U.S. Fish and Wildlife Service

Klamath River Fish Die-off September 2002

Causative Factors of Mortality

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Executive Summary

This report provides information describing the biological, hydrological, meteorological, and water quality conditions associated with the die-off of an estimated 34,056 fish in the Klamath River, California in September 2002. The proximate cause of death was heavy infections of two fish pathogens, Ich and columnaris. However, given that these ubiquitous pathogens are normally found in the Klamath River, additional factors must have played a role for them to have become lethal. It is our conclusion based on multiple lines of evidence that the fish die-off in the lower Klamath River in 2002 was a result of a combination of factors that began with an early peak in the return of a large run of fall Chinook salmon. Low river discharges apparently did not provide suitable attraction flows for migrating adult salmon, resulting in large numbers of fish congregating in the warm waters of the lower River. The high density of fish, low discharges, warm water temperatures, and possible extended residence time of salmon created optimal conditions for parasite proliferation and precipitated an epizootic of Ich and columnaris. Based on a review of available literature and historical records, this was the largest known pre-spawning adult salmonid die-off recorded for the Klamath River and possibly the Pacific coast.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

INTRODUCTION

The California Department of Fish and Game (CDFG) received a verbal report of dead and dying salmon in the lower Klamath River on September 19, 2002. The caller indicated that on the previous day he had seen large numbers of dead and dying salmon in the lower river. The CDFG then notified the U.S. Fish and Wildlife Service (USFWS) about the incident. The subsequent investigation involved collaboration with representatives of the Yurok Tribal Fisheries Program, Hoopa Valley Tribe, Karuk Tribe of California, and CDFG.

Various factors were investigated as potential causes for the fish die-off. These factors included poor water quality, pathogens, reduced river discharges, large run size and associated crowding, impaired migration, run timing, and environmental contaminants. This report evaluates and identifies those factors most likely associated with and/or contributing to the observed fish die-off. Information examined included recent and historical water quality, hydrology, meteorology, fisheries data, agency reports, scientific articles, and pathology reports. This report provides an analysis of the immediate and contributing factors associated with this fish die-off, and conclusions regarding the most likely causative factors.

METHODS

Literature Review

In order to evaluate the relative influence of each potential factor, a search of existing data and other pertinent background literature on anadromous salmonid die-offs and associated variables related to pathogen infection including discharge, run size, run timing, and water quality was conducted. Reports of massive die-offs or cases of pre-spawning mortality of salmon are rare.

Fish Mortality Assessment

Methods for estimating numbers of fish that died during the die-off are described in more detail in a report by Guillen (2003). Biological data collected during the die-off included presence or absence of dead fish, species identification, numbers of dead fish, coded wire tags (CWT) for determining hatchery composition, length measurements, scales for aging, disease incidence, and decay condition. These data were collected during three primary survey dates (September 20, 24, and 27, 2002) at four mainstem survey reaches below Coon Creek at Klamath river mile (RM) 36 (Figures 1 and 2). These observations were supplemented by various other surveys conducted throughout the event.

Supplemental Field Observations

During the response to the fish die-off, biologists made observations regarding the appearance of the Klamath River such as color, turbidity, and odors of the water, and examined a few samples of water for phytoplankton. In addition, green sturgeon in the area of the die-off were tracked using mobile radio receivers and stationary acoustic receivers. These fish had been tagged previously and were tracked from May through December 2002 by the Yurok Tribal Fisheries Program and U.S. Fish and Wildlife Service (USFWS). Preliminary data were examined to determine potential impacts of the die-off on this species.

Fish Pathology

Fish tissue samples were collected and external necropsy examinations were conducted on specimens collected on September 26, 2002, near Blake's Riffle (Klamath RM 7.3) and at the confluence of Blue Creek (Klamath RM 16.4) by USFWS and CDFG fish pathologists (Foott 2002; Veek 2002). Necropsy samples were collected from dead and moribund fish. In addition, numerous field pathological examinations were conducted by USFWS, Yurok Tribal Fisheries, and CDFG biologists while counting dead fish.

Tidal Data

Tidal data were obtained from the National Oceanic Atmospheric Administration (NOAA) real-time tide gages located at Crescent City, approximately 25 miles north of the mouth of the Klamath River. Our purpose was to determine tidal conditions during and prior to the die-off and possible mechanisms that could affect river discharge in the lower river or salmon immigration.

Meteorological Information

Air temperature and precipitation data were obtained from National Weather Service (NWS) stations located at Klamath (Klamath River), Hoopa (Trinity River), Orleans (Klamath River), Yreka (Shasta River), Sawyers Bar (Salmon River), and Fort Jones (Scott River) (Figure 1). In addition, recent data collected at the Yurok weather station at Weitchpec were made available to the USFWS by the Yurok Tribe.

River Discharge

River discharge refers to the volume of water passing through a channel during a given time, usually measured in cubic feet per second (cfs). Average daily and monthly river discharge measurements were obtained from the U.S. Geological Survey (USGS) gage sites located below Iron Gate Dam (Klamath RM 189.8), Shasta River (Shasta RM 0.5), Scott River near Ft. Jones (Scott RM 21), Salmon River (Salmon RM 1.01), Orleans (Klamath RM 59.1), Trinity River at

Lewiston Dam (Trinity RM 111), Trinity River at Hoopa (Trinity RM 12.4), and Terwer (also called Turwar or Klamath) (Klamath RM 6.7) (Figure 1). Historical and recent provisional data were obtained from the USGS web site.

Water Quality

Continuous Water Quality Monitoring

Continuous water quality data including water temperature, dissolved oxygen, pH, and specific conductance were measured using Hydrolab® datasondes operated by the Yurok Tribe and the USFWS monitoring network in the lower Klamath River. These data were collected at several fixed stations in the lower River including Weitchpec (Klamath RM 43.5), Martins Ferry (Klamath RM 40.4), and Terwer (Klamath RM 6.7) (Figure 2). These were monitored daily at 30-minute intervals continuously from June through October 2002. Data from August through October 2002, are presented in this report. Prior to deployment and upon retrieval the instruments were calibrated. In some cases Hydrolab® datasonde temperature data were augmented with data collected from co-located Hobo® tidbit thermistors.

Data collected during 2002 were compared with the 2001 USFWS/Yurok Tribal water quality monitoring data from the Martin's Ferry and Terwer sites. We also compared the 2002 data with the data from 1995 collected by the USFWS at mainstem sites located below Blue Creek (Klamath RM 16.4), and below Coon Creek (Klamath RM 35.9) using Hydrolab® datasondes. Finally, continuous water temperature data collected during 1997 through 1999 were provided by the Yurok Tribal Fisheries Program for Omagar Creek (Klamath RM 10.5). These studies used Hobo® tidbit thermistors.

Grab Samples

Grab samples are a single water sample drawn over a short time period. Water grab samples were collected and analyzed from July 30 to October 8 during 2002 as part of the USFWS/Yurok routine sampling program and in support of the die-off investigation on a bi-weekly to weekly basis. The primary sites sampled were Weitchpec, Martin's Ferry, and Terwer, which are also continous water quality monitoring sites as noted above. Water quality variables measured included water temperature, dissolved oxygen, pH, specific conductance, phytoplankton chlorophyll-*a*, ammonia nitrogen, nitrate nitrogen, turbidity, total suspended solids, total phosphorus, orthophosphate phosphorus, periphyton biomass, and chlorophyll-*a*. Grab sample data from the 2001 monitoring season at Weitchpec, Terwer, and Martin's Ferry were also included for comparison. Data from 2001 were used for comparison, because they were collected at the same sites and with the same protocol as the 2002 data.

Additional sites within the die-off zone were monitored less frequently. Variables monitored at those sites included water temperature, dissolved oxygen, pH, specific conductance, chlorophyll-*a* levels, and ammonia nitrogen. Water samples were collected and analyzed for a suite of herbicides and pesticides. These samples were collected on September 26, 2002, in the mouths of two tributaries of the Klamath, including Tectah Creek (Klamath RM 22.1) and Blue Creek (Klamath RM 16.4), in the Klamath River about 0.25 mile downstream of Blue Creek (Klamath RM 16.1), and in the Klamath River at the 101 Bridge (Klamath RM 2.8). On October 8, 2002, additional water samples were collected in the estuary (Klamath RM 1.8), and mainstem Klamath at Terwer (Klamath RM 6.7) and analyzed for the same variables. Analysis of these samples was conducted by the North Coast Laboratories Ltd. in Arcata, California, under contract to the North Coast Regional Water Quality Control Board (NCRWQCB) or the Service.

Grab water samples were collected using standard operating procedures to ensure good data quality (American Public Health Association (APHA) 1998, USGS 1999). In addition, each laboratory sample was subjected to internal laboratory quality control and quality assurance procedures including matrix spikes, blanks, and duplicate analyses. Water sampling, in general, consisted of collecting a sample using a USGS composite collection churn. After water was collected it was stirred carefully to ensure complete mixing. Water samples were then transferred through the drain spigot to individual sample containers. Sample containers were preserved by placing them on ice and for selected parameters preserved with sulfuric acid. Measurements of water temperature, specific conductance, pH, turbidity, and dissolved oxygen were made using either pre-calibrated YSI® and Hydrolab® meters, or, in the case of dissolved oxygen, a Winkler titration procedure. In addition, turbidity was measured using a LaMotte nephelometer.

These water quality samples were analyzed by the North Coast Laboratories Ltd. located in Arcata, California. Water quality data collected by continuous monitors and grab samples were compared to NCRWQCB State standards and/or proposed U.S. Environmental Protection Agency (EPA) Region 10 criteria for salmonids where such criteria exist.

Fish Tissue Samples for Contaminants

A single moribund coho salmon carcass was collected by the USFWS on October 3, 2002, at the mouth of Blue Creek for tissue analysis. The carcass was immediately placed on ice, then frozen and submitted to the CDFG Fish and Wildlife Water Pollution Control Laboratory in Rancho Cordova, California, for pesticide and organic contaminant analysis.

Hazardous Materials Spills and Reports

Data from August and September 2002 State and national pollution reports generated by the State of California Office of Emergency Service and the U.S. Coast Guard National Response Center were reviewed for the presence of any reported spills on the Klamath River.

Permitted Point Source Discharges

The EPA web-based database on National Pollutant Discharge Elimination System permits was reviewed for the presence of any permitted discharges in the vicinity of the fish die-off including Humboldt, Del Norte, and southwestern Siskiyou counties during August and September 2002.

Hazardous Waste Sites

The EPA web-based database Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) was reviewed for the presence of any unpermitted hazardous waste site in the vicinity of the fish die-off including Del Norte, Humboldt and southwestern Siskiyou counties. CERCLIS contains information on hazardous waste sites, potential hazardous waste sites, and remedial activities across the nation, including sites that are on the National Priorities List or being considered for this list.

Comparison of Salmon Run Size with Environmental Factors

We evaluated the relationship of run size with various environmental variables, including mainstem and tributary discharges and local precipitation. This analysis was limited to data from 1978 to 2002. These are years for which data on total instream run size are available from the CDFG (CDFG 2003a).

Salmon Run Size

Historical and recent run size estimates were obtained from the 2003 CDFG electronic database called the megatable (CDFG 2003a). It contains age-specific estimates of run size from 1978 to 2002 (Klamath River Technical Advisory Team) (KRTAT 2003). At the time of this writing the 2002 data are considered preliminary (Sinnen 2003). The Klamath River megatable is used for Klamath Chinook stock management purposes and estimation of escapement (Pierce 1998). It also includes estimates of hatchery and tributary composition, and projections for future years based on estimates derived by the KRTAT (Sinnen 2002). Run size estimates are obtained from hatchery returns, tribal harvest data, carcass surveys, and recreational creel surveys. The estimated number of fish that died during the 2002 die-off was included in the overall run estimate for 2002 (Guillen 2003).

River Discharge

River discharges used in our analysis were obtained from USGS gage stations via their internet web site (USGS 2003). Generally, discharges before 2002 are validated data. Discharges during most of 2002 are considered “provisional” and subject to further revision. Sites used in our analysis included significant gaged discharges including Iron Gate Dam (IGD), Trinity River at Hoopa, Salmon River, Scott River near Fort Jones, and the Shasta River. August and September monthly average discharges from each of these five sites during 1978 through 2002 were used in our evaluation. These historical discharges were used to classify various years of record from 1978 through 2002 based on the overall pattern of significant discharges. Using this approach, the influences of mainstem discharges at IGD and significant tributary sources were included in the classification of various years.

Cluster Analysis

In order to evaluate how 2002 may have been different from other years, we wished to focus our analysis on years that possessed similar hydrology, but did not have a fish die-off. For years with available run size estimates (1978-2002), we applied the statistical technique of cluster analysis to classify years based on the pattern of significant gaged discharges during August and September in the Klamath Basin below Iron Gate Dam. Cluster analysis is a multivariate statistical analysis designed to classify objects based on various common traits. It is widely used to conduct complex pattern recognition and classification (Legendre and Legendre 1998). For example, cluster analysis has been used to develop regional classifications of streamflow drought series (Stahl and Demuth 1999).

In order to examine the similarity of various years based on patterns of basin hydrology, we analyzed August and September discharges from significant tributaries and mainstem flows using a familiar cluster analysis technique with the SPSS ™ version 10.07 statistical package (SPSS 2000). The traits used were August and September monthly average discharges from the Klamath River at Iron Gate Dam, the Trinity River at Hoopa, the Salmon River, the Scott River, and the Shasta River. Monthly average discharge from the Klamath River at Iron Gate Dam during September 2002 was adjusted by recalculating this value using daily average flows from September 1 to 27, 2002. This removes the influence of the pulse flow during September 2002. Therefore, a total of 10 traits or discharges were used to classify each year. The cluster analysis methods are described in more detail in Appendix A. After conducting the cluster analysis, we compared environmental factors including including run size, precipitation, and individual tributary discharges for the group that included 2002 with the next most similar group based on hydrologic conditions.

Fall-Run Chinook Timing

Data from CDFG's lower Klamath River recreational creel survey and Trinity River Willow Creek weir counts (CDFG 2003b), and from the Yurok Tribal Fisheries monitoring program (Hillimier 2003) were used to determine the timing of the 2002 fall Chinook run. The Karuk Tribe provided data on the dip net fishery harvest upstream at Ishi Pishi Falls (Klamath RM 67) (Chamberlain 2002). The Karuk data were used to evaluate the response of the fall-run Chinook to the increased river discharge (pulse flow) provided in late September from the upper reservoirs to help stimulate fish movement. Published reports on general overall trends in spawning periodicity for the lower Klamath River were also reviewed.

Fish Passage

We reviewed the literature on minimum passage requirements to determine if there was a potential for reduced fish movement due to physical obstructions or insufficient river depths. This information was compared to largely anecdotal information provided by various biologists working on the lower river during the die-off. No detailed surveys were conducted to evaluate physical passage conditions at critical locations during the investigation.

RESULTS AND DISCUSSION

In this section, we will describe the mortality event and the environmental conditions that existed at the time of the event. Conditions and factors that might have contributed to the die-off will be assessed individually, followed by evaluation of effects resulting from interactions between these variables.

Mortality Estimates

Details regarding mortality counts and fish species and age composition were reported by Guillen (2003). Initial reports of fish mortality were received on September 19, 2002. According to reports, dead and dying fish were observed on September 18, 2002, by a fisherman in the lower Klamath River. Unconfirmed reports suggested dead fish may have been observed as early as September 16, 2002.

An estimated 34,056 fish died during the incident (Guillen 2003). Of 33,527 anadromous salmonids estimated to have succumbed during this event, about 97 percent (estimated 32,533) were fall-run Chinook salmon, *Oncorhynchus tshawytscha*, 2 percent (estimated 629) were steelhead, *O. mykiss*, and 1 percent (estimated 344) were coho salmon, *O. kisutch*. One coastal cutthroat, *O. clarki clarki* was found dead during the investigation.

The KRTAT (2003) estimated that dead fall-run Chinook salmon represented about 19 percent of the total (estimated 169,297) in-river Klamath-Trinity River run. The KRTAT estimated that about 7,060 (22 percent) of the dead Chinook were of hatchery origin. A total estimate of 2,921 (9 percent) of the dead Chinook were of Iron Gate (Klamath River) Hatchery origin and an estimated 4,139 (13 percent) of the dead Chinook were of Trinity River Hatchery origin.

Approximately 91 percent of the coho salmon, and 39 percent of the steelhead observed had marks indicating a hatchery origin (Guillen 2003). All hatchery coho were from the Trinity River Hatchery.

Other dead fish observed during the investigation included sculpins, *Cottus spp.* (87 fish), speckled dace, *Rhinichthys osculus* (9 fish), Klamath smallscale sucker, *Catostomus rimiculus* (311 fish), one American shad, *Alosa sapidissima*, and one green sturgeon, *Acipencer medirostris*. In addition to the above counts, we estimated that a total of 120 unidentifiable carcasses were present during the die-off.

Throughout the investigation, live adult and juvenile fish of affected and unaffected species were observed in the River. Some species (e.g., American shad, speckled dace, and green sturgeon) did not appear to experience extensive mortality. Over 99 percent of the dead fish observed were adults or larger species of fish. In addition, dead invertebrates, amphibians, or terrestrial vertebrates were not observed during the incident.

The lack of dead juvenile salmonids may be explained by previous studies that documented low numbers of juveniles in the River during the time of the year when the fish die-off occurred (Wallace 1997; Weskamp et al. 1998). By September, most juvenile salmonids have emigrated to the estuary.

Dead and/or dying fish were observed by survey crews from at least September 20, 2002, through October 3, 2002. Even as late as October 3, 2002, a few recently dead fish were observed. Small numbers of dead fish were also observed by Yurok Tribal biologists after October 1, 2002, for about another week. However, the majority of fish had died by September 27, 2002. It appears that mortality occurred primarily over a 10-day period, with peak mortality occurring between September 18 and September 24, 2002.

Greater than 85 percent of the recently dead fish examined exhibited one or more outward gross signs of disease including white spots, gill necrosis, bacterial growth, sores, bloody vents, and ulcerations.

It should be noted that the conservative fish die-off estimate may have resulted in an underestimate of the actual total 2002 in-river run size (Guillen 2003). We evaluated the potential effect on estimated run size of underestimating the number of fish that died during the 2002 fish die-off using several estimators that were available, and supported by the literature on fish kills and spawner carcass surveys (AFS 1992; Pisano 1994). Using an estimator of an additional 100% of the fish die-off, the total 2002 in-river run becomes 203,353 fish, which is approximately equal to the 2001 run size, and becomes the sixth largest run during the period between 1978 to 2002.

Supplemental Field Observations

Phytoplankton

Very few phytoplankton cells were observed in the 100-ml sample collected near the mouth of Terwer Creek in the Klamath River (Klamath RM 5.3) on September 20, 2002. The lack of high numbers of phytoplankton cells indicate that an algal bloom was not occurring during the fish die-off.

Odors and Discolored Water

Besides decaying fish, unusual odor or discolored water was not observed by any investigator during the entire response between September 20 and October 1, 2002. The lack of any obvious odors or discolored water suggests that visible or odor-producing contaminants such as gasoline, diesel, or other pollutants were absent during the die-off.

Green Sturgeon Tracking Data

Nine green sturgeon were tagged with acoustic and radio transmitters during May through June 2002. In addition, one white sturgeon was tagged. During May through November 2002 these fish were tracked using a series of stationary acoustic receivers and mobile radio receivers. At least 8 of the 10 fish were observed throughout the area affected by the fish die-off during August through September (Table 1). All of these fish survived and eventually moved downstream to the estuary. The lack of any significant green sturgeon mortality suggests that contaminants or any other factors that would cause extensive non-selective mortality across all species were absent in the lower River where green sturgeon were present.

Fish Pathology

Examination of specimens collected during the die-off indicated that all the moribund or recently dead fish were infected by Ich (*Icththyophthirius multifiliis*) and/or columnaris (*Flavobacterium columnare*) (Foott 2002a; Veek 2002).

Many pathogens are ubiquitous along the northwestern Pacific coast of the United States in salmon populations. However, they are normally present at low levels and do not usually affect the host to the point of causing disease (Arkoosh 1998). Only when other stressors are present are there increased incidences of disease outbreaks. These stressors can include elevated water temperature, low dissolved oxygen, crowding, high levels of ammonia, and presence of pollutants (Wedemeyer 1974). The susceptibility of anadromous salmonids to these pathogens is also influenced by hydrological regime, behavior, and physiological changes associated with spawning activity.

Ichthyophthirius multifiliis or Ich

Ich is a fresh-water ciliated protozoan. The life cycle includes the following stages: an attached parasitic stage (trophont), a detached reproductive stage (tomont), and a free-swimming infective stage or "tomite" (Figure 3) (Dickerson and Dawe 1995). Up to 2,000 tomites can be produced in a 12-hour period from one tomont at the optimal temperatures (Meyer 1974). The optimal temperature for Ich development is 21.1-23.9 degrees centigrade (°C) (70 - 75 degrees Farenheit (°F)) (Meyer 1974). Within this optimal range, the higher the temperature the faster the parasite replicates (Gratzek 1993).

The parasitic phase of Ich can encyst in the skin or gill. Damage to the skin and gill results in osmoregulatory and respiratory distress (Ewing et al. 1985). As the infection progresses, the capacity of infected fish to absorb oxygen and excrete ammonia is severely reduced and their blood ammonia levels rise because of gill impairment. Mortality from Ich may be caused by the parasite when the gills are too damaged to function. Breaching the protective barrier of the skin by Ich may also allow opportunistic bacteria or fungi access to underlying tissues resulting in death from secondary infections (Post 1987).

Bodensteiner et al. (2000) described a study in which increasing the discharge in catfish raceways reduced mortality due to Ich. Velocities greater than 75 cm/min (0.041 ft/s), resulting in a turnover rate of greater than 1.9 volumes per hour, prevented any disease outbreaks. The increased discharges and velocities reduced the probability of the tomites finding a host, since the parasite was swept away downstream. Ich outbreaks in epidemic proportions are rare in flowing rivers and streams (Allison and Kelly 1963).

Outbreaks of Ich occur when conditions are favorable for rapid multiplication of the parasite. This includes a suitable environment and susceptible fish. There may be a requirement for some minimum number of fishes before an epizootic occurs (McCallum 1985). Ich epizootics occur when fishes are stressed, densities are high, and the water temperature is relatively elevated (Dickerson and Dawe 1995). A wide variety of factors can induce stress in fishes including crowding, high temperature, low dissolved oxygen, changes in conductivity or salinity, chemical pollutants, and spawning activities. Frequently, spawning adults of only one species are affected (Pickering and Christie 1980; Wurtsbaugh and Tapia 1988). Outbreaks are most common during warmer months and also during periods when fish are spawning. Increased stress associated with spawning migrations of salmonids has been shown to increase the prevalence of disease outbreaks (Fagerlund et al. 1995).

Ich is a freshwater parasite. Thus, in the Klamath River die-off, Ich would have been transmitted to returning adults from resident freshwater species such as suckers or sculpin, or possibly from resident or previously-infected emigrating salmonids.

Flavobacterium columnare or Columnaris

Columnaris is the common name for the bacterial pathogen *Flavobacterium columnare*, formerly *Flexibacter columnare.* The earliest sign of columnaris disease in fish is a thickening of the mucus at various spots on the head, opercula and fins. Well-developed columnaris disease on the skin usually has tiny bloody spots or petechia within the lesions. Fringes of gill filaments are lost to advancing necrosis and sloughing of gill tissue. Eventually respiratory and osmoregulatory function is lost at the gill surface (Post 1987).

Resident non-salmonids, such as suckers, have been reported to be carriers of columnaris and a source of infection for migrating adult salmon in the Columbia River (Becker and Fujihara 1978). Columnaris is usually pathogenic at temperatures higher than 15 °C (Noga 2000). Columnaris outbreaks are common in adult salmon populations held at hatcheries in warm waters (15 to 18 °C) (Foott 2002b). In laboratory studies, host immune and nutritional status have been demonstrated to affect mortality from columnaris infections. Further, mortality rates in groups of juvenile Chinook salmon challenged with columnaris were related to the density of fish (Fujihara et al. 1971).

Normal, healthy fish are usually resistant to columnaris (Shotts and Starliper 1999). However, it can develop as a secondary infection due to environmental stress or trauma. Stress can include crowded conditions, handling stress, low dissolved oxygen, elevated temperatures, and high organic loads (Thune 1993). Columnaris often appears in association with one or more other pathogens and is secondary to the primary disease organism (Plumb 1999), which can include ectoparasites such as Ich.

Extensive mortality of summer-run Chinook salmon, coho salmon, suckers, and sockeye salmon has occurred in the Columbia River as fish migrated into warm upstream waters (Becker and Fujihara 1978). Becker and Fujihara (1978) found that highest incidents of infection and mortality occurred during periods of high spring water temperatures, hot summers, and associated low river flows. Epizootics involving columnaris and high temperatures also have been documented in the Rogue River, Oregon (Oregon Department of Fish and Wildlife, (ODFW)1992). There, they found that the incidence of mortality and columnaris infection were more correlated with high water temperature than fish density. They also found that river flows were highly correlated with water temperature and therefore affected the probability of contracting this pathogen. Increased flows were used to reduce water temperatures, fish stress, and resulting infections due to columnaris. ODFW (1992) also concluded that extensive prespawning mortality of Pacific salmon has been observed in other streams and seems to occur primarily when streams are unusually warm during periods of low flow.

Relationship of Pathogens and Spawning Activity

In Pacific salmon, the spawning migration from the sea to the natal stream induces stress from changes in osmoregulation, increased activity, starvation, and sexual maturation. Cumulative stress debilitates the fish sufficiently that they become highly susceptible to a variety of diseases and die soon after spawning (Smith 1993). Delays in spawning activity increase the likelihood of pre-spawning mortality due to susceptibility to ubiquitous pathogens.

Tidal Stages

During the period of the fish die-off, tidal amplitude decreased (Figure 4). During the early part of September, tidal amplitudes reached 8.5 feet, with maximum tidal heights of 7.5 feet. However, from September 14, 2002, onward, tidal amplitude decreased to 6.5 feet or less. From September 28 through 30 the tidal amplitude decreased to approximately 5 feet. In addition, according to Borok (2003) and Wallace (2003), the mouth of the Klamath River was open continuously from August through September 2002. These observations suggest that conditions were optimal for immigration of large numbers of salmonids during early September.

Precipitation

During the months of August through October 2002, rainfall amounts were low across the Klamath Basin at the stations surveyed (Figure 5). No precipitation was recorded at the mainstem stations of Weitchpec and Hoopa, or the Salmon River weather station. The only significant rainfall occurred at the Klamath weather station on September 18, 2002, when 0.35 inch of rain fell. Lesser amounts of rainfall were recorded infrequently in the upper basin within the Shasta and Scott River drainages. Rainfall amounts measured in the lower basin were lower than long-term averages (Figure 6). Therefore, we conclude that August and September precipitation did not significantly contribute to discharges in the lower Klamath River, and flows were primarily dependent on upstream and tributary discharges.

River Discharges

Mainstem Discharges, August through October 2002

Iron Gate Dam represents the upper limit of anadromous fish migration in the Klamath Basin (PacifiCorp 2000). Discharges are measured at a USGS gage located below the Dam at Klamath

River mile 189.8. During the months of August and September, River discharges below Iron Gate Dam were fairly constant (Figure 7). Average daily discharges during August and September were 666 cfs and 813 cfs, respectively. The mean daily average discharge was 760 cfs until September 27, 2002.

On September 27, a pulse flow was released from Iron Gate Dam in an effort to increase the volume of flow through the die-off reach to reduce crowding, and to stimulate fish to begin upstream movement (McInnis 2002, McCracken 2002). Ramping from 767 cfs to 1,350 cfs occurred over a 2-day period. This discharge was maintained through October 9, 2002, after which discharges declined to 885 cfs by October 13, 2002. This resulted in an additional 36,000 acre-feet of water provided over a 2-week period. October discharges averaged 882 cfs after the pulse flow subsided.

The USGS Orleans gage is located on the Klamath River at river mile 59.2. The Orleans gage exhibited similar hydrological patterns to those observed at Iron Gate Dam (Figure 7). Mean monthly discharge was 1,263 cfs during August 2002. Average daily discharge increased to 1,305 cfs in September as a result of the pulse discharge released from Iron Gate Dam on September 27, 2002. Daily average discharges increased from 1,290 cfs to 1,860 cfs from September 28, 2002, to October 3, 2002. Without the pulse flow the daily average September discharge is projected to have been 1,287 cfs in contrast to 1,305 cfs.

The Terwer gage is located at Klamath River mile 6.7. This particular gage is influenced by tidal backwater effects that can alter the stage discharge relationship (Lyons 2003; Lynch and Risley 2003). As a result, the discharge measured by this gage could be in error by more than 15 percent in certain years (Lyons 2003). During elevated tides and low discharges, discharges could be overestimated due to tidal back water effects. In addition, the mouth of the Klamath River becomes constricted or completely blocked in some years, causing water levels in the lower river to increase. During August and most of September 2002, the Klamath River mouth remained open. In contrast, the mouth of the Klamath River closed from September 16 though 30, 2001 (Wallace 2003; Borok 2003). As a result, water levels at the Terwer gage may have been slightly higher in the lower river during those dates in 2001 due to blockage of the mouth. Data on the status of the blockage of the River mouth for past years is not readily available.

During August 2002 average daily discharge at Terwer gradually declined from 2,590 to approximately 2,000 cfs (Figure 7). Discharge during September was fairly constant and fluctuated between 1920 and 2190 cfs. The highest daily average discharge was 2,190 cfs and was recorded on September 30, 2002. This reflected the beginning of the pulse flow that was released from Iron Gate Dam on September 27, 2002. The USGS has indicated that there may have been a partial blockage of the mouth of the Klamath River during late September, resulting in increased water levels and subsequent predicted flows 1 to 2 days before the pulse flow arrived (Bower 2003).

Mean monthly discharge measured at the Terwer gage was 2,327 and 1,993 cfs, during August and September 2002, respectively. Without the pulse flow which reached the gage on September 30, 2002, the mean daily average September discharge is projected to have been 1,987 cfs. From October 1 to October 14, 2002, daily mean discharge varied between 2,510 and 2,580 cfs due to the increased releases from Iron Gate Dam. After October 14, 2002, discharge declined.

Tributaries, August through October 2002

The three major tributaries that discharge into the Klamath River between Iron Gate Dam and the confluence of the Trinity River are the Shasta (Klamath RM 176.6), Scott (Klamath RM 143), and Salmon Rivers (Klamath RM 66) (Figure 1).

During August the mean discharge from the Shasta River was 23.9 cfs (Figure 7). During September, the average discharge increased to approximately 31.8 cfs with a small increase in discharge occurring September 7 to 13, 2002. Discharge increased significantly between September 27 and October 9, 2002 from 33 to 149 cfs. This increase coincided with the end of the irrigation season within the Shasta River watershed.

Scott River discharges were measured at the Fort Jones gage. This gage is located upstream of the confluence with the Klamath River (Klamath RM 143) on the Scott River (Scott RM 21) (Figure 1). Consequently, this gage does not capture the entire discharge of the river, particularly lower River accretions. Scott River discharge was even lower than Shasta River discharge during August and September (Figure 7). The Scott River exhibited a mean discharge of 14.9 cfs during August 2002. September discharge was lower with a mean of 11.5 cfs. Discharge was fairly constant and gradually decreased from August through September.

Salmon River discharge was measured at the USGS gage near the mouth (Figure 1). Salmon River discharge declined from about 271 cfs starting on August 1, 2002 to about 119 cfs on September 30, 2002 (Figure 7). The mean monthly discharges for August and September were 171 and 124 cfs, respectively. Small increases in discharge were observed on September 8 and 19, 2002.

The Trinity River is the largest tributary of the Klamath River (Figure 1), emptying into the Klamath at river mile 43.5. Discharges are primarily regulated in the lower Trinity River by Lewiston Dam located on the Trinity River at river mile 111. Lewiston Reservoir serves as an afterbay to the Trinity Powerplant and regulates releases into the Trinity River and diversions to the Sacramento River basin.

During August and September 2002, the mean monthly discharges were 471 and 454 cfs, respectively, below Lewiston Dam (Figure 7). Daily average discharges were fairly constant. From September 5 to 20, 2002, daily average discharge declined from 485 to 440 cfs.

The Hoopa gage is located on the Trinity River at river mile 12.4, and is the primary measure of total discharge of the Trinity River into the Klamath River (Figure 1). Mean monthly discharges measured at the Hoopa gage were 696 and 631 during August and September 2002, respectively. During this time period daily average discharge gradually decreased from 760 to 609 cfs (Figure 7). However, daily average discharge increased between September 5 and 9, 2002, from 636 to 693 cfs. Discharge slowly declined to 638 cfs by September 12, 2002, and thereafter.

Combined Hoopa and Orleans Gage Discharges, August through October 2002

Due to the problems associated with operation of the Terwer gage under certain conditions, we also computed combined Orleans and Hoopa gage discharges for comparison (Figure 8). There are problems with this approach since there are other ungaged tributaries located below Orleans and Hoopa that could influence the total discharge measured at Terwer. In general, the average daily discharge pattern observed at Orleans was similar to that measured at Terwer during September and early October 2002 (Figures 8). During July through October 2002, deviations between the combined Hoopa/Orleans discharge and the Terwer gage varied between between 179 and 1,075 cfs and averaged 298 cfs. To evaluate the relationship more accurately, we added a 1-day lag between Terwer and the combined Orleans and Hoopa discharges based on observations observed during the pulse discharge on September 27 to October 14, 2002. Using this approach, the difference between the combined Orleans and Hoopa discharges and Klamath observations averaged 283 cfs and ranged between 27 and 1,069 cfs. If we remove the large deviations caused by the October 30 and 31, 2002, Terwer gage measurements, the difference between the combined Orleans and Hoopa discharges and the Terwer gage averaged 273 cfs and fluctuated between 27 and 709 cfs. This deviation is still considerable and reflects the potential influence of tidal action and accretions below the two upstream gages.

The difference between drainage area gaged at Terwer in comparison to the Hoopa/Orleans gage is 760 mi^2 (Pacific Southwest Inter-agency Committee 1973). The total drainage area captured by the Terwer gage is approximately 12,100 mi^2, including the regulated flows above Iron Gate Dam, Shasta River, Scott River, and Lewiston Dam (Pacific Southwest Inter-agency Committee 1973). Due to the potential for significant additional accretions below Hoopa and Orleans, within the area closest to the fish die-off, we believe it was prudent to include Terwer gage data for analysis and comparison.

Lynch and Risley (2003) provided a summary and analysis of hydrologic conditions prior to the September 2002 fish die-off. Their analysis focused on conditions that were present between September 1 and 24, 2002. During this period they recorded average daily discharges of 759 cfs, 1,290 cfs, and 639 cfs at the Iron Gate Dam, Orleans, and Hoopa gages, respectively. They did not cite discharges at the Terwer gage because they indicated that this site is subject to extensive error variability exceeding 15 percent in certain years. This is primarily due to the influence of tidal action. They further indicated that Orleans gage accuracy is within 10 percent of the actual discharge. They recommended using the combined Orleans and Hoopa discharge as a surrogate for Terwer gage discharges. However, as mentioned above we believe that because there can be significant accretions below the Hoopa and Orleans gages it is prudent to include Terwer gage data for comparison and analysis.

River Discharge Summary, August through September 2002

Overall, the hydrology of the Klamath River was driven by discharges from Iron Gate Dam during August and September 2002 (Figure 7). Accretions from the Shasta, Scott, and Salmon Rivers represented a minor fraction of the overall accretion between Iron Gate Dam and Orleans, but it appears that accretions from other tributaries also contributed to the Klamath River below Iron Gate Dam and Orleans. The Trinity River provided significant accretion below Orleans representing about 19 percent of the total discharge.

Historical versus 2002 discharges

Discharges at gage stations during 2002, were compared to historical gaged discharges within the Basin (Table 2). Discharges in 2002, were compared to the total period of record for each station for August and September average discharges and also in relation to the 3 lowest years of record. With the exception of Trinity River gages at Lewiston and Hoopa, all gages showed that 2002 flows were below the average values for the respective periods of record. In addition, most gages showed the discharges for 2002 ranked near or below the 3 driest years of record with the same exceptions noted above.

For the purposes of the operation of the Klamath Project, which is located approximately 50 miles upstream of Iron Gate Dam, the U.S. Bureau of Reclamation (BOR) utilizes forecasts based partly on projections of the net inflow into Upper Klamath Lake as a means of designating water year types (BOR 2000). During 2002 the BOR classified the year as “dry.” Hardy and Addley (2001) estimated that the unimpaired discharge for a dry year type as measured at Iron Gate Dam would be approximately 1,141 and 1,174 cfs, respectively, during August and September (Table 2). Unimpaired discharge was defined as discharge that would occur without the influence or diversion of water to the Klamath Project.

Lynch and Risley (2003) found that Iron Gate Dam releases for September 2002 averaged 759 cfs prior to the pulse flow. They found that September discharges at Iron Gate Dam were 59 percent of the average for the period 1960 through 2002. They also reported that September 2002 discharges measured at various gages within the Klamath Basin above the confluence with the Trinity River ranged between 11 and 64 percent of historical averages. However, discharge measured on the Trinity River at Hoopa gage was 96 percent of the historical average.

River Discharges Summary

Our conclusion is that August and September 2002 were characterized by low discharges within the Klamath River Basin above the confluence with the Trinity River relative to historic records.

Air Temperature

Air temperature is one of the primary variables affecting water temperature (Hanna and Campbell 2000). A major portion of the upper part of the Klamath River is isolated from the moderating coastal weather. This, combined with the lower elevation of the middle basin relative to the surrounding terrain, can create warm conditions conducive for increasing water temperatures (Bartholow 1995).

Air temperature data were collected at three weather stations: Weitchpec, the closest to the fish die-off; Orleans; and Klamath (Figures 9, 10, 11). Data from the Orleans and Klamath stations were compared to historical records to determine if it was unseasonably hot in 2002 (Figures 12, 13). Long term data sets do not exist for Weitchpec.

The analysis shows that although air temperatures were high during the months of August and September, temperatures were not unusually elevated compared to previous years. Water temperatures were likely warmed by climatic conditions, but no more so than in past years. Therefore, we conclude that air temperature, in and of itself, was not a major factor contributing to the die-off.

Water temperature

Water temperature data are the most complete data series collected by the USFWS and other agencies. We focused on several sites for collection of data. These included Weitchpec, Martins Ferry, and Terwer. These sites spanned the area affected by the die-off. In addition, historical data for several sites within the affected area were used for comparison.

We also compared our data to proposed water quality criteria for protection of adult salmonid migration and reduction in disease pathogens (EPA 2003a). The proposed guideline for reduction of high risk from disease pathogens is a daily temperature consistently below 18 °C (64.4 °F). The proposed EPA guidelines for the protection of adult migration (daily average of 21 °C) and reduction of lethality (weekly constant of 21 °C) are based on previous research regarding the behavior of migrating salmon (Beschta et al. 1987; Sauter et al. 2001). The recommended criterion for protection of adult salmon during the period of summer maximum temperature is a 7-day average of daily maximum temperatures less than 18 °C (EPA 2003).

Water Temperature - Weitchpec (Klamath RM 43.5) - 2002-2001

Weitchpec August 2002 average daily water temperatures varied between 20.5 and 24.1 °C (68.9 °F and 75.4 °F) (Figure 14). Maximum temperature reached was 24.8 °C (76.6 °F) on August 15, 2002. These temperatures were consistently above the recommended criterion for protection of adult salmon migration.

During September 2002, average daily water temperatures declined from 22.8 to 17.3 °C (73.0 to 63.1 °F). While this coincided with the increased discharges from Iron Gate Dam, air temperatures had already started to decline by September 23, 2002 (Figures 7 and 8).

Nonetheless, water temperatures during September were mostly above 18 °C (64.4 °F), the EPA-proposed criterion for reduction of risk to disease pathogens and protection of adult migration. Water temperatures appeared to respond to fluctuations in air temperature within 2-4 days during 2002 (Figures 9 and 14). Water temperature measurements made in 2001, were similar to 2002 values (Figure 14).

Water Temperature - Martin's Ferry (Klamath RM 40.4) - 2002-2001

Due to instrument problems, water temperature data were not consistently collected throughout the month of August 2002 at the Martin's Ferry site (Figure 14). Based on limited data, average daily water temperatures varied from 20.1 to 23.5 °C (68.2 to 74.3 °F). Maximum temperatures peaked at 24.0 °C (75.2 °F) on August 1, 2002. These temperatures were frequently above the recommended criterion, 18 °C, for protection of adult salmon migration and reduction of risk to disease pathogens.

During the month of September 2002, average water temperatures varied between 17.3 and 20.0 °C, reaching a maximum of 20.5 °C (68.9 °F). Water temperatures were frequently above the 18 °C EPA-proposed overall criterion for reduction of risk to disease pathogens and protection of adult migration. Water temperatures measured at Martin's Ferry in 2001, were similar to 2002 values (Figure 14).

Water Temperature - Terwer (Klamath RM 6.7) - 2002-2001

The average daily water temperature measured at Terwer near Klamath during August 2002 varied between 20.0 and 22.6 °C (68 and 72.7 °F)(Figure 14). The maximum temperature reached 23.5 °C (74.3 °F) on August 13, 2002. During September 2002, average daily water temperature fluctuated between 18.7 and 22.3 °C (65.7 and 72.1°F) with an average temperature above 21 °C (69.8 °F) from September 1 to 4, 2002. Maximum water temperatures reached 21.7 °C (71.1 °F) on September 4, 2002 and generally declined afterward. Water temperature during August and September 2002 were frequently above the 18 °C EPA-proposed overall criterion for reduction of risk to disease pathogens and protection of adult migration.

Due to instrument problems, continuous water temperature data were not collected for the entire month of August 2001 at the the Terwer site (Figure 14). However, the data suggest average water temperatures varied from 21.8 to 23.4 °C (71.2 to 74.1 °F). September 2001 water temperatures at Terwer were generally lower in comparison to August 2001 values (Figure 14). Water temperatures were similar in 2001 and 2002.

Water Temperature - Inter-annual Station Comparisons All Sites

Maximum daily water temperatures were compiled for several different sites on the Klamath River and years including Weitchpec (RM 43.5) during 2001 and 2002, Martin's Ferry (RM 40.4) during 2001 and 2002, below Coon Creek (RM 35.9) during 1995, below Blue Creek (RM 16.4) during 1995, Omagar Creek (RM 10.5) during 1997 through 1999, and Terwer (RM 6.7) during 2001 and 2002 (Figure 15). These water temperature measurements were compared to recommended EPA screening levels and proposed criteria for migrating salmonids (daily average temperature less than 21 °C or 7- day average of daily maximum temperatures less than 18 °C) and reduction of probability of severe disease outbreak (daily temperatures consistently below 18 °C) (EPA 2003a; Materna 2001; Sauter et al. 2001).

Maximum daily temperatures measured at Weitchpec, Martin's Ferry, and Terwer in 2002 were similar overall to levels observed at the locations and for the years noted above (Figure 15). Maximum water temperature for all years combined fluctuated between 19.5 and 25.5 °C during August and between 18.5 and 23.5 °C during September. During 2002, maximum water temperature fluctuated between 19.5 and 25.0 °C during August, and between 17.5 and 21.5 °C during September. In general, maximum daily water temperatures below the confluence of the Trinity River in August and September were similar throughout all years (Figure 16).

Water Temperature - USGS Report

Lynch and Risley (2003) provided a summary and analysis of hydrologic conditions prior to the September 2002 fish die-off. They also provided limited data on water quality conditions based primarily on data collected at the Orleans and Hoopa gages. The Orleans gage measured water temperatures that ranged between 18.3-23.3 °C (65 and 74 °F) during September 1 to 24, 2002. The average daily minimum and maximum temperatures during this period were 19.7 and 20.3 °C, respectively (67.4 and 68.6 °F). The average daily minimum and maximum temperatures from the Hoopa gage during this period were 18.6 and 20.5 °C (65.5 and 68.9 °F), respectively. Based on mass loading and mixing, they estimated that the average daily minimum and maximum temperatures below the confluence of the Trinity and Klamath Rivers during this period were 19.3 and 20.4 °C (66.8 and 68.7 °F), respectively. Based on a limited literature review, they further concluded that these temperatures can increase disease rates in salmonids.

Water Temperature - Grab Samples

In 2002, water grab samples and concurrent water temperature measurements were taken during morning and early afternoon hours (Table 3). Therefore, characterization of water temperature by grab samples was biased low due to diel trends. These data were used in interpretation of the temperature-dependent variables measured in grab samples (e.g., ammonia nitrogen criteria), and to evaluate spatial trends in water temperature, pH, and dissolved oxygen at sites between Weitchpec and Terwer.

During late July though early October 2002, grab sample water temperature measurements varied between 14.5 and 23.6 °C (58.1 and 74.5 °F) and averaged 19.3 °C (66.7 °F). These values were consistent with measurements collected with the continuous monitoring Hydrolab® datasondes. Temperature gradually increased in the upstream direction. During 2001, water temperature measurements fluctuated between 13.0 and 22.5 °C (55.4 and 72.5 °F) and averaged 18.0 °C (64.4 °F). These values and trends were also consistent with measurements made with the continuous monitoring Hydrolab® datasondes during August and September 2001.

Water Temperature Summary

Water temperature at all three mainstem sites monitored during August and September 2002 in the area of the die-off were high, but within the range of observed Klamath River water temperatures for August and September since 1995. Similar thermal regimes occurred in previous years with no accompanying fish die-offs.

Dissolved Oxygen

Dissolved oxygen is one of the primary water quality variables affecting aquatic life. The concentration of dissolved oxygen is influenced by temperature, elevation and barometric pressure, diel and long-term primary producer population dynamics, biochemical oxygen demand, water density and temperature-driven vertical stratification, depth, and mechanical re-aeration (Colt 1984).

Dissolved oxygen is one of the more sensitive variables in terms of susceptibility to measurement error. The accuracy of continuous measurement of dissolved oxygen by mechanical instruments can be compromised by membrane fouling by abiotic factors such as sediment or chemical coating, and by biotic factors such as periphyton growth. As such, our protocol involved the weekly retrieval and calibration of our instruments to ensure accurate data. Other operational issues that influence the quality of the data include potential burial of the instrument into sediments in deposition areas, vandalism, battery failure, and software or hardware malfunction. Any suspect data were identified in our analyses and excluded from the data set or discussed where appropriate. Consequently, the dissolved oxygen data are less complete than data from temperature monitoring.

The minimum dissolved oxygen criterion of 8.0 milligrams per liter (mg/l) is provided in the Water Quality Control Plan for the North Coast Region (NCRWQCB 1996). The minimum NCRWQB criterion specific for Klamath tributaries including the Trinity River is 7.0 mg/l. The general dissolved oxygen standard developed for California cold interstate waters is 6.0 mg/l. The recommended EPA criterion for avoidance of acute mortality in adult and juvenile salmonids is 4.0 mg/l (EPA 1986). Studies by Alabaster (1988) documented delays in upstream adult migration of Chinook salmon on the Willamette River at dissolved oxygen levels below 3.5 mg/l.

Dissolved Oxygen - Weitchpec - (Klamath RM 43.5) - 2002-2001

Dissolved oxygen levels measured at Weitchpec were consistently above 6.0 mg/l throughout August and September 2002 (Figure 17) with no apparent large diel fluctuations. Levels observed in 2001 at Weitchpec were similar to 2002 values (Figure 17), with most measurements above 6.0 mg/l during August and September.

Dissolved Oxygen - Martin's Ferry - (Klamath RM 40.4) - 2002-2001

During August and September 2002, dissolved oxygen levels at Martin's Ferry were consistently above 6.0 mg/l (Figure 17). During September 2002 average values increased and were generally above 8.0 mg/l. In August and September 2001, dissolved oxygen levels were similar to 2002, and were typically about 8.0 mg/l, with no large diel fluctuations (Figure 17).

Dissolved Oxygen - Terwer - (Klamath RM 6.7) - 2002-2001

Dissolved oxygen measurements were generally above 6.0 mg/l during August and September 2002 (Figure 17), with daily average values fluctuating near 8.0 mg/l. Throughout September 2002, average daily dissolved oxygen values were below 8.0 mg/l (Figure 17). Dissolved oxygen levels appeared to be more variable at the Terwer site when compared to the other stations.

Limited data from 2001 were similar to 2002 (Figure 17). Most of the dissolved oxygen measurements were above 6.0 mg/l. While they were below recommended levels for salmonids, they were not at levels (i.e. 3 - 4 mg/l) that would cause mortality.

Dissolved Oxygen - Grab Samples

Dissolved oxygen concentrations measured at the same time grab samples were collected ranged between 5.7 and 10.0 mg/l and averaged 8.6 mg/l during late July through early October 2002 (Table 3). Most values were above or near the NCRWQB criterion of 8.0 mg/l. September 2002 dissolved oxygen values were generally higher than August 2002. In general, dissolved oxygen concentrations were higher at upstream stations than those located downstream river. These values and trends are consistent with measurements made with the continuous monitoring Hydrolab® datasondes during August and September 2002. Measured dissolved oxygen concentrations during 2002, were never at levels that are known to cause direct mortality of fish. Dissolved oxygen concentrations measured during August through October 2001, varied between 7.4 and 10.4 mg/l, with an average of 8.9 mg/l (Table 3). Most values were above or near the NCRWQB criterion of 8.0 mg/l.

Dissolved Oxygen Summary

Dissolved oxygen at all three sites monitored during 2002 in the area of the die-off were within the range of conditions routinely observed in the Klamath River during August through September. Diel fluctuations caused by changes in primary production and respiration were evident but within the range of values observed in 2001 when a fish die-off did not occur. Dissolved oxygen during September 2002 never reached critical levels that could cause a fish die-off. Dissolved oxygen never reached levels below 3.5 mg/l, which has been shown in the literature to delay upstream spawning migration (Alabaster 1988). Based on these data, there was no evidence indicating the presence of any contaminants such as a reducing agent, sewage discharge, non-point source organic loading, or a large phytoplankton bloom that would have depressed dissolved oxygen levels during the month of September 2002.

pH

Typically, natural waters have a pH between 6.5 and 9.0 (Boyd 1990). Factors influencing pH include diel and long-term primary producer population dynamics, biochemical oxygen demand, buffering capacity of the water, and introduction of acids or caustic materials. Biological processes including growth and distribution of organisms, and toxicity of the water are also influenced by pH. Extreme pH values induce stress in fish by affecting the acid-base equilibrium and associated cation-anion balance of the organism (Fromm 1980). During algal blooms pH values typically fluctuate by more than 2 pH units over a 24-hour period (Boyd 1990).

The accurate continuous measurement of pH by mechanical instruments is influenced by membrane fouling by abiotic factors such as sediment or chemical coating and by biotic factors such as periphyton growth. Our protocol involved the weekly retrieval and calibration of our instruments to ensure accurate data. Other operational issues that influenced the quality of the data included burial of the instrument in sediments, vandalism, battery failure, and software or hardware malfunction. Suspect data lacking adequate quality control or considered to be in error were deleted from our analyses. Consequently, the pH data are less complete than data from temperature monitoring.

We compared measured pH concentrations with the NCRWQCB minimum and maximum pH criteria of 7.0 and 8.5 for the Klamath River (NCRWQCB 1996). Values below 4 or above 11 are known to cause death in fish (Fromm 1980; Boyd 1990). Rapid changes in pH can also cause stress and death even at levels that are considered within the normal range of tolerance.

pH - Weitchpec (Klamath RM 43.5) 2002 - 2001

During August 2002, maximum pH values frequently exceeded the recommended pH maximum criterion (Figure 18), yet tended to fluctuate near a pH of 8. The majority of pH measurements made during September 2002, were within the recommended minimum and maximum criteria. Diel differences were approximately 1 pH unit during the months of August and September 2002. The majority of pH values observed during 2001 were within the recommended NCRWQCB criteria (Figure 18). Diel differences of approximately 1 pH unit were common during 2001, as well.

In general, pH values during both years exhibited only minor fluctuations, and although they exceeded recommended criteria occasionally, levels that would cause mortality were not detected. In addition, diel fluctuations were relatively minor and did not indicate the presence of any algal bloom.

pH - Martin's Ferry (Klamath RM 40.4) 2002 - 2001

At Martin's Ferry, pH levels were generally within NCRWQCB criteria during 2002 and generally varied between 8.0 and 8.5 (Figure 18). Similar patterns were observed during 2001. In summary, pH levels at Martin's Ferry were within the range of acceptable maximum and minimum NCRWQB criteria during both 2001 and 2002. In addition, no large fluctuations in pH were observed.

pH - Terwer - (Klamath RM 6.7) 2002 - 2001

At Terwer, pH levels seldom exceeded NCRWQB water quality criteria during August and September 2002 (Figure 18) with values fluctuating no more than 0.5 unit per day. Similar trends were also observed in 2001 (Figure 18). The pH levels at Martin's Ferry were within the range of acceptable NCRWQB aquatic life criteria during both 2001 and 2002, with no large fluctuations observed in either year.

pH - Grab Samples

During 2002, pH values measured during grab samples ranged between 7.7 and 8.9 (Table 3). These were similar to pH values in 2001, which varied between 7.8 and 8.3. These values and trends are consistent with measurements made with the continuous monitoring Hydrolab ® datasonde probes during August and September 2001 and 2002. Grab samples indicated that NCRWQCB water quality criteria levels were seldom exceeded in 2002 and never exceeded in 2001.

pH Summary

Of the three sites that were monitored during 2002 in the areas of the die-off, pH values were within the range routinely observed in the mainstem Klamath River for the months of August and September. Because there were no large daily fluctuations in pH, it is unlikely that algal blooms or contaminants such as an acid or caustic material were present.

Specific Conductance

Specific conductance can be used for approximating the total dissolved solids content of water by testing its capacity to carry an electrical current. Specific conductance is used as an indication of the presence of ions of chemical substances that may have been released by a contaminant source. Naturally high specific conductances greater than 500 microsiemens per centimeter (µS/cm) are

typically found in areas influenced by estuarine or marine waters. The NCRWCB has set a maximum specific conductance criterion of 350 uS/cm for the non-tidal portions of the Klamath River.

Specific Conductance - Weitchpec (Klamath RM 43.5), Martin's Ferry (Klamath RM 40.4), Terwer (Klamath RM 6.7)

Specific conductance varied between 88 and 184 µS/cm during August and September 2002 and between 147 and 192 µS/cm during August and September 2001. Very little variation occurred on a daily basis. Specific conductance during both years was well below the NCRWQB water quality criterion. This suggests that there was no substance in the water that could affect specific conductance. This includes any chemical possessing a high concentration of ions, including acid, alkali, or salt solutions.

Specific Conductance - Grab Samples

In 2002, specific conductance collected during grab sampling ranged between 61 and 933 uS/cm (Table 3). Highest values were encountered in the estuary. Also, additional sites monitored during the fish die-off exhibited values similar to the three primary monitoring locations. These values and trends are consistent with measurements obtained with the continuous monitoring Hydrolab® datasondes during August and September 2001 and 2002. Specific conductance generally did not exceed the NCRWQB water quality criterion level. The higher levels in estuary were elevated due to the intrusion of marine waters. River water quality criteria do not apply to this area.

Other Water Quality Measurements - Grab Samples

Various grab samples were collected prior to and during the fish die-off (Tables 3, 4, and 5). Variables measured in addition to water temperature, specific conductance, dissolved oxygen, and pH were biochemical oxygen demand, ammonia nitrogen, phytoplankton chlorophyll-*a*, periphyton chlorophyll-*a*, nitrate nitrogen, total phosphate phosphorus, orthophosphate phosphorus, total suspended solids, and turbidity using nephelometric turbidity units. We used data from late July through early October 2002 to evaluate conditions during the period of the fish die-off. We compared these data to data collected during August, September, and October 2001. Most of the grab samples were collected at the same sites of the Hydrolab® datasondes; however, there were other sites sampled as well.

Chlorophyll-a

Chlorophyll represents the common green pigments of plants, algae and phytoplankton. There are seven known types of chlorophyll. Chlorophyll-*a* is the most common and abundant form typically measured. High levels of chlorophyll-*a* indicate eutrophic conditions and can be associated with other conditions such as widely fluctuating dissolved oxygen and pH. Currently there are no legally recognized water quality standards for chlorophyll-*a*. The EPA has developed recommended nutrient and chlorophyll criteria by ecoregion (EPA 2000). The Klamath River falls within the nutrient Ecoregion II or western forested mountains, where the recommended criterion is 0.66 microgram per liter (ug/l) chlorophyll-*a*. However, there is considerable variation between baseline conditions at various locations used to derive this criterion.

During 2002, chlorophyll-*a* levels averaged 1.09 ug/l and ranged between less than 0.1 and 3.7 ug/l (Table 3). These values suggest that the lower Klamath River is mildly eutrophic during certain periods. However, under classification schemes developed for reservoirs and lakes, these values would warrant an oligotrophic determination (Wetzel 2001). Because discharges into the lower Klamath River are dominated by four reservoirs and one natural lake, this may be an acceptable comparison. Similar values were recorded in 2001 (Table 6). Other signs of eutrophic conditions such as algal blooms with bright green water or wide diel fluctuations in dissolved oxygen or pH were not observed in the area of the die-off (Figures 22 and 23). The presence of chlorophyll-*a* supports our conclusion about the absence of any toxic compounds, especially herbicides, because of their known negative effect on phytoplankton.

Ammonia Nitrogen

Ammonia occurs naturally in water bodies and arises from the breakdown of nitrogenous organic and inorganic matter. Sources include waste products from terrestrial and aquatic biota, atmospheric gas exchange, decay processes mediated by microorganisms, direct discharges into water bodies by industrial processes (e.g., pulp and paper production), fertilizer application, or municipal waste. At high pH values most ammonia is in the un-ionized form (NH_3). Although both un-ionized and ionized ammonia are toxic, the un-ionized form is the most toxic (Meade 1985). The un-ionized ammonia concentration is dependent upon pH and temperature. Consequently, the EPA-recommended national criterion for un-ionized ammonia is based on pH and temperature relationships (EPA 1999). In addition, this criterion is determined for both cold-water and warm-water species.

During both 2002 and 2001, ammonia nitrogen levels seldom exceeded the detection limit of 0.1 mg/l (Table 3). For the given pH and temperature values observed, ammonia nitrogen levels were well below any derived criteria (EPA 1999). The EPA standard for ammonia nitrogen on the Klamath River in 2002 ranged between 1.0 and 7.8 mg/l. Therefore, there was no evidence that ammonia levels reached any concentration that would negatively affect fish survival. In 2002, levels were similar to 2001 levels when a fish die-off did not occur.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is a measure of the quantity of dissolved oxygen, in milligrams per liter, necessary for the decomposition of organic matter by microorganisms, such as bacteria. It is also defined as a measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms for their metabolic requirements. The measurement of BOD is used to determine the level of organic pollution of a stream or lake. The greater the BOD, the greater the degree of water pollution. Because complete decomposition of organic waste can take up to several weeks, it is more common to measure the amount of oxygen consumed with a defined time period. The most common measure is biochemical oxygen demand over 5 days or $BOD_{5,}$ here referred to as BOD.

BOD levels measured during both 2001 and 2002, were below detection limits, and therefore at concentrations that are known to not have a deleterious effect on dissolved oxygen levels in the stream. (Table 4). BOD levels provided no evidence of any type of discharge of organic waste.

Turbidity

Elevated turbidity can be associated with a number of factors including discharges of pollutants, sediment runoff, or algal blooms. The recommended criterion for turbidity associated with protection against excess nutrients and algae is 1.30 nephelometric turbidity units (NTU) (EPA

2000). Elevated turbidity associated with suspended solids can cause increased gill stress at levels of 30 to 40 NTU (Bash et al. 2001). Prolonged exposure can lead to increased stress and mortality. During August through October 20002, NTU levels varied between 0 and 1.0 and averaged 0.42 (Table 4). Higher concentrations were encountered during 2001. The NCRWQCB standard for the Klamath River states that turbidity shall not exceed background levels by 20 percent. We saw no evidence that turbidity was elevated during 2002 above any background levels as determined by 2001 data. In fact, 2002 turbidity levels were lower in general. These levels were far below any concentrations that would indicate elevated suspended solids or dissolved materials that would stress fish. These data also support the observations that an algal bloom was not present.

Total Suspended Solids

Total suspended solids (TSS) are solids found in waste water or streams that can be removed by filtration. The origin of suspended matter may be man-made wastes or natural sources such as silt. Therefore, during periods of excessive runoff such as rainstorms, TSS levels will increase (Meehan 1991). Increased TSS are particularly prevalent if the watershed has undergone extensive alteration such as deforestation, road construction, mining, grazing, removal of vegetation, or other disturbances. Generally, levels above 1,400 mg/l TSS will impair gill function and cause fish mortality (Bash et al. 2001). The NCRWQB standard for the Klamath River states that suspended sediment load shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

During August through October 2002, TSS levels ranged between 1.0 and 5.2 mg/l with an average concentration of 2.4 mg/l (Table 4). TSS levels during 2001 were similar, ranging between 1.0 and 4.4 mg/l, with an average 2.6 mg/l. These levels are slightly higher than historical late summer values of 1.0 mg/l measured upstream of Orleans (Steel and Cahoon 1987).

Based on these data, there is no evidence to suggest that any type of turbid release occurred or elevated suspended solids were present during the time of the die-off. Levels were far below concentrations that would cause mortality of fish.

Nitrates

The presence of nitrates in groundwater occurs from the conversion of nitrogenous matter into nitrates by bacteria. This is the process whereby ammonia in wastewater is oxidized to nitrite and then to nitrate by bacterial or chemical reactions (for example, effluent discharges from septic tank systems). If stream water concentrations of nitrate are limiting, small additions can trigger excessive plant or algal growth. Nitrate is seldom toxic at concentrations typically observed in stream waters.

Nitrate nitrogen levels ranged between 0.05 to 0.25 mg/l and averaged 0.07 mg/l during late July through early October 2002. (Table 4). Slightly higher levels were encountered during August through October 2001, when levels fluctuated between 0.10 and 0.55 mg/l with a mean concentration of 0.24 mg/l. Both of these ranges of values are consistent with past concentrations (0.0 to 0.52 mg/l) measured upstream in the mainstem Klamath River (Steel and Cahoon 1987). Based on these data, there is no evidence that release of nitrates was occurring during the time of the die-off.

Total Phosphorus and Orthophosphorus

Phosphoric acid, when used as a fertilizer ingredient, can cause excessive algae growth and oxygen losses in rivers. In natural waters and in waste waters, phosphorus occurs mostly as dissolved orthophoshates, polyphosphates, and organically bound phosphates. Natural sources of phosphorus include weathering of phosphorus-bearing rocks and decomposition of organic matter. Domestic wastewaters (especially those containing detergents), industrial effluents, and fertilizer runoff contribute to elevated levels in surface waters.

Total phosphorus represents the combined orthophosphates plus less readily available forms including organic phosphorus. The difference between orthophosphates phosphorus and total phosphate phosphorus levels is usually a good indicator of the organic phosphorus content (Mills 1997). In domestic sewage, organic phosphorus represents about 40 percent of the total phosphorus content. Organic phosphorus content can vary between 30 and 60 percent of the total. Percentages above 60-70 percent may indicate the presence of organic-based phosphorus compounds such as pesticides (Mills 1997). For the Klamath River ecoregion the recommended criterion for total phosphorus is 0.010 mg/l (EPA 2000). This value was developed for reservoirs and not rivers, but the Klamath and Trinity Rivers are dominated by reservoir releases, so it provides a useful point of reference.

Total phosphate phosphorus levels fluctuated between 0.03 to 0.18 mg/l with a mean concentration of 0.10 mg/l during late September through October 2002 (Table 4). Ratios of organic to total phosphorus as derived by comparison to orthophosphate phosphorus ranged from 62 to 66 percent. In 2001, total phosphate phosphorus levels ranged from 0.09 to 0.21 mg/l and averaged 0.13 from September to October. Ratios of organic to total phosphorus ranged between 53 to 65 percent. During both years total phosphate phosphorus levels exceeded the EPA-recommended criterion and were considered eutrophic using the reservoir classification scheme. These values are consistent with previous data collected during the late 1980's in the mainstem Klamath River near Orleans by California Department of Water Resources (Steel and Cahoon 1987).

Although phosphorus levels were elevated, they were similar to levels observed in years when no fish die-off occurred. In addition, excess organic phosphorus was not observed, indicating it is unlikely that high levels of organophosphorus pesticides were present. There is no evidence that any spill of phosphorus-containing compounds occurred.

Periphyton

Periphyton is an assemblage of microorganisms (plants and animals) firmly attached to and growing upon solid surfaces, such as the bottom of streams, rocks, logs, pilings, and other structures. While primarily consisting of algae, the periphyton also includes bacteria, fungi, protozoa, rotifers, and other small organisms. Periphyton is a useful indicator of water quality. Poor growth may indicate impaired water quality due to toxic compounds or insufficient nutrients. Two common indices are often computed to describe periphyton populations. The first is the autotrophic index (AI) which is the ratio of total biomass to chlorophyll-*a* concentration. The higher the AI, the lower the primary production for overall biomass. The other index is the ratio of chlorophyll-*a* to phaeophytin pigment or CP ratio. Phaeophytin is the breakdown product of chlorophyll-*a*. High levels of phaeophytin and low AI's indicate recently dead phytoplankton or algae. Low AI's would correlate with poor periphyton primary producer (algae) populations.

We deployed periphyton samplers at Terwer gage for intervals of approximately 2 weeks. Results of 2002 periphyton samples show that the periphyton were initially dominated by consumer organisms as indicated by the high AI and low chlorophyll-*a* levels (Table 5). Periphyton primary producer populations increased during September based on higher CP and lower AI ratios (Table 5). Results of these samples suggest that periphyton populations were doing well during the time of the fish die-off and that heterotrophic organisms, although depressed, were still present in moderate concentrations. These data support our conclusion that toxic compounds were not present during the die-off.

Chlorinated Hydrocarbons and Pesticides in Water

On September 26, 2002, pesticide samples were collected with the North Coast Regional Water Quality Control Board staff in the vicinity of the fish die-off. The Yurok Tribal Environmental Program staff also participated in the collection. Collecting data at this time was most useful for determining persistent or ongoing contamination that may have been associated with the die-off. Grab samples were collected in the mainstem Klamath River near Tectah Creek, downstream of Blue Creek, at the Highway 101 bridge, and at Terwer. A sample was also collected within Blue Creek near the mouth.

During the first sampling event, samples were collected for analysis of organochlorine pesticides, triazine pesticides, and glyphosate (Table 6). Glyphosate is a broad-spectrum, non-selective systemic herbicide used for control of annual and perennial plants including grasses, sedges, broad-leaved weeds, and woody plants. It is a common ingredient used in herbicides such as Rodeo® and Roundup®. Some common applications in the Klamath Basin would be forestry applications to control competing plants, roadside weed control, and residential usage.

Results of those analyses showed only one compound above detection limit: the glyphosate level was 45 ug/l at the Highway 101 bridge on September 26, 2002. Because of this the downstream location in the estuary along with Terwer were re-sampled on October 8, 2002. Glyphosate was not detected during the second sampling event.

The level of glyphosate detected during the first sampling was extremely low and toxicologically insignificant. Laboratory studies show that technical grade glyphosate is nearly nontoxic to fish and may only be slightly toxic to invertebrates (Oregon State University (OSU) 2002). Based on the concentrations detected, glyphosate did not pose a risk to aquatic life and was not associated with the fish die-off. If glyphosate had been involved, significant numbers of other species including macroinvertebrates would have been affected.

Fish Tissue Sample

On October 3, 2002, one moribund coho salmon measuring 77 cm Fork Length (FL) was collected for tissue analysis of contaminants. This fish possessed a right maxillary clip, indicating that it originated at the Trinity River Hatchery. The gill, because it is an active site of contaminant uptake, was excised by the CDFG for tissue analysis. The gill tissue was analyzed for organochlorine, organophosphate, pyrethroid and carbamate pesticides. In addition, the laboratory analyzed the tissue for triazine herbicides, glyphosate and surfactants, and PCB congeners. Their analyses did not detect any contaminants (Crane 2003)(Table 7). These analyses, although based on a fish collected later during the fish die-off, support the finding of no persistent toxic pesticide, herbicide, or PCB congener in the water at the time of the die-off.

Chemical Spill Reports

During August and September 2002 there were no reported incidents involving chemical spills in the Klamath River below Iron Gate Dam or its tributaries, including Humboldt, Del Norte, and Siskiyou counties.

Permitted Discharges

According to EPA records there are no National Pollutant Discharge Elimination System permitted facilities and associated discharges within or immediately upstream of the area affected by the die-off.

Hazardous Waste Sites

According to the EPA web-based database CERCLIS, there was only one unpermitted hazardous waste facility near the area of the fish die-off (EPA 2003b). This dump site is located on Cappell Road in Weitchpec, California. This is approximately 10 miles upstream from the upper end of the major concentration of dead fish. This site serves as a unauthorized dump for various forms of trash and debris. Due to overall low risks to human health and/or the environment the site was not listed on the National Priorities List and was recommended for cleanup using local resources. There are also uncomfirmed accounts of various smaller dump sites located downstream of this site.

Relationship among Run Size, River Discharge and Precipitation

Run Size and Discharge

We evaluated the relationship of total run size of fall-run Chinook salmon in the Klamath Basin, local precipitation, and gaged discharges as factors contributing to the die-off. Run size information has only been tabulated since 1978; consequently, our analysis is limited to only the last 25 years (1978-2002). In 2002, neither run size nor discharge at Terwer during August and September were outside of the range of values measured during the previous 24 years, suggesting that those factors were probably not individually responsible for the die-off.

The 2002 run was the eighth largest among the years of record, and occurred in the fourth lowest discharge in both months as measured at the Terwer gage nearest the die-off site (Figures 19, 20 and 21). Among the 8 years with the largest run sizes, 2002 had the lowest discharge during both months as measured at Terwer; and among the 4 years with the lowest discharge, 2002 had the highest run size. Thus, based on discharge measured at Terwer, 2002 was unique because it had the lowest discharge among those years with high runs.

As previously discussed, measurement error occurs at the Terwer gage under certain conditions (Lynch and Risley 2003). Consequently, we also analyzed our discharge and run size data using the combined Hoopa and Orleans discharges (Figures 22 and 23). To delete the effect of the pulse discharge in late September 2002, we only used data from September 1 to 28 in that year. The 2002 fall Chinook run occurred during the fifth lowest flow conditions based on August and September Hoopa/Orleans discharges for the period between 1978 and 2002. Five of the 7 years with run sizes higher than 2002 had higher August discharges, while the other 2 years (1987 and 2001) had lower August discharges (Figure 22). In September, 6 of the 7 years with run sizes higher than 2002 had higher discharges, while the other year (2001) had a lower discharge (Figure 23). Thus, combined discharge measured at Hoopa/Orleans in 2002 was not exceptional among those years with high runs.

The Hoopa/Orleans and Terwer data suggest that the combination of the large run size and low flows may have contributed to the die-off. In order to evaluate this relationship, we examined those years with higher runs than 2002, and associated discharges at key gage locations.

Figure 24 displays the discharge values for the 8 highest run years for five key locations: Iron Gate, Orleans, Lewiston, Hoopa, and Terwer. In addition, we displayed the combined discharge of the Hoopa/Orleans gages. Several points stand out in Figure 24. First, the regulated discharges in August and September from Iron Gate and Lewiston were relatively constant during the 8 highest run years, while total discharges at Hoopa/Orleans and Terwer varied substantially. Second, in 2002, all discharges except Lewiston were among the lowest values observed. It is also notable that when compared to past years, little accretion of flow took place between Hoopa/Orleans and Terwer in September 1988 and 2002.

Finally, in 2002, Iron Gate discharge was the lowest on record among the 8 highest run years, and comprised less than 40 percent of total flows at the Hoopa/Orleans and Terwer gages (Figure 25). Within the 8 highest run years, there was considerable variation in the percentage of total discharge provided by Iron Gate at Hoopa/Orleans and Terwer.

We also examined the set of 4 years (1987, 1988, 2001, and 2002) with the lowest flows among the highest run years (Figure 26). Little difference among these years was seen in the discharge at the two sites closest to the die-off (Hoopa/Orleans and Terwer) or at Lewiston. Differences in discharges between 2002 and the other 3 low-flow years were greater at Iron Gate than at Orleans/Hoopa, Terwer, and Lewiston. In the other 3 lowest flow years with large runs, Iron Gate provided a larger proportion of the total flow at Terwer and Hoopa/Orleans compared to 2002 (Figure 25).

Run Size and Precipitation

Very little precipitation fell in the lower Klamath Basin in August and September 2002 (Figure 6). This occurrence was not unique during the 1948-2002 period of record (Western Regional Climate Center 2003), and it does not appear that lack of precipitation alone was a causative factor in the fish die-off in 2002. However, lack of precipitation could have delayed upstream fall-run Chinook salmon migration in 2002, and contributed to the possible extended exposure of a large number of these fish to disease pathogens.

We specifically examined the relationship between monthly precipitation measured at Orleans and the town of Klamath, during August and September 2002, with the other 7 years having higher runs of fall Chinook. Among the 8 years with the highest runs, we found considerable variation in August and September precipitation, and 2002 was low but not unique in having minimal precipitation (Figure 27).

Summary

Throughout our investigation we have sought to identify conditions that would likely trigger a fish die-off and that were different in 2002 in comparison to other years. The fish die-off in 2002 coincided with low total basin discharge and the lowest discharge at Iron Gate for years with large run sizes. Also, in 2002, the proportion of total flow contributed by Iron Gate was the lowest among high run years with the four lowest flows. However, we are unable to conclude that there is a cause and effect relationship with the die-off based upon mean monthly discharge data alone. Lack of precipitation may have been a factor that impeded migration, although rainfall in August and September 2002 was similar to several other years with high run sizes.

Cluster Analysis - Run Size 1978 to 2002 versus Discharge and Precipitation

We used the statistical technique of cluster analysis to identify groups of years possessing similar hydrology, based on August and September discharges from the mainstem and significant tributaries. This enabled an objective selection of years for comparison with 2002, the year of the die-off. Methods and results are described in detail in Appendix A. Based on discharges, the cluster analysis assigned 2002 to Group 2, along with 1991, 1992, and 1994 (Figure 28). These years all had similarly low discharges at the gages analyzed, but 2002 had a much larger run size than other members of Group 2. We compared Group 2 with the next most hydrologically similar group, Group 1, which included 1981, 1987, 1988, and 2001. Group 1 had generally higher discharges at gages on the lower Klamath River, with some overlap in values among the two groups at all gages except Iron Gate Dam. However, discharges on the Trinity River were generally lower during Group 1 years than during Group 2 years. Flows from the Shasta, Scott, and Salmon Rivers made relatively minor contributions to total discharge in both Groups, and did not vary substantially across the years examined. Group 1 had higher run sizes than the years of Group 2, except for 2002. The 2002 run size was unique among Group 2 years, but was similar to the average run size in the years of Group 1. August and September precipitation were not markedly different among Groups. This analysis supports the conclusion that 2002 featured an unique combination of low discharges (especially from Iron Gate Dam) and high run size.

Fish Density: Effects of Run Timing, Harvest, and Fish Behavior

The proximate cause of mortality during the 2002 fish die-off was an epizootic of Ich and columnaris. Fish density can enhance the spread of disease pathogens during an outbreak, and "Severe infections occur most commonly in dense populations of fishes." (Dickerson and Dawe 1995). In addition to our review of discharge and run size as factors in the die-off, we also investigated the available information regarding run timing and harvest as contributing factors.

Adult fall Chinook salmon, steelhead, and coho salmon primarily return to the mouth of the Klamath River from August through October (Leidy and Leidy 1984, Anglin 1994, Polos and

Craig 1994, Shaw et al. 1997)(Table 8). As a general rule, Klamath River fall Chinook salmon stocks arrive earlier than Trinity River stocks (Polos and Craig 1994).

Consistent with our understanding of run timing for Klamath River wild and hatchery fish, fall Chinook were present in the lower River during late August and early September in 2002. Most of what we know about run-size and timing of salmon in the lower Klamath River comes from information collected in the course of monitoring the salmonid fisheries of the Klamath River. CDFG regulates and tracks the Lower River recreational fishery between the mouth and Coon Creek Falls. Tribal fisheries are conducted by the Yurok Tribe; mostly in the estuary, the Karuk Tribe; at Ishi Pishi Falls, and the Hoopa Valley Tribe; in the lower Trinity River, and are monitored by each respective Tribe. Between 1978 and 1994, staff from the Arcata FWO conducted monitoring of the Tribal fishery in the estuary.

Catch-per-unit-effort (CPUE) data from the lower Klamath River recreational creel census for 2002 were evaluated and compared to other low discharge years with available CPUE data (Figure 26)(CDFG 2003b). These data suggest that in 2002 a larger proportion of the run arrived in the lower River by late August, up to 2 weeks earlier than most years, and well in advance of the first observed signs of the die-off.

We also evaluated CPUE data from the Yurok Tribal gill net fishery, which is conducted substantially within the estuary, and downriver from the primary river reaches where the fish die-off occurred (Figure 25)(Hillimier 2003). These data for 2002 further suggest that a larger proportion of fall Chinook salmon were in the lower Klamath River between mid-August through early September, earlier than in most other years for which data is available. In addition, a significant peak in the 2002 estuary net harvest CPUE data in early September indicates that a large number of fish may have moved through the estuary into the lower river about a week prior to the first observed signs of the fish die-off.

It is important to note that fall Chinook salmon from the Klamath and Trinity sub-basins comprised about 82 and 18 percent, respectively, of the total spawning escapement in 2002 (Table 10). The percent contribution of Klamath sub-basin fish to total in-river returns appears to have increased in recent years and in 2002 was the highest percentage observed for the 1978 through 2002 period of record. This is significant considering that, (1) there was a large in-river run in 2002, (2) Klamath stocks tend to arrive in the river before Trinity stocks, and (3) peak numbers of fish apparently arrived in the river even earlier. As such, there appears to be several pieces of evidence that support the premise that an unusually large number of fall Chinook salmon were holding in the lower River in 2002, prior to the fish die-off.

Another factor that may have affected the density in the lower river was the percentage of the fall Chinook run that was harvested in 2002. For in-river fisheries, when comparing years of low discharge and high run size (1987, 1988, 2001, 2002), the Yurok Tribal fishery harvested between

11,029 and 20,296 fewer salmon in 2002 compared to the other 3 years (Table 9). Total estimated in-river harvest of fall Chinook in 2002 was also lowest, 34,528 versus 50,779 (2001), 73,854 (1988), and 73,265 (1987) respectively, in comparison to the other three years (KRTAT 2003) Lower tribal and in-river sport harvest in 2002 may have resulted in more fish moving upstream and a higher density of fall-run Chinook salmon in the lower River.

Finally, it appears that fish behavior may have also played a role in affecting fish density in the lower River in 2002. In addition to the earlier arrival of Klamath stocks noted above, there is evidence from past Service studies that Klamath fall Chinook stocks also tend to linger in the estuary for a longer period of time than do Trinity stocks (USFWS 1988). Because a high percentage of the large fall Chinook run were Klamath sub-basin fish in 2002, a larger number of fish than usual may have remained in the lower River for a longer period of time compared to those years when the run was dominated by Trinity sub-basin fish.

Also, information from the Karuk Tribal fishery at Ishi Pishi Falls (RM 66.5) indicated an increase in salmon moving upriver in response to increased releases from Iron Gate Dam at the end of September (Figure 28) (Chamberlain 2002). This response suggests that many salmon holding in the lower River were not stimulated to migrate upriver until an olfactory or other significant environmental cue was triggered by increased discharge.

Summary

The large fall Chinook run in 2002 returned to the Klamath River within the range of historical migration dates, but the run appeared to peak between 1 to 2 weeks earlier than in other low flow years. Recreational and Yurok Tribal harvest CPUE data indicate that a large number of salmon were in the estuary and lower River in 2002 prior to the initiation of the die-off. It also appears that a high percentage of these fish were Klamath sub-basin fish which tend to return earlier than Trinity sub-basin fish and which have a tendancy to linger in the estuary before migrating upriver. Compared to the other 3 years with large returns and low discharge, Tribal and recreational harvest in the lower river in 2002 was about one-third to one-half less than in those previous years, also potentially contributing to a higher number of fish in the river. It also appears that many of these fish had not been stimulated to migrate by the ambient environmental conditions, but did later migrate in response to an increase in discharge after the die-off was underway. The sum of this information leads us to reason that fish, consisting mostly of fall Chinook salmon, occurred in the lower Klamath River in high density, which has been identified as a key factor in the manifestation of severe Ich epizootics.

Fish Passage

During the fish die-off, the potential blockage of fish migration due to low water levels was raised as an issue. Minimum depth criteria for passage of adult salmon and steelhead have been developed by Lauman (1976) and Thompson (1972). Recommendations for minimum depths to allow adequate passage of adult fish migrating upstream are 0.24 meter (9.5 inches) for adult Chinook salmon, and 0.18 meter (7.1 inches) for steelhead and coho salmon. It is not known if sufficiently large expanses of the River declined to these critical depth levels during the die-off. Some adult salmonid passage was occurring prior to and during the fish die-off based on the data provided by CDFG at the Willow Creek weir (Figure 32) and on observations of a few dead and stressed fish in the lower Trinity River (Guillen 2003). However, visual observations made by various Federal, State, and Tribal biologists working on the lower Klamath River suggested that low water depths in 2002 may have partially impeded upstream passage of the majority migrating adult salmonids.

U.S. Fish and Wildlife Service staff conducting green sturgeon radiotelemetry surveys using jet boats reported difficulty in navigating shallow riffles in the lower Klamath River during September 2002 (Pinnix 2002). These same areas were easily navigable earlier in the year. In addition, observations made by a USFWS biologist (Shaw 2002) indicated that water depth at the Pecwan and Ah Pah riffles appeared shallow enough to act as a partial adult fish passage barrier. Confounding a definitive conclusion concerning fish passage is the fact that lower or similar discharges have occurred in the past with no adult fish die-off.

CDFG (2003b) reported that in 1997 and 1998 high discharge events occurred in northern California that could have altered the channel of the Klamath River. They suggested that the input of high sediment loads during high discharge events could have resulted in the filling of pools and increased the elevation of riffles in the lower Klamath River. Furthermore, they speculated that discharges that may have been sufficient for fish passage in low discharge years prior to 1997 were inadequate for passage in September 2002. In summary, if fish movement was impeded due to shallow depths, or lack of suitable attraction flows, residence times would have been prolonged and fish would have been exposed to pathogens for a longer period of time.

Many studies have shown that fish migrate upstream in response to sudden pulses of water, called freshets, that result from a rainfall event (Erkinaro et al. 1999, Jonsson 1991, Smith 1985). In addition, Chinook salmon tend to enter rivers when the barometric pressure is falling, possibly in anticipation of rainfall. However, if conditions in a stream are unsuitable, coho salmon have been known to mill about in the vicinity of the stream mouth, sometimes waiting weeks for conditions to change (Sandercock 1991).

Fish also move in response to olfactory stimuli of water from the original natal stream or river (Barigna 1999; Healy 1991; Smith 1985). Salmon possess acutely sensitive chemoreceptors and can differentiate between the specific odors of rivers (Groves 1967; Hasler and Scholz 1983). The presence of adequate discharges from natal streams or rivers is critical for induction of sustained spawning migrations. The absence of these discharges may delay fish movement.

During the fish die-off, there were no freshets and limited rainfall in the lower Klamath River. Only 0.01 inch of rain fell on August 24, 2002 and, during September 17 and 18, 2002, approximately 0.10 and 0.45 inch of rain, respectively was recorded at the Klamath weather station (Figure 4) (NOAA 2002a and NOAA 2002b). Because the fish die-off had already started on September 18, 2002, it is unlikely that this minimal rainfall had any effect in dispersing fish that were already heavily infected with Ich and columnaris. Overall, 2002 August and September precipitation at Klamath was far below historical averages (Figure 6). Precipitation levels were below levels compared to years when run sizes were larger and river discharges were higher (Figures 27, A.3-A.4, A.10-A.11). In past years with low precipitation and large run sizes, fish die-offs did not occur. During these years, however, mainstem discharges were generally higher. Thus, our conclusion is that reduced precipitation in lower Klamath River, by itself, did not play a major role in the fish die-off. Rather, reduced precipitation during 2002 reinforced the overall low river discharge observed the lower Klamath River.

Summary

Delays in upstream movement to natal streams increases long-term energy expenditures and stress in migrating salmon. Delays can be caused by inadequate depths caused by low discharges and or lack of stimulus from freshets or discharges from natal streams. The lack of freshets, due to low rainfall, reinforced the already low discharges in the river and may have contributed to the delay in migration, due to lack of suitable attraction flows. However, we have no conclusive evidence that either adequate river depths or olfactory stimulus were lacking.

Historic Fish Die-offs

Salmonids

There is no recorded historical or Tribal cultural record of a large adult salmonid die-off on the Klamath River that resembles what occurred in 2002. However, in the literature, there are some rare instances where fish die-offs have occurred under similar conditions in other locations. The most similar incidents in comparison to the Klamath River die-off were the Skeena River die-offs involving sockeye salmon, *Oncorhynchus nerka*, and the parasite Ich (Traxler et al. 1998). Resident fish were the most likely source of the parasite in the watershed because several species were found with light infections of Ich. Transmission of the parasite to anadromous sockeye salmon was enhanced by the high density of fish held below the spawning grounds for days or weeks prior to moving into the spawning channel. The primary cause of this fish die-off was crowding of fish due to physical blockage. This inhibited upstream movement of fish and created conditions for the rapid spread of the pathogen.

Extensive mortality of adult summer-run Chinook salmon, coho salmon, suckers, and sockeye due to columnaris disease has occurred in the Columbia River as fish migrated into warm waters upstream (Becker and Fujihara 1978). The highest incidents of infection and mortality occurred during hot summers. The authors concluded that future disease outbreaks would be influenced by restricted river discharges and reduced water volumes resulting from stricter discharge regulations at dams and greater consumptive withdrawals for irrigation.

In addition, fish die-offs have occurred in the Klamath River basin involving juvenile salmon, and lower numbers of adult spring-run Chinook. In late June 2000, a fish die-off was reported in the Klamath River downstream of the Salmon River confluence (Pisano 2000). Dead and moribund salmonids, particularly young-of-year (YOY) Chinook salmon, were observed in a 64-mile stretch of the Klamath River. High densities of live fish in upriver areas were found at the mouths of tributaries, feeding in the relatively cooler water of the tributary plume. The highest densities of dead fish also occurred near the mouths of a few of these tributaries. Pisano (2000) believed that a combination of at least two pathogens endemic to the Klamath Basin, *Ceratomyxa shasta* (ceratomyxosis) and columnaris were responsible for the mortalities. Water temperature conditions in the Klamath River were in excess of 24 °C, and tributaries that normally provide thermal refugia were also warm in 2000, due to diminished or depleted snow packs.

Significant juvenile salmonid mortality resulting from water quality impairment was documented in 1994 and 1997 (Halstead 1997). In late June of 1994, USFWS biologists observed large numbers of dead and dying juvenile Chinook salmon in the Klamath River. USFWS biologists and technicians from the Yurok Tribe reported seeing from a few to several hundred dead juvenile Chinook on some gravel bars over a 30-mile section of the River. USFWS staff found that juvenile salmonids collected by the Big Bar rotary screw trap (Klamath RM 49.8) exhibited elevated mortality when compared to Trinity River samples at Willow Creek in 1992, 1994, 1995, and 1996 (Halstead 1997). Halstead (1997) evaluated water temperature as a probable contributing factor to the higher mortality rates of Klamath River fish. However, the annual seasonal temperature profiles of the two rivers, as measured at the Big Bar and Willow Creek trap locations were very similar. The disparity in terms of mortality rates despite similar water temperatures indicated that water temperature alone did not explain the differentially higher mortality rates of Klamath River fish. Further, in 1994, 1995, and 1996 field investigations reported increased levels of the parasite *Ceratomyxa shasta* which was believed to be one of primary causes of the mortality of juvenile fish in the Klamath River. Clearly, there are fundamental differences in the Klamath River that allow the proliferation of this parasite and/or the intermediate host that are not present in the Trinity River.

Significant (>30%) pre-spawning mortality of adult spring-run Chinook has been documented as far back as 1987, the earliest year for which reliable records were collected (CDFG 1994). During early July through August 2002, adult spring-run Chinook were observed dying prior to spawning in the lower Trinity River (McKay 2002). Both columnaris and *C. shasta* were found in some of the moribund and dead fish. During 2001, there were also reports of spring-run Chinook salmon in the Trinity River experiencing pre-spawn mortality. These die-offs in the Trinity River suggest that disease pathogens are also found in the Trinity River, although diseases could have been picked up as the fish migrated through the lower Klamath River.

Smallscale Sucker Mortality - 1997

Another fish die-off occurred on the Klamath River in August 1997 (Halstead 1997). The first indications were numbers (over 50 per day) of dead adult Klamath smallscale suckers collected at the trap. Typically, live adult suckers are captured in very low numbers on the order of a few each month. Other dead and dying suckers were also observed in the River and along the shoreline along with speckled dace and sculpin juveniles and adults. Hendrickson (1997) examined specimens collected during the fish die-off and found various pathogens present including *Aeromonas hydrophila* and columnaris.

CONCLUSIONS

Measuring impacts or factors responsible for fish die-offs is difficult due to the high number of uncontrollable factors and their inherent variability. Scientists often have limited data and no controls with which to compare or isolate variables. The die-off of 2002 in the Klamath River illustrates the complexity of identifying causes and effects. However, in this case, considerable historical data were available to help analyze potential trends and differences in factors such as temperature, water quality, run size, timing of runs, and pathogens present, and to draw conclusions about the causes of the die-off.

Evidence that the proximate cause of death was heavy infections of Ich and columnaris is unequivocal, based on pathological examinations. However, given that these ubiquitous pathogens are normally found in the Klamath River, additional factors must have played a role for such pathogens to have become lethal.

One of the potential causative factors was the large run size of fall Chinook salmon returning to the lower Klamath River. The numbers returning in 2002, represented the eighth largest run in the period for which we have data (1978-2002). Further, our analysis showed that while both higher and lower run sizes occurred in years with similar hydrology, 2002 still ranked among one of the largest runs among those years.

Another potential causative factor was the low discharge in the lower Klamath River. Average monthly flow in 2002 was the fifth lowest during the period 1978-2002, based on combined Hoopa and Orleans gaged discharges. Results of our cluster analysis of discharges in the basin indicated that 2002 featured an unique combination of low discharges (especially from Iron Gate Dam) and high run size. Large numbers of fish congregated in the lower Klamath River, in part due to constant low flows that resulted in a lack of cues for upstream migration. This conclusion is supported by the positive response of fish movement at Ishi Pishi Falls when flows were increased from Iron Gate Dam in late September 2002. Low discharge also would have resulted in lower river volume, lower water velocities, and consequently a lower exchange/turnover rate for water in the deep pools of the lower river where salmon were holding. These flow conditions are more conducive to an outbreak of the Ich pathogen. As noted previously, Ich outbreaks in epidemic proportions are rare in flowing rivers and streams, and a common treatment for Ich in a hatchery setting is to increase raceway velocities or reduce fish density so that the infective free swimming Ich theronts are less likely to encounter a host fish.

High fish densities in the lower River were likely also a contributing factor to the die-off. The large fall Chinook run in 2002 returned to the Klamath River within the range of historical migration dates, but the run appeared to peak between 1 to 2 weeks earlier than in other low flow years. Recreational and Yurok Tribal harvest CPUE data indicate that a large number of salmon were in the estuary and lower River in 2002 prior to the initiation of the die-off. It also appears that a high percentage of these fish were Klamath sub-basin fish which tend to return earlier than Trinity sub-basin fish and which have a tendancy to linger in the estuary before migrating upriver. Compared to the other 3 years with large returns and low discharge, Tribal and recreational harvest in the lower river in 2002 was about one-third to one-half less than in those previous years, also potentially contributing to a higher number of fish in the river. It appears that many of these fish had not been stimulated to migrate by the ambient environmental conditions, but did later migrate in response to an increase in discharge after the die-off was underway. The sum of this information leads us to reason that fish, consisting mostly of fall Chinook salmon, occurred in the lower Klamath River in high density, which has been identified as a key factor in the manifestation of severe Ich epizootics.

Seasonally high water temperatures in 2002 were conducive to rapid proliferation and transmission of the pathogen Ich, and also exacerbated the stressed condition of adult salmonids preparing to spawn. However, these temperatures were within the range of conditions observed on the lower Klamath River in previous years when no fish die-off occurred. Laboratory and field studies have documented epizootics of Ich associated with high water temperatures, as well as the predisposition of sexually mature fish to increased prevalence and severity of infection. It is also known that higher densities of fish not only increase stress and reduce their ability to cope with pathogens, but also increase the frequency of transmission from fish to fish. Because both high water temperatures and high fish densities were present, conditions for an outbreak among susceptible hosts were ideal. Because years with similar water temperatures did not have a die-off, we conclude that elevated water temperature was not the sole cause of the 2002 fish die-off, but was a contributing factor.

We were able rule out several factors as probable causes of the fish die-off. Primarily, there was no evidence for a toxic spill or other debilitating water conditions. The specificity of the die-off, which was primarily confined to adult salmonids, demonstrates that toxics were not the cause. Toxic compounds would have affected a wider range of species and ages of fish, as well as other organisms such as amphibians and invertebrates. Multiple measurements confirmed that dissolved oxygen, pH, conductivity, ammonia, nutrients, turbidity, and suspended solids were within accepted limits for survival of migrating adult salmonids. In addition, chlorophyll-*a* measurements indicated that no excessive growth of phytoplankton or periphyton occurred, thus ruling out toxic algal blooms.

It is our conclusion based on multiple lines of evidence that the fish die-off in the lower Klamath River in 2002 was a result of a combination of factors that began with an early peak in the return of a large run of fall Chinook salmon. Low river discharges apparently did not provide suitable attraction flows for migrating adult salmon, resulting in large numbers of fish congregating in the warm waters of the lower River. The high density of fish, low discharges, warm water temperatures, and possible extended residence time created optimal conditions for parasite proliferation and precipitated an epizootic of Ich and columnaris, which resulted in the death of an estimated 34,056 fish. Based on a review of available literature and historical records, this was the largest known pre-spawning adult salmonid die-off recorded for the Klamath River and possibly the Pacific coast.

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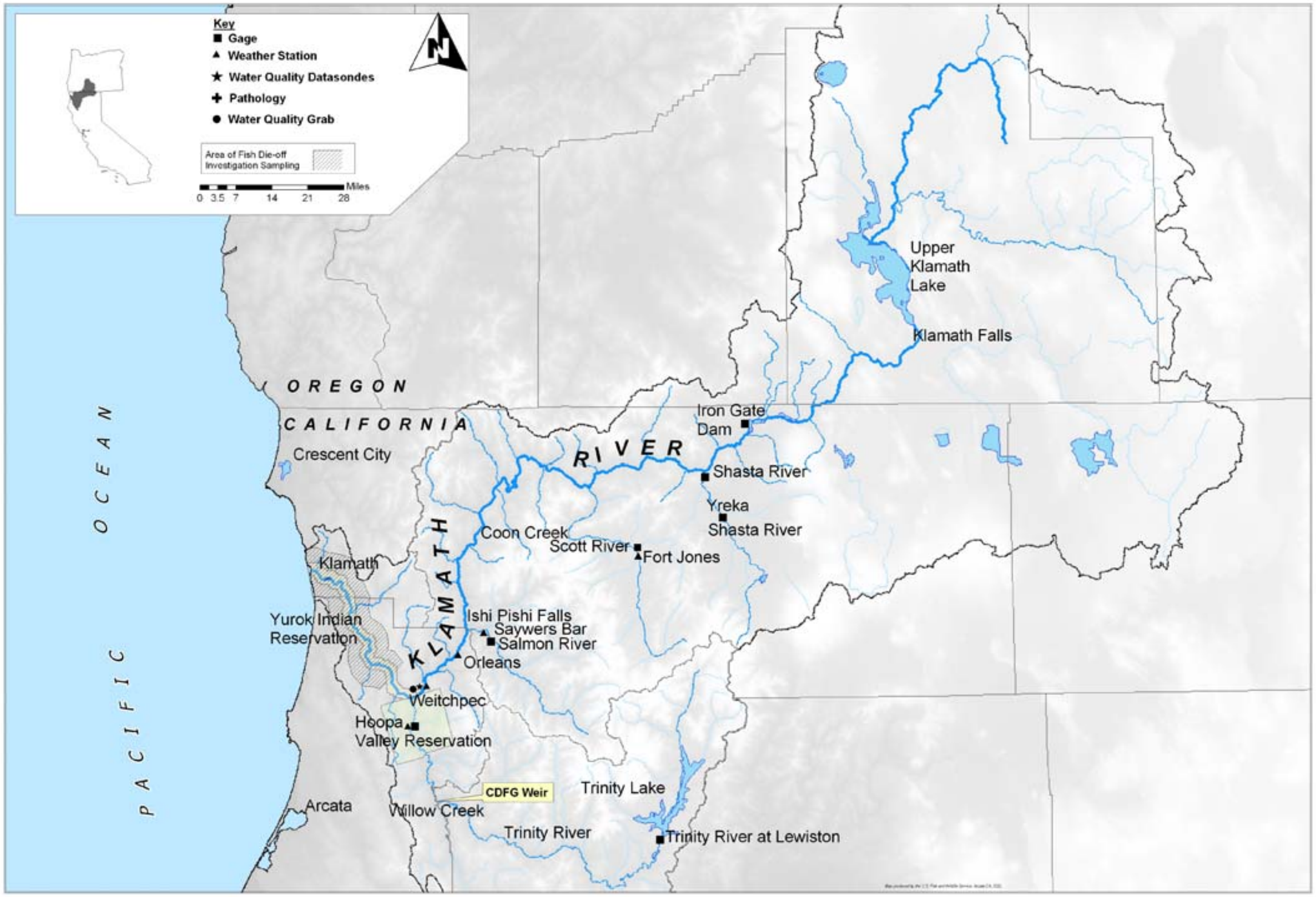

Figure 1. Klamath River basin showing fish die-off sampling areas.

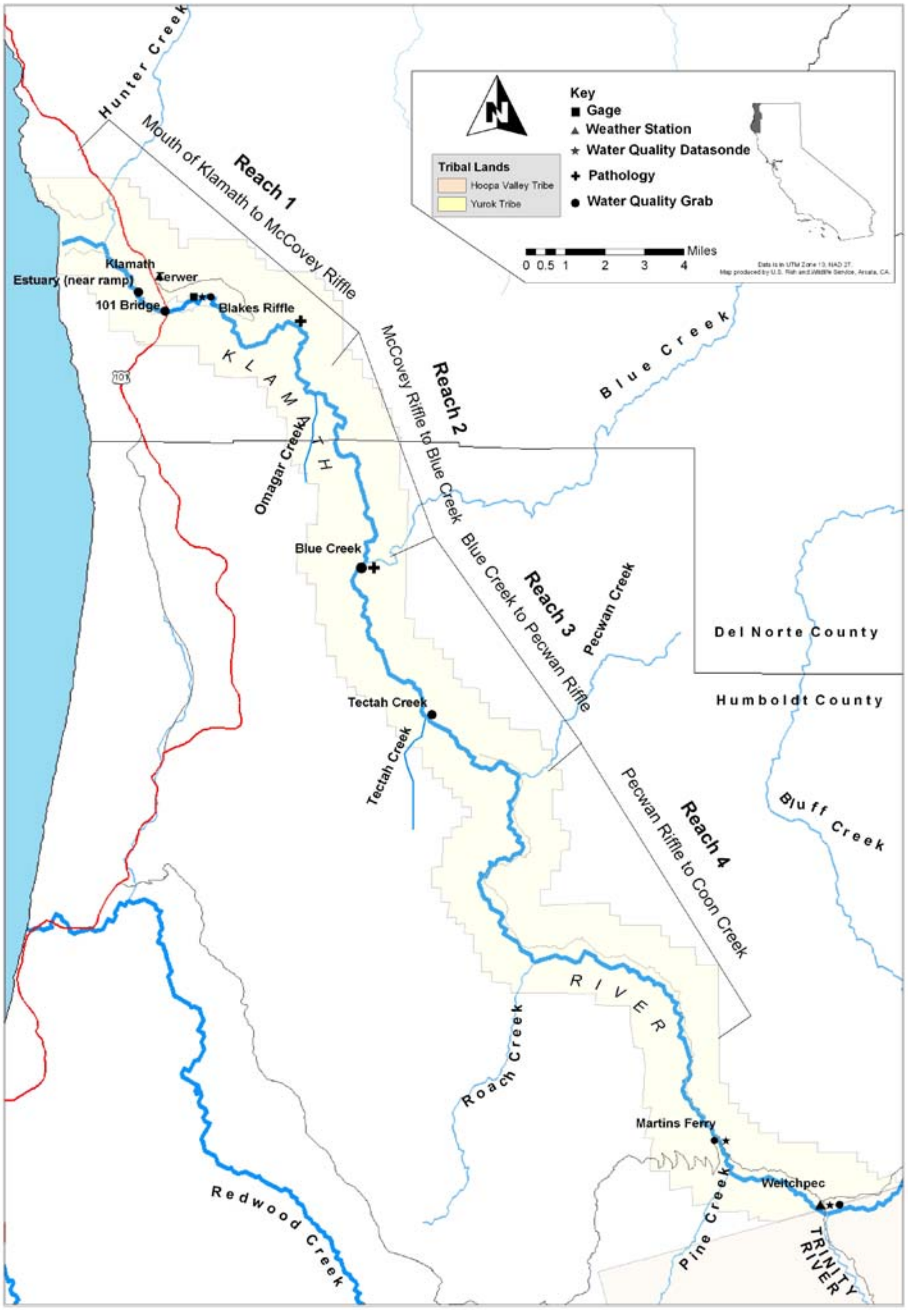

Figure 2. Map of lower Klamath River depicting reaches surveyed during fish die-off. investigations conducted during September and October 2002.

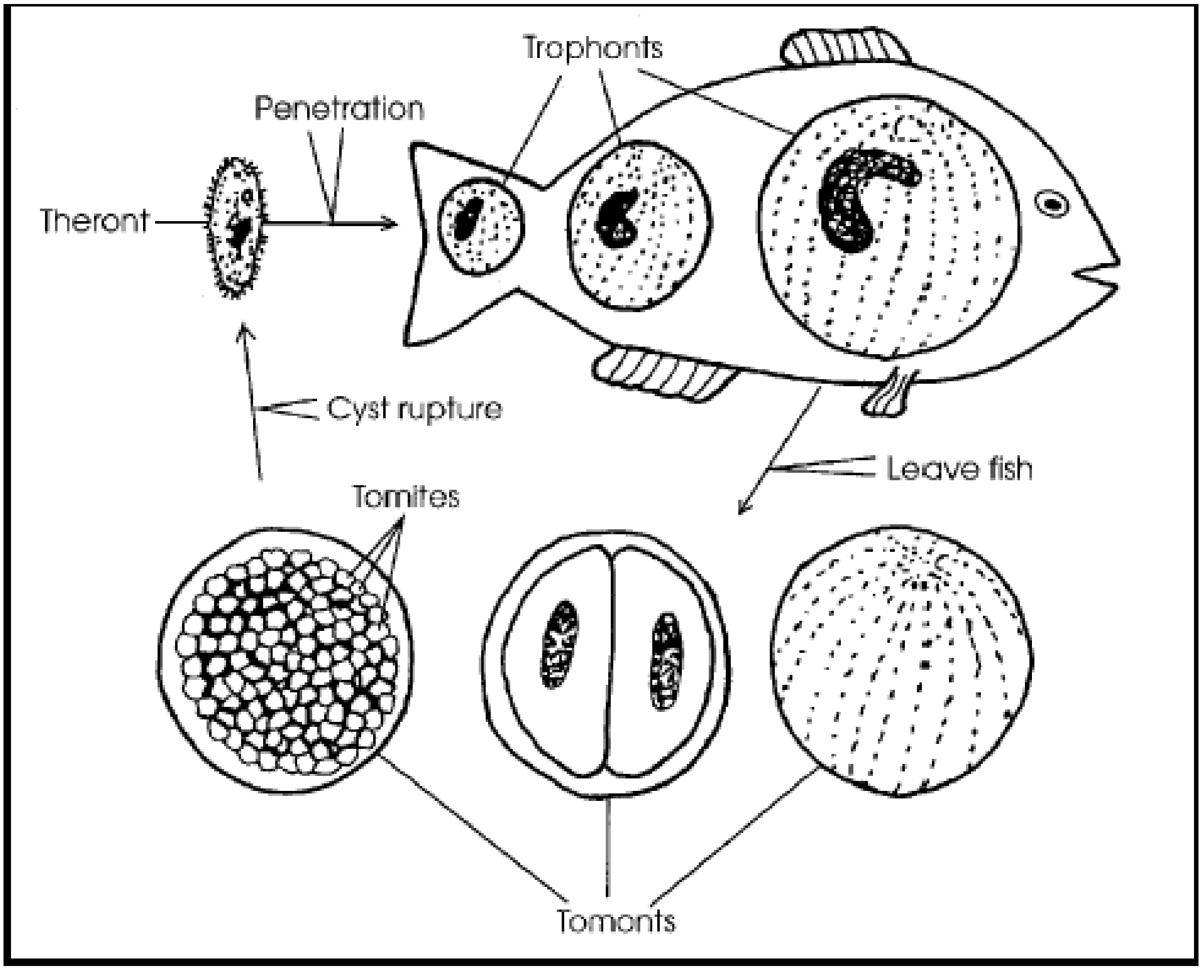

Figure 3. Life cycle of *Ichthyophthirius multifiliis*. Trophonts not to scale. Trophonts normally appear as white grain sized spots on fish. From (Durborow et al. 1998)(Drawing by Wyvette Williams and Drew Mitchell).

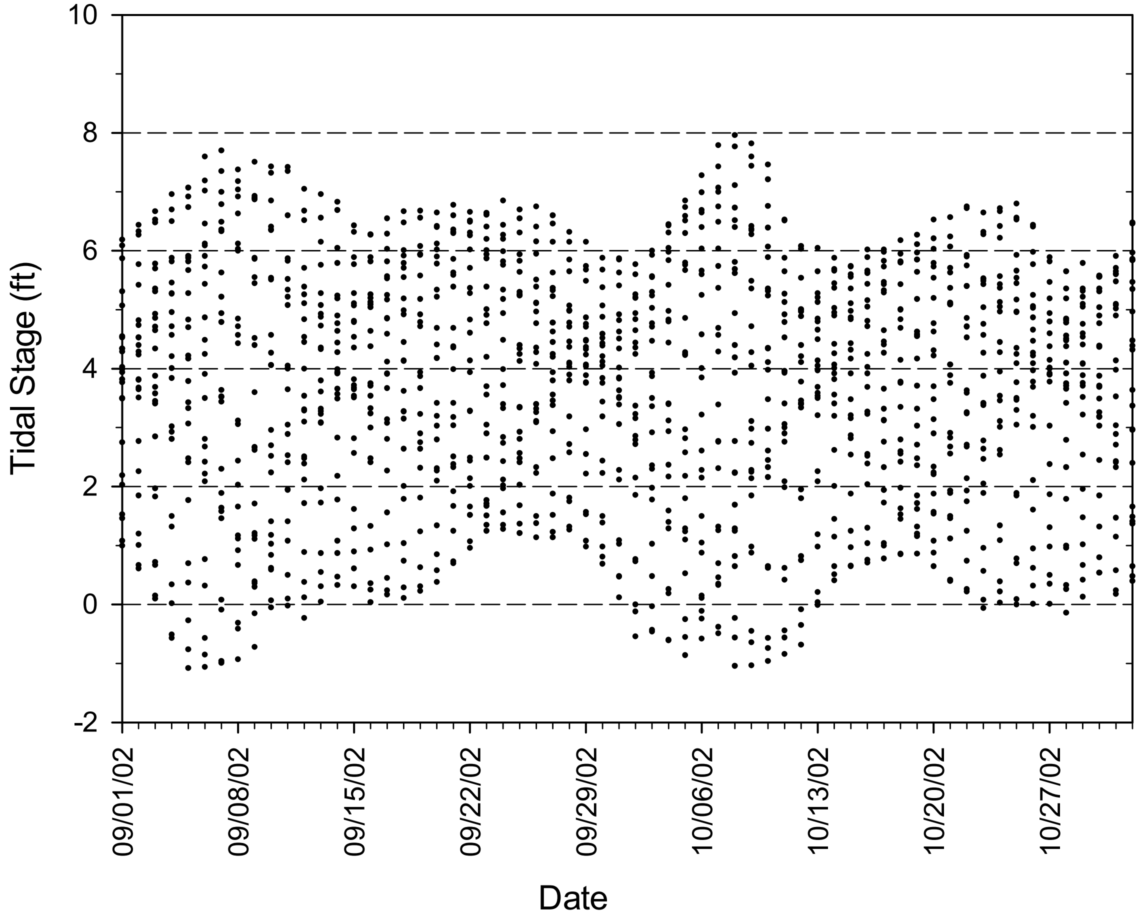

Figure 4. Tidal stages measured from 9/1/02 to 10/31/02 at the NOAA tide gage in Crescent City, California.

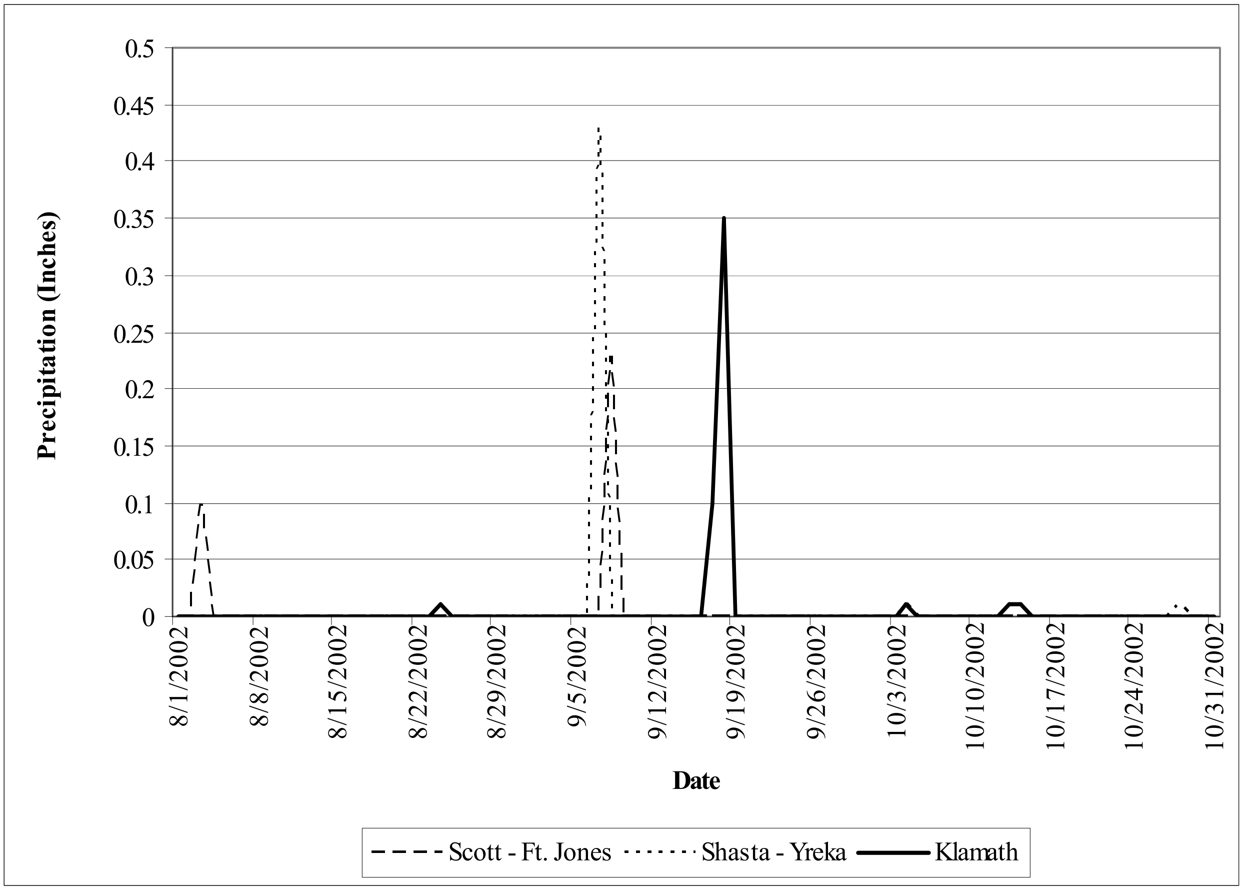

Figure 5. Daily precipitation measured at the National Weather Service meteorological stations located in Fort Jones near the Scott River, Yreka near the Shasta River and Klamath near the lower Klamath River. No precipitation was recorded at the Hoopa (Trinity River), Sawyers Bar (Salmon River) or Orleans gages (Klamath River) during this period of time.

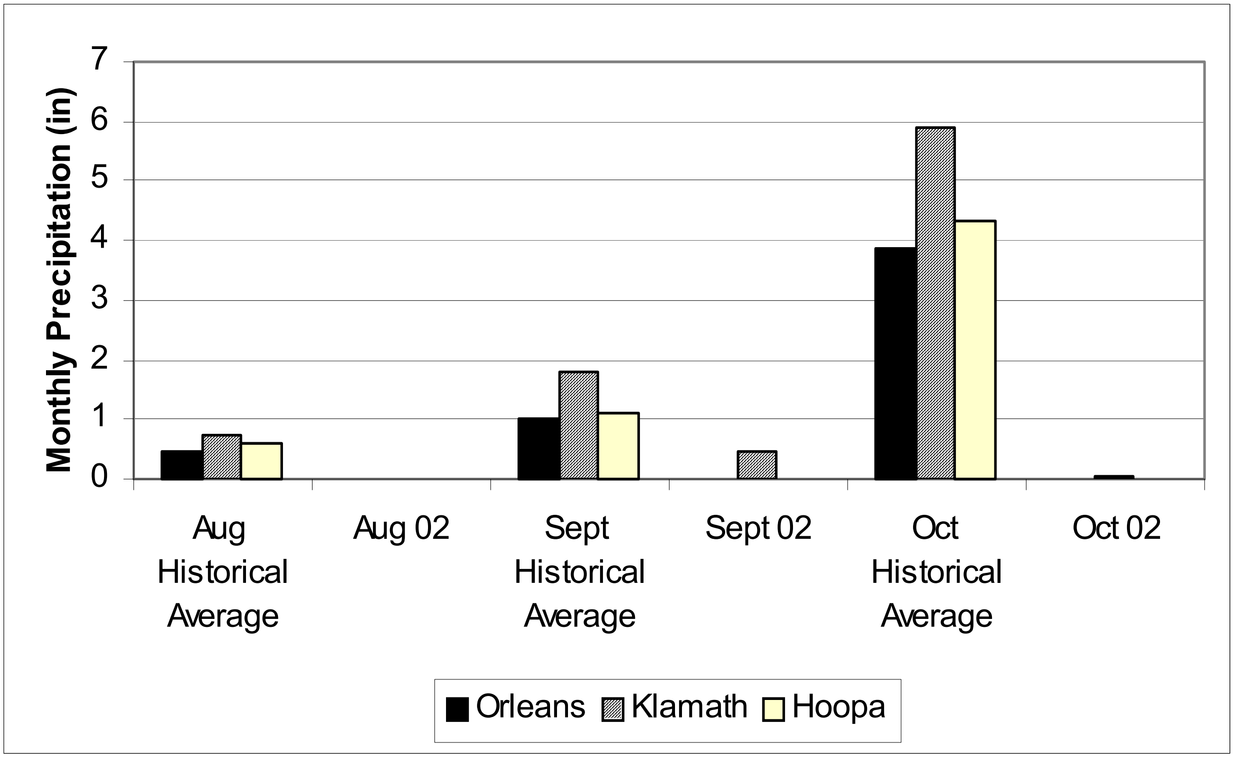

Figure 6. Precipitation measured at Orleans, Klamath and Hoopa during August, September and October 2002 compared with historical average values. Data obtained from the Western Regional Climate Center (2003).

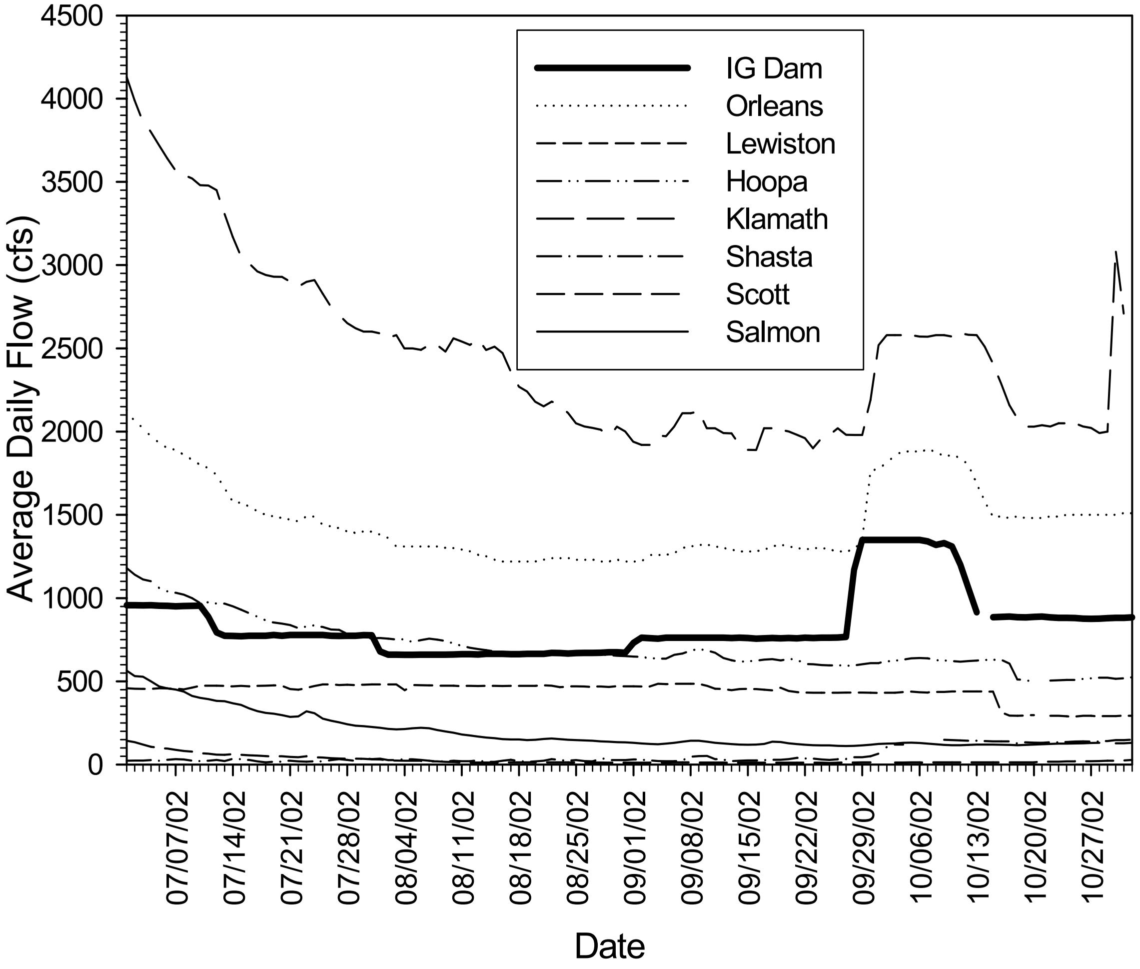

Figure 7. Comparison of discharge regimes between major tributaries and the Klamath River mainstem below Iron Gate Dam from July 1 through November 1, 2002. Data obtained from USGS data web site.

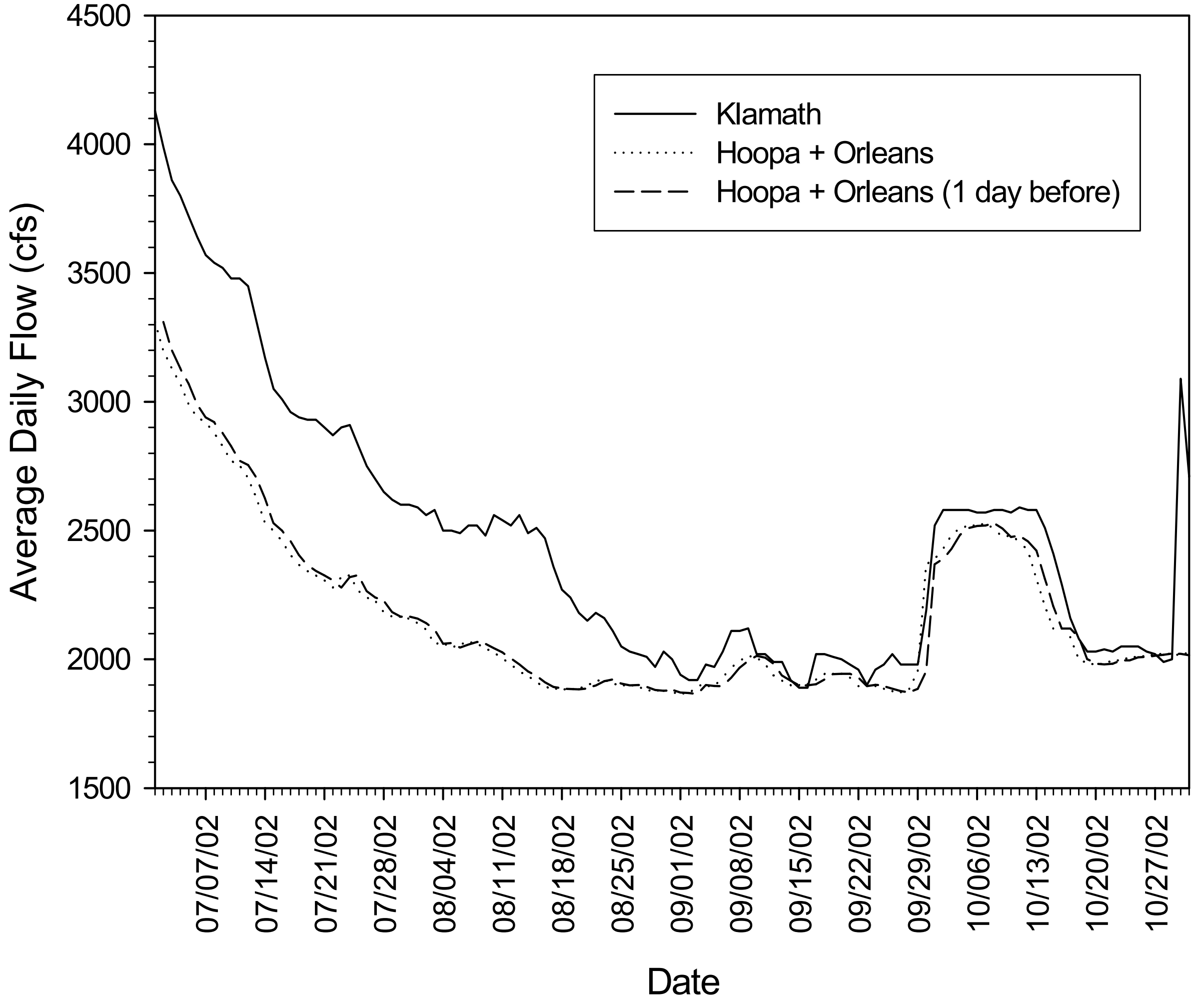

Figure 8. Combined mean daily discharges measured at U.S. Geological Survey gages located in the Klamath River Basin near Orleans (Klamath RM 59.1) and Hoopa (Klamath RM 43.5, Trinity RM 12.4) from July 1 to October 31, 2002. Information based partly on provisional discharge data. Discharges from day before and the Terwer gage (Klamath RM 6.7) site are also plotted for comparison. Data obtained from USGS web site.

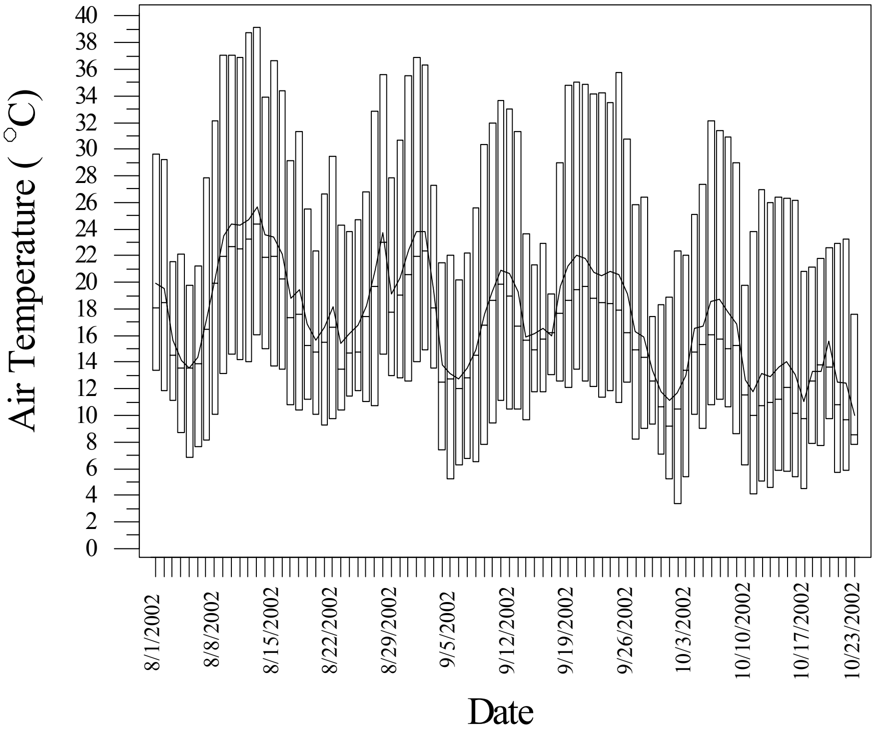

Figure 9. Air temperatures (maximum, mean, median, and minimum) observed at the Yurok Weitchpec weather station. Continuous line denotes mean value. Data generated from raw half hour readings.

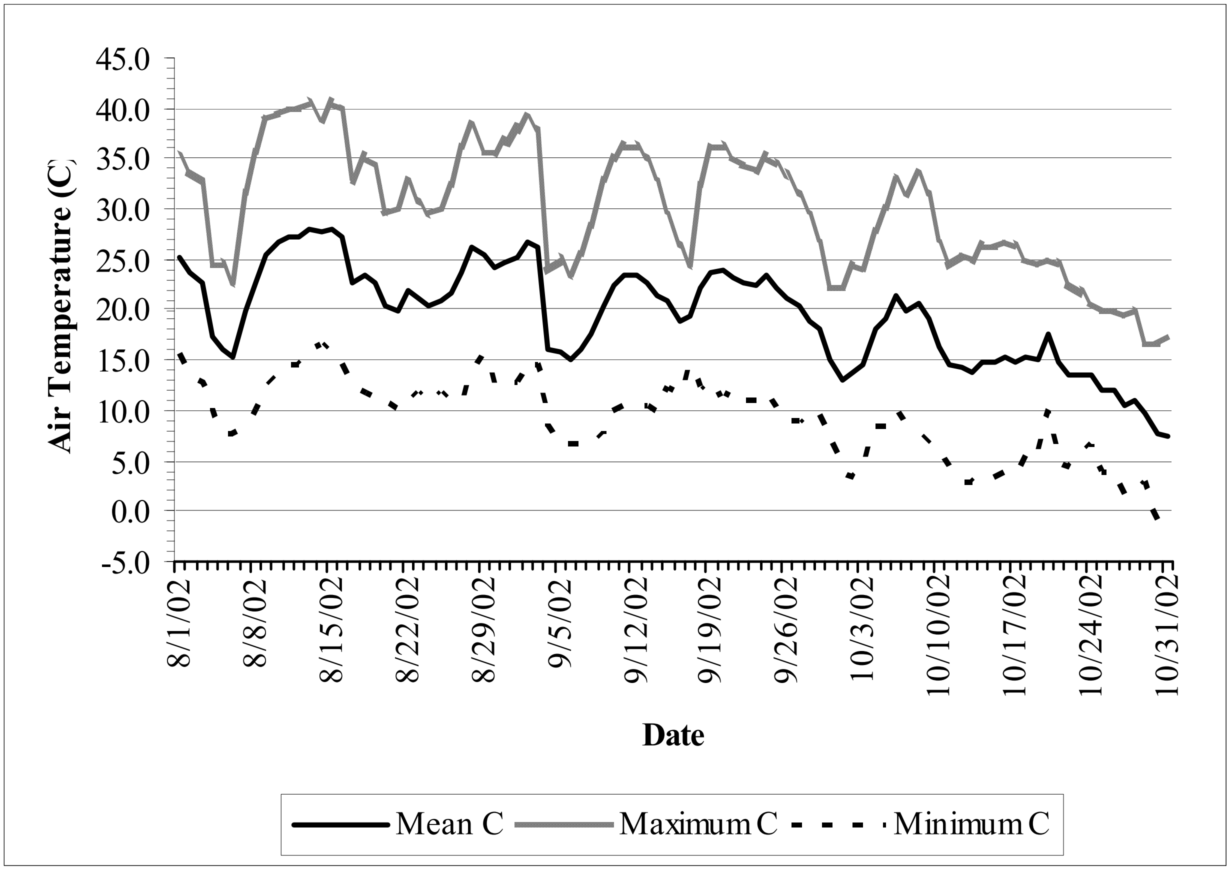

Figure 10. Maximum, mean, and minimum air temperatures observed at the Orleans National Weather Service weather station during August through September 2002. Summary data provided by National Weather Service.

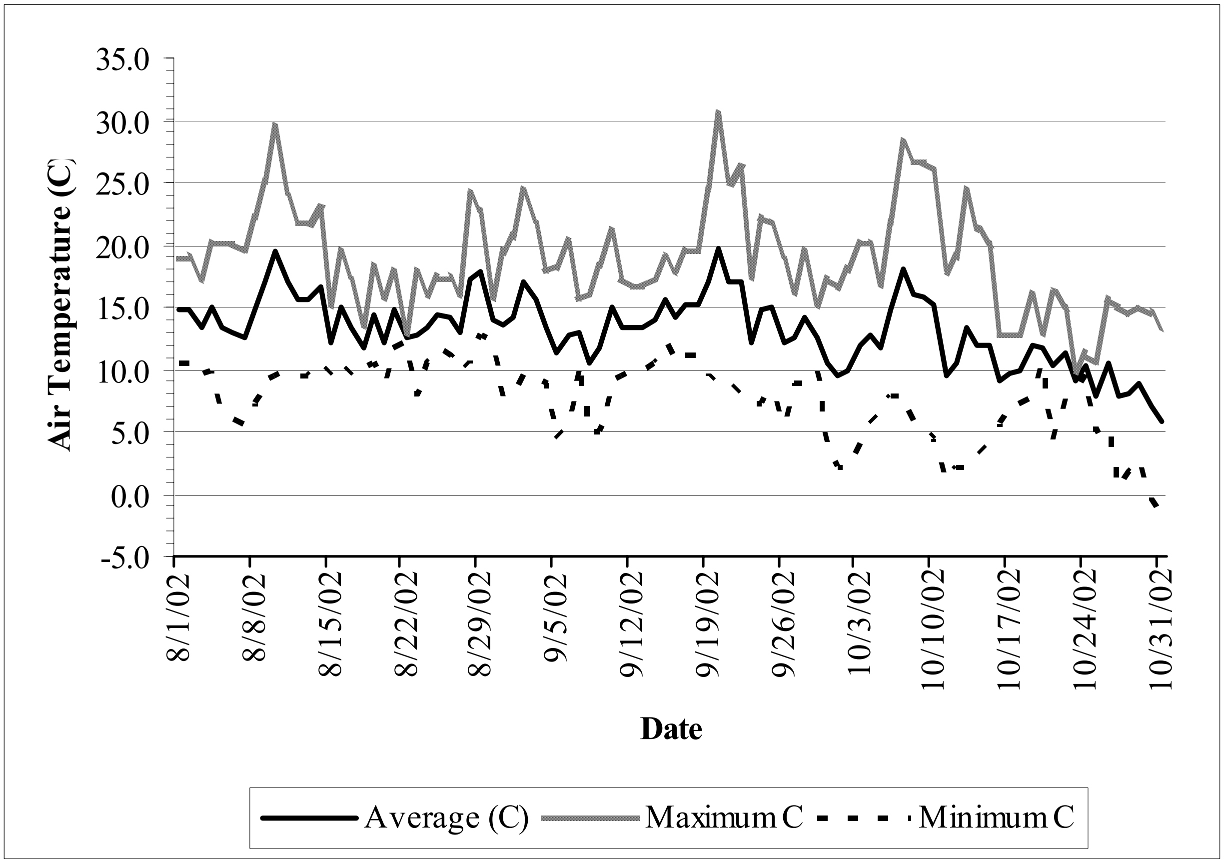

Figure 11. Maximum, mean and minimum air temperatures observed at the Klamath National Weather Service weather station during August and September, 2002. Summary data provided by National Weather Service.

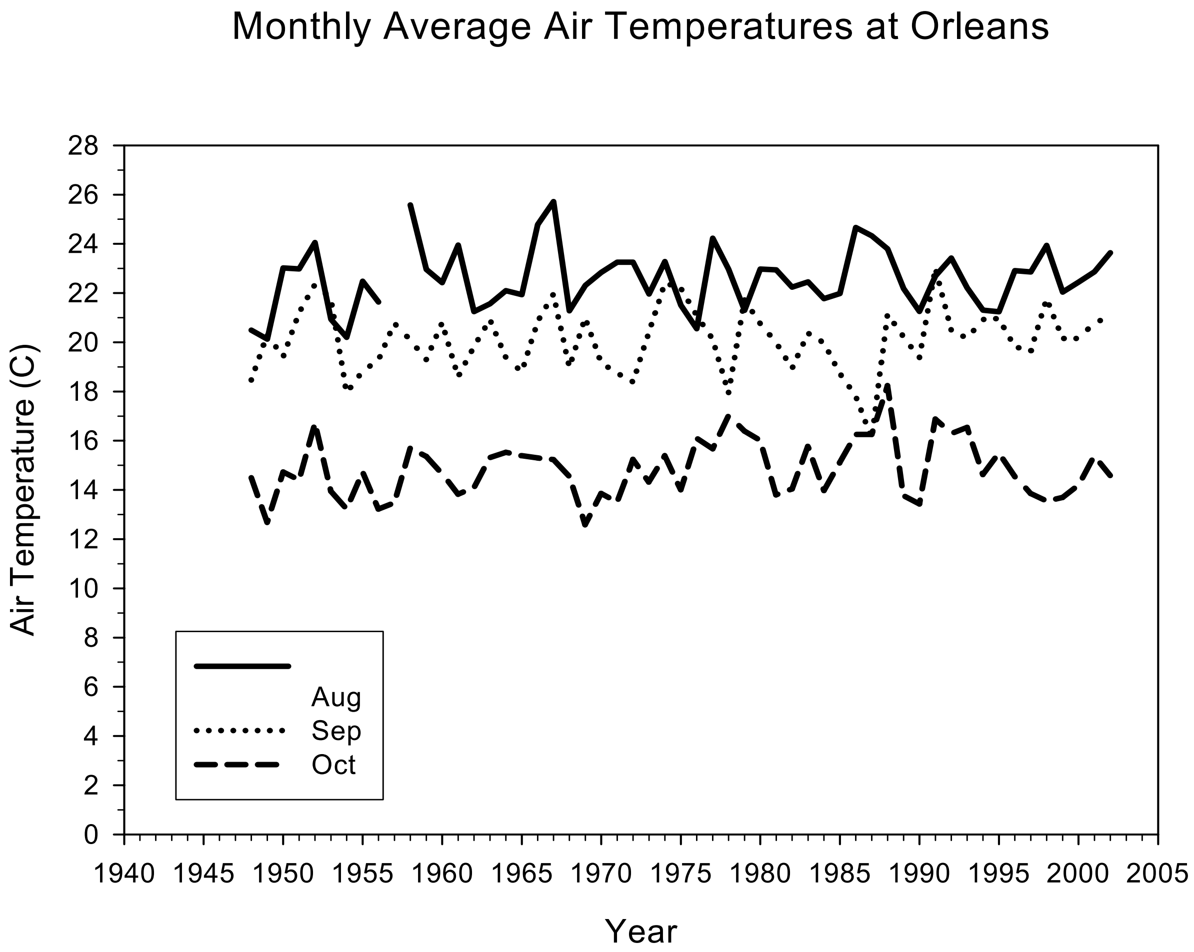

Figure 12. Average daily air temperature measured at the Orleans National Weather station from 1940 to 2002 during August through October. August, September and October temperatures averaged 22.6, 20.1 and 14.8 °C during the period of record.

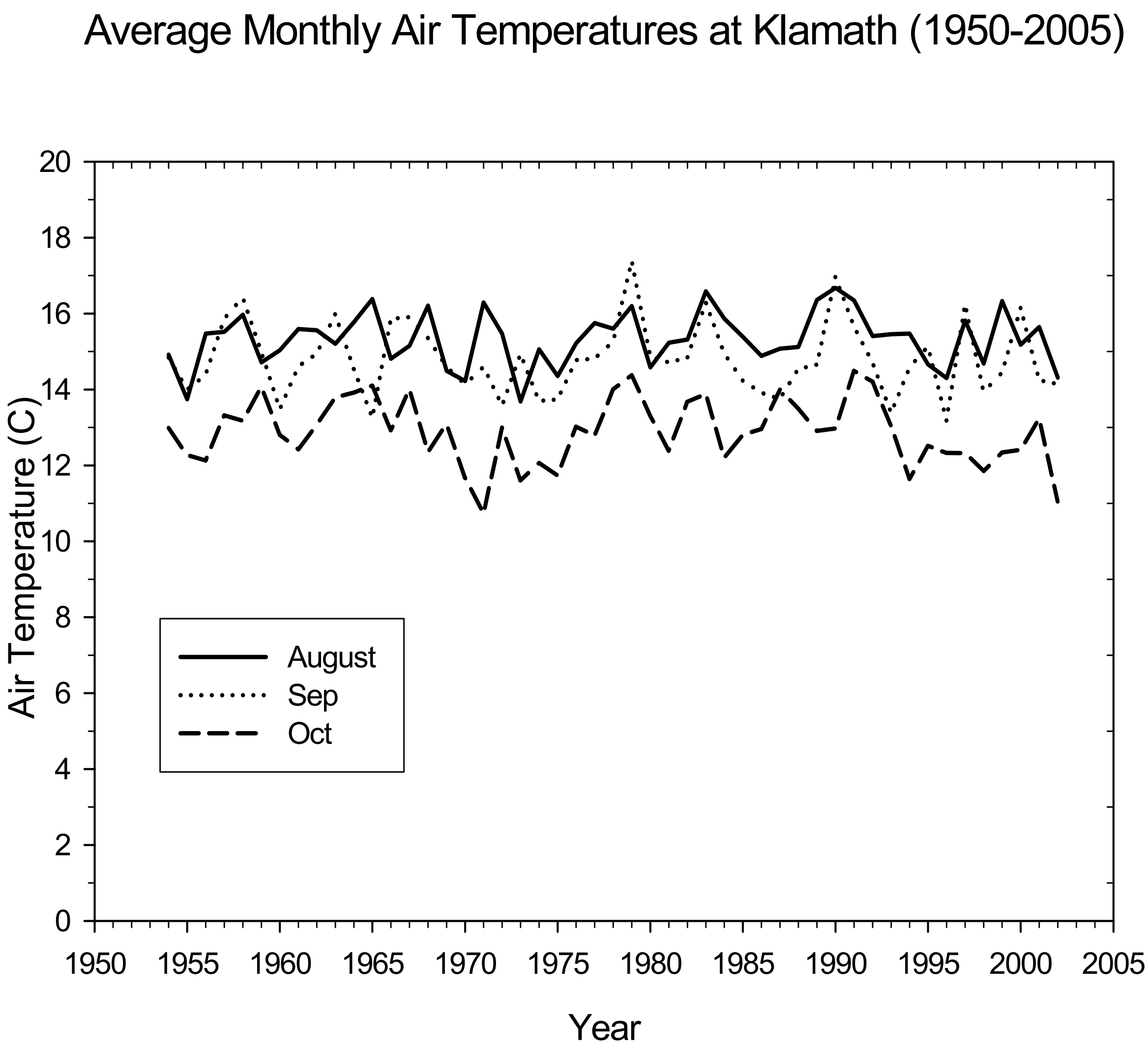

Figure 13. Average daily air temperature measured at the Klamath, California National Weather station from 1940 to 2002 during August through October. August, September and October temperatures averaged 15.3, 14.8 and 12.9 °C during the period of record.

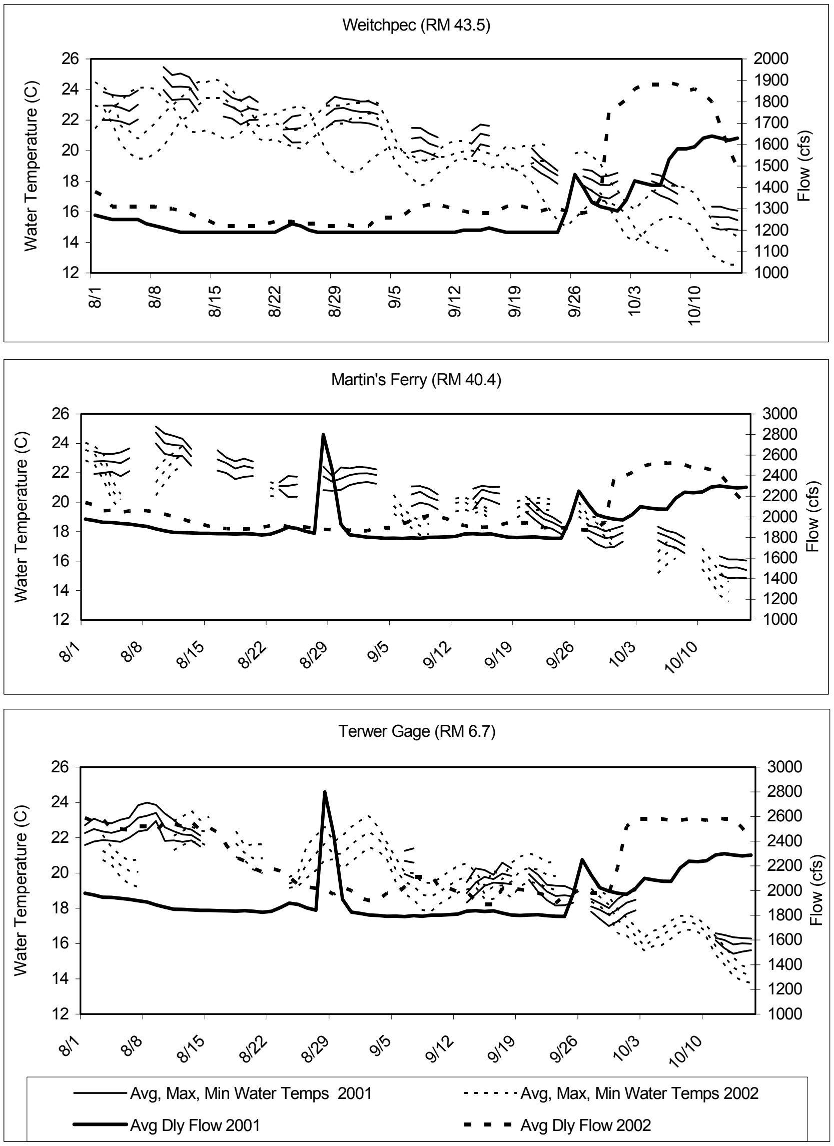

Figure 14. Daily average, maximum, and minimum water temperatures and average daily discharge recorded at the Weitchpec (RM 43.5), Martin's Ferry (RM 40.4) and Terwer (RM 6.7) on the Klamath River during May to October in 2001 and 2002 using Hydrolab® datasondes. Discharges derived from USGS gage sites at Orleans (RM 59.2) , Hoopa/Orleans (Klamath RM 43.5 + Trinity RM 12.4) , and Terwer gages respectively.

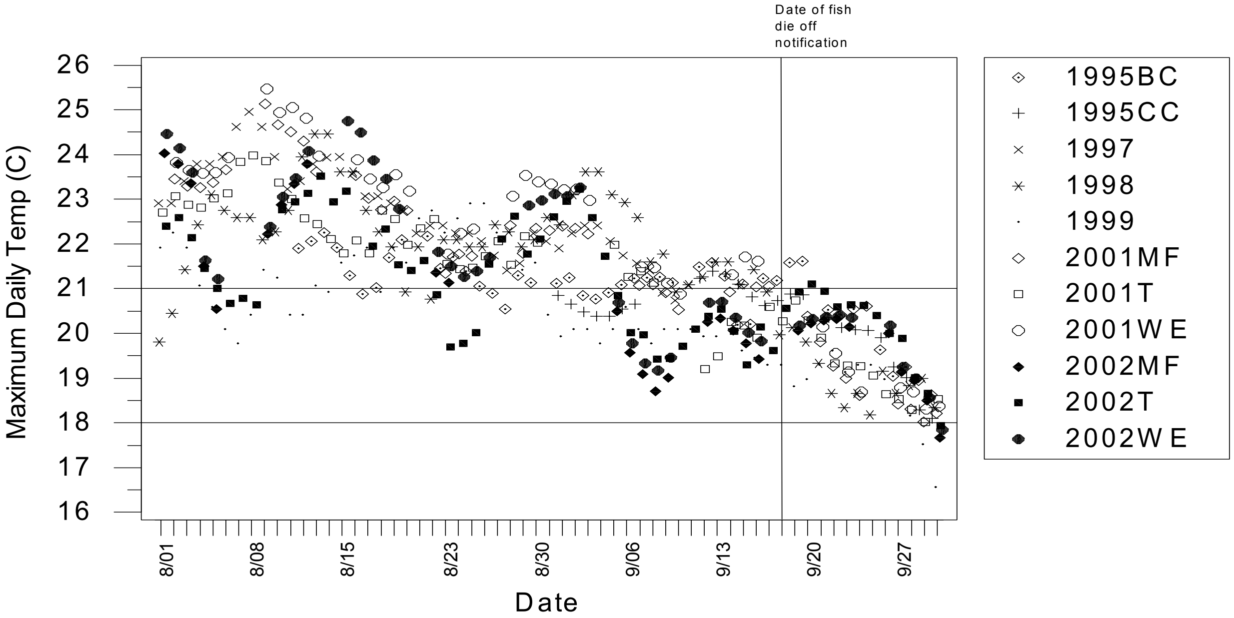

Figure 15. Maximum daily water temperatures measured at the Weitchpec (2001WE and 2002WE, RM 43.5), Martin's Ferry (2001MF and 2002MF, RM 40.4), Terwer (2001 and 2002, T, RM 6.7), below Blue Creek (1995, BC, RM 16.4), below Coon Creek (1995, CC, RM 35.9), below confluence with Omagar Creek (1997-1999, RM 10.5) using Hydrolab® datasondes or Hobo® tidbits (1997-99). Recommended EPA criteria for migrating salmonids (21°C) and reduction of probability of severe disease outbreak (18 °C) are depicted (EPA, 2002).

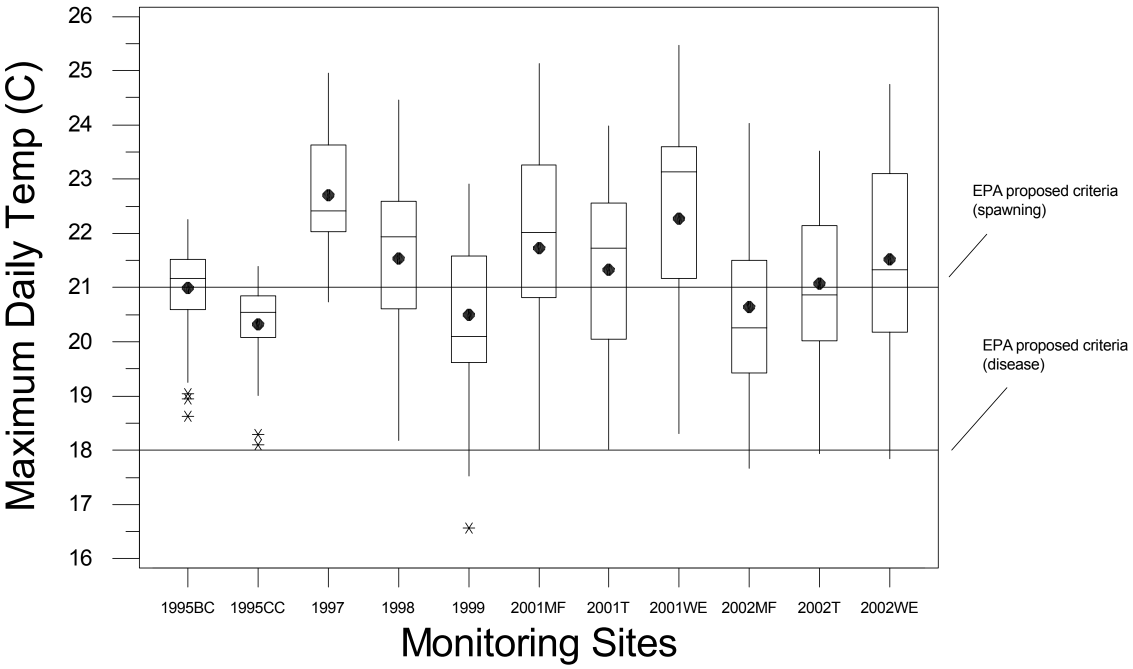

Figure 16. Box and means plot of August and September maximum daily water temperatures measured at the Weitchpec (2001WE and 2002WE, RM 43.5), Martin's Ferry (2001MF and 2002MF, RM 40.4), Terwer (2001 and 2002, T, RM 6.7), below Blue Creek (1995, BC, RM 16.4), below Coon Creek (1995, CC, RM 35.9), and Omagar Creek (1997-1999, RM 10.5) using Hydrolab® datasondes or Hobo® tidbits (1997-1999). Horizontal bar within box is the median; box is 25th and 75th percentiles; vertical line is remaining non-extreme values; * denotes extreme values; • denotes mean. Proposed Region 10 EPA criteria depicted at 21 °C (spawning migration) and 18 °C (reduction in disease).

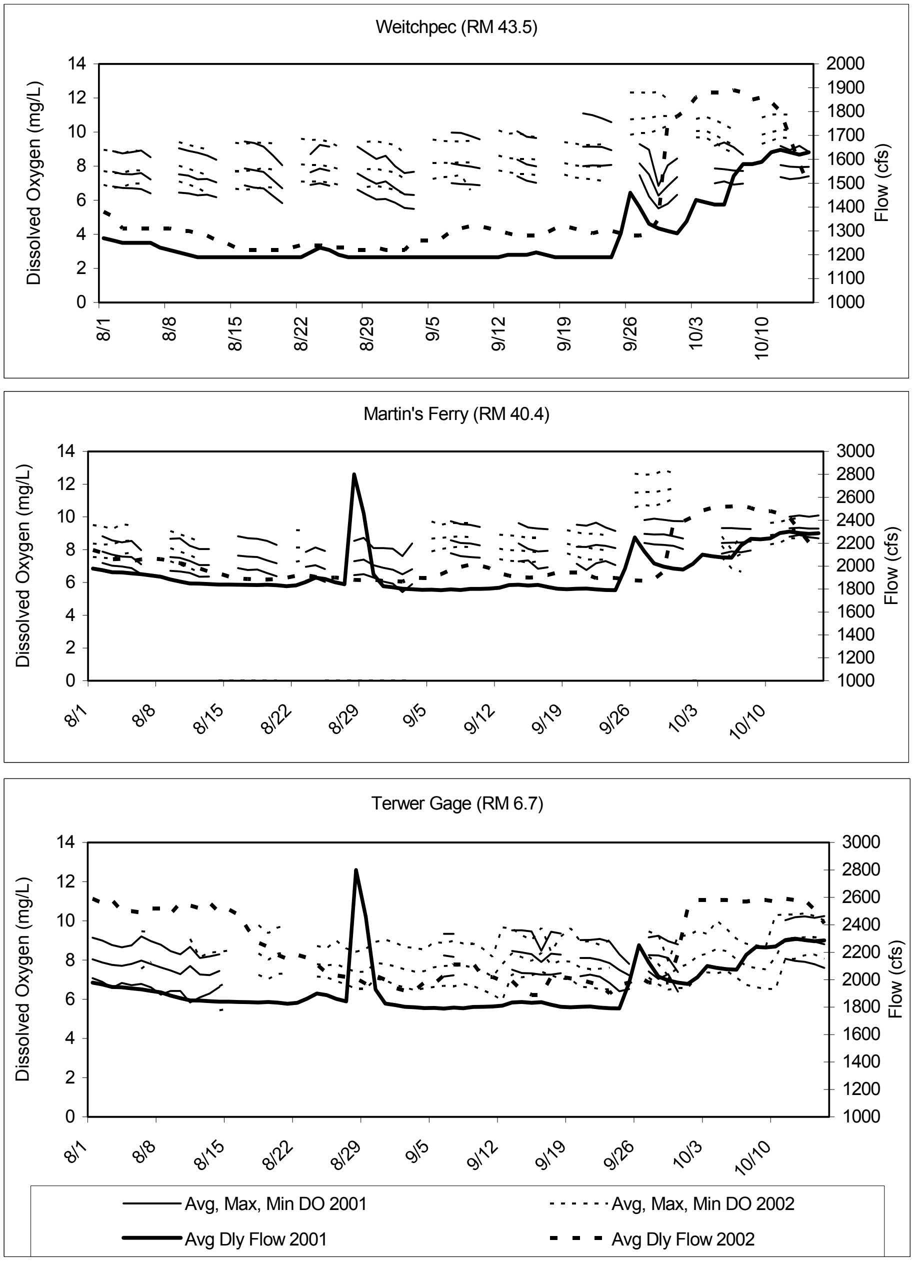

Figure 17. Daily average, maximum, and minimum dissolved oxygen and average daily discharge recorded at the Weitchpec (RM 43.5), Martin's Ferry (RM 40.4) and Terwer (Klamath RM 6.7) on the Klamath River during May to October in 2001 and 2002 using Hydrolab® datasondes. Discharges derived from USGS gage sites at Orleans (RM 59.2), Hoopa/Orleans (Klamath RM 43.5 + Trinity RM 12.4), and Terwer gages respectively.

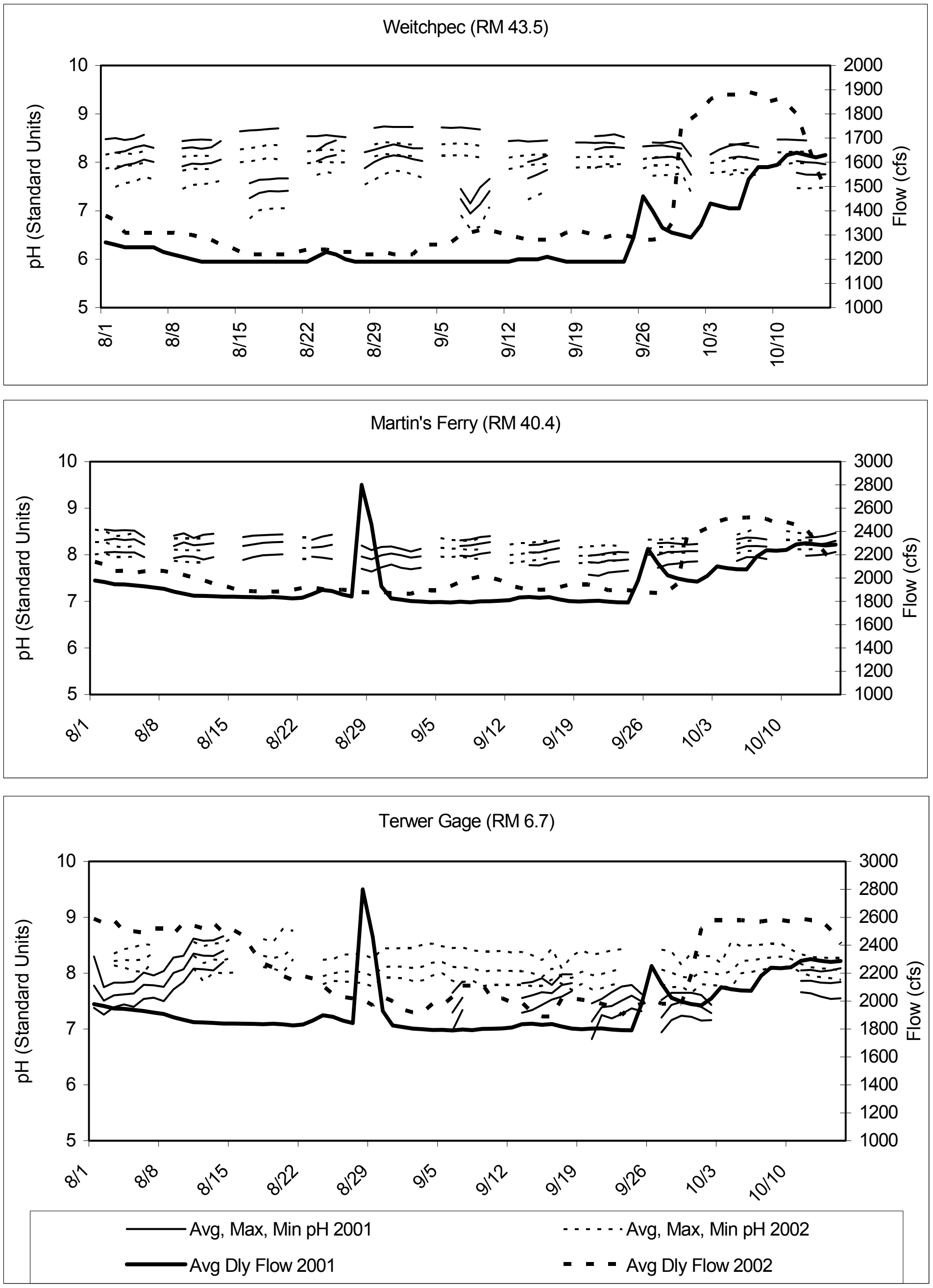

Figure 18. Daily average, maximum, and minimum pH and average daily discharge recorded at the Weitchpec (RM 43.5), Martin's Ferry (RM 40.4) and Terwer (Klamath RM 6.7) during May to October in 2001 and 2002 using Hydrolab® datasondes. Discharges derived from USGS gage sites at Orleans (RM 59.2) , Hoopa/Orleans (Klamath RM 43.5 + Trinity RM 12.4), and Terwer gages respectively.

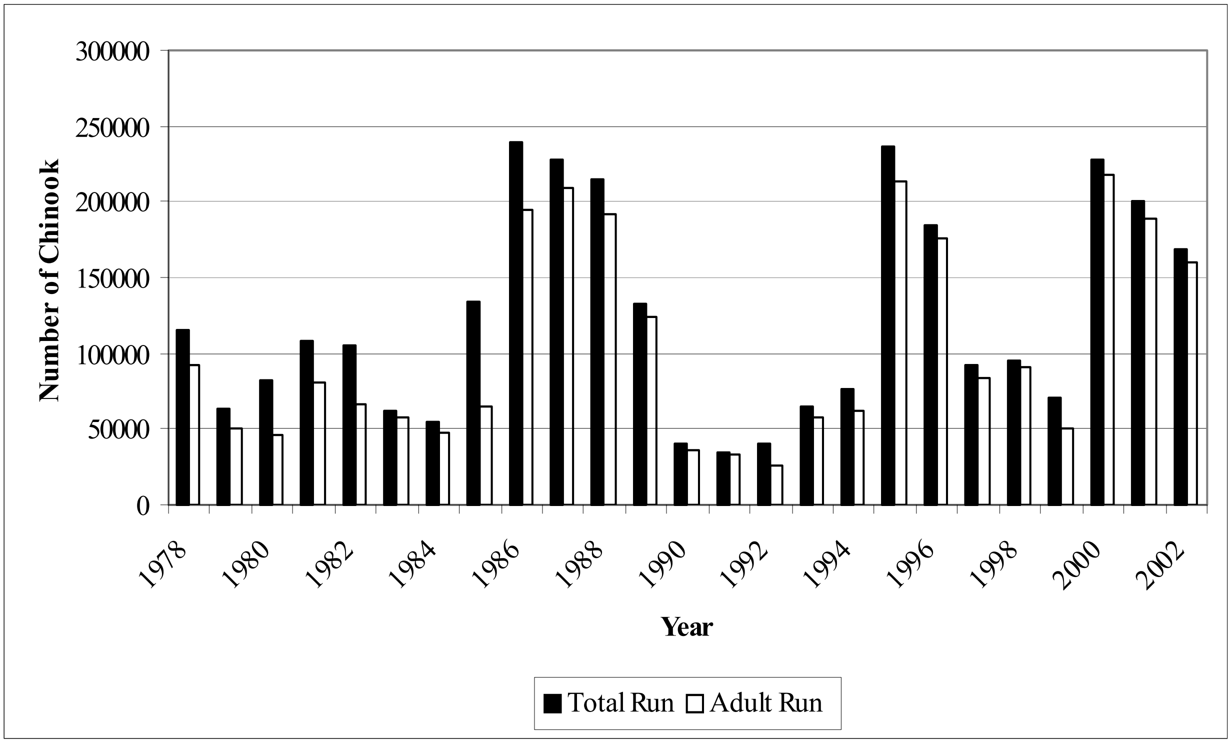

Figure 19. Total and adult in-river Chinook run during 1978 through 2002. Run size data compiled from CDFG megatable and KRTAT records (CDFG 2003a). The 2002 run size may be biased low due to conservative fish die-off number estimates.

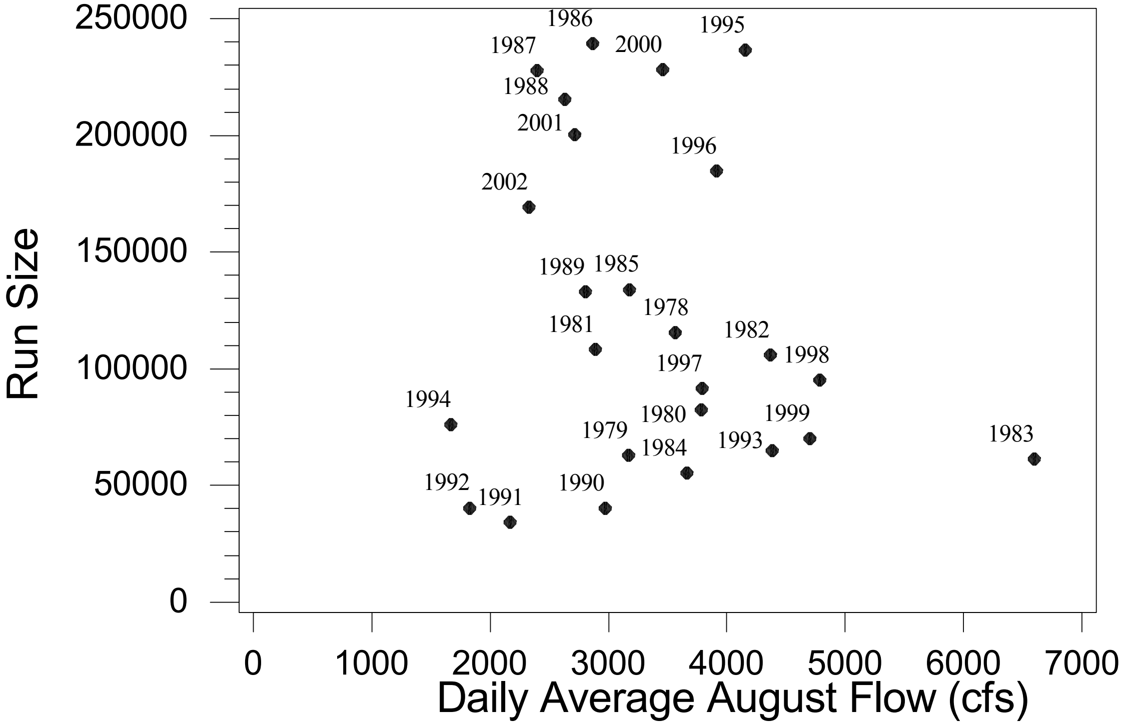

Figure 20. Relationship between total in-river Chinook run size and daily average August discharges measured at the Terwer gage during 1978 through 2002. Run size data compiled from CDFG megatable and KRTAT records (CDFG 2003a). Discharges during 1996 and 1997 were estimated from up river discharges using the following equation: Terwer gage discharge = - 171 + 1.33 (Hoopa gage discharge) + 1.36 (Orleans gage discharge), r^2 = 92.9. The 2002 run size may be biased low due to conservative fish die-off number estimates.

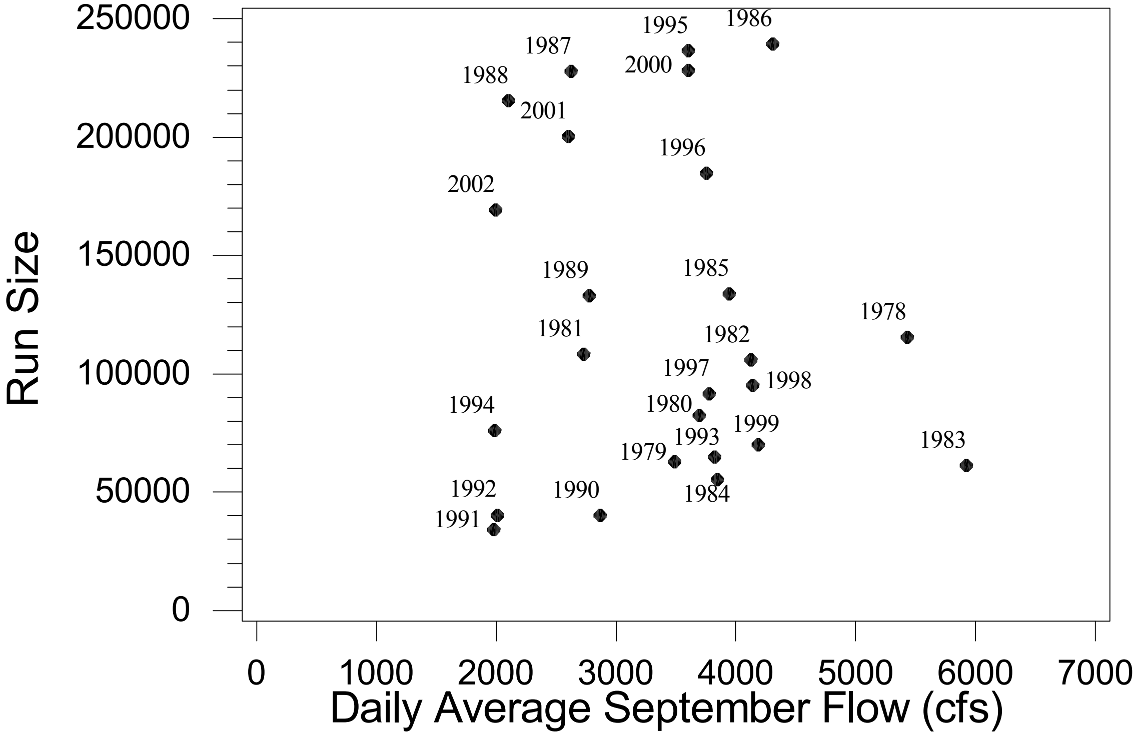

Figure 21. Relationship between total in-river Chinook run size and daily average September discharges at the Terwer gage during 1978 through 2002. Run size data compiled from CDFG megatable and KRTAT records (CDFG 2003a). Discharges during 1996 and 1997 were estimated from up river discharges using the following equation: Terwer gage discharge = - 123 + 1.12 (Hoopa gage discharge) + (1.39 Orleans gage discharge), $r^2 = 88$. The 2002 run size may be biased low due to conservative fish die-off number estimates.

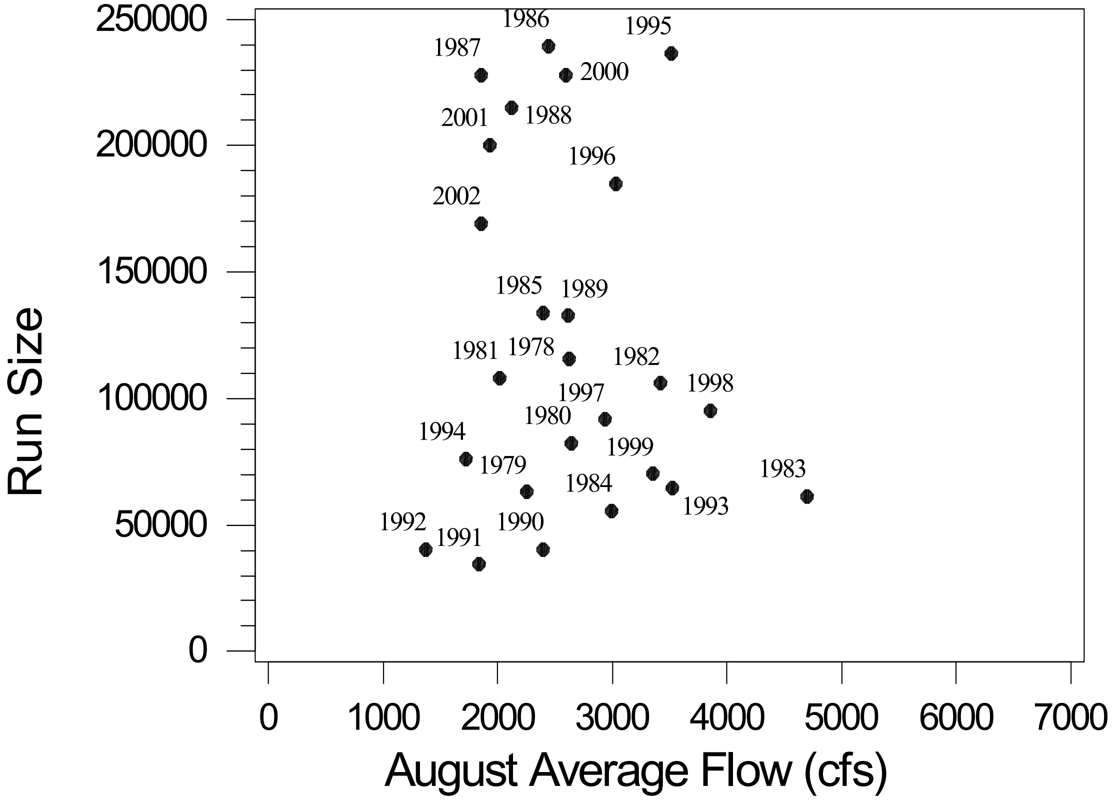

Figure 22. Relationship between total in-river Chinook run size and combined August average discharges measured at the Hoopa/Orleans gages during 1978 through 2002. Run size data compiled from CDFG megatable and KRTAT records (CDFG 2003a). The 2002 run size may be biased low due to conservative fish die-off number estimates.

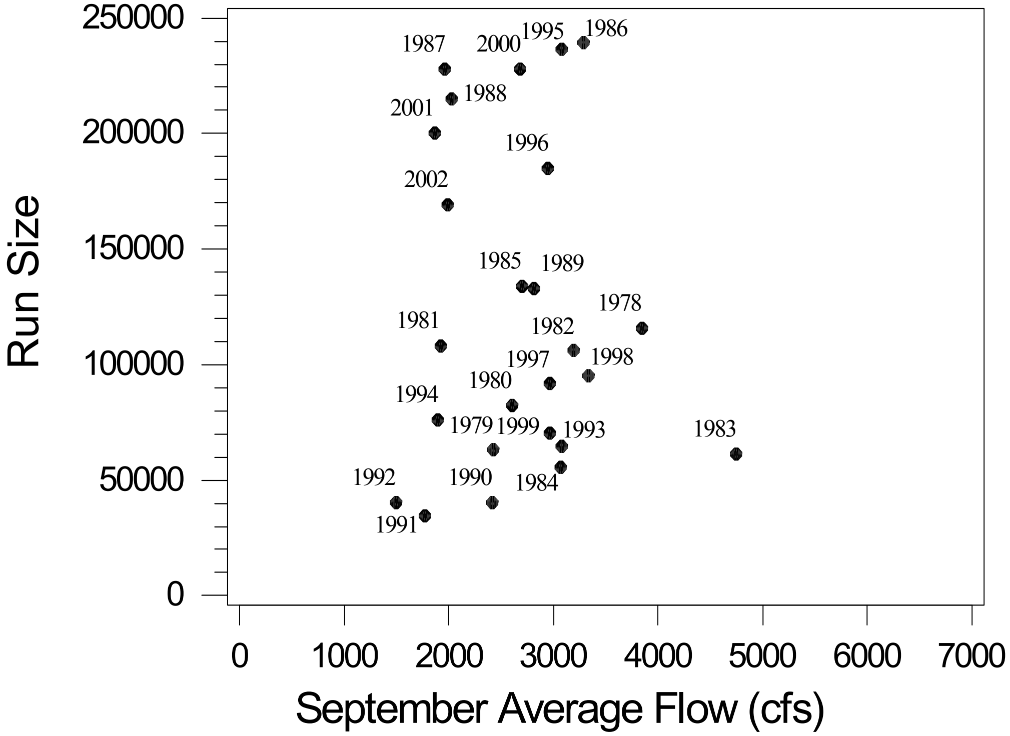

Figure 23. Relationship between total in-river Chinook run size and combined September average discharges measured at the Hoopa/Orleans gages during 1978 through 2002. Run size data compiled from CDFG megatable and KRTAT records (CDFG 2003a). Orleans gage average discharges were adjusted by deleting data from September 28-31, 2002, which removes the influence of the pulse discharge. The 2002 run size may be biased low due to conservative fish die-off number estimates.

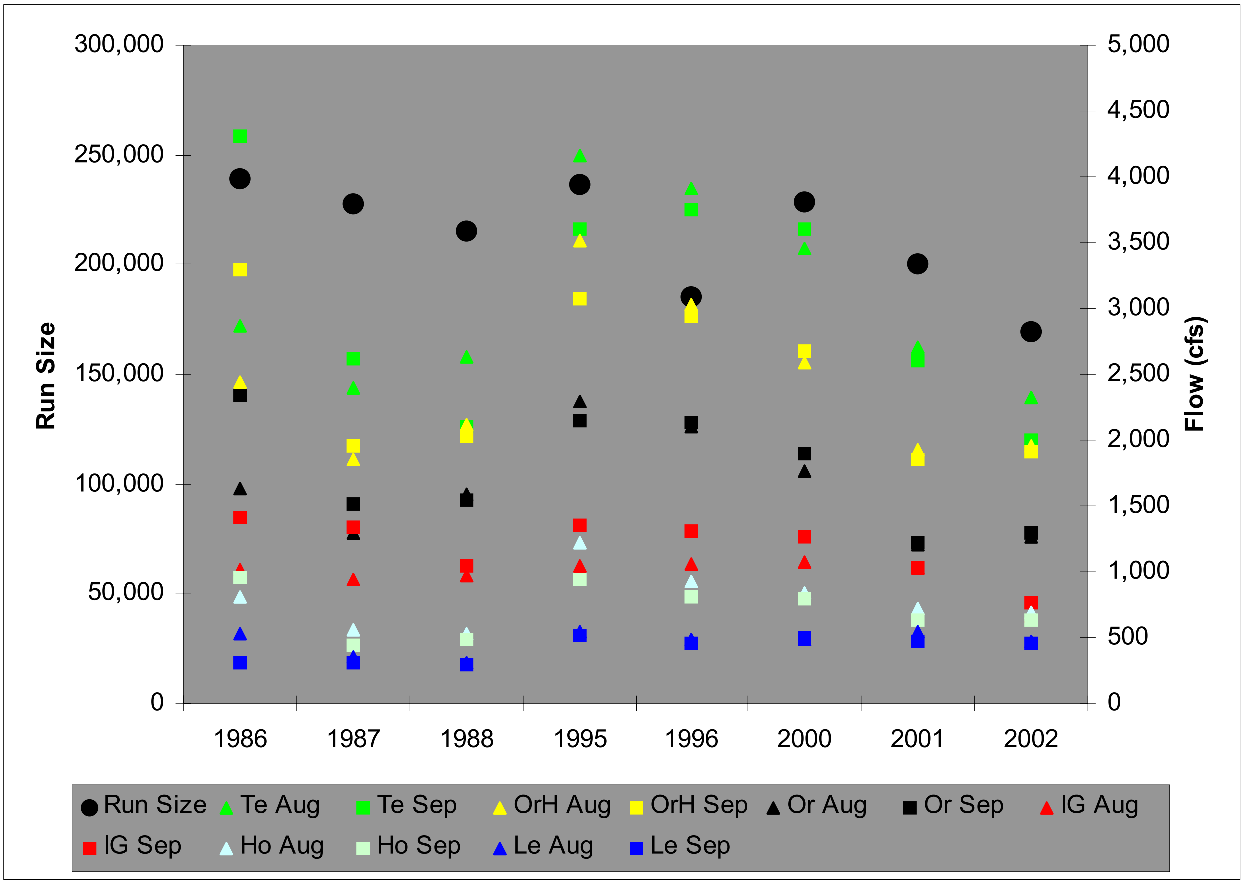

Figure 24. Relationship among the eight highest total in-river Chinook run sizes and August and September discharges measured at Lewiston (Le), Hoopa (Ho), Iron Gate (IG), Orleans (Or), and Terwer (Te) gages. Combined Hoopa/Orleans (OrH) discharges were also calculated. Run size data was compiled from CDFG megatable (CDFG 2003a). Iron Gate, Orleans, and Hoopa/Orleans average discharges were adjusted by deleting data from the September 2002 pulse discharge. The 2002 run size may be biased low due to conservative fish die-off number estimates.

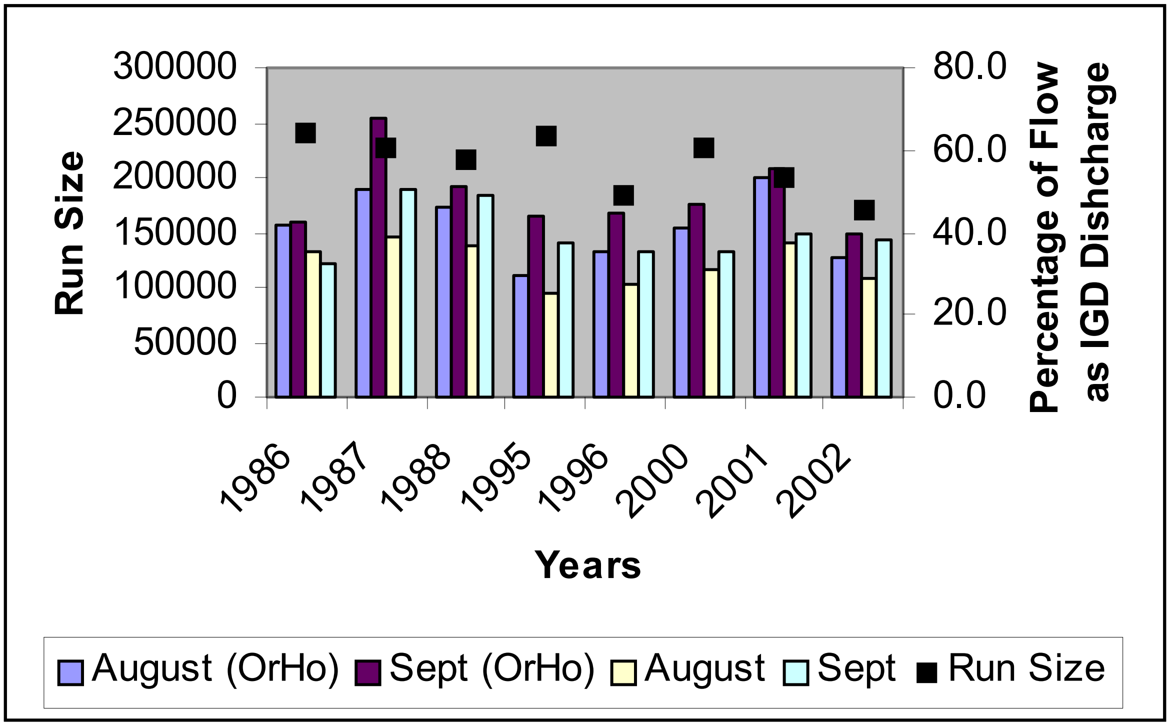

Figure 25. Relationship among the eight highest total in-river Chinook run sizes and August and September percentage of Hoopa/Orleans (OrHo) and Terwer discharges composed of Iron Gate discharges. Run size data was compiled from CDFG megatable (CDFG 2003a). Iron Gate, Orleans, and Hoopa/Orleans average discharges were adjusted by deleting data from the September 2002 pulse discharge. The 2002 run size may be biased low due to conservative fish die-off number estimates.

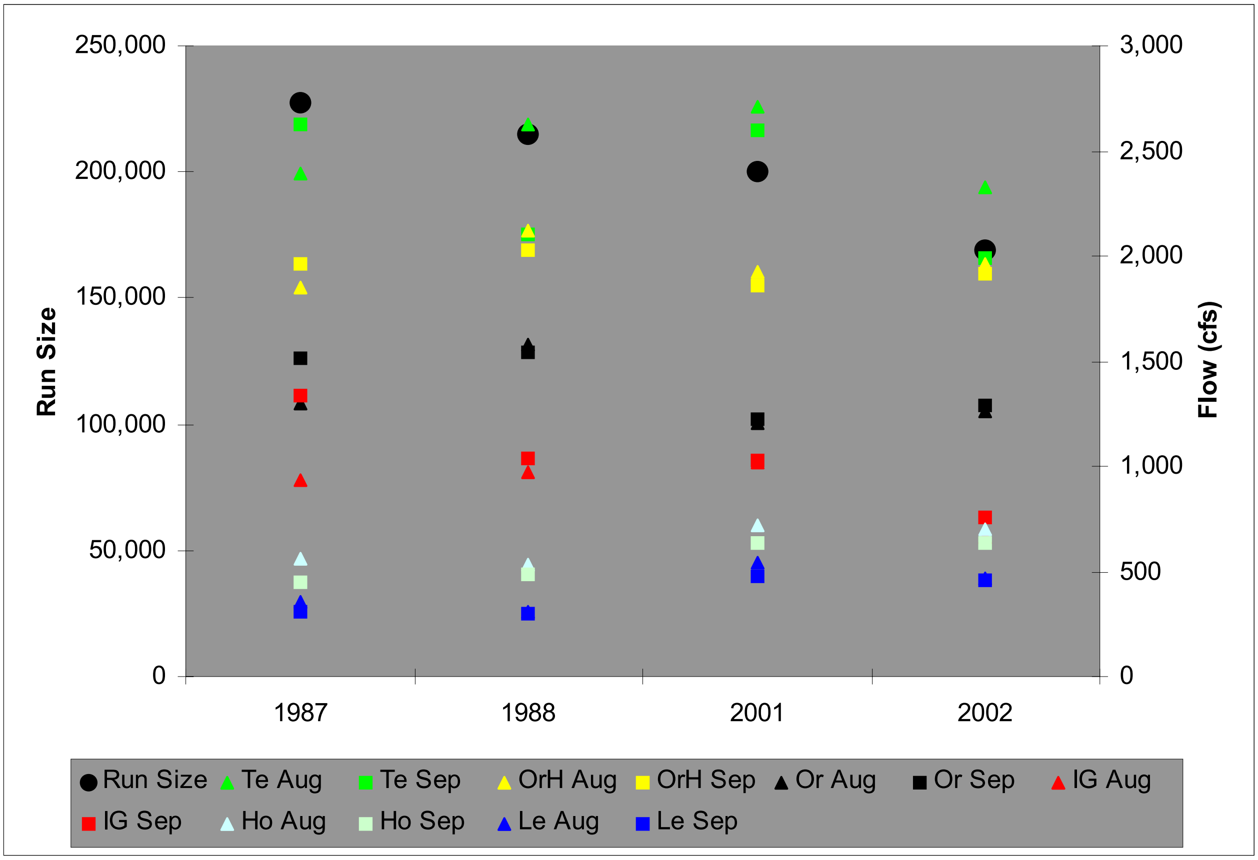

Figure 26. Relationship among the four years with the lowest flows and high total in-river Chinook run sizes and August and September discharges measured at Lewiston (Le), Hoopa (Ho), Iron Gate (IG), Orleans (Or), and Terwer (Te) gages. Combined Orleans and Hoopa (OrH) discharges were also calculated. Run size data was compiled from CDFG megatable (CDFG 2003a). Iron Gate, Orleans, and combined Orleans and Hoopa average discharges were adjusted by deleting data from the September 2002 pulse discharge. The 2002 run size may be biased low due to conservative fish die-off number estimates.

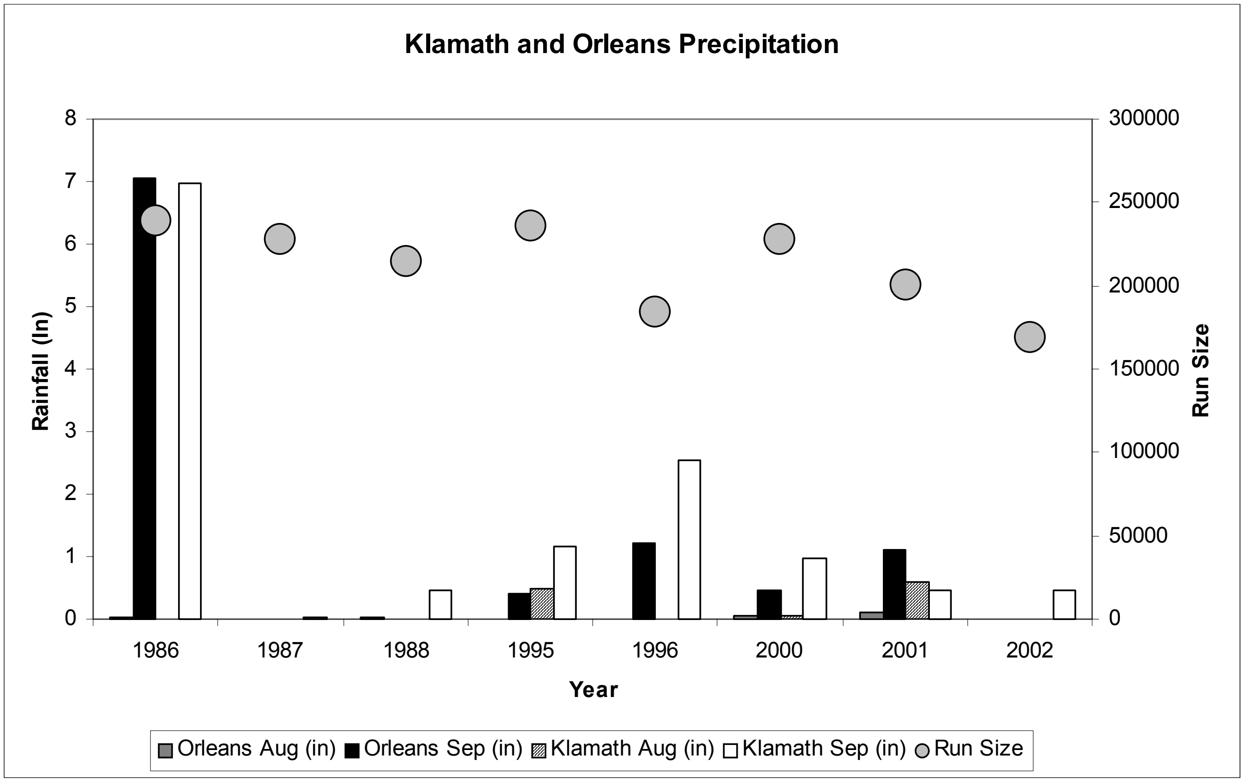

Figure 27. Comparison of precipitation measured at Klamath and Orleans during August and September in 2002 and years with larger total runs of Chinook. The 2002 run size may be biased low due to conservative fish die-off number estimates.

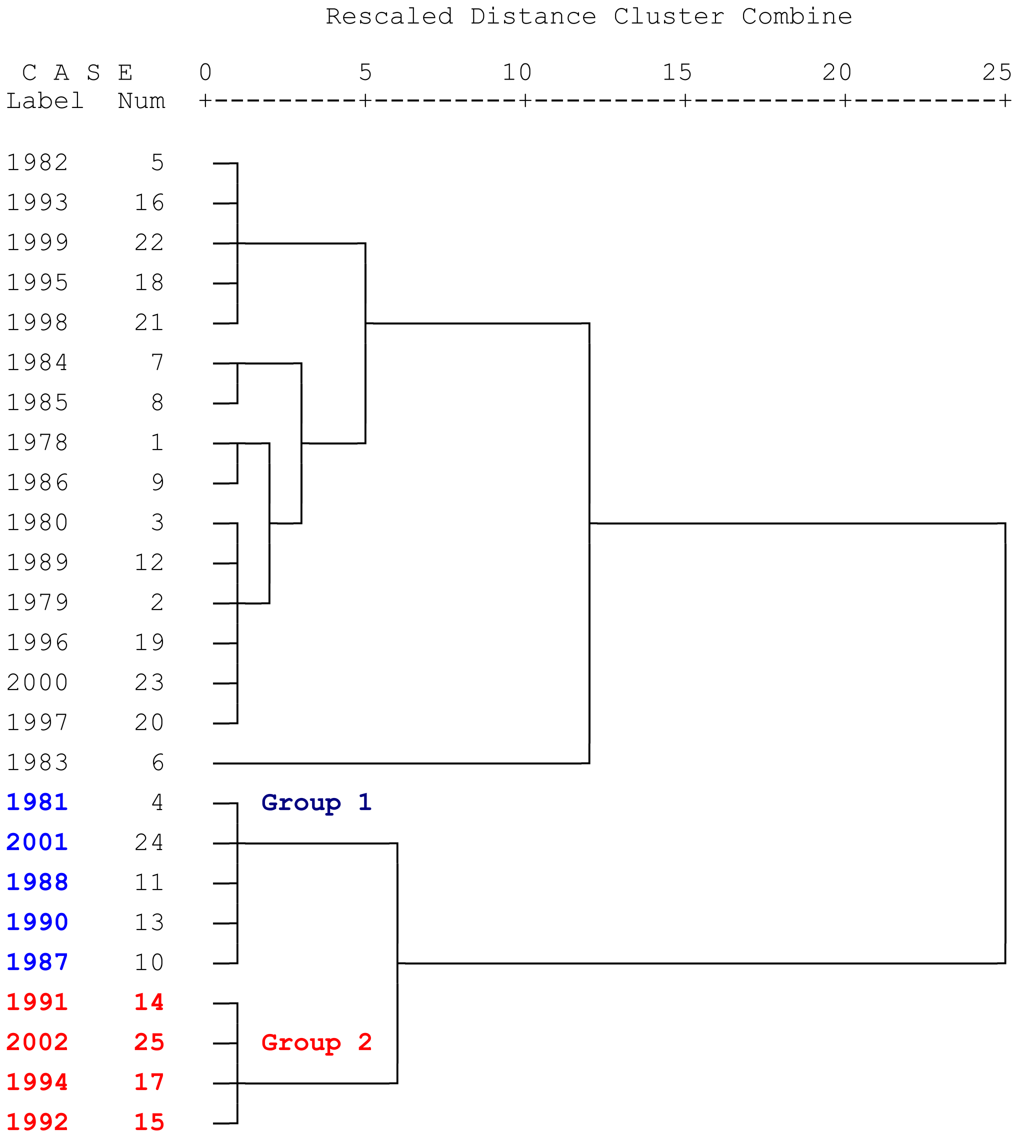

Figure. 28. Dendrogram produced from cluster analysis showing classification of various years. Ward's clustering algorithm and squared Euclidean distance were used. Variables included August and September average discharges at Scott River, Klamath River at Iron Gate Dam, Shasta River, Salmon River, and the Trinity River at Hoopa. September Iron Gate discharges were adjusted for pulse discharge release from Iron Gate on 9-27-02.

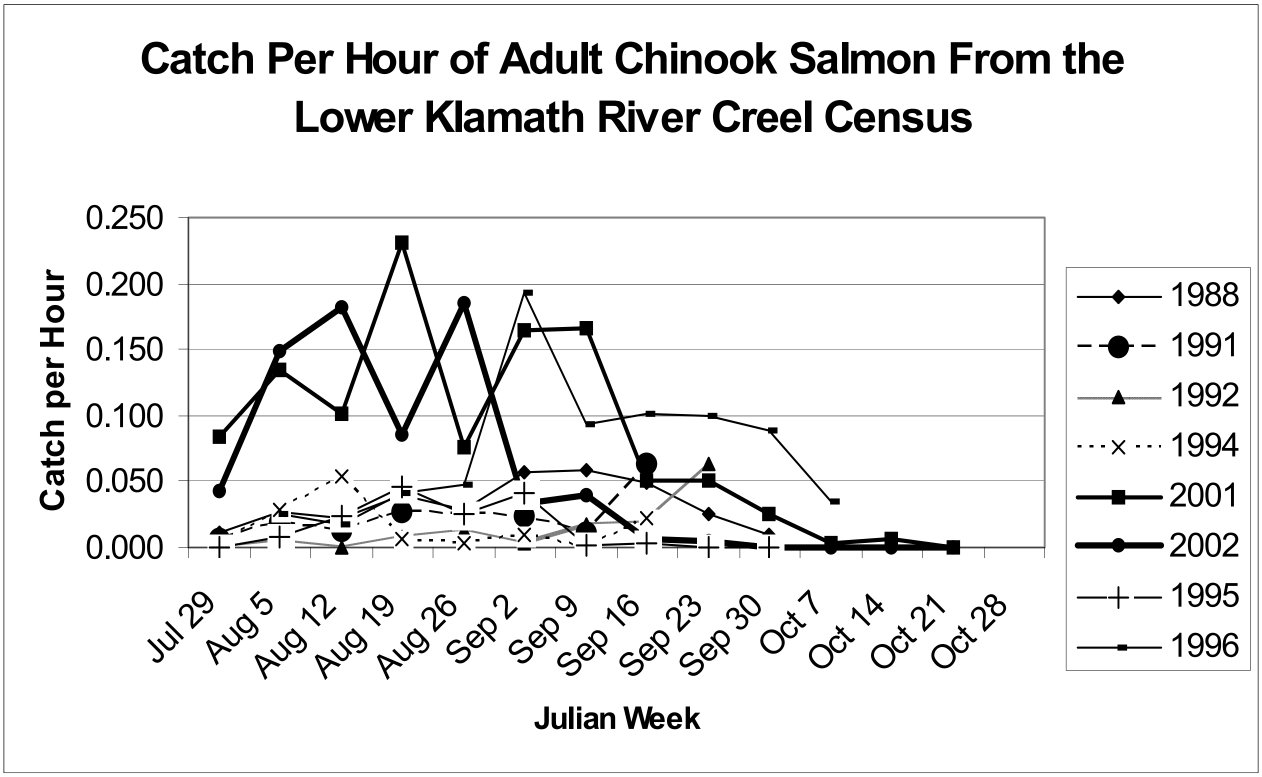

Figure 29. Comparison of CDFG lower Klamath River data recreational creel catch per unit effort for 2002 (group 2), 2001 (Group 1), 1988 (Group 1), 1992 (Group 2), 1991 (Group 2), 1994 (Group 2), 1995, and 1996. Data Source: CDFG (2003b).

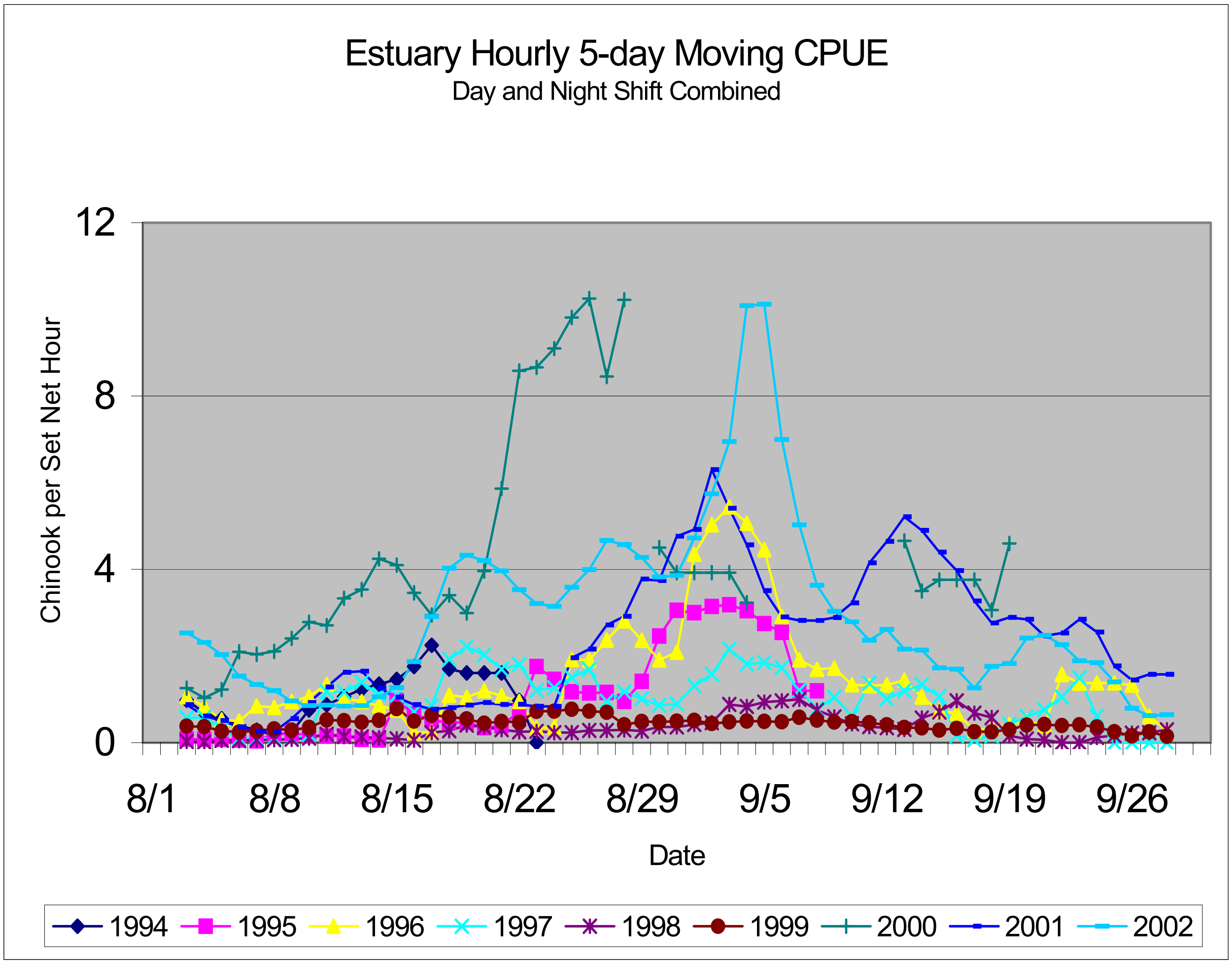

Figure 30. Comparison of tribal net harvest catch per unit effort for 1994-2002 in the lower Klamath River and estuary for the August 1 - September 28 time period, except for the periods that the fishery was closed during 1994, 1995, and 2000.

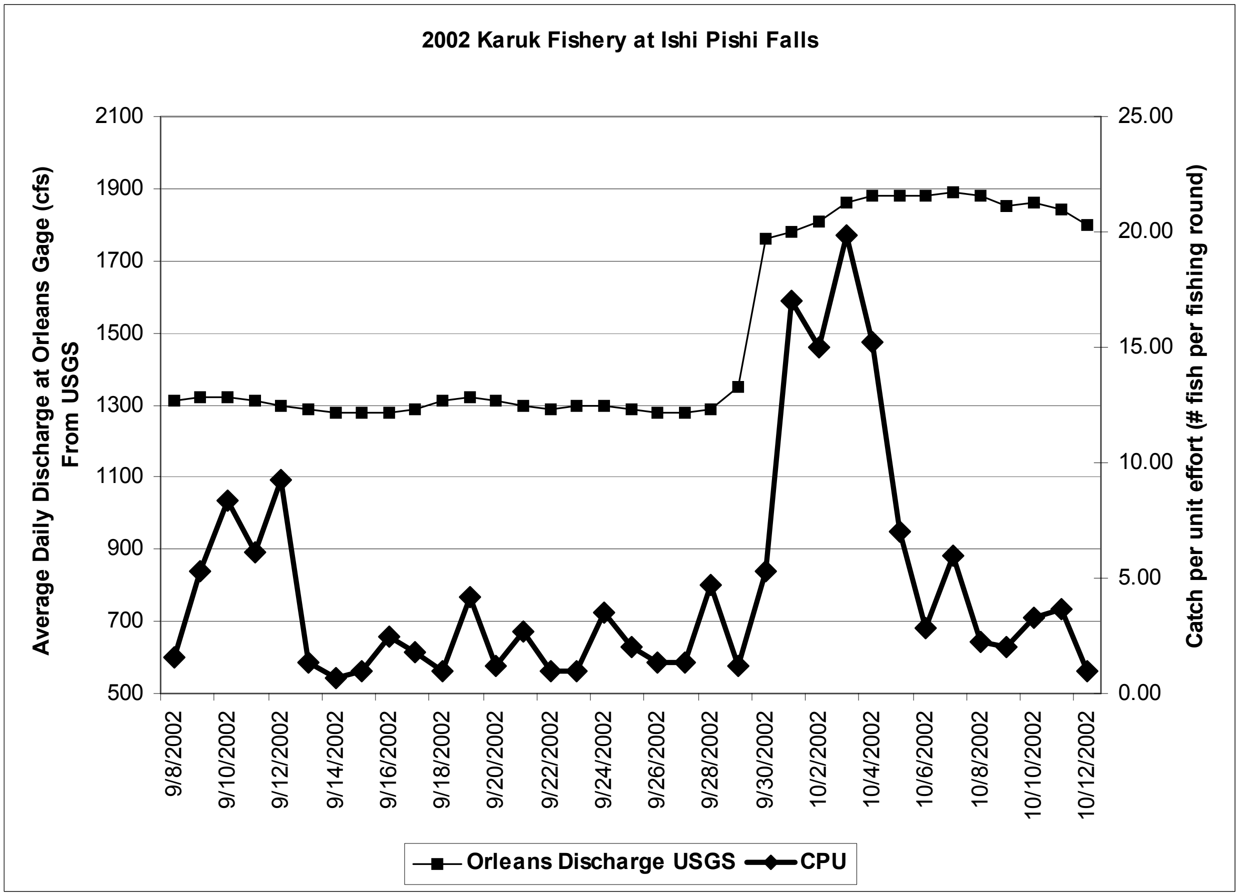

Figure 31. Karuk Tribal Fishery catch per unit effort data collected at Ishi Pishi falls (RM 66.5) during 2002. Daily average discharge data obtained from USGS Orleans station.

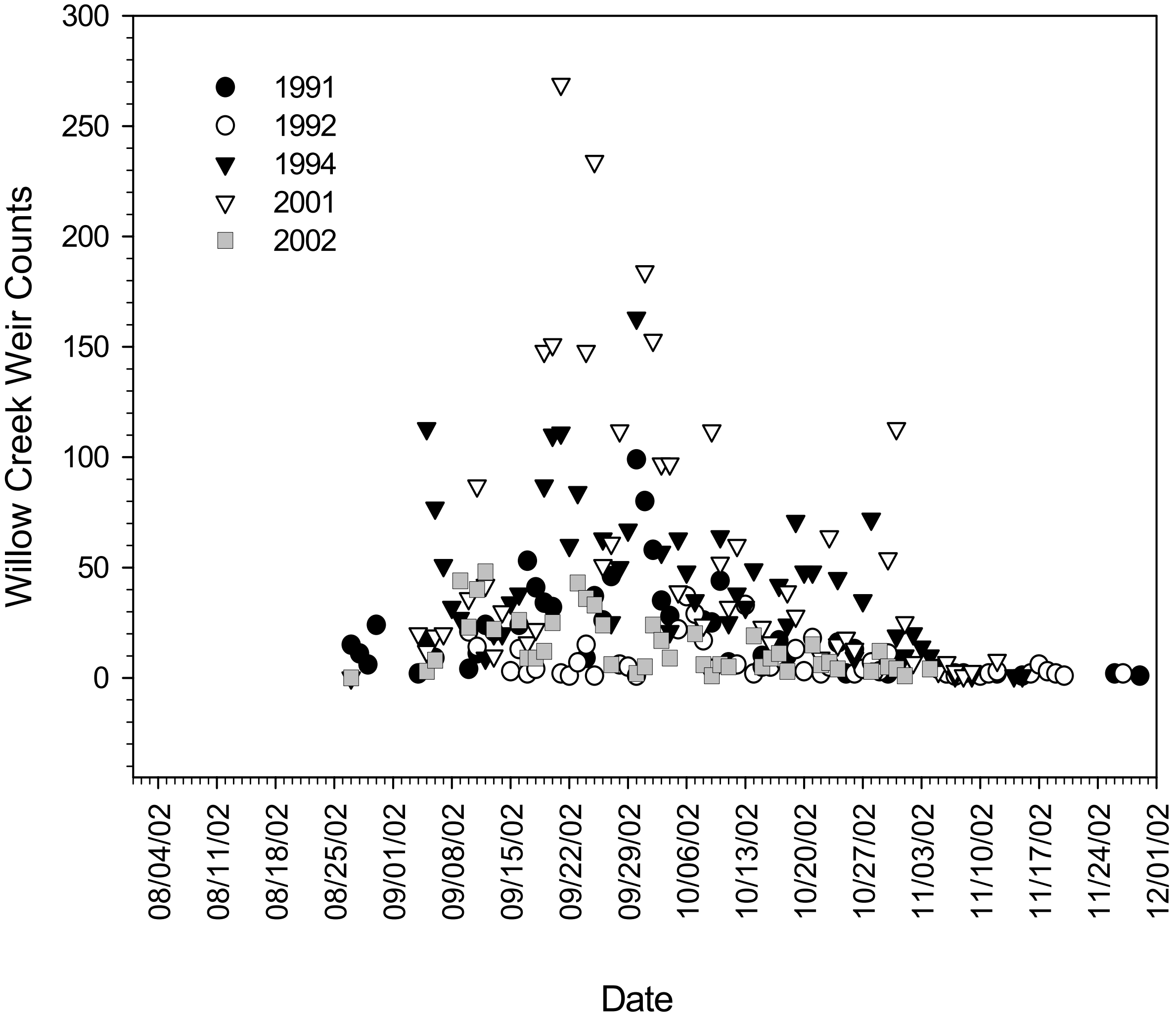

Figure 32. Willow Creek weir counts of migrating salmon during 2002, 2001 and the four lowest years of record based on September discharges at Klamath (Terwer). Data source: CDFG (2003b).

Table 1. Summary of green sturgeon movement obtained from preliminary combined radiotelemetry and acoustic monitoring data.

Green Sturgeon	Disposition
151.5	Tagged in May at Coons Creek fall, rest of summer at Moore Rock (RM 26.7), entered estuary 11-10-02, left 11-12-02
151.172	Tagged in May in estuary, last seen above Cirliah Creek on 11-19-02
151.193	Tagged in May Below Coon Creek, found below falls through 11/8/02, final date tracked
151.251	Tagged below Bens Creek in May, found near Ah Pah Creek from August through Oct 3, 2002, last seen at Requa on 10-13-02
151.273	Tagged in May near Bens Creek. Last observed at Moores Rock on 9-27-02
151.291	Tagged at Moores Rock in May. Found at Johnson's Bar from 6/4/02 to 11/8/02. Last seen in estuary on 11/16/02
151.313	Tagged in May at Coon Creeks fall. From 6/25 to 10/3/02 at Coon Creeks fall. Last seen in estaury on 11/9/02
151.353	White Sturgeon: Tagged in May near Mettah Creek, From 9/5/ to 10/18/02 found above Johnson Creek. Last seen in estuary on 11/8/02
151.375	Tagged in June at Coons Creek fall. From 6/8 to 11/8 found below Coon Creek. Last seen in estaury on 11/10/02
151.391	Tagged in May Below Coon Creek, found at various locations in lower river, last seen in estuary on 11/10/02.

Table 2. Comparison of discharge regimes at various gage sites for the period of record during August and September. Orleans Hoopa is the combined discharge from the Hoopa and Orleans gage.

Gage **Month**	**IGD** **Aug**	**IGD** **Sept**	**Orleans** **Aug**	**Orleans** **Sep**	**Lewiston** **Aug**	**Lewiston** **Sep**	**Hoopa** **Aug**	**Hoopa** **Sep**	**Terwer** **Aug**	**Terwer** **Sept**
Mean (cfs)	976	1281	2045	2191	261	234	701	588	4898	3231
Median (cfs)	1030	1330	1968	2142	189	197	662	565	4064	2968
Minimum (cfs)	398	538	549	790	41	41	249	213	2134	1441
Maximum (cfs)	1208	2052	3666	3807	628	556	1681	1308	18950	6599
Years of Operation	1961-02	1961-02	1928-02	1928-02	1912-02	1912-02	1912-13, 1917-18, 1932-02	1912-13, 1917-18, 1932-02	1911-26, 1951-02	1911-26, 1951-02
Years of Record	42	42	75	75	91	91	75	75	66	66
2002 Flow[1]	666	813	1263	1305	471	454	696	631	2327	1993
2002 Percentile	7.3	7.3	9.4	7	85.5	90	55	65	15.30	4.6
2002 Rank (high =1 to low)	39	39	68	70	14	10	34	27	56	63
3 lowest flow years and rank	1991 (40)	1991 (40)	1994 (73)	1991 (73)	1920 (89)	1929 (89)	1977 (73)	1939 (73)	1994 (64)	1994 (64)
	1994 (41)	1973 (41)	1992 (74)	1931 (75)	1931 (90)	1931 (90)	1939 (74)	1932 (74)	1918 (65)	1991 (65)
	1992 (42)	1992 (42)	1931 (75)	1992 (75)	1924 (91)	1924 (91)	1934 (75)	1934 (75)	1977 (66)	1918 (66)
Estimated dry year un-impaired flows (cfs)[2]	1141	1174								

Gage **Month**	**Salmon** **Aug**	**Salmon** **Sept**	**Scott** **Aug**	**Scott** **Sep**	**Shasta** **Aug**	**Shasta** **Sep**	**Orlean Hoopa** **Aug**	**Orleans Hoopa** **Sep**
Mean (cfs)	260	200	63	53	38	74	2776	2790
Median (cfs)	237	192	60	49	33	73	2619	2697
Minimum (cfs)	82	80	6	4	8	27	1353	1489
Maximum (cfs)	839	528	269	228	111	182	5031	4750
Years of Operation	1912-15, 1928-02	1912-15, 1928-02	1942-02	1942-02	1934-02	1934-02	1932-02	1932-02
Years of Record	79	79	61	61	66	66	71	71
2002 Flow[1]	171	125	15	12	24	32	1960	1936
2002 Percentile	18.0	12	13.3	10	32	6.1	11.4	8.5
2002 Rank (high =1 to low)	65	70	52	55	45	62	63	65
3 lowest flow years and rank	1977 (77)	1992 (77)	1981 (59)	1981(59)	1955 (64)	1977 (64)	1994 (69)	2001 (69)
	2000 (78)	1931 (78)	1994 (60)	1994 (60)	1981 (65)	2001 (65)	1992 (70)	1991 (70)
	1931 (79)	2001 (79)	2001 (61)	2001 (61)	1939 (66)	1981 (66)	1977 (71)	1992 (71)

[1] Removing the additional pulse flow on September 27, 2002 from IGD, reduces September IGD flows to 760; Orleans flows to 1287; Klamath flows to 1987, Orlean-Hoopa flows to 1918.

[2] Hardy and Addley 2001.

Table 3. Results of water quality monitoring for water temperature, specific conductance, pH, dissolved oxygen, chlorophyll-a, and ammonia nitrogen during 2001 and 2002 in the lower Klamath River.

Station	Type	Date	Time	RM	Water Temp C	Sp. Cond. (uMHOs)	pH	DO (mg/l)	Chlorophyll-a (ug/l)	Ammonia-N (mg/l)
2001 Data										
Martin's Ferry	MAIN	08/07	1045	40.4	22.48	158	8.29	8.2	4.5	< 0.1
Terwer Gage	MAIN	08/07	750	6.7	22.4	159	8.18	7.45	5.3	< 0.1
Martin's Ferry	MAIN	08/21	929	40.4	21.3	154	8.29	7.81	1.3	< 0.1
Terwer Gage	MAIN	08/21	703	6.7	20.9	157	8.33	7.51	2.9	< 0.1
Martin's Ferry	MAIN	09/04	955	40.4	21.08	160	8.25	8.28	0.3	< 0.1
Terwer Gage	MAIN	09/04	720	6.7	21.1	160	8.05	8.6	2.1	< 0.1
Martin's Ferry	MAIN	09/18	1025	40.4	20.12	163	8.09	8.58	1.6	< 0.1
Terwer Gage	MAIN	09/18	730	6.7	19.48	164	8.2	7.97	1.1	< 0.1
Martin's Ferry	MAIN	10/02	1035	40.4	17.65	188	7.97	9.76	1.1	< 0.1
Terwer Gage	MAIN	10/02	750	6.7	17.91	192	7.89	8.58	1.1	< 0.1
KR @ WEITHCPEC	MAIN	10/02	1140	43.6	17.5	207	7.95	9.74	1.1	< 0.1
Martin's Ferry	MAIN	10/16	1110	40.4	14.83	176	8.03	9.78	1.6	< 0.1
Terwer Gage	MAIN	10/16	750	6.7	15.6	177	7.99	8.78	2.1	< 0.1
KR @ WEITHCPEC	MAIN	10/16	1120	43.6	15.04	187	8.1	9.72	1.8	0.14
Martin's Ferry	MAIN	10/30	1121	40.4	13.05	184	7.85	10.19	2.4	0.1
Terwer Gage	MAIN	10/30	755	6.7	13.31	185	7.81	9.32	1.9	< 0.05
KR @ WEITHCPEC	MAIN	10/30	1217	43.6	13.23	189	8.15	10.36	3.6	0.18
Average					18.06	174.12	8.08	8.86	2.11	0.10
Maximum					22.48	207.00	8.33	10.36	5.30	0.18
Minimum					13.05	154.00	7.81	7.45	0.30	0.05
2002 Data										
Klamath Estuary	MAIN	07/30	656	0.1	21.35	472	8.48	8.4	0.5	< 0.1
Martin's Ferry	MAIN	07/30	1005	40.4	22.45	173	8.19	7.99	1.4	< 0.1
Terwer Gage	MAIN	07/30	750	6.7	21.39	169	8.22	7.57	1.1	< 0.1
KR @ WEITHCPEC	MAIN	07/30	1200	43.5	22.87	188	8.37	8.94	1.6	< 0.1
Klamath Estuary	MAIN	08/13	730	0.1	21.9	411.8		7.96	< 0.1	< 0.1
Martin's Ferry	MAIN	08/15	1145	40.4	23.57	166	8.21	8.42	< 0.1	< 0.1
Terwer Gage	MAIN	08/15	757	6.7	21.54	166	8.14	7.07	0.3	< 0.1
KR @ WEITHCPEC	MAIN	08/15	1059	43.5	23.6	188	8.49	8.14	1.1	< 0.1
Klamath Estuary	MAIN	08/27	926	0.1	20.3	462.6		7.41	< 0.1	< 0.1
Martin's Ferry	MAIN	08/27	925	40.4	20.83	161	8.05	7.85	0.3	< 0.1
Terwer Gage	MAIN	08/27	735	6.7	20.23	175	7.97	7.58	1.1	0.1
KR @ WEITHCPEC	MAIN	08/27	1010	43.5	21.14	176	8.02	8.56	3.7	< 0.1
Klamath Estuary	MAIN	09/10	707	0.1	18.66	933	8.26	9.59	1.6	< 0.1
Martin's Ferry	MAIN	09/10	1005	40.4	18.39	164	7.95	8.68	1.9	NA
Terwer Gage	MAIN	09/10	812	6.7	18.29	167	7.82	7.99	1.9	< 0.1
KR @ WEITHCPEC	MAIN	09/10	1056	43.5	18.56	179	7.92	9.31	2.9	< 0.1
Above Blue Creek	MAIN	09/20	1600	16.2	21.07	168	8.39	10.06	NA	< 0.1
Below Blue Creek	MAIN	09/20	1615	16.6	21	170	8.36	9.81	NA	< 0.1
Below Johnson Crk	MAIN	09/20	1130	24.3	19.48	172	8.18	8.99	NA	< 0.1
Below Pecwan Crk	MAIN	09/20	1010	25.3	17.75	147	7.65	8.53	NA	< 0.1
River Mile 20	MAIN	09/20	1430	19.9	20.12	174	8.19	9.68	NA	< 0.1
Boat Ramp Klamath [1]	MAIN	09/20	900	5.9	18.76	171	7.72	7.63	NA	<0.1
Below Tectah Crk	MAIN	09/20	1345	22.1	20.28	169	8.28	9.68	NA	NA
Klamath Estuary	MAIN	09/24	715	0.1	19.4	454	8.18	9.52	0.1	< 0.1
Martin's Ferry	MAIN	09/24	940	40.4	19.47	170	7.98	8.03	2.9	0.1
Above Pecwan Crk	MAIN	09/24	1110	25.5	19.7	148.5	8.89	9.1	NA	0.2
Pecwan Creek	TRIB	09/24	1125	25.3	16.1	61.7	8.32	5.78	NA	< 0.1
Below Pecwan Crk	MAIN	09/24	1135	25.1	19.6	149.6	8.39	7.85	NA	< 0.1
Terwer Gage	MAIN	09/24	800	6.7	19.09	171	7.82	7.56	0.8	< 0.1
KR @ WEITHCPEC	MAIN	09/24	1020	43.5	14.47	192	7.98	8.55	< 0.1	< 0.1
Blue Creek	TRIB	09/26	NA	16.4	NA	NA	NA	NA	NA	< 0.1
Downstream B. Creek	MAIN	09/26	NA	16.2	NA	NA	NA	NA	NA	< 0.1
Tectah Creek	TRIB	09/26	NA	22.1	NA	NA	NA	NA	NA	< 0.1
Terwer Gage	MAIN	09/26	NA	6.7	NA	NA	NA	NA	NA	< 0.1
Martin's Ferry	MAIN	09/27	1205	40.4	18.65	175	8.36	8.73	NA	< 0.1
KR @ WEITHCPEC	MAIN	09/27	1255	43.5	18.56	192	8.3	9.1	NA	< 0.1
Martin's Ferry	MAIN	10/01	1110	40.4	16.06	181	8.09	9.31	1.3	< 0.1
Terwer Gage	MAIN	10/01	925	6.7	16.47	176	8.17	8.44	0.5	< 0.1
KR @ WEITHCPEC	MAIN	10/01	1140	43.5	15.99	196	8.08	9.54	0.5	< 0.1
Klamath Estuary	MAIN	10/08	740	0.1	16.89	279	8.38	9.89	0.3	< 0.1
Martin's Ferry	MAIN	10/08	950	40.4	16.17	193	7.92	9.12	NA	< 0.1
Terwer Gage	MAIN	10/08	805	6.7	16.88	191	7.99	8.34	NA	< 0.1
KR @ WEITHCPEC	MAIN	10/08	1010	43.5	16.21	209	8.1	9.36	NA	0.1
Average					19.31	222.08	8.16	8.57	1.09	0.11
Maximum					23.60	933.00	8.89	10.06	3.70	0.20
Minimum					14.47	61.70	7.65	5.78	0.10	0.10

Table 4. Results of water quality monitoring for turbidity (NTU), 5 day biochemical oxygen demand (BOD), nitrate nitrogen (NO3-N), total suspended solids (TSS), total phosphate phosphorus (total-P) and orthophosphate phosphorus (Ortho-P) during 2001 and 2002 in the lower Klamath.

Collection	Type	Date	Time	RM	Turbidity NTU)	5 Day BOD (mg/l)	NO3-N (mg/l)	TSS (mg/l)	Total P (mg/l)	Orthophos phate-P (mg/l)
2001 Data										
Terwer Gage	MAIN	8/7/2001	750	6.7	1.85		< 0.10	2.8	0.15	0.032
Martin's Ferry	MAIN	8/7/2001	1045	40.4	1.40		< 0.10	4.4	0.14	0.038
Terwer Gage	TRIB	8/21/2001	703	6.7	1.38	< 5	< 0.10	2.8	0.11	0.037
Martin's Ferry	MAIN	8/21/2001	929	40.4	0.96	< 5	< 0.10	< 1.0	0.09	0.041
Terwer Gage	MAIN	9/4/2001	720	6.7	2.17	< 5	< 0.10	2.8	0.09	0.065
Martin's Ferry	MAIN	9/4/2001	955	40.4	5.25	< 5	< 0.10	3.6	0.10	0.061
Terwer Gage	MAIN	9/18/2001	730	6.7	0.21		0.10	1.4	0.11	0.041
Martin's Ferry	MAIN	9/18/2001	1025	40.4	0.51		0.16	2.5	0.14	0.062
Terwer Gage	MAIN	10/2/2001	750	6.7	1.15		0.13	3.6	0.12	0.046
Martin's Ferry	MAIN	10/2/2001	1035	40.4	1.10		0.17	1.8	0.18	0.061
KR @ WEITHCPEC	MAIN	10/2/2001	1140	43.6	0.80		0.26	1.6	0.21	0.095
Terwer Gage	MAIN	10/16/2001	750	6.7	0.60		0.34	2.0	0.13	0.060
Martin's Ferry	MAIN	10/16/2001	1110	40.4	0.60		0.41	2.4	0.15	0.074
KR @ WEITHCPEC	MAIN	10/16/2001	1120	43.6	1.07		0.53	3.2	0.21	0.100
Terwer Gage	MAIN	10/30/2001	755	6.7	0.87		0.42	2.2	0.10	0.060
Martin's Ferry	MAIN	10/30/2001	1121	40.4	1.17		0.46	2.4	0.14	0.066
KR @ WEITHCPEC	MAIN	10/30/2001	1217	43.6	1.10		0.55	3.4	0.11	0.090
Average					1.31		0.24	2.6	0.13	0.061
Maximum					5.25		0.55	4.4	0.21	0.100
Minimum					0.21		0.10	1.0	0.09	0.032
2002 Data										
Klamath Estuary	MAIN	7/30/2002	656	0.1			< 0.05	1.8	0.04	0.012
Terwer Gage	MAIN	7/30/2002	750	6.7	0.91		< 0.05	< 1.0	0.03	0.013
Martin's Ferry	MAIN	7/30/2002	1005	40.4	0.49		< 0.05	< 1.0	0.04	0.017
KR @ WEITHCPEC	MAIN	7/30/2002	1200	43.5	0.49		< 0.05	< 1.0	0.06	0.028
Klamath Estuary	MAIN	8/13/2002	730	0.1			< 0.05			
Klamath Estuary	MAIN	8/27/2002	926	0.1			< 0.05	< 1.0	0.07	0.020
Terwer Gage	MAIN	8/27/2002	735	6.7			< 0.05	3.2	0.07	0.019
Martin's Ferry	MAIN	8/27/2002	925	40.4			< 0.05	2.4	0.06	0.025
KR @ WEITHCPEC	MAIN	8/27/2002	1010	43.5			< 0.05	3.2	0.09	0.039
Klamath Estuary	MAIN	9/10/2002	707	0.1			< 0.05	1.8	0.05	0.022
Terwer Gage	MAIN	9/10/2002	812	6.7			< 0.05	3.2	0.06	0.027
Martin's Ferry	MAIN	9/10/2002	1005	40.4			< 0.05	3.2	0.08	0.033
KR @ WEITHCPEC	MAIN	9/10/2002	1056	43.5			< 0.05	4.0	0.11	0.055
Klamath Estuary	MAIN	9/24/2002	715	0.1			< 0.05	< 1.0	0.08	0.028
Terwer Gage	MAIN	9/24/2002	800	6.7			< 0.05	2.2	0.15	0.032
Martin's Ferry	MAIN	9/24/2002	940	40.4			< 0.05	1.4	0.12	0.039
KR @ WEITHCPEC	MAIN	9/24/2002	1020	43.5			< 0.05	1.0	0.15	0.061
Terwer Gage	MAIN	9/26/2002		6.7			< 0.10		0.16	0.036
Downstream B. Creek	MAIN	9/26/2002		16.2			< 0.10		0.16	0.037
Blue Creek	TRIB	9/26/2002		16.4			< 0.10		0.09	<0.01
Tectah Creek	TRIB	9/26/2002		22.1			< 0.10		0.18	0.037
Martin's Ferry	MAIN	9/27/2002	1205	40.4	0.16		< 0.05	1.0	0.11	0.043
KR @ WEITHCPEC	MAIN	9/27/2002	1255	43.5	0.23		< 0.05	1.0	0.14	0.065
Terwer Gage	MAIN	10/1/2002	925	6.7	0.00	< 2	< 0.05	2.2	0.08	0.035
Martin's Ferry	MAIN	10/1/2002	1110	40.4	0.88	< 2	< 0.05	2.6	0.10	0.053
KR @ WEITHCPEC	MAIN	10/1/2002	1140	43.5	0.55	< 2	< 0.05	3.0	0.14	0.074
Klamath Estuary	MAIN	10/8/2002	740	0.1	0.00	< 2	< 0.05	1.8	0.18	0.049
Terwer Gage	MAIN	10/8/2002	805	6.7	0.00	< 2	< 0.05	4.4	0.12	0.057
Martin's Ferry	MAIN	10/8/2002	950	40.4	0.00	< 2	< 0.05	4.2	0.13	0.069
KR @ WEITHCPEC	MAIN	10/8/2002	1010	43.5	0.00	< 2	< 0.05	5.2	0.17	0.094
Terwer Gage	MAIN	8/15/2003	757	6.7	0.71		< 0.10	1.8	0.05	0.016
Martin's Ferry	MAIN	8/15/2003	1145	40.4	1.01		< 0.10	4.8	0.06	0.026
KR @ WEITHCPEC	MAIN	8/15/2003	1059	43.5	0.83		< 0.10	2.0	0.08	0.040
Average					0.42	2	0.07	2.4	0.10	0.038
Maximum					1.01	2	0.25	5.2	0.18	0.094
Minimum					0.00	2	0.05	1.0	0.03	<0.01

Table 5. Periphyton growth at Terwer during the period of the fish die-off. Slides were incubated for approximately two weeks prior to removal.

Date	Periphyton chlorophyll-a mg/m^2	Periphyton phaephytin	Chloro/Phae ratio	Periphyton biomass (mg/cm^2)	Autrophic Index
7/30/2002	0.1	<.1	1.1	460	4181.818
8/27/2002	0.2	0.0	22.0	160	727.2727
9/10/2002	5.0	<.1	49.9	360	72.14429
9/24/2002	2.8	0.0	280.0	300	107.1429

Table 6. List of analytes examined in water samples collected during 9/26/02 and 10/8/02.

Parameter (All unites in ug/l)	Techtah Creek 9/26/2002	Blue Creek 9/26/2002	Downstream Blue Creek	Terwer 9/26/2002	101 Bridge 9/26/2002	Terwer 10/8/2002	Estuary 10/8/2002
Organochlorine Pesticides and PCB's							
alpha-BHC	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
beta-BHC	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Lindane	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
delat-BHC	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Heptachlor	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Aldrin	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Heptachlor Epoxide	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Endosulfan I	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
4,4'-DDE	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Dieldrin	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Endrin	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Endosulfan II	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
4,4'- DDD	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Methoxychlor	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Chlordane	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Toxaphene	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1016	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1221	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1232	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1242	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1248	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1254	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
PCB Arochlor 1260	< 0.10	< 0.10	< 0.10	< 0.10	N/S	N/S	N/S
Triazine Pesticides							
Atatron	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Simazine	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Prometon	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Atrazine	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Propazine	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Simetryn	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Ametryn	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Prometryn	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Terbutryn	< 0.50	< 0.50	< 0.50	< 0.50	N/S	N/S	N/S
Glyphosate	< 5.0	< 5.0	< 5.0	< 5.0	45 ug/l	< 5.0	< 5.0

N/S = Not sampled

Table 7. Results of chemical analysis of coho gill tissue CDFG laboratory. Coho collected on 10-3-02 at Blue Creek mouth. Fish was 77 cm FL and possessed right maxillary clip.

Chemical Constituent	Amount	Chemical Constituent	Amount	Chemical Constituent	Amount
Organochlorine Pesticides	ng/g	PCB congeners	ng/g	Carbamates	ng/g
aldrin	< 0.500	5	< 10.0	Aminocarb	< 0.2
Chlordane, cis	< 0.500	8	< 10.0	Barban	< 0.2
Chlordane, trans	< 0.500	15	< 10.0	Baygon	< 0.2
Chlordane, alpha	< 0.500	27	< 10.0	Carbaryl	< 0.2
Chlordane, gamma	< 0.500	28	< 10.0	Carbofuran	< 0.2
Dacthal	< 0.500	29	< 10.0	Chlorpropham	< 0.2
DDD, o,p'	< 0.500	31	< 10.0	Diuron	< 0.2
DDD, p,p'	< 0.500	33	< 10.0	Fenuron	< 0.2
DDE, o, p'	< 0.500	44	< 10.0	Fluometuron	< 0.2
DDE, p, p'	< 0.500	49	< 10.0	Linuron	< 0.2
DDMU, p,p'	< 0.500	52	< 10.0	Methiocarb	< 0.2
DDT, o,p'	< 0.500	56	< 10.0	Methomyl	< 0.2
DDT, p,p'	< 0.500	60	< 10.0	Monuron	< 0.2
Dieldrin	< 0.500	66	< 10.0	Neburon	< 0.2
Endosulfan I	< 0.500	70	< 10.0	Oxamyl	< 0.2
Endosulfan II	< 0.500	74	< 10.0	Propham	< 0.2
Endosulfan sulfate	< 0.500	87	< 10.0	Siduron	< 0.2
Endrin	< 0.500	95	< 10.0	Swep	< 0.2
Endrin Aldehyde	< 0.500	97	< 10.0		
Endrin Ketone	< 0.500	99	< 10.0	Triazines	
HCH, alpha	< 0.500	101	< 10.0	Ametryn	< 10.0
HCH, beta	< 0.500	105	< 10.0	Atraton	< 10.0
HCH, gamma	< 0.500	110	< 10.0	Atrazine	< 10.0
HCH, delta	< 0.500	114	< 10.0	Prometon	< 10.0
Heptachlor	< 0.500	118	< 10.0	Prometryn	< 10.0
Heptachlor epoxide	< 0.500	128	< 10.0	Propazine	< 10.0
Hexachlorobenzene	< 0.500	137	< 10.0	Secbumeton	< 10.0
Methoxychlor	< 0.500	138	< 10.0	Simazine	< 10.0
Mirex	< 0.500	141	< 10.0	Simetryn	< 10.0
Nonachlor, cis	< 0.500	149	< 10.0	Terbuthylazine	< 10.0
Nonachlor, trans	< 0.500	151	< 10.0	Terbutryn	< 10.0
Oxadiazone	< 0.500	153	< 10.0		
Oxychlordane	< 0.500	156	< 10.0	Pyrethroids	
Tedion	< 0.500	157	< 10.0	Bifenthrin	< 10.0
		158	< 10.0	Lambda	< 10.0
		170	< 10.0	Permethrin	< 10.0
		174	< 10.0	Cyfluthrin	< 10.0
		177	< 10.0	Cypemethrin	< 10.0
		180	< 10.0	Esfenvalerate	< 10.0
		183	< 10.0	Fenvalerate	< 10.0
		187	< 10.0		
		189	< 10.0	Glyphosate	
		194	< 10.0	Glyphosate	< 5.0
		195	< 10.0	AMPA	< 10.0
		200	< 10.0		
		201	< 10.0	Surfactant	
		203	< 10.0	Nonylphenol	< 10.0
		206	< 10.0	Nonylphenolethoxylate	< 10.0
		209	< 10.0		

Table 8. Estimated immigration timing of major stocks of salmonids into the lower Klamath River based on review of literature.

Source	Stock	Jul	Aug	Sep	Oct	Nov	Dec
Anglin 1994	IGH and Wild Chinook	▨	XXXXX	▨	▨		
	Trinity Chinook	▨	XX	XX	▨		
	Late Stocks Chinook			▨	▨	▨	▨
	coho		▨	XX	XXXX	▨	▨
	Fall Adult Steelhead	▨	XXX	XXX	▨		
Polos and Craig 1994	Shasta Fall Chinook		XXXX	X			
	Bogus Creek Chinook		XXX	XX			
	Scott River Chinook		X	XX			
	Shasta+Bogus+Scott		XXXX				
	Iron Gate Hatchery		XXXX				
	Trinity River Hatchery		X	XXX			
Shaw et al. 1997	Fall Chinook (tribal harvest)	▨	XXX	XXX	▨		
	Fall Steelhead	▨	XXX	XXX	▨	▨	

XXX = peak activity

Table 9. Fall Chinook spawning escapement (jacks and adults) for the Klamath and Trinity sub-basins, 1978-2002.[1]

Year	Klamath	Trinity	Total	%Klamath	Inriver Run
1978	43,482	43,123	86,605	50%	115,557
1979	26,277	14,263	40,540	65%	62,864
1980	24,641	30,892	55,533	44%	82,318
1981	30,213	24,620	54,833	55%	108,171
1982	41,260	23,716	64,976	64%	105,900
1983	22,648	23,902	46,550	49%	61,335
1984	17,233	12,002	29,235	59%	55,408
1985	40,077	59,420	99,497	40%	133,730
1986	42,327	132,411	174,738	24%	239,366
1987	46,111	94,256	140,367	33%	227,799
1988	47,943	77,346	125,289	38%	215,322
1989	24,952	43,359	68,311	37%	133,117
1990	15,189	9,642	24,831	61%	40,199
1991	10,299	7,936	18,235	56%	34,353
1992	13,821	13,692	27,513	50%	40,346
1993	36,364	9,921	46,285	79%	64,740
1994	35,926	21,117	57,043	63%	75,936
1995	101,143	102,392	203,535	50%	236,495
1996	46,980	53,784	100,764	47%	184,903
1997	43,895	20,559	64,454	68%	91,642
1998	32,505	40,922	73,427	44%	95,210
1999	30,454	17,971	48,425	63%	70,190
2000	131,301	53,890	185,191	71%	228,114
2001	82,576	55,502	138,078	60%	200,358
2002	78,787	17,881	96,668	82%	169,297

1. Data source. KRTAT megatable.

Table 10. Total fall Chinook Tribal harvest and semi-monthly catch effort (Chinook/net-hour) for Agust and September in the Klamath River Estuary Area, 1984-1992, 1994-2002.[1]

		Catch/Effort (Chinook per net-hour)				
Year	Harvest	Aug 1-15	Aug 16-31	Sept 1-15	Sept 16-30	Comments
1984	12,010	0.23	1.56	1.91	0.06	
1985	5,832	2.08			0.04	Closed Aug 11-Sept 15
1986	15,477	0.80	2.44	7.18		Closed Sept 8
1987	40,014	1.24	2.16	4.59		Closed Sept 6
1988	37,052	1.30	1.63			Closed Aug 25
1989	37,130	1.07	1.72	2.02		Closed Sept 4
1990	3,661	0.47	0.67	0.60	0.27	
1991	3,909	0.27	0.23	0.72	0.61	
1992	1,276	0.03	0.26	0.27	0.39	
1993[1]	3,079					
1994	4,443	0.82	1.61			Closed Aug 22
1995	5,256	0.12	1.07	2.98		Closed Sept 6
1996	49,276	0.92	1.66	3.12	0.91	
1997	5,595	0.69	1.30	1.48	0.42	
1998	3,470	0.08	0.28	0.67	0.48	
1999	4,513	0.39	0.59	0.47	0.30	
2000	17,313	2.54	6.54	4.06	3.76	Closed Aug 26[2]
2001	30,747	0.97	1.53	4.47	2.66	
2002	19,718	1.36	3.75	3.93	1.51	

1. Comparable catch-effort data not available for 1993.
2. The fishery was reopened from Sept 1-2, and Sept 15-17.

APPENDIX A. CLUSTER ANALYSIS: RUN SIZE AND RELATIONSHIP TO DISCHARGE AND PRECIPITATION

In order to evaluate how 2002 may have been different from other years, we focused our analysis on years that possessed similar hydrology, but did not have a fish die-off. We wanted to examine these years to determine which factor or factors, including run size, precipitation, and individual tributary discharges, may have varied from conditions during 2002. We hypothesized that the synergistic effects caused by the combination of river discharge, population size of returning adult salmonids, and precipitation may have contributed to the die-off. In order to test this hypothesis, we needed an objective method to select groups for comparison. For years with available run size estimates (1978-2002), we applied the statistical technique of agglomerative hierarchical cluster analysis to classify years into groups based on the pattern of significant gaged discharges during August and September in the Klamath Basin below Iron Gate Dam.

Cluster analysis is a multivariate statistical analysis that is designed to classify objects based on various common traits. It is widely used to conduct complex pattern recognition and classification (Legendre and Legendre 1998). This technique attempts to identify groups based on similarity of multiple attributes. For example, cluster analysis has been used to develop regional classifications of streamflow drought series (Stahl and Demuth 1999; Haan 2002; Pao-Shan and Min-Luen 2002).

Methods

In order to examine the similarity of various years based on patterns of basin hydrology, we analyzed August and September discharges from significant tributaries and the mainstem ~~flows~~ using a standard cluster analysis technique with the SPSS ™ version 10.07 statistical package (SPSS 2000). The similarity between years was determined using a measure called squared Euclidean distance (Legendre and Legendre 1998). This measure determines the hyperspace distance between two years based on the variation of all "traits." An intermediate computation step involves the creation of a distance matrix using this measure of similarity.

Individual mean daily discharges, during August and September, can be used as traits to classify years using data from the gage sites listed. However, we decided to use monthly average values because 1) changes in daily discharge are minimal during August and September in the Klamath Basin 2) during this time of the year snowmelt run-off has subsided and rainfall is limited and infrequent, resulting in a less variable hydrograph, and 3) computational problems can arise due to the excessively large data matrix and the influence of missing values.

The traits we used were August and September monthly average discharges on the Klamath River at Iron Gate, the Trinity River at Hoopa, the Salmon River, the Scott River, and the Shasta River. Therefore, a total of 10 traits or monthly average discharges were used to classify each year. September Iron Gate data included the entire month in all years except 2002. Data used for

September 2002 was limited to September 1 to 27, thus eliminating the influence of days when additional water was released to create a “pulse” flow to attract fish upstream.

Years with similar patterns of discharges from all gage sites resulted in smaller squared Euclidean distance between them in comparison to years with more dissimilar patterns in discharge. Therefore, we considered these years more hydrologically similar. The program formed clusters of similar years based on these combined hyperspace distances at each step in the clustering process. The linkage method (or decision model) used to determine which groups of years and/or individual years should be combined was Ward's minimum variance method (Romesburg 1990). At each step, this linkage algorithm selects additional members for an existing cluster of years, or year pair, that produces the lowest increase in variance between all of the prospective member years of the cluster and the "centroid" or central tendency of the existing cluster. The method seeks to select groups that minimize the variance of squared Euclidean distance between each year and the central distance tendency of the group of years.

Results of this grouping were displayed in a tree diagram, or dendrogram, that depicts similar groups of years based on a similarity index displayed on one of the axes. The dendrogram rescales the actual squared Euclidean distances to numbers between 0 and 25, preserving the ratio of the distances between steps.

The investigator must decide the method for selecting the final number of clusters for evaluation. No standard objective procedure exists for making the selection (Afifi and Clark 1997). The distances between clusters at successive steps may serve as a guide. The investigator can complete groups when the distance exceeds a specified value or when the successive differences in distances between steps make a sudden jump. Also, the underlying situation may suggest a natural number of clusters.

In our case, the final number of yearly clusters was defined after analysis by using a cutoff similarity index that yielded six clusters. At this point, the distance between clusters began to increase quickly. After determining the number of clusters, we selected the cluster that contained 2002 for further characterization and analysis. We also decided *a priori* to evaluate the next most similar cluster grouping. Thus, the year 2002 and its group of most similar years could be compared with the next most similar group, as determined by the methodology. An example using simulated data is illustrated below.

Monthly Average Discharge (cfs)

Cluster 1	Aug Gage 1	Sep Gage 1	Aug Gage 2	Sep Gage 2
1960	100	250	500	450
1951	200	350	450	445
1962	100	290	490	450
Cluster 2				
1961	250	100	507	450
1964	350	200	404	449
1958	290	100	300	450

Years in Cluster 1 group together because they show a similar pattern in discharge (e.g., low flows at August gage 1, and high flows at September gage 1). Years in cluster 2 show opposite patterns for August and September gage 1. However, note that the overall average for gage 1 (215 cfs) is identical between groups even though the pattern is different. Thus when comparing the groups it is important to look at pattern within and among the member years as well as the mean. This difference in patterns would have been missed using a traditional descriptive univariate method.

After conducting the cluster analysis, we compared environmental factors including run size, precipitation, and individual tributary discharges for the group that included 2002 with the next most similar group based on hydrologic condition. We examined the differences in average monthly discharge from each gage station within the cluster of years that included 2002, as well as the next most similar cluster. We accomplished this by simply averaging the individual gage discharges within each cluster, and also by plotting individual yearly discharges from each gage within each cluster. We also used data from the Orleans and Klamath National Weather Service stations to examine differences in monthly precipitation between the two groups.

Results

Using cluster analysis, we identified six primary groupings based on overall major tributary and mainstem discharge regime (Figure 25). We compared Group 2, which included 2002, 1991, 1992, and 1994, with Group 1, which was the next most similar group. Group 1 included 1981, 1987, 1988, 1990 and 2001. The following discussion compares discharges by groups at specific gages. Discussion of comparison between groups is presented in more detail for gages that provided a larger percentage of the flows in the lower River.

Comparison of IGD Gage Discharges by Cluster Groups

August average discharge was higher in Group 1 (989 cfs) than Group 2 (567 cfs)(Figure A.1 and Table A.1). Likewise, September average discharge was 1,096 cfs in Group 1, and 738 cfs in Group 2 higher in Group 1 (1,096 cfs) than in Group 2 (738 cfs)(Figure A.1 and Table A.1). In addition, Iron Gate Dam discharges were lower in all years in Group 2, compared to Group 1. There was no overlap in values between the two groups.

Comparison of Orleans Gage Discharges by Cluster Groups

In both months, the group average monthly discharge at Orleans was higher in Group 1 compared to Group 2; however, there was some overlap in discharges among member years of the two groups. August average monthly discharge was 1,434 cfs in Group 1 and 1,072 cfs in Group 2 (Figure A.2, Table A.1). September average monthly discharge was 1,487 cfs in Group 1, and 1,146 cfs in Group 2 (Figure A.2, Table A.1). August discharges in some years in Group 2 (2002 and 1991) were higher than 2001 Group 1 (Figure A.2). Some Group 2 September discharges were higher (2002 and 1994) than 2001 in Group 1. The values for Orleans are included in the combined Orlean/Hoopa evaluation and discussed later in this section.

Comparison of Terwer Gage Discharges by Cluster Groups

Differences in discharge using the Terwer gage were observed between groups and years (Figure A.3 and Table A.1). During August, average discharge was higher for Group 1 (2,719 cfs) compared to Group 2 (1,999 cfs) (Figure A.3, Table A.1). September average discharges were also higher, at 2,585 cfs in Group 1 compared with 1,990 cfs in Group 2 (Figure A.3, Table A.1). In addition, Terwer discharges were lower in all years in Group 2 than in Group 1 when comparing the same months. The only overlap between the two groups involved Group 2 August 2002 flows, which were higher than Group 1 September 1988 flows. Thus, the two groups were almost entirely distinct from one another in regard to Terwer gage discharges.

Comparison of Combined Orleans and Hoopa Gage Discharges by Cluster Groups

Combined Orleans and Hoopa discharges exhibited different yearly and group patterns than the Terwer discharges for the same period of record. These differences reflect variations in accretion of flow below Hoopa and Orleans, and probably, variations in the Terwer gage.

Differences in discharge using the Hoopa/Orleans gage data were observed between groups and years (Figure A.4 and Table A.1). During August, average discharge was higher for Group 1 (2,061 cfs) than Group 2 (1,720 cfs) (Figure A.4, Table A.1). September average discharge was also higher for Group 1 (2,034 cfs) than Group 2 (1,768 cfs) (Table A.1). Several individual monthly daily average flow within Group 2 overlapped with Group 1. Group 2 August 2002 discharge was higher than Group 1 August 1987 and higher than Group 1 August and September 2001. Also, Group 2 September 2002 was higher than Group 1 September 2001. Thus, there was not a complete difference in the pattern of monthly discharges between Groups 1 and 2 in the combined Hoopa/Orleans discharge.

Tributary - Shasta River at Yreka

Within the two groups, August and September discharges on the Shasta River were quite low in comparison to those on the mainstem Klamath and Trinity Rivers, ranging from xx to yy. Group 2 average August and September discharges in the Shasta River were lower than Group 1 discharges for those months (Figure A.5 and Table A.2). However, there was considerable overlap between individual years and months between the groups (Figure A.6), indicating that the groups were not distinct with respect to Shasta River discharge.

Tributary - Scott River at Fort Jones

Within the two groups, average monthly discharges on the Scott River were quite low in comparison to those on the mainstem Klamath and Trinity Rivers, ranging from 4 to 26 cfs. Average monthly August Scott River discharges were essentially identical (11 cfs) for both Groups (Table A.3). Average September Scott River discharges were higher in Group 2 than in Group 1 (Table A.2), which is a different pattern than that of most gages, but the minimal flows probably render this difference inconsequential. Average monthly discharges in August and September 2001 were lower than in 2002. There was considerable overlap between individual years and months between the groups (Figure A.6), indicating that the groups were not distinct respect to Scott River discharge.

Tributary - Salmon River at Somes Bar

At the Salmon River, Group 1 exhibited higher monthly average August and September discharges than Group 2 (Table A.2). There was some overlap among months and years, indicating that the groups were not distinct (Figure A7).

Tributary - Trinity River at Lewiston Dam and Hoopa

The two Trinity River gages (Lewiston and Hoopa) exhibited a different pattern from the other gages, as Group 2 average monthly flows were higher than those for Group 1 (Table A.2). However, at both gages, 2001 was unique because August discharges were the highest among the two groups and September discharges were higher than most Group 2 discharges.
Thus, the two groups were not completely distinct. In general, the two groups were not greatly different from each other at either gage. The Hoopa values were combined with the Orleans discharge data and discussed above.

Comparison of Groups - Precipitation

We examined differences in local monthly precipitation measured by rain gages at Orleans and the town of Klamath (Table A.2). In general, Group 2 years exhibited lower average rainfall during August and September in comparison to Group 1 (Figures A.10 and A.11), and Group 2 had more intra-group variation. There is also extensive overlap in monthly total precipitation between years across the two groups, indicating that the two groups are not strongly different.

Comparison of Run Sizes by Cluster Groups

We compared run sizes of the two groups and their member years. Mean run size for Groups 1 and 2 were 158,369 and 79,983 Chinook salmon, respectively (Table A.1). There was considerable variation in annual run size within both groups. For example, 1981 and 1990 had considerably smaller run sizes in comparison to the other years within Group 1. Importantly, the 2002 run size of 169,297 fish was much larger than the average run size of 79,983 for the hydrologically similar Group 2, and was more similar to the Group 1 average of 158,370 (Table A.2).

Comparison of Run Size, Discharges, and Precipitation by Cluster Groups - Overall Patterns

Cluster analysis provided an objective method for classifying years by basin-wide patterns in monthly discharge. We used monthly average discharges, during August and September, to group years with similar hydrology. Since we only have reliable run size estimates for fall-run Chinook salmon in the Klamath Basin starting in 1978, we only classified years from 1978 to 2002.

The year 2002 was classified into Group 2, which also contained 1991, 1992 and 1994. These years were most similar to 2002 hydrologically. For example, monthly average discharges measured at Iron Gate, Orleans, Hoopa/Orleans, Terwer, and the Shasta River were very similar to each other across all years and months in Group 2. Discharges measured during 2002 at the Scott River, although less similar, were within the range of values recorded at other gages within Group 2. In addition, monthly total precipitation measured during 2002 at Orleans and the town of Klamath meteorological stations were within the range of values recorded in other years within Group 2. In contrast to the patterns of similarity observed in discharge and precipitation, the run size during one year, 2002, was much larger than other years in Group 2.

We also compared Group 2 to the next most similar group, Group 1, to determine what traits varied between them. Group 1 contained 1981, 1987, 1988, 1990 and 2001. Group 2 had lower average monthly discharges at Iron Gate, Orleans, Hoopa/Orleans, Terwer, the Shasta River, and the Salmon River, when compared to Group 1. However, there was overlap in individual monthly average discharges between years among groups when comparing Orleans, Hoopa/Orleans, Shasta River, and the Salmon River. There was only a slight overlap in individual monthly average discharge measurements between years among groups at the Terwer gage, and no overlap at Iron

Gate Dam. Average Group 2 Scott River discharges were similar to Group 1. In addition, there was overlap in individual monthly discharges between years among groups at the Scott River. As in most years, during 2002 individual monthly discharges measured at the Shasta and Scott River contributed little flow to the lower Klamath River. In contrast to most of the other gage stations, Group 2 exhibited higher average monthly discharges at Lewiston and the Hoopa on the Trinity River in comparison to Group 1.

Average total monthly precipitation within Group 2 was higher than Group 1, however, there was overlap among years and months between the two groups. For the years examined, there did not appear to be a strong relationship between local precipitation and discharge during September and August. This may be due to the small amount of rainfall that normally occurs during this time of the year, and the significant effect from upstream mainstem and tributary discharges.

Finally, despite the high run size in 2002, Group 2 had a lower average run size in comparison to Group 1. The 2002 run size from Group 2 was similar to the average run size in Group 1.

It appears that the major differences between Group 1 and Group 2, which contained 2002, ~~was~~ were the lower average run size and the lower monthly discharges at Iron Gate Dam and Terwer gages observed in Group 2. The apparent inconsistency between patterns at Terwer and at Orleans and Hoopa/ Orleans (which measure the mainstem flows of the Klamath and Trinity before they reach Terwer) might be attributed to variations in accretion from numerous minor tributaries downstream of Orleans, local precipitation, and potential cumulative error in Terwer and Orlean gage readings.

Summary

Our primary purpose was to identify ways in which 2002, the year of the die-off, might have been different from other years. In this regard, the most distinct features evident in this analysis were: 1) Average monthly discharge was consistently low at Iron Gate and Terwer in the years of the hydrologically similar Group 2; although flows at the Trinity gages were somewhat higher during those years than during the years of Group 1; 2) There was not substantial difference between Groups in August and September precipitation at stations just above and below the die-off site; and 3) The large 2002 run size was unique among Group 2, and was more similar to run sizes in the higher discharges of Group 1. Thus, in summary, there have been several years during the period of record that can be objectively identified as hydrologically similar to 2002; and, among those years, 2002 had a uniquely large run size.

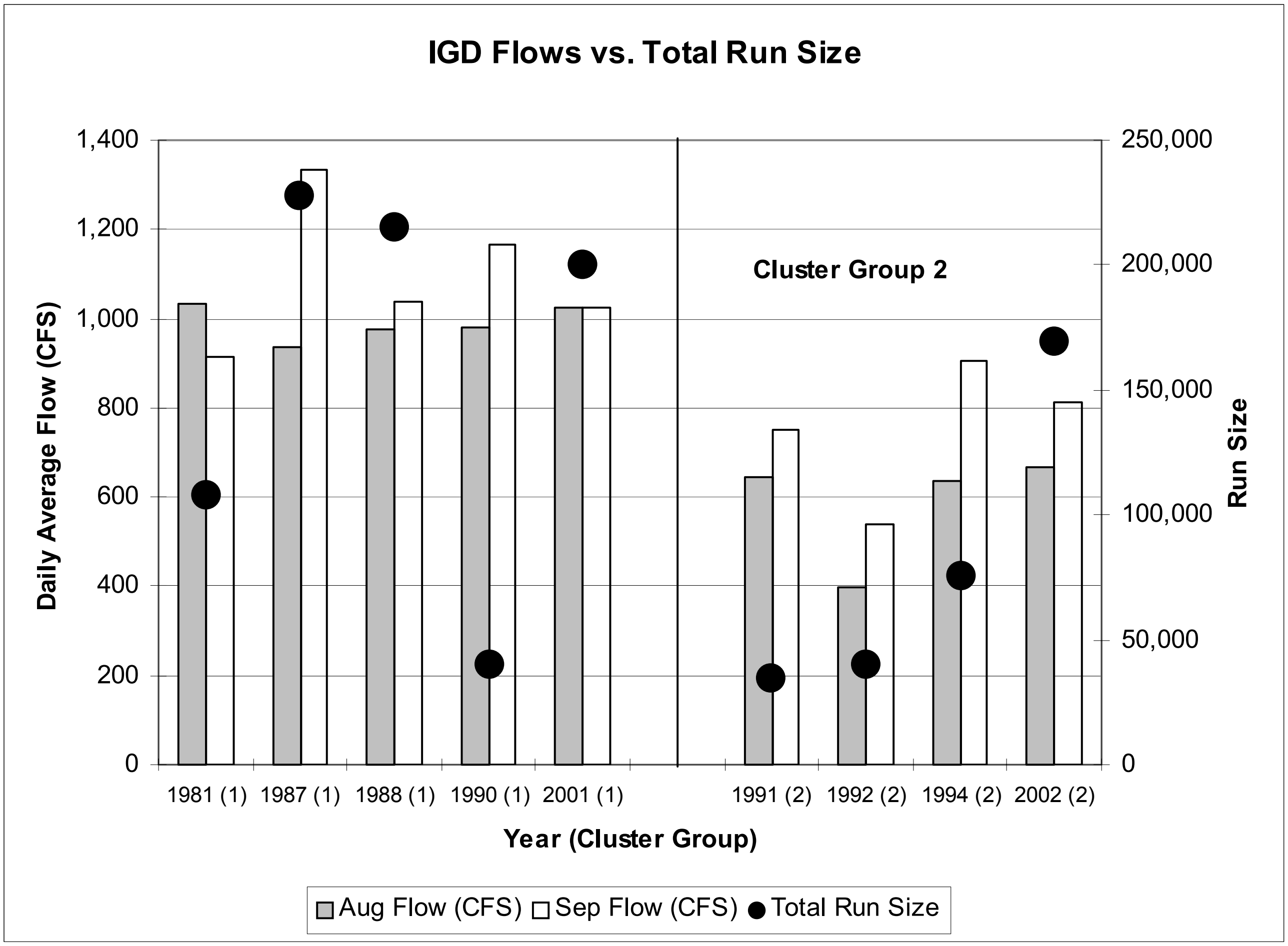

Figure A.1. Comparison of two major clusters of years using August and September discharges, including pulseflow, from Iron Gate and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates. Adjusted September 2002 discharges were 760 cfs after removing the pulse flow versus 813 cfs (unadjusted).

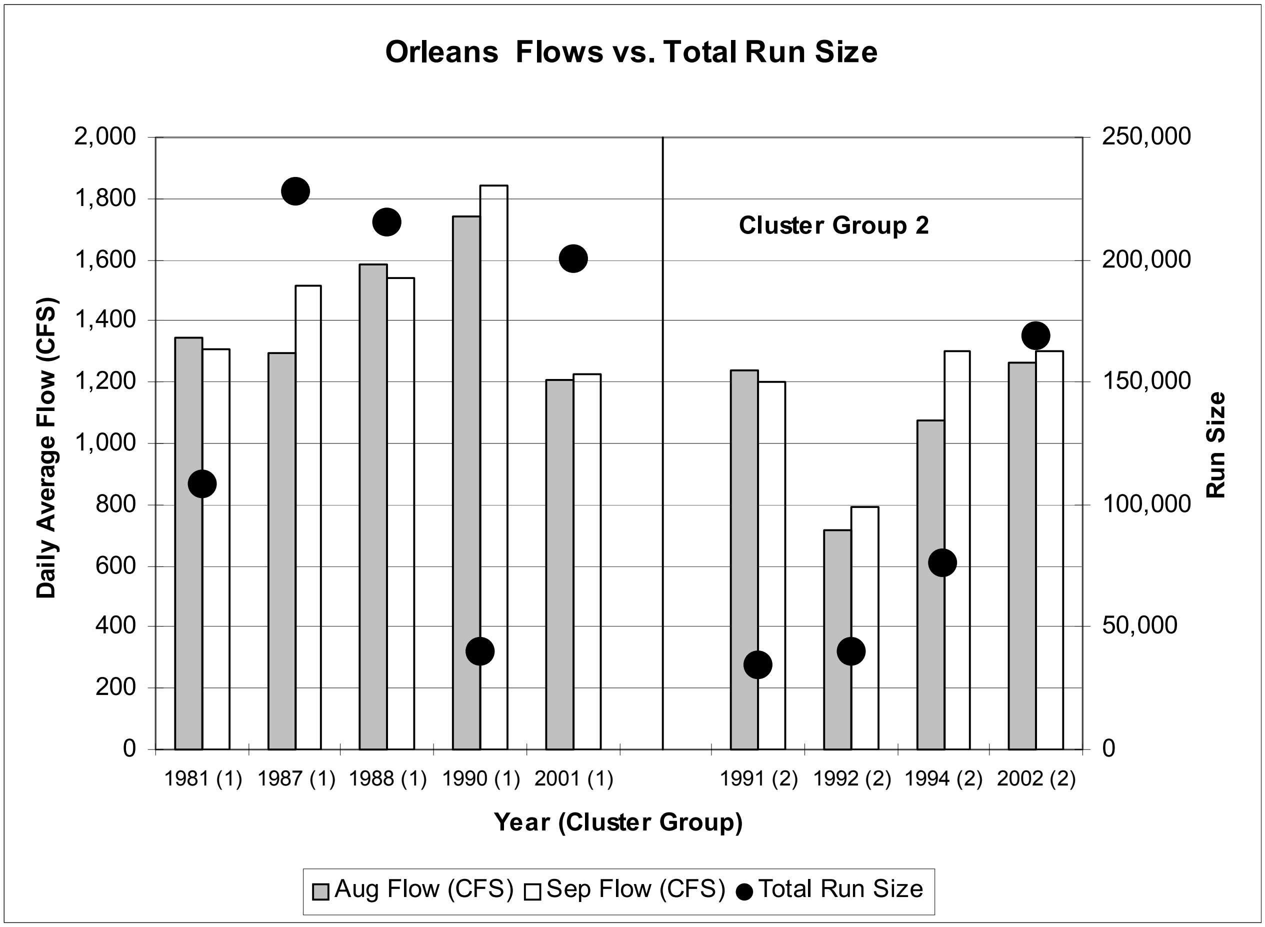

Figure A.2. Comparison of two major clusters of years using August and September discharges from Orleans and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates. Adjusted September 2002 discharges were 1,287 cfs after removing the pulse flow versus 1,305 (unadjusted).

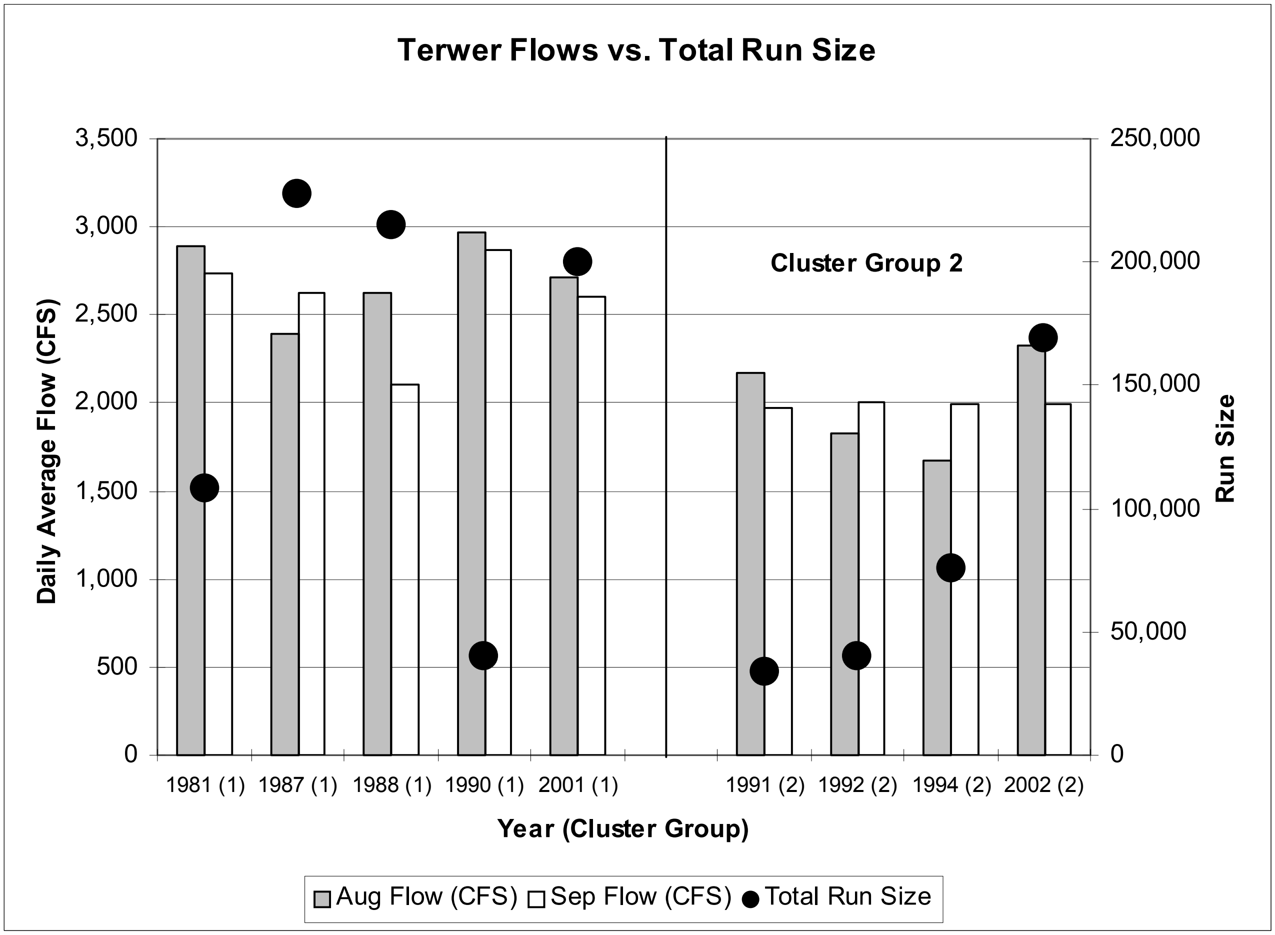

Figure A.3. Comparison of two major clusters of years using August and September monthly average discharges, including pulse flow, measured at Terwer (Klamath) and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates. The adjusted average discharge for September 2002, was 1,987 cfs versus 1,993 cfs (unadjusted).

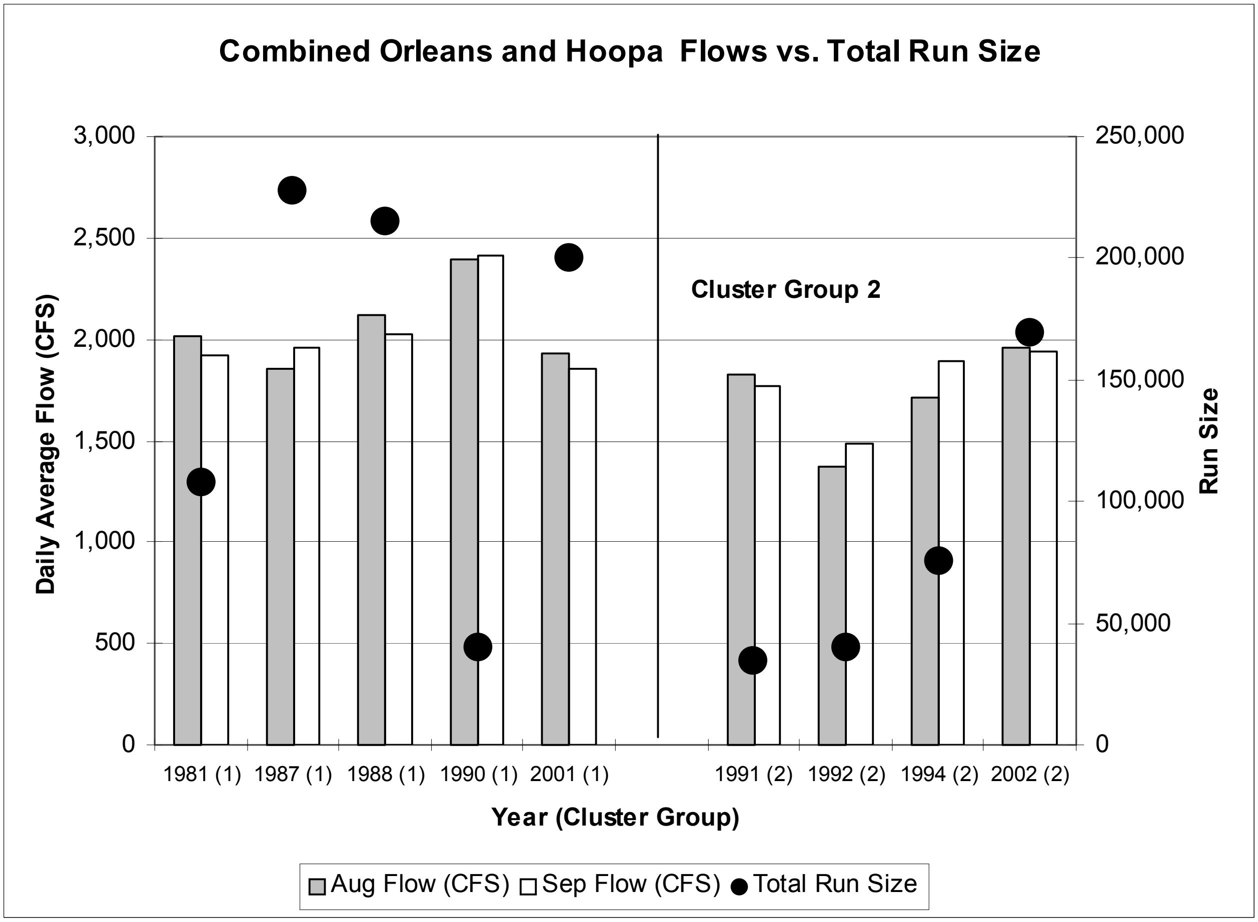

Figure A.4. Comparison of two major clusters of years using August and September combined discharges, including pulse flow, measured at Hoopa/Orleans and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates. Adjusted September 2002 dishcharges were 1,918 cfs after removing the pulse flow versus 1,936 cfs (unadjusted).

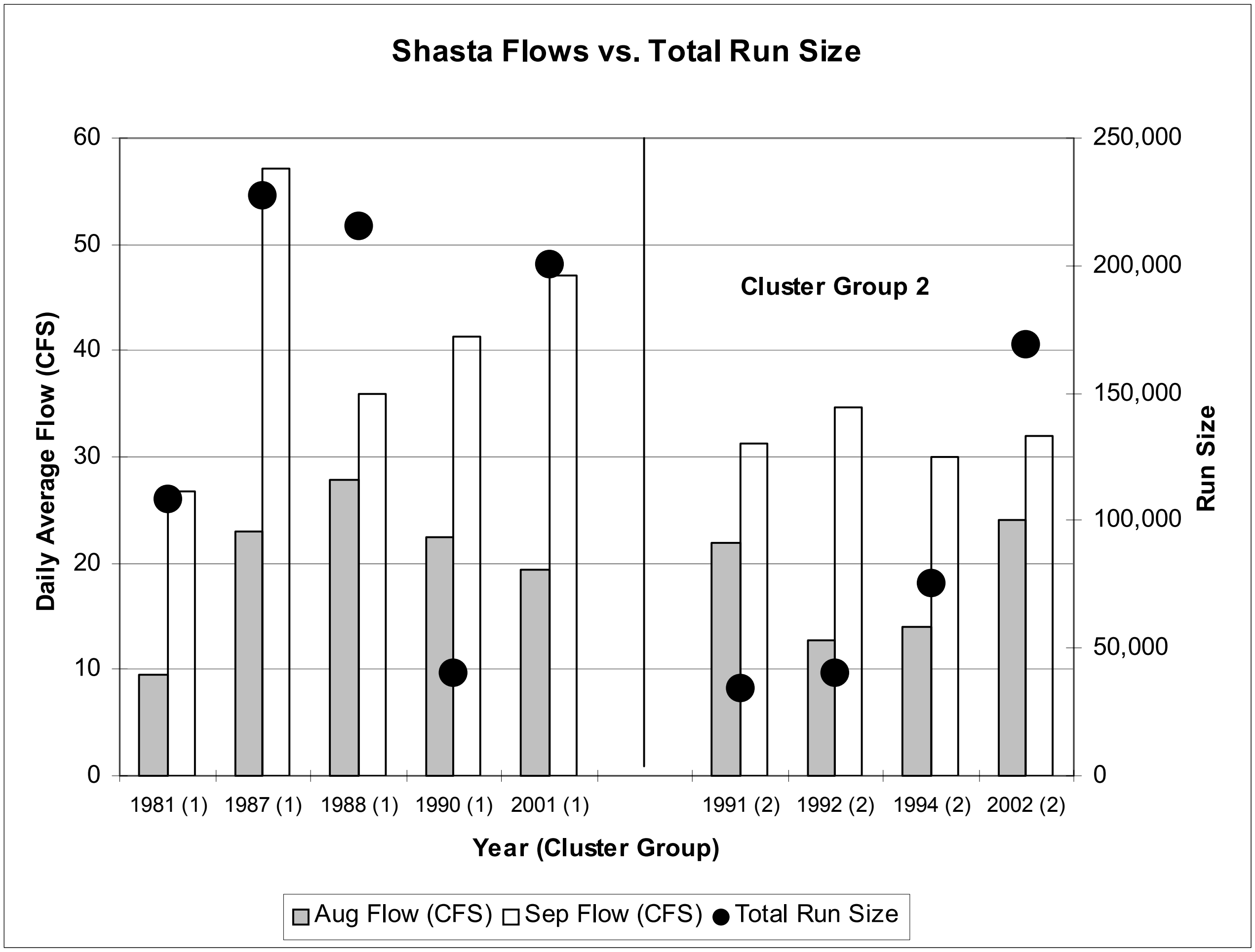

Figure A.5. Comparison of two major clusters of years using August and September discharges measured at Shasta River at Yreka gage and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

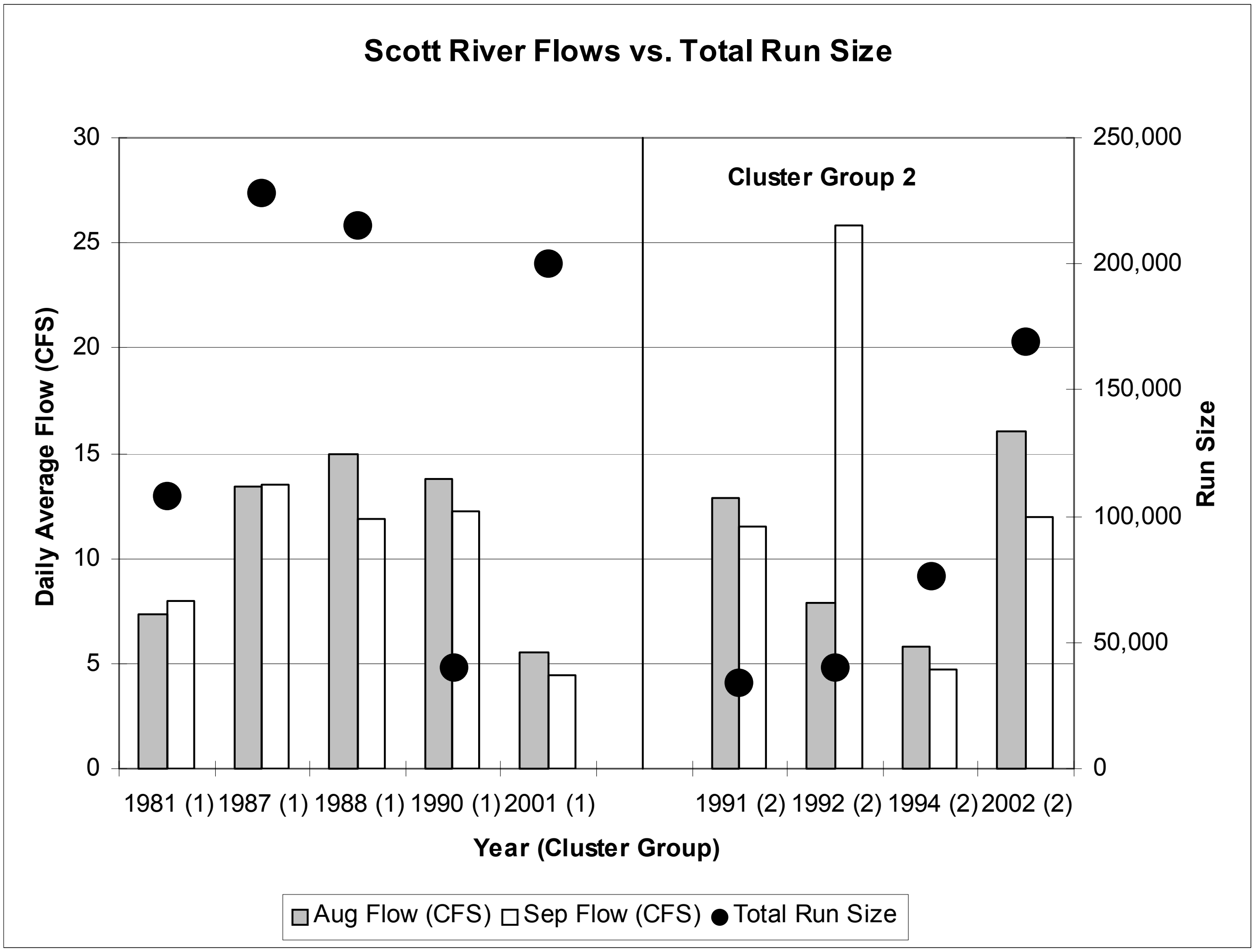

Figure A.6. Comparison of two major clusters of years using August and September discharges measured at Scott River Fort Jones gage and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

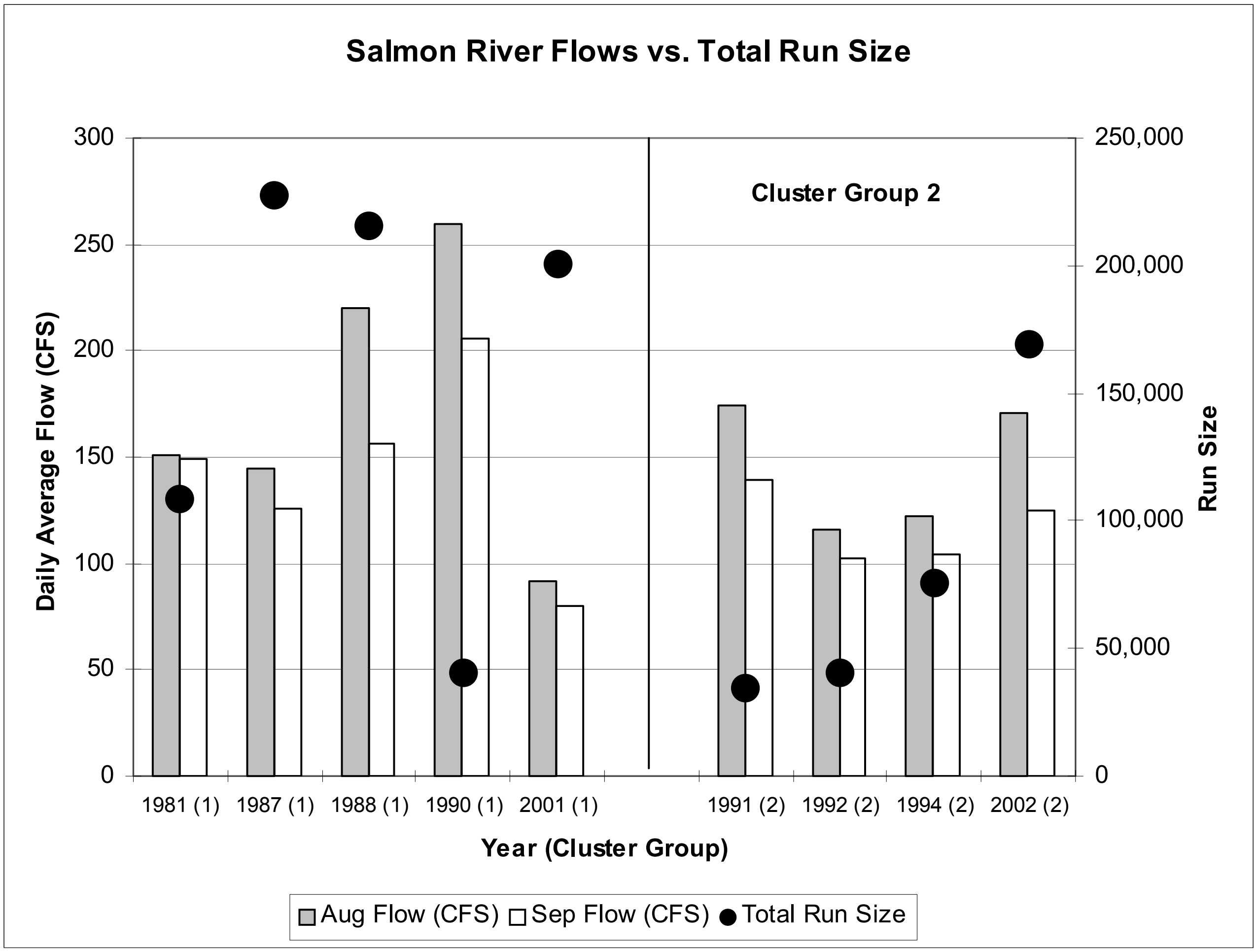

Figure A.7. Comparison of two major clusters of years using August and September discharges measured at the Salmon River at Somes Bar gage and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

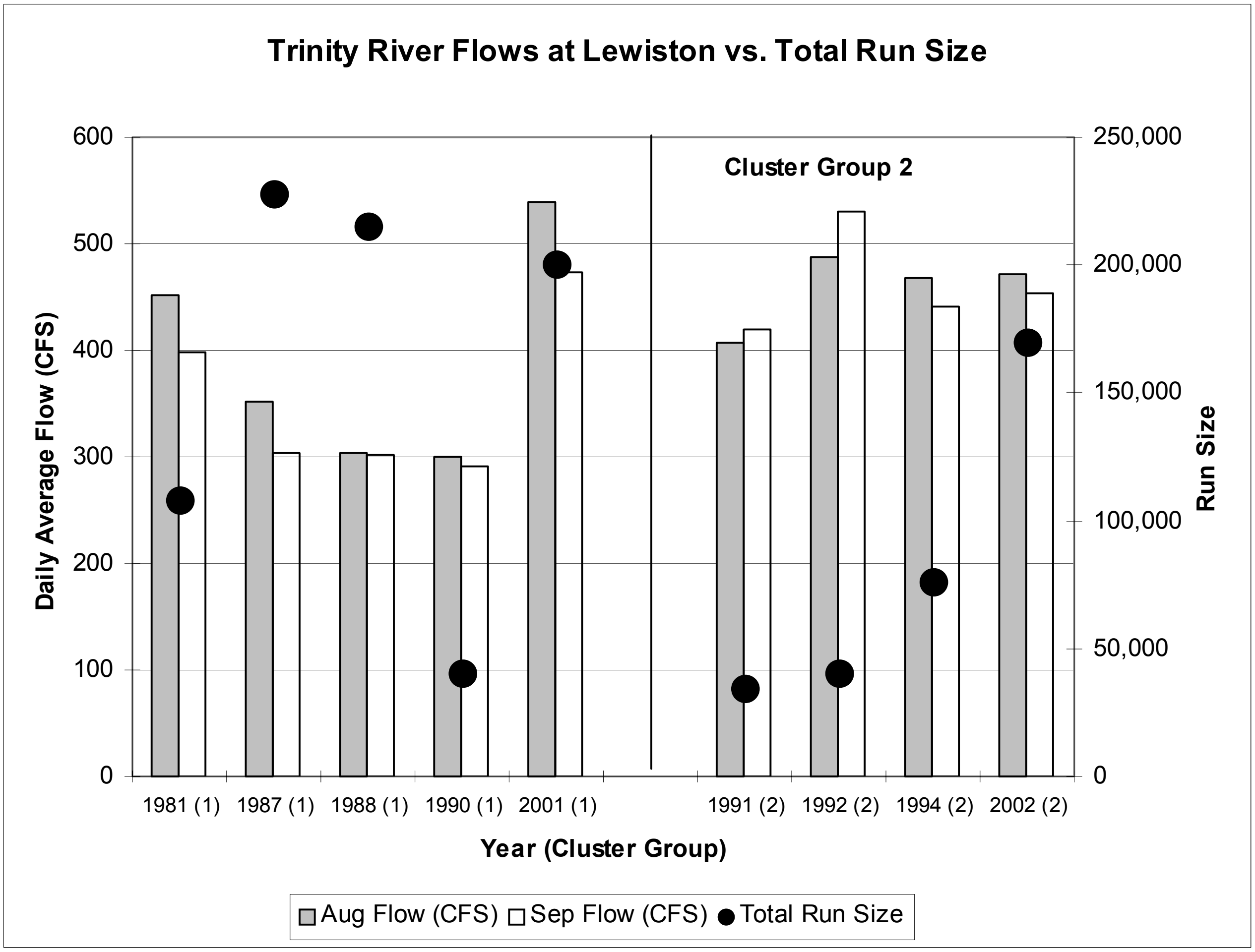

Figure A.8. Comparison of two major clusters of years using August and September discharges measured at the Trinity River at Lewiston Dam gage and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

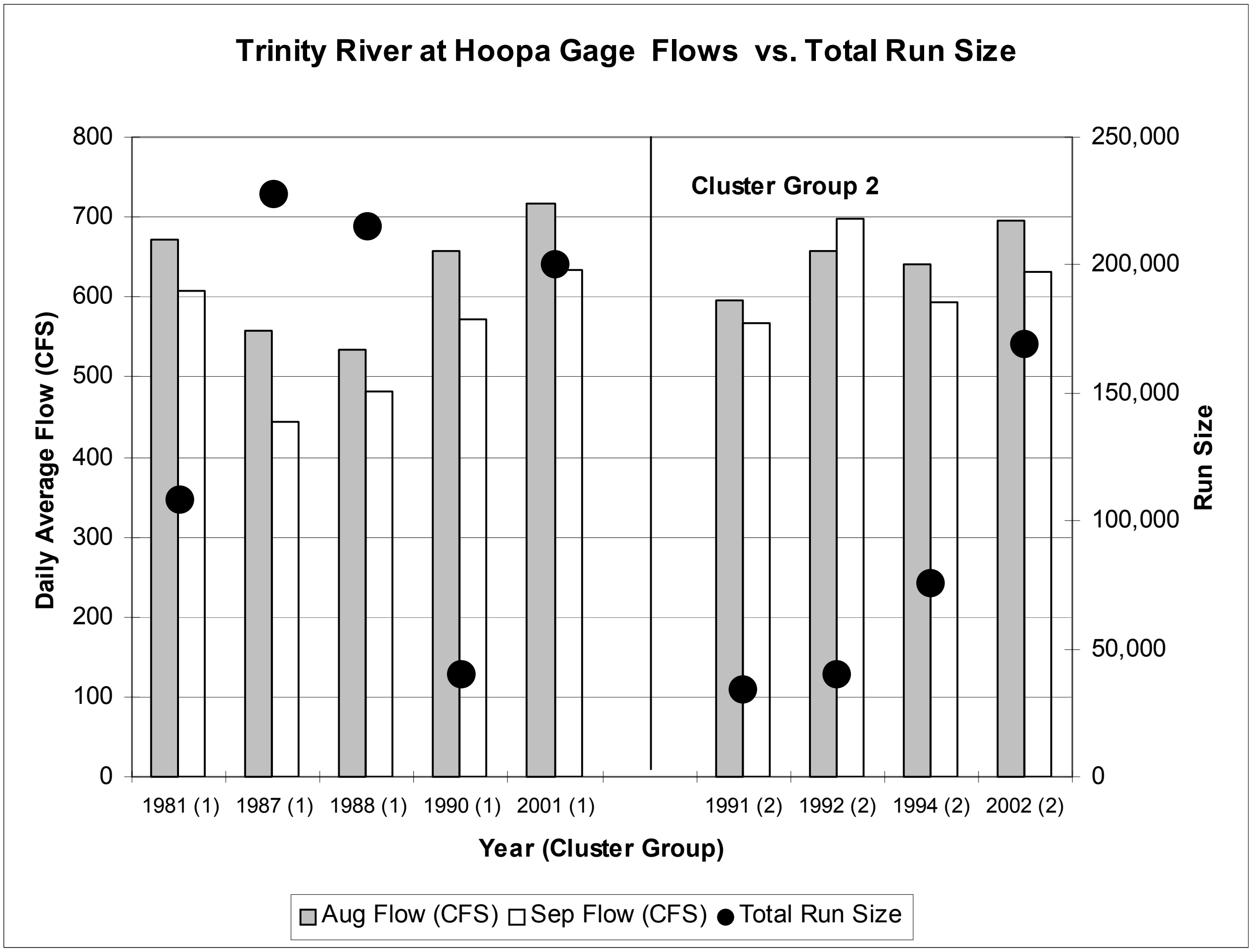

Figure A.9. Comparison of two major clusters of years using August and September discharges measured at the Hoopa gage on the Trinity River and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

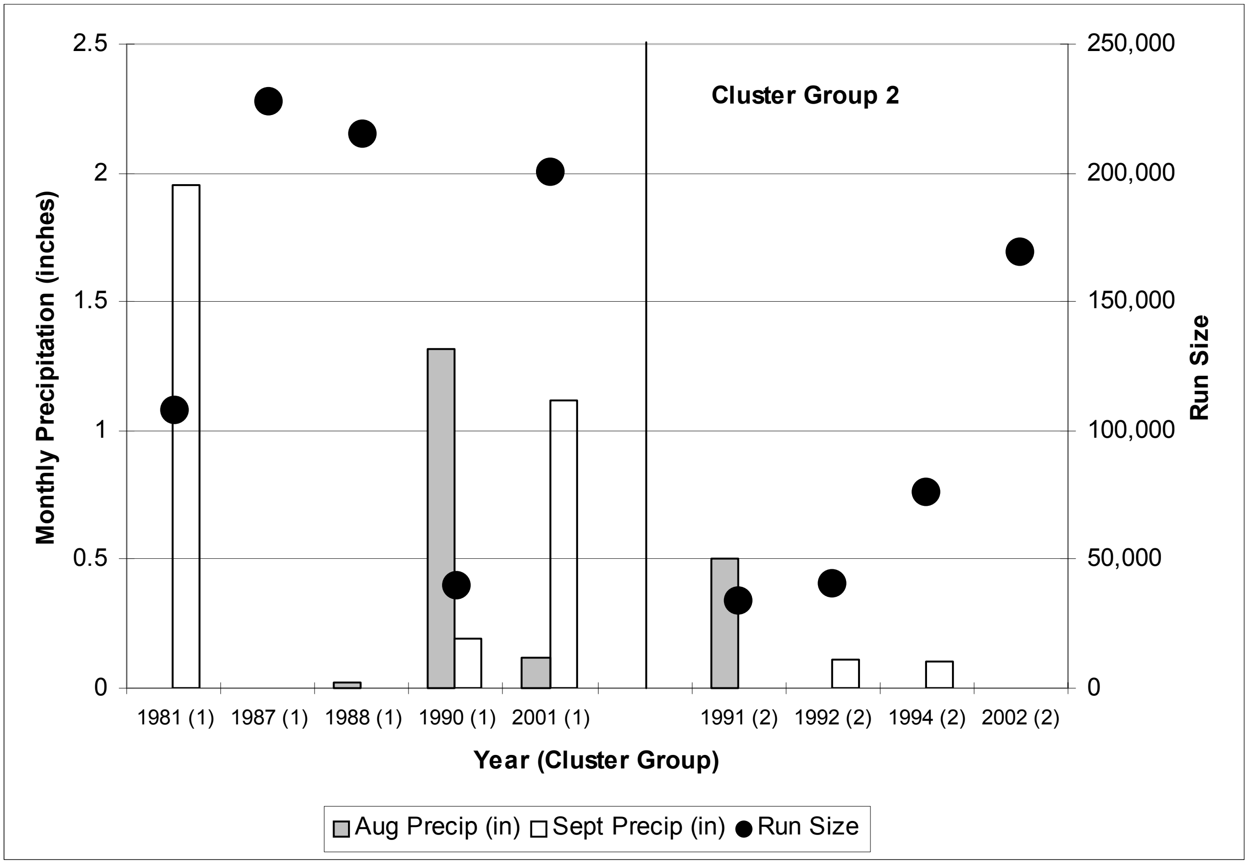

Figure A.10. Comparison of two major clusters of years using August and September monthly total precipitation measured at the Orleans weather station, and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

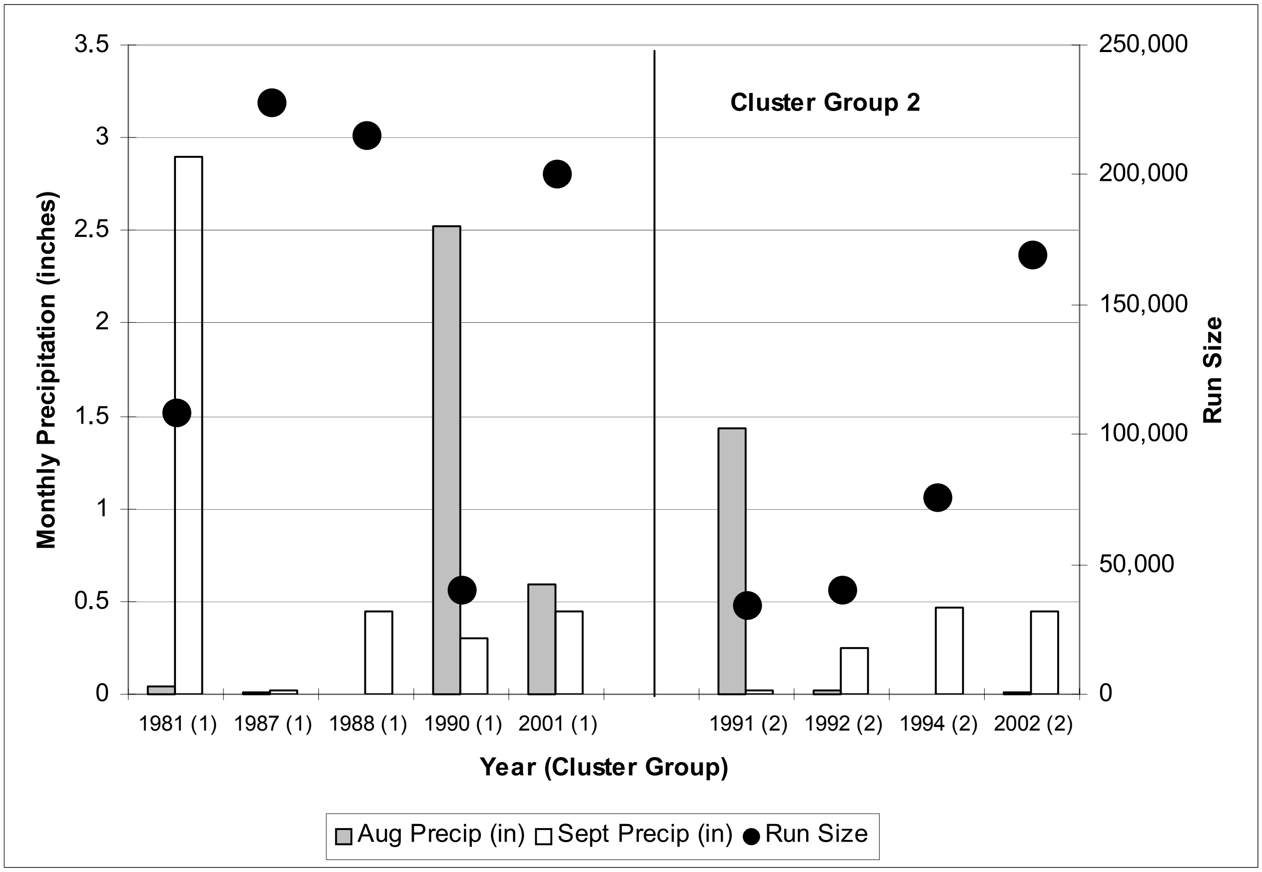

Figure A.11. Comparison of two major clusters of years using August and September monthly total precipitation measured at the Klamath weather station, and total Chinook run size. The 2002 run size may be biased low due to conservative fish die-off number estimates.

Table A.1. Comparison of yearly cluster groups 1 and 2 using major mainstem gage stations.

	Avg. Group 1	Avg. Group 2 (contains 2002)
Total Run Size (# fish)	158,370	79,983
Gage and Month		
IGD Aug (CFS)	989	567
IGD Sep (CFS)	1,096	752
IGD Sep (CFS) (without pulse)	1,096	738
Orleans Aug (CFS)	1,434	1,072
Orleans Sep (CFS)	1,487	1,150
Orleans Sep (CFS) (without pulse)	1,487	1,146
Orlean+Hoopa Aug (CFS)	2,061	1,720
Orlean+Hoopa Sep (CFS)	2,034	1,773
Orleans + Hoopa Sep (CFS) (without pulse)	2,034	1,768
Klamath (Terwer) Aug (CFS)	2,719	1,999
Klamath (Terwer) Sep (CFS)	2,585	1,991
Klamath (Terwer) Sep (CFS) (without pulse)	2,585	1,990

Table A.2. Comparison of yearly cluster groups 1 and 2 using tributary gage stations and mainstem weather stations.

River and Month	Avg. Group 1	Avg. Group 2 (contains 2002)
Salmon River Aug (CFS)	174	146
Salmon River Sep (CFS)	143	118
Shasta River Aug (CFS)	20	18
Shasta River Sep (CFS)	42	32
Scott River Aug (CFS)	11	11
Scott River Sep (CFS)	10	14
Lewiston Dam Aug (CFS)	389	459
Lewiston Dam Sep (CFS)	354	462
Hoopa Aug (CFS)	628	648
Hoopa Sep (CFS)	548	623
Orleans Aug Avg Precipitation (in)	0.292	0.125
Orleans Sep Avg Precipitation (in)	0.652	0.052
Klamath Aug Avg Precipitation (in)	0.632	0.365
Klamath Sep Avg Precipitation (in)	0.824	0.298