, further depleting surface water supplies and causing streams and lakes to dry sooner than they might have. Thus, ground water management is not merely a water supply issue, but an environmental conservation issue as well. Little active management of ground water has been undertaken in California. In some regions which face severe overdraft problems, there have been attempts to control pumping and well-drilling; however, for the most part, ground water remains a poorly regulated resource.

Recent proposals to expand existing water projects into new basins also need to be examined critically from an ecological perspective. Water projects have been a principal means by which invasive exotics have moved into new areas. Since the early 1970s, native and introduced fishes of the Central Valley have been carried into southern California reservoirs with imported water. Some of these introduced fishes, such as prickly sculpin and chameleon goby, have subsequently become established in reservoir outlet streams (Swift, et al., *1993*). As discussed above, exotics pose an ongoing threat to native fishes and natural ecosystems, and may reduce the overall resiliency of native communities to drought.

Finally, the recent drought points out the need to restore native species and ecosystems to sustainable levels. The critical state of environmental resources became one of the central concerns during the recent drought. This marks a change in the period since 1977. The recent drought pointed out how poorly we have managed some of California's most important and unique resources. While anadromous fisheries are the most discussed example, many species have been nearly eliminated. If populations are allowed to decline to marginal levels, they will become vulnerable to extinction during a severe drought. If environmental concerns are in fact a priority, then they must be addressed directly, and comprehensively, in drought and water planning.

Summary and Conclusions

Efforts to plan for natural ecosystems in the face of increasing pressures have moved too slowly to avoid dramatic losses. While many native species have been declining since the early part of the century, losses within the last decade have, in many cases, been unprecedented. The recent drought has shown that our past actions have made the region's ecosystems vulnerable to natural variations in climate. Yet the next drought will almost certainly have still greater impacts on natural ecosystems, as human demands for water increase and our resiliency to drought is further reduced. If we are concerned about the resiliency of ecosystems, however, the traditional response to water shortages -- additional storage capacity -- must be viewed more skeptically. Large reservoirs represent a costly investment with few direct benefits for natural ecosystems.

The drought has also shown that water and conservation planning are inseparable in California, although they are usually conducted separately, by different agencies, often with competing priorities. Clearly there is a need to plan for water-supply contingencies and to answer questions about the importance and priority of particular resources *prior* to onset of the next dry period. Most importantly, perhaps, we need to seize the opportunity afforded by wetter years to implement long-term management strategies and to build up native plant and wildlife populations to sustainable levels. This will require that Californians reach a consensus on water-management priorities and demonstrate an ongoing commitment to environmental protection.

Environmental needs must be adequately represented in long-term drought and water planning, preferably at the administrative level. In particular, a conservation-oriented agency, such as CDFG, should have a lead role in drought and water planning. As part of this planning, moreover, state agencies need to develop an institutional definition of drought and associated contingency plans. At a minimum, these plans should encompass rules for the management of large reservoir systems and major ground water basins, as well as for ecosystem protection. In addition, the state should require localities to identify important ecological resources and to assess their vulnerability to drought, much as communities have been required to assess the vulnerability of their water-supply systems to potential water shortages and to develop appropriate conservation strategies.

Flexibility, particularly in how we manage water, offers the best opportunity to reduce both socioeconomic and environmental vulnerability to drought. More flexible institutions would help to move water towards environmental uses where that is appropriate. In particular, there is a critical need in some areas to develop dry-year options on ground or surface waters. Although seemingly a simple recommendation, the development of such options is extremely difficult in California given existing legal and institutional constraints. A permanent water bank, if appropriately designed, can help fulfill this need. In addition, ongoing efforts to pass water-transfer legislation are extremely important.

It is important that the impacts of drought be adequately assessed and incorporated into the planning process; this is an essential element of good policy.

An independent group should be designated at the state level to carry out this task. While this group might be within the government, it should not be housed within a client agency, such as CDFG or CDWR. This group should focus on standardizing methods of data collection and assessment and should establish priorities for data gathering.

Finally, there is a need to put more effort into monitoring critical environmental resources. Although the dedication of funds to monitoring is difficult in a period of chronic budget shortfalls, monitoring and research should be viewed as an important, long-term investment. Selective monitoring of key species should be undertaken on an annual basis to provide an indication of the overall state of larger ecosystems or ecological preserves. Moreover, annual monitoring is needed as a means of testing the efficacy of management goals and plans. Our lack of knowledge about the impact of drought on ecosystems is, in a sense, intentional. Without monitoring, we cannot establish realistic management goals. Currently the lack of information is frequently appalling, even for recreationally important species such as steelhead, while information for many less-glamorous species is almost non-existent. Many of these species could easily disappear unnoticed in the next dry year.

REFERENCES

Arthur, J.F. and M.D. Ball, 1979. Factors influencing the entrapment of suspended material in the San Francisco Bay-Delta Estuary. In T.J. Conomos (ed.), *San Francisco Bay: The Urbanized Estuary*. San Francisco: American Association for the Advancement of Science, Pacific Division.

Blausten, A. and D. Wake, 1990. Declining amphibian populations: A global phenomenon? *Bulletin of the Ecological Society of America* 71:127-128.

California Department of Fish and Game (CDFG), 1991a. Annual report on the status of California state listed threatened and endangered animals and plants. Sacramento, CA: The Resources Agency.

California Department of Fish and Game (CDFG), 1991b, Lower Yuba River fisheries management plan. CDFG Stream Evaluation Report No. 91-1 (February).

California Department of Fish and Game (CDFG), 1991c. Lower Mokelumne River fisheries management plan. CDFG Streamflow Requirements Program (November).

California Department of Fish and Game (CDFG), 1992a. Impact of water management on splittail in the Sacramento-San Joaquin estuary. Exhibit WRINT-DFG-Exhibit #5 for the State Water Resources Control Borad, 1992 Water Qaulity/Water Rights Proceedings on the San Francisco Bay/Sacramento-San Joaquin Delta.

California Department of Fish and Game (CDFG), 1992b. Estuary Dependent Species. Exhibit WRINT-DFG-Exhibit #6 for the State Water Resources Control Borad, 1992 Water Quality/Water Rights Proceedings on the San Francisco Bay/Sacramento-San Joaquin Delta.

California Department of Water Resources (CDWR), 1992. Water quality conditions in the Sacramento-San Joaquin Delta during 1990. Report to the State Water Resources Control Board in accordance with Water Right Decision 1485, Order 4f. Sacramento: CDWR (May).

Campbell, E.A. and P.B. Moyle, 1990. Ecology and conservation of spring-run chinook salmon: Reversing the effects of water projects. University of California Water Resources Center, Technical Completion Report W-719 (August).

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. *Science* 199:1302-1310.

Coppock, R.H. and M. Kreith (eds.), 1993. California water transfers: gainers and losers in two northern counties. Proceedings of a conference sponsored by the University of California Agricultural Issues Center and Water Resources Center on November 4, 1992, Sacramento, CA. Davis, CA: University of California, Agricultural Issues Center.

Earle, C.J. and H.C. Fritts, 1986. Reconstructing riverflow in the Sacramento Basin since 1560. Sacramento: California Department of Water Resources Report No. B-55395.

Erman, D.C., 1986. Long-term structure of fish populations in Sagehen Creek, California. *Transactions of the American Fisheries Society* 115:682-692.

Extence, C.A., 1981. The effect of drought on benthic invertebrate communities in a lowland river. *Hydrobiologia* 83:217-224.

Feminella, J.W. and V.H. Resh, 1990. Hydrologic influences, disturbance, and intraspecific competition in a stream caddisfly population. *Ecology* 71(6):2083-2094.

Fenner, P., W.W. Brady, and D.R. Patton, 1985. Effects of regulated water flows on regeneration of fremont cottonwood. *Journal of Range Management* 38(2): 135-138.

Fingado, R.F., 1990. California's drought planning and actions. In N.S. Grigg and E.C. Vlachos, *Drought Water Management*, Proceedings of a Workshop held November 1-2, 1988 in Washington, D.C. Fort Collins, CO: Colorado State University, International School for Water Resources, 141-148.

Fritts, H.C. and G.A. Gordon, 1980. Annual precipitation for California since 1600: Reconstructed from western North American tree rings. Sacramento: California Department of Water Resources.

Gleick, P.H. and L. Nash, 1991. The societal and environmental costs of the continuing California drought. Berkeley: Pacific Institute for Studies in Development, Environment, and Security (July).

Governor's Drought Action Team, 1991. Report of the Governor's Drought Action Team. State of Cailfornia (February 15).

Grossman, G.D., P.B. Moyle, and J.O. Whitaker, Jr., 1982. Stochasticity in structural and functional characteristics of an Indiana stream fish assemblage: a test of community theory. *The American Naturalist* 120(4): 423-454.

Hayes, M.P. and M.R. Jennings, 1986. Decline of ranid species in western North America: Are bullfrogs (*Rana catesbeiana*) responsible? *Journal of Herpetology* 20(4):490-509.

Herbold, B., A.D. Jassby, and P.B. Moyle, 1992. Status and trends report on aquatic resources in the San Francisco Estuary. Oakland, CA: San Francisco Estuary Project (March).

Holling, C.S., 1986. The resilience of terrestrial ecosystems: Local surprise and global change. In W.C. Clark and T.E. Munn (eds.), *Sustainable Development of the Biosphere*. Cambridge: Cambridge University Press.

Hough, R.A., T.E. Allenson, and D.D. Dion, 1991. The response of macrophyte communities to drought-induced reduction of nutrient loading in a chain of lakes. *Aquatic Botany* 41:299-308.

Howitt, R., N. Moore, and R.T. Smith, 1992. A retrospective on California's 1991 emergency drought water bank. Sacramento: California Department of Water Resources (March).

Huston, M., 1979. A general hypothesis of species diversity. *American Naturalist* 113:81-101.

Hynes, H.B.N., 1958. The effect of drought on the fauna of a small mountain stream in Wales, *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 13:826-833.

Iverson, T.M., P. Wiberg-Larsen, S.B. Hansen, and F.S. Hansen, 1978. The effect of partial and total drought on the macroinvertebrate communities of three small Danish streams. *Hydrobiologia* 60:235-242.

Jensen, D.B., M. Torn, and J. Harte, 1990. In our own hands: A strategy for conserving biological diversity in California. Berkeley: California Policy Seminar.

Larimore, R.W., W.F. Childers, and C. Heckrotte, 1959. Destruction and re-establishment of stream fish and invertebrates affected by drought. *Transactions of the American Fisheries Society* 88:261-285.

Lehman, P.W. and R.W. Smith, 1991. Environmental factors associated with phytoplankton succession for the Sacramento-San Joaquin Delta and Suisun Bay Estuary, California. *Estuarine, Coastal and Shelf Science* 32:105-128.

Klamath National Forest (KNF), 1992. Summer steelhead recovery strategy (draft). Yreka, CA: KNF.

Klamath National Forest (KNF), 1992. Salmon, Scott, and mid-Klamath sub-basin spawning ground utilization surveys, 1989/90 and 1990/91. Annual report. Yreka, CA: KNF.

Loaiciga, H.A., J. Michaelsen, and S.Garver, 1992. Droughts in rivers basins of the western United States. *Geophysical Research Letters* 19(2):2051-2054.

McBride, U.R. and J. Strahan, 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. *The American Midland Naturalist* 112: 235-245.

McElravy, E.P., G.A. Lamberti, and V.H. Resh, 1989. Year-to-year variation in the aquatic macroinvertebrate fauna of a northern California stream. *Journal of the North American Benthological Society* 8(1):51-63.

Michaelsen, J.C., L. Haston, and F.W. Davis, 1987. 400 years of central California precipitation variability reconstrcuted from tree rings. *Water Resources Bulletin* 23:809-818.

Monterey Peninsula Water Management District (MPWMD), 1993. Monterey Peninsula water supply project: Supplemental draft EIR/EIS II, Volume I. Monterey, CA: MPWMD (February).

Morrison, B.R.S., 1990. Recolonisation of four small streams in central Scotland following drought conditions in 1984. *Hydrobiologia* 208:261-267.

Moyle, P.B. and J.P. Ellison, 1991. A conservation-oriented classification system for the inland waters of California. *California Fish and Game* 77:161-180.

Moyle, P.B., B. Herbold, D.E. Stevens and L.W. Miller, 1992. Life history and status of Delta smelt in the Sacramento-San Joaquin Estuary, California. *Transactions of the American Fisheries Society* 121:67-77.

Moyle, P.B. and G.M. Sato, 1991. On the design of preserves to protect native fishes, in Minckley, W.L. and J.E. Deacon, *Battle Against Extinction: Native Fish Management in the American West*. Tucson: University of Arizona Press, 155-169.

Moyle, P.B., J.E. Williams, and E.D. Wikramanayake, 1989. Fish species of special concern of Cailfornia. Final report submitted to State of California Department of Fish and Game, Inland Fisheries Division, Rancho Cordova (October).

Moyle, P.B. and R.M. Yoshiyama, 1992. Fishes, aquatic diversity management areas, and endangered species: A plan to protect California's native aquatic biota. Berkeley: The California Policy Seminar.

National Marine Fisheries Service (NMFS), 1993. Biological opinion for the operation of the federal Central Valley Project and the California State Water Project. United States Department of Commerce, National Oceanic and Atmospheric Administration, NMFS, Southwest Region (February 12).

Nichols, F.H., 1985. Increased benthic grazing: An alternative explanation for low phytoplankton biomass in northern San Francisco Bay during the 1976-77 drought. *Estuarine, Coastal and Shelf Science* 21:379-388.

Nichols, F.H., J.K. Thompson, and L.E. Schemel, 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*, part II, displacement of a former community. *Marine Ecology Progress Series* 66:95-101.

Niemi, G.J., P. DeVore, N. Detenbaeck, D. Taylor, A. Lima, J. Pastor, J.D. Yount, and R.J. Naiman, 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14:571-587.

Pacific Fishery Management Council (PFMC), 1993. Review of 1992 ocean salmon fisheries. Portland: PFMC (February).

Pearson, R.G., 1984. Temporal changes in the composition and abundance of the macroinvertebrate communities of the River Hull. *Archiv für Hydrobiologie* 100:273-298.

Pelzman, R.J., 1973. Causes and possible prevention of riparian plant encroachmnet on anadromous fish habitat. California Department of Fish and Game, Environmental Services Branch, Administrative Report No. 73-1. Sacramento: CDFG.

Pimm, S.L., H.L. Jones, and J. Diamond, 1988. On the risk of extinction. *American Naturalist* 132:757-785.

Reichert, M. and A. Olson, 1993. Stream temperature data compilation: Final report, Klamath River Basin. R-5 Fish Habitat Relationship Technical Report (February).

Resh, V.H., 1982. Age structure alteration in a caddisfly population after habitat loss and recovery. *Oikos* 38(3):280-284.

Resh, V.H., 1992. Year-to-year changes in the age structure of a caddisfly population following loss and recovery of a springbrook habitat. *Ecography* 15:314-317.

Resh, V.H., J.K. Jackson, and E.P. McElravy, 1990. Disturbance, annual variability, and lotic benthos: examples from a California stream influenced by a mediterranean climate. *Memorie dell'Istituto Italiano di Idrobiologia* 47:309-329.

Resh, V.H., G.A. Lamberti, E.P. McElravy, and J.R. Wood, 1983. Evaluating the influence of geochemical origin and drought conditions on aquatic biota of the Geysers known geothermal resources area of California. University of California Water Resources Center, Technical Completion Report, W-548 (March).

Riebsame, W.E., S.A. Changonon, Jr., and T.R. Karl, 1991. *Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987-89 Drought*. Boulder, CO: Westview.

Rood, S.B. and S. Heinze-Milne, 1989. Abrupt downstream forest decline following river damming in southern Alberta. *Canadian Journal of Botany* 67:1744-1749.

Rood, S.B. and J.M. Mahoney, 1990. Collapse of riparian poplar forests downstream from dams in western prairies: Probably causes and prospects for mitigation. *Environmental Management* 14(4):451-464.

Roos, M., 1992. The hydrology of the 1987-1992 California drought. California Department of Water Resources, Technical Information Paper (October).

Schlesinger, W.H. and C.S. Jones, 1984. The comparative importance of overland runoff and mean annual rainfall to shrub communities in the Mojave Desert. *Botanical Gazette* 145:116-124.

Schindler, D.W., K.G. Beaty, E.J. Fee, D.R. Cruikshank, E.R. DeBruyn, D.L. Findlay, G.A. Linsey, J.A. Shearer, M.P. Stainton, M.A. Turner, 1990. Effects of climatic warming on lakes of the central boreal forest. *Science* 250:967-970.

Scoppettone, G.G. and G. Vinyard, 1991. Life history and management of four endangered lacustrine suckers, in Minckley, W.L. and J.E. Deacon, *Battle Against Extinction: Native Fish Management in the American West*. Tucson: University of Arizona Press, 359-377.

Smith, S.D., A.B. Wellington, J.L. Nachlinger, and C.A. Fox, 1991. Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada. *Ecological Applications* 1(1):89-97.

Stockton, C.W., D.M. Meko, and W.R. Boggess, 1991. Drought history and reconstructions from tree rings. In F. Gregg (ed.), Severe Sustained Drought in the Western United States. Unpublished report (Mimeo).

Swift, C.C., T.R. Haglund, M. Ruiz, and R.N. Fisher, 1993. The status and distribution of the freshwater fishes of southern California. *Bulletin of the Southern California Academy of Sciences, in press.*

Swift, C.C., J.L. Nelson, C. Maslow, and T. Stein, 1989. Biology and distribution of the tidewater goby, *Eucyclogobius newberryi* (Pisces: gobiidae) of California. *Contributions in Science* 404:1-19.

U.S. Army Corps of Engineers (USACOE), 1991. The national study of water management during drought: A research assessment. IWR Report 91-NDS-3 (August). Fort Belvoir, VA: USACOE-IWR.

U.S. Bureau of Reclamation (USBR), 1987. Report documenting the operation of the Shasta/Trinity system for temperatures in the Sacramento River during water-year 1987. U.S. Bureau of Reclamation, Central Valley Operation Coordination Office (December). Mimeo.

U.S. Bureau of Reclamation (USBR), 1989. Report on refuge water supply investigations, Central Valley hydrologic basin. Sacramento: USBR, Mid-Pacific Region.

U.S. Bureau of Reclamation (USBR), 1992. Biological Assessment on Long-term project operations (Klamath Project). Medford, OR: USBR-Klamath Project (February 28).

U.S. Fish and Wildlife Service (USFWS), 1992. Formal consultation of the effects of the long-term operation of the Klamath Project on the Lost River sucker, shortnose sucker, bald eagle, and American peregrine falcon. Portland: U.S. Department of Interior, USFWS (July 22).

U.S. Forest Service (USFS), 1992. Management of potentially threatened, endangered, or sensitive anadromous salmonids. PACFISH Briefing Paper No. 2. USFS, Pacific Southwest Region (October 20).

White, P.S. and S.T.A. Pickett, 1985. Natural disturbance and patch dynamics: an introduction. In S.T.A. Pickett and P.S. White (eds.), *The Ecology of Natural Disturbance and Patch Dynamics*. Orlando, FL: Academic Press.