The Klamath River Fish Kill of 2002; Analysis of Contributing Factors

Yurok Tribal Fisheries Program

February 2004

Final Report

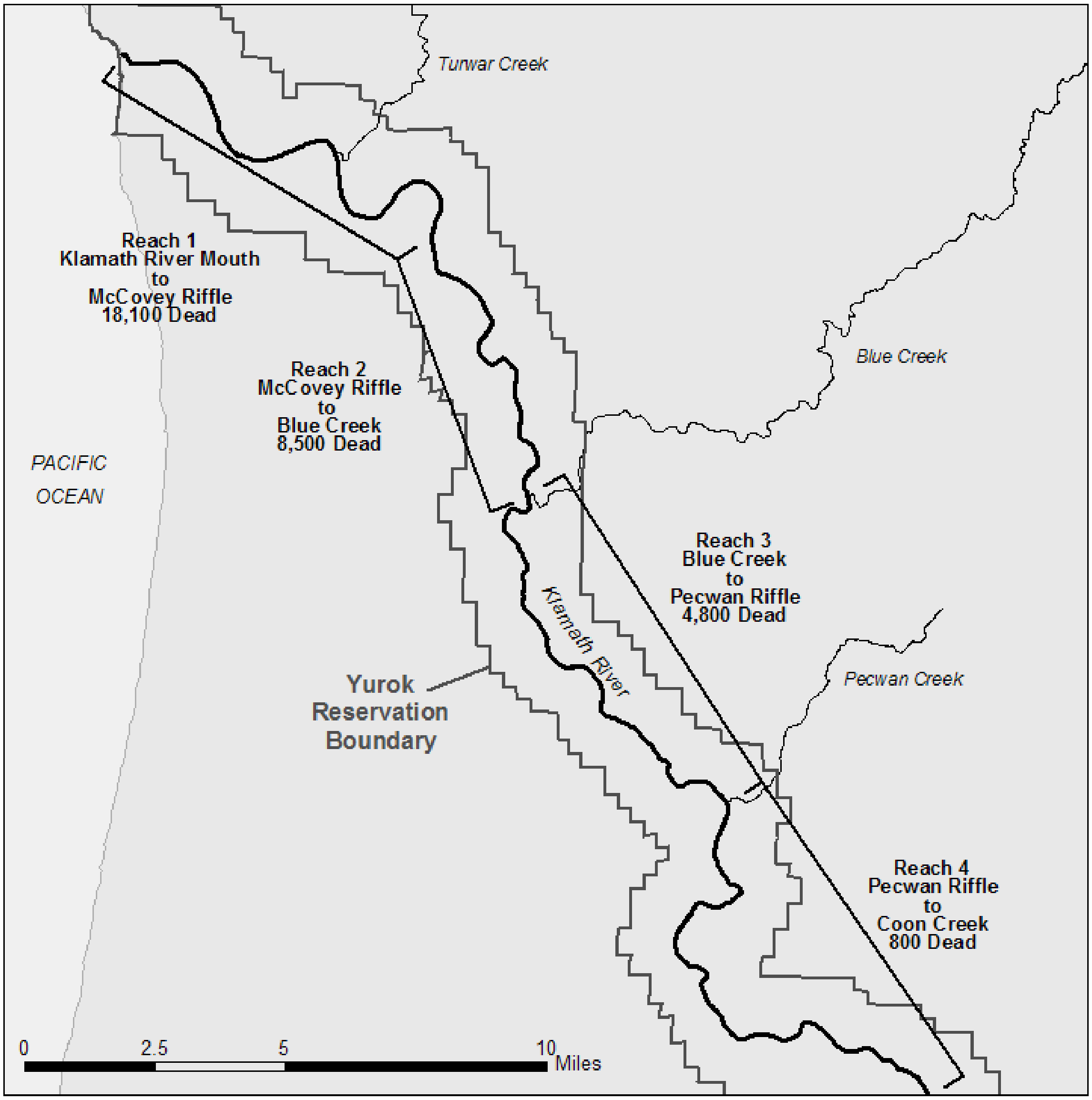
Prepared by:
Michael Belchik
Dave Hillemeier
Ronnie M. Pierce

Abstract

Consideration of all pertinent data led to the conclusion that in 2002 a relatively robust run of adult fall Chinook entered the Klamath River approximately one week earlier than usual. Environmental conditions in the River at the time of the 2002 fall-run Chinook salmon run were characterized by low flow rates and volume, and an apparent lack of migration cues to proceed upriver. The resultant migration delay, crowded conditions, and warm water temperatures provided an ideal environment for the proliferation of the parasite *Ichthyopthirius multifilis* (ich) and the bacterial pathogen *Flavobacter columnare* (columnaris).

Isolation and identification of causative factors of fish kills in general are complex tasks that generally do not identify a single independent "cause". Rather, the cause of this fish kill was a unique combination of factors that led to a severe epizootic outbreak. Despite the complexity of this fish kill, once the interdependent causative factors have been identified, one can formulate data-supported conclusions regarding likely contributing factors, and from those, determine what management actions could have been undertaken to prevent such an outbreak.

In this instance, low flow from Iron Gate Dam was a substantial causative factor in the fish kill of 2002. It is also the only factor that is controllable by human action. Had the flow from Iron Gate Dam in August and September been at or above approximately 1000 cfs, as they were in all other years of above average escapements, it is likely that the fish kill would not have occurred.



Estimated numbers of dead Chinook salmon per fish kill survey area within the Yurok Reservation.

Introduction

On September 19, 2002, reports of dead and dying fish in the Lower Klamath River were received by the Yurok Tribal Fisheries Program and other fisheries agencies. By September 27, over 34,000 fish, mostly adult fall Chinook salmon, were dead in the Lower Klamath River. This fish kill was unprecedented for returning adult salmon on the Klamath River, profoundly affecting the Yurok People and other local residents both economically and spiritually.

As noted by the elders of the Yurok Culture Committee on October 3, 2002; "Never in our time have we, the elders of the Yurok Culture Committee, seen such a mass destruction of our salmon resource." Despite repeated inquiries, the Yurok Tribal Fisheries Program could find no evidence of such an event recorded in Yurok myth, legend, and stories that have been passed along from generation to generation, even though salmon have formed a central pillar of Yurok spirituality, culture, and society. No fisheries management agencies are aware of any historical accounts of large-scale adult Chinook salmon fish kills on the Klamath. With this background it was concluded that something unique, or a unique combination of factors, caused the catastrophic fish kill in 2002. The purpose of this report is to understand the causes of the fish kill of 2002 so that the reoccurrence of such a tragedy can be prevented.

Because an adult fish kill of this magnitude is unique for the Klamath River, investigations into the cause of the kill must focus on the differences between 2002 and previous years when fish kills did not occur. This report takes a general approach of: 1) analyzing available facts and data, 2) looking for empirical data correlations and relationships, and 3) reaching data-supported conclusions regarding the cause of the fish kill based on data and known relationships.

Background: The Klamath River Fish Kill of 2002

<u>Chronology</u>

On September 19, 2002, the Yurok Tribal Fisheries Program began receiving reports of dead and dying adult salmon and steelhead on the Klamath River. Independent reports were received from near Weitchpec (river mile 44), and from near the mouth of the river. Based on these reports, the Yurok Tribal Fisheries Program (YTFP) launched a full-scale investigation in cooperation with the Karuk Tribe, the Hoopa Valley Tribe, the U.S. Fish and Wildlife Service (USFWS), and the California Department of Fish and Game (CDFG). Initial investigations started on Friday September 20. Participating agencies divided the river up into reaches, floated assigned reaches by boat and surveyed for dead and dying fish. The initial survey reported several thousand dead adult salmon in the lower reaches of the Klamath River below Blue Creek (River mile 16). No dead fish were observed in the Klamath River above the confluence of the Trinity River.

From September 20 forward, the rate of mortality increased dramatically and by the time the fish kill had run its course, an estimated 34,000 adult fall Chinook and coho migrating spawners had died.[1] It was clear that the Klamath had suffered an unprecedented biological catastrophe.

Location, Magnitude, and Species Affected: The fish kill event was generally confined to the lower 30 miles of the Klamath River on the Yurok Indian Reservation in northwest California (Figure 1). Few dead fish were observed in the Klamath River above the confluence with the Trinity River, or in the lower Trinity River.

Utilizing data supplied by CDFG and the Yurok Tribal Fisheries Program, USFWS used standard quantitative methods[2] to estimate the magnitude of the kill. The official estimate, as stated by USFWS, stands at 34,925 dead salmonids.[3] CDFG and USFWS have both acknowledged that the estimate is conservative.[4]

Data show that the fish kill primarily affected adult *Oncorhynchus tshawytscha* (Chinook salmon), although *Oncorhynchus kisutch* (coho salmon), *Oncorhynchus mykiss* (steelhead), and smaller numbers of *Acipenser medirostris* (green sturgeon)[4], *Catostomus rimiculus* (Klamath small scale sucker), *Alosa sapidissima* (American shad), *Rhinichthys osculus* (speckled dace), and *Oncorhynchus clarki (*cutthroat trout), were also observed. Approximately 97% of the salmonid mortalities were adult Chinook salmon. Coho salmon were also affected; 344 total coho of which 315 and 29 were of hatchery and natural origin respectively. For more detailed information regarding the magnitude and species composition of the fish kill, see USFWS report titled *Klamath River Fish Die-off September 2002, Report on Estimate of Mortality*. [5]

[1] USFWS, Klamath River Fish Die Off September 2002:. Report on Estimate of Mortality Number AFWO-02-03, November 7, 2003.
[2] AFS (American Fisheries Society). 1992. Investigation and valuation of fish kills. AFS Special Publication 24. AS. Bethesda, MD.
[3] USFWS, Klamath River Fish Die Off September 2002: Report on Estimate of Mortality Number AFWO-02-03, November 7, 2003.
[4] Only one dead green sturgeon was found.
[5] USFWS, Klamath River Fish Die Off September 2002: Report on Estimate of Mortality. Report Number AFWO-02-03, November 7, 2003.

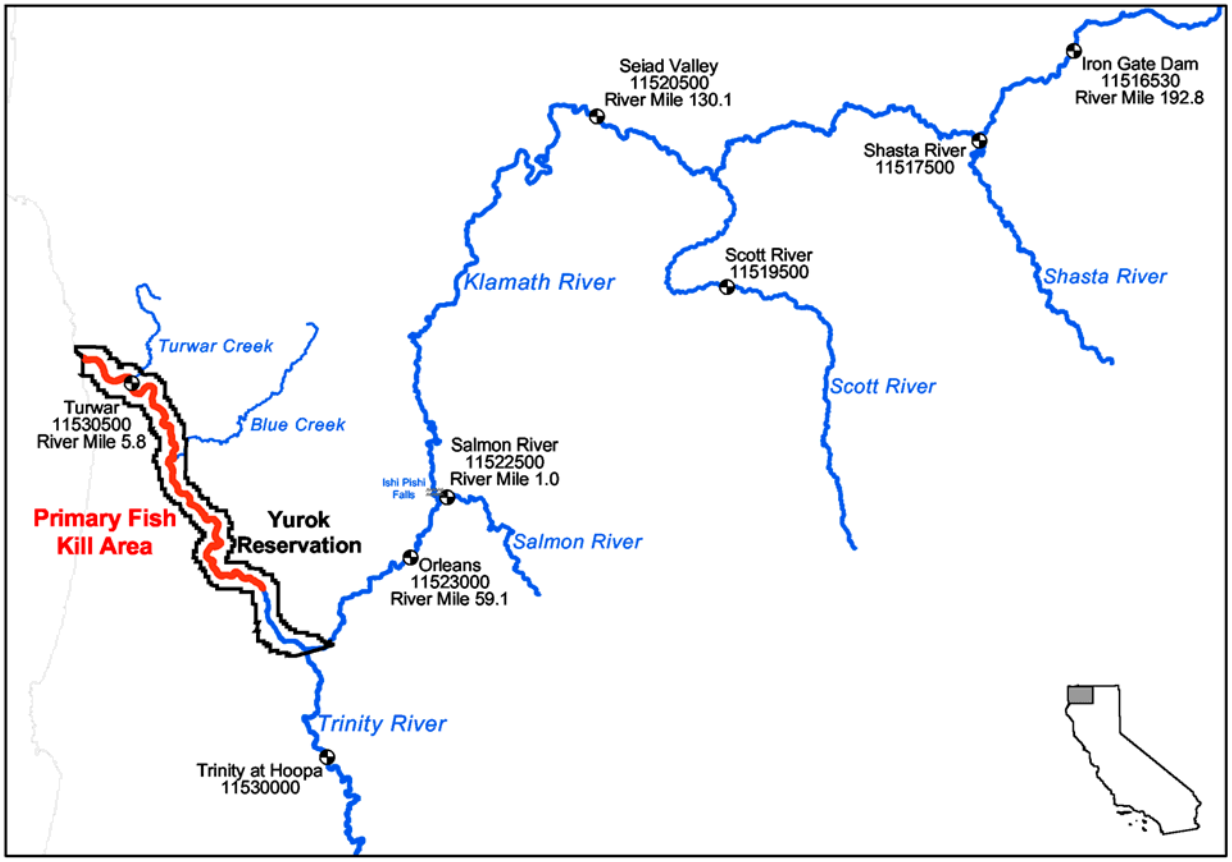


Figure 1: Gauge location map of the Klamath Basin showing primary location of the 2002 fish kill. The fish kill was generally confined within the boundaries of the Yurok Indian Reservation.

Clinical Cause of Death

The clinical cause of mortality was massive infections of ich and columnaris. This fact was confirmed by direct observations, as well as pathology reports by USFWS[6] and CDFG.[7]

Ich is a ciliate protozoan parasite found throughout the world. Outbreaks of ich occur when conditions are favorable for rapid multiplication of the parasite, such as warm water, high fish densities, and stressed fish. Stress to fish can result from poor water quality and high densities. The adult phase of this parasite is called a trophozoite, and resides and feeds on the skin and gills of the infected fish. These are visible as small white spots on infected fish, and this disease commonly known as "white spot disease". Cysts break off the fish, find substrate (the bottom of the river), and multiply into thousands of free swimming bodies called tomites. The free swimming tomites then seek out a new host, grow to full size, and the cycle repeats itself. Larger, sexually mature fish, such as those that died in the Klamath River fish kill, are more susceptible to ich[8]and[9]. Development and growth of the life stages of this parasite are highly dependent on temperature; the detached reproductive stage develops in approximately 10 to 14 days at 59°F as opposed to 3 to 4 days at 69.8°F. [10] Daily maximum water temperatures were within the higher temperature range for approximately 12 days two weeks prior to the fish kill (Figure 2). Temperatures above 69.8° to ich were also present in all years from 1997 through 2001 (Figure 16). For infections of ich in hatcheries, increasing the flow is often used to ameliorate the infection.[11–12]

Approximately 20-26 days after a heavy infection by ich, at 71.6°F (22°C), mortality occurs[13]. Given that ich cannot survive in salt water (salt is a treatment for ich[14]), infection could only begin after the fish entered freshwater. Therefore, the fish that died from ich in the lower Klamath River must have entered the fresh water, become infected, and remained in the lower River at least 20-26 days. This evidence suggests that there was a migration delay in the fall of 2002 (see discussion on page 33).

---

[6] USFWS Klamath River Fish Die-Off September 2002: Causative Factors of Mortality. Report Number AFWO-F-02-03. November 7, 2003

[7] State of California, The Resources Agency Department of Fish And Game. 2003. September 2002 Klamath River Fish Kill: Preliminary Analysis of Contributing Factors Special Report

[8] Pickering, A. D., and P. Christie. 1980. Sexual differences in the incidence and severity of ectoparasitic infestations of the brown trout, Salmo trutta L. Journal of Fish Biology 16:669-683.

[9] Wurtsbaugh, W. A., and R. A. Tapia. 1988. Mass mortality of fishes in Lake Titicacca (Peru-Bolivia) associated with the protozoan parasite Icthyophthirius multifilis. Transactions of the American Fisheries Society 117:1722-1725.

[10] Traxler et al, Ichithyophthirius multifiliis (Ich) Epizootics in Spawning Sockeye Salmon in British Columbia, Canada. Journal of Aquatics Animal Health 10:143-151, 1998.)

[11] Post, George. 1987. *Revised and Expanded Textbook of Fish Health*. T.F.H. Publications, Inc. Neptune City, NJ.

[12] L.R. Bodensteiner, R.J. Sheehan, and P. S. Wills 2000. Flowing Water: An Effective Treatment for Ichthyophthiriasis. Journal of Aquatic Animal Health: 12: 209-219.

[13] Lom, Jiri, and Dykove, Iva. 1992. Ciliates (Phylum Ciliophora Doflein, 1901) in *Protozoan Parasites of Fish.* Elsevier Publisher Amsterdam, London, New York, Tokyo.

[14] Ibid

<u>Intermediate Conclusion on Conditions for Ich:</u> The presence of ich in the system was not unique to 2002, as ich has been endemic to the River. Temperature conditions within the area of the fish kill were conducive to the ich reproductive cycle in all years for which we have temperature records, 1997 through 2001, with no epidemic occurrences. Fish that died from ich were in the lower Klamath River for at least 20-26 days, which appears to indicate a migration delay was a unique contributing factor in 2002 that increased fish density in the lower River.

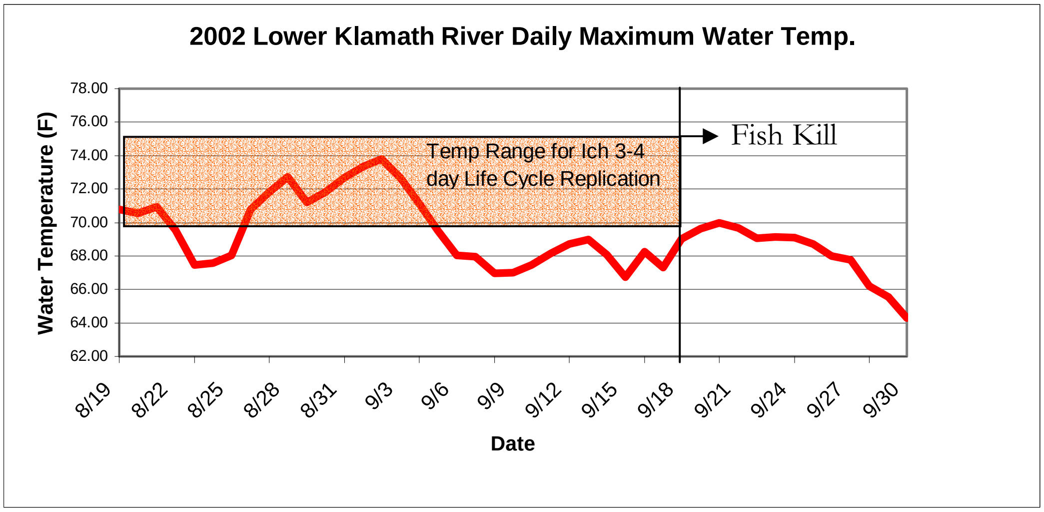


Figure 2: The rate of development of the increases with temperature. The detached reproductive stage of the Ich life cycle may be completed in 3-4 days at 69.8F – 75.2F (21 – 24 Degree C) or 10-14 days at 59F (15 Degree C).

Columnaris is common throughout the world, and is present at all times in the aquatic environment. In general, columnaris is not a problem unless water temperatures are higher than optimal[15]. Overcrowding of fish can also exacerbate problems with columnaris[16] In several previous years, columnaris has been observed in migrating Klamath River fall Chinook[17], but prior to 2002, had not caused widespread mortalities.

---

[15]Post, George. 1987. *Revised and Expanded Textbook of Fish Health*. T.F.H. Publications, Inc. Neptune City, NJ.
[16] Ibid
[17] Yurok Tribal Fisheries Program, unpublished data.

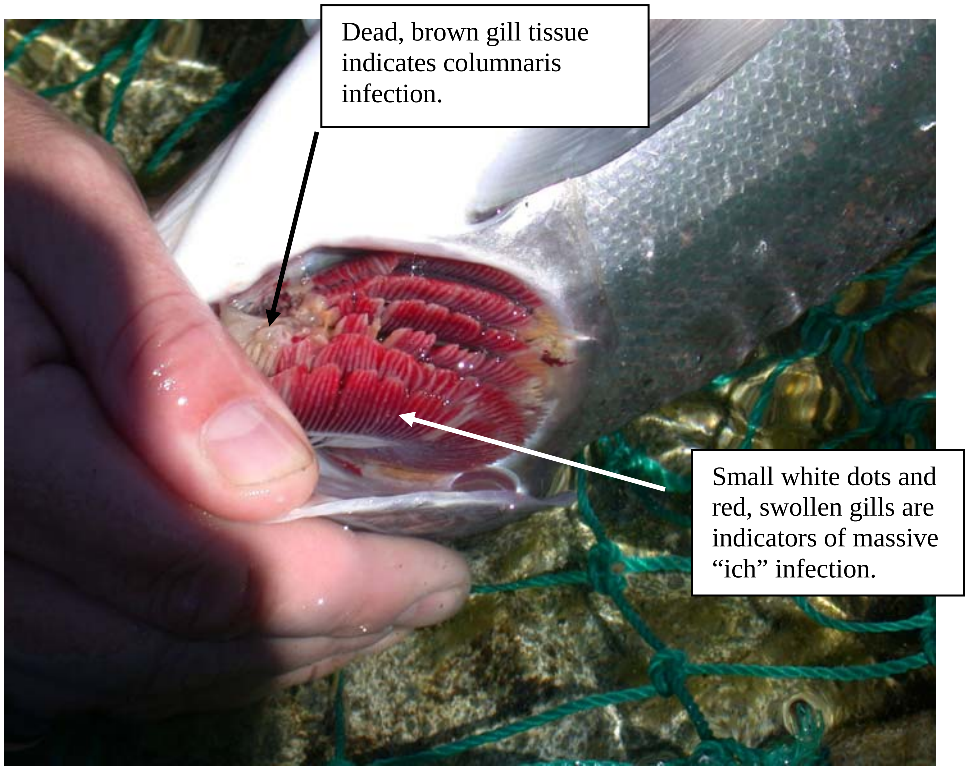


Figure 3: Photograph of steelhead captured alive with landing net in fish kill zone on September 24, 2002. Gills clearly show effects of dual "ich" and columnaris infections. Healthy gills are a uniform pink (Photo taken by Yurok Tribal Fisheries Program).

Analysis of Potential Contributing Factors

This section examines available data regarding environmental parameters that could be potential contributing factors to the fish kill event. The goal was to isolate factors, or combinations of factors, unique to 2002 which were not present in other years with similar hydrologic conditions. Parameters examined include: water temperature, run size and timing, estuary gauge height, river flow rates, dissolved oxygen, pH, ammonia, and possible water born toxins. Also reviewed were investigations of fish kills in British Columbia to determine if any factors in those fish kills were similar to the Klamath River event.

Period of analysis: Preliminary Yurok Tribal Fisheries Program harvest data show that the 2002 fall Chinook run had entered the River from the ocean for its upstream migration during the week ending August 19, 2002. Because the fish kill had largely subsided within a week of its beginning, September 27 was selected as the end of the period of analysis. September 27 was also the date that PacifiCorp released increased the flow from Iron Gate Dam in response to the fish kill. Although run timing can vary somewhat from year to year, the period of August 19 to September 27 generally encompasses the onset of the upstream migration of the fall Chinook run in the Klamath (Figure 4). Unless specifically stated otherwise, all charts and graphs will use this time period as the period of analysis.

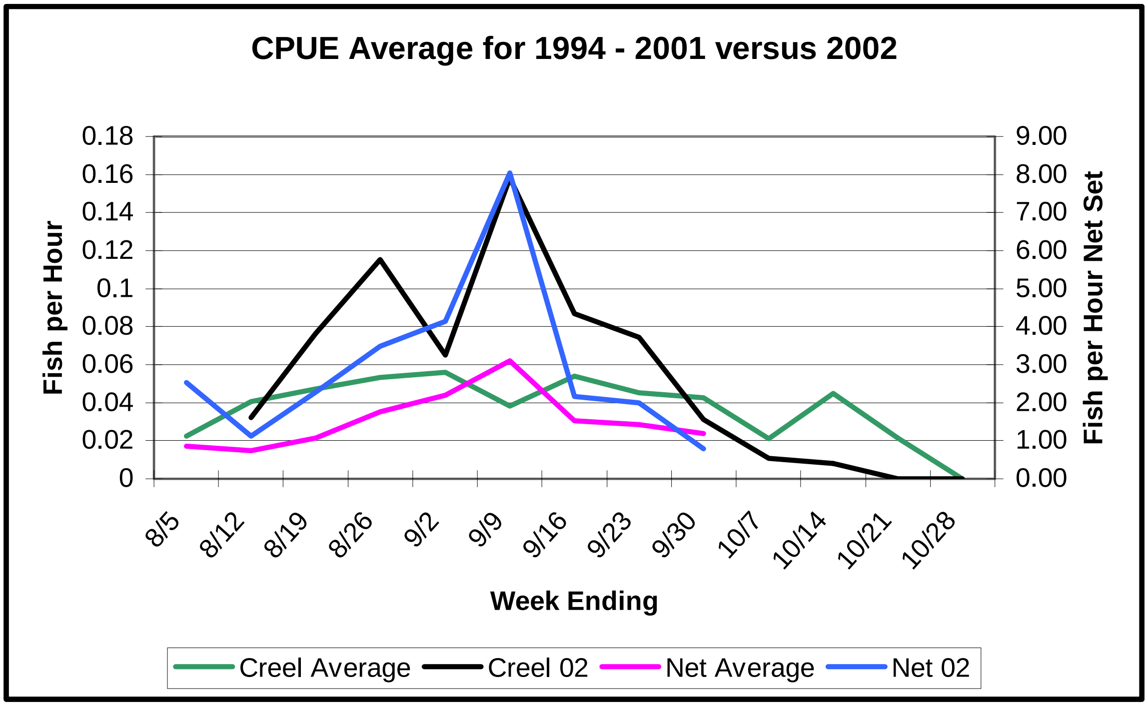


Figure 4: Run timing for the Klamath River in 2002 based on estimated average Catch Per Unit of Effort (CPUE, i. e. fish caught per hour) for the Yurok Estuary Net Harvest and Lower Klamath River Sport Creel compared with average run timing from 1994-2001[18].

Factors needed for epidemic occurrence: For an epidemic such as occurred in 2002 to occur, three factors must be present: the pathogen must be present, environmental conditions must be favorable for the pathogen to thrive, and a host for the pathogen must be present and susceptible.

1) Pathogen present: The two primary pathogens, ich, and columnaris are ubiquitous to the Klamath River, that is, they are present in at least low levels at all times.

2) Environmental Conditions: Warm water temperatures speed up the life cycle of ich while simultaneously reducing the resistance of the host fish. The same is true for columnaris. The temperatures present before and during the time of the fish kill were high enough so that the ich organism could develop into its detached reproductive stage in 3-4 days[19] (Figure 2).

3) Host present and susceptible: The ocean escapement of 160,000 adult Chinook salmon to the Lower Klamath was above average. After estuary tribal and recreational harvest, approximately 140,000 were present in the river immediately prior to the fish kill. Water

[18] CDFG: September 2002 Klamath River Fish Kill Final Analysis (Draft Report, figure used with permission).

[19] Traxler et al, *Ichithyophthirius multifiliis* (Ich) Epizootics in Spawning Sockeye Salmon in British Columbia, Canada. Journal of Aquatics Animal Health 10:143-151, 1998.)

temperatures were high, which contributes to stress of the fish and renders them even more susceptible under crowded conditions. The salmon, as host organisms for the ich disease, were present in large numbers immediately preceding the epidemic. Fish density has been shown to be an important factor in the transmission of ich. The free swimming life stage of ich has a short life span that requires rapidly locating a host fish; crowded fish conditions promote rate of infection. Crowded conditions are also stressful to fish, which makes them more susceptible to ich. Higher densities of fish can lead to explosive multiplication of the disease organism and large-scale fish mortalities[20].

Selective Years for Comparative Analysis: As with many diseases, ich and columnaris proliferate when fish densities become extreme. Since flow and run size can both contribute to high fish densities, this investigation into causative factors of the fish kill considered years when low flows occurred in conjunction with relatively large fish runs.

Data were analyzed to identify years with the combination of relatively low flows and high escapements. USGS estimated September 1–24, 2002 period low-flow conditions in the reach of the Klamath River where the fish die-off occurred by averaging and adding together flow measured during this period at the Trinity River at Hoopa and the Klamath River at Orleans gauges and compared with their historical average summed September flows. September 2002 flows in the reach where the die-off occurred were the sixth lowest since 1964. On the basis of this analysis, lower September flows occurred in 1981, 1991, 1992, 1994, and 2001.[21]

Recorded flow releases at Iron Gate Dam show the same categorical low water years with 2002 having the second lowest average since 1985 (Figure 5). The years 1985 through 2002 were selected for analysis as they cover the time period of consistently recorded estimates for Klamath River adult fall Chinook run, harvest, and escapement. Years with 1000 cfs or less average September flow from Iron Gate Dam were 1992, 2002, 1991, and 1994 in ranked order (Figure 5).

---

[20] Traxler, G. S., J. Richard, and T. E. McDonald. 1998. *Icthyopththirius multifiliis*. Journal of Aquatic Animal Health 10:143-151.

[21] U.S. Department of the Interior U.S. Geological Survey *Klamath River Basin Hydrologic Conditions Prior to the September 2002 Die-Off of Salmon and Steelhead* DENNIS D. LYNCH and JOHN C. RISLEY Water-Resources Investigations Report 03–4099

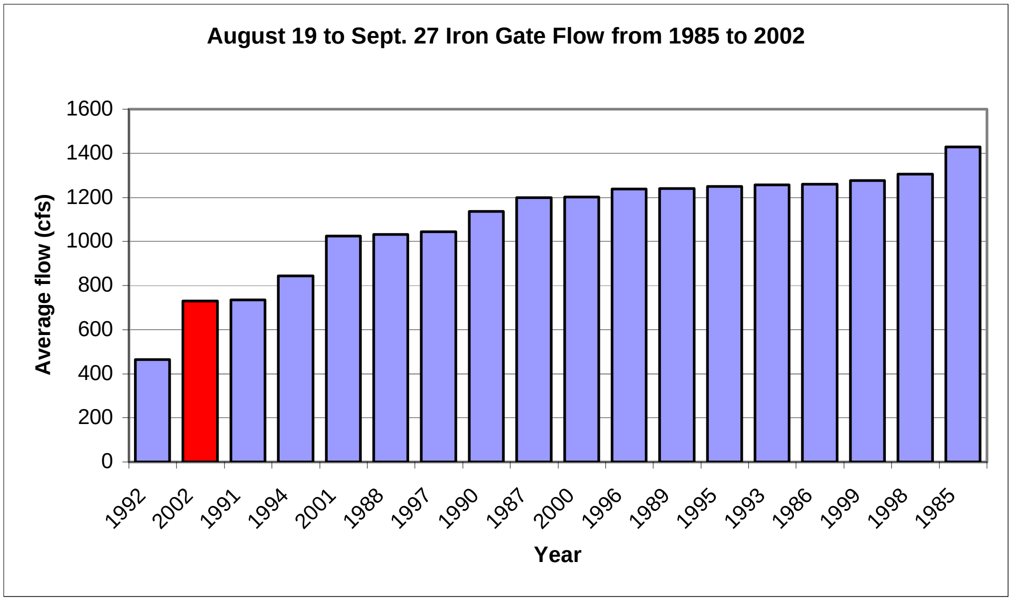


Figure 5: Ranked order of 1981 through 2002 average Aug. 19 – Sept. 27 flow release from Iron Gate Dam, (September 2002 was averaged from September 1 through September 27 when flows were increased in response to the fish kill).

The 1981 through 2002 adult fall Chinook run size or ocean escapements (those fish that escape ocean harvest and enter the River estuary from the ocean) range from 217,900 in the year 2000 down to 26,700 in 1992 (Figure 6). The 2002 ocean escapement was 160,000. The average ocean escapement since 1981 is 109,200.

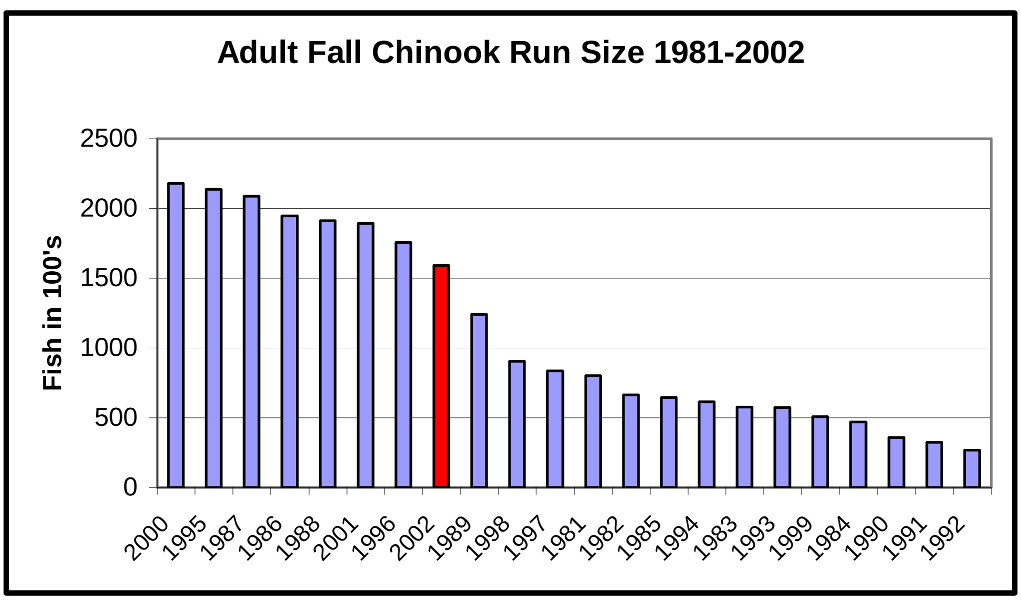


Figure 6: Ranked order of adult fall Chinook ocean escapements 1981 through 2002 (red column is 2002).

During the period of 1981 – 2002, there were only three years when above average ocean escapement coincided with flows near or below 1,000 cfs at Iron Gate Dam; those being 1988 with a run of 191,300, 2001 with 189,300, and 2002 with an escapement of 160,000 (Figure 7). It is possible that the 2002 run size may have been underestimated based on the likelihood that mortalities in the fish kill were underestimated. The USFWS, in investigating other valid but less conservative estimators than those used in their final report, calculated that the estimated mortalities may have been 100 percent greater and the 2002 ocean escapement may have been as high as 203,000 adult fall Chinook.[22] Based on the combination of low flow and high escapements, the years 1988, 2001, and 2002 were chosen for comparative analysis. All other low flow years had relatively small ocean escapements (See Table 1).

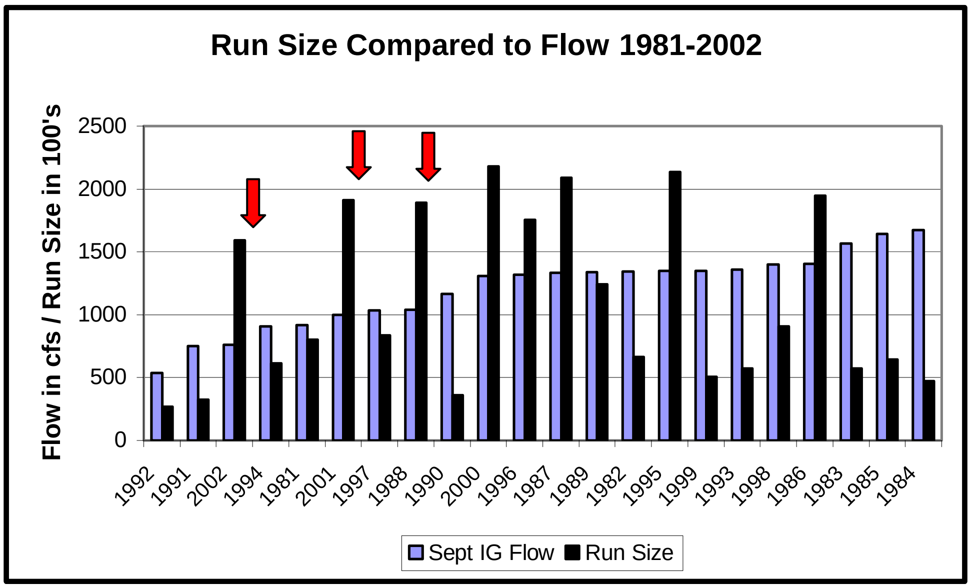


Figure 7: Ocean escapement of adult fall Chinook compared to average September Iron Gate Dam flow releases. Years are ranked from the lowest September flow releases to the highest.

[22] USFWS Klamath River Fish Die-Off September 2002: Causative Factors of Mortality. Report Number AFWO-F-02-03. November 7, 2003 (at pg 9)

Comparison of Iron Gate flow releases with ocean escapement of fall Chinook reveals that the year 2002 is unique as an extremely low flow year (based on Iron Gate releases) with an above average run size (Figure 8).

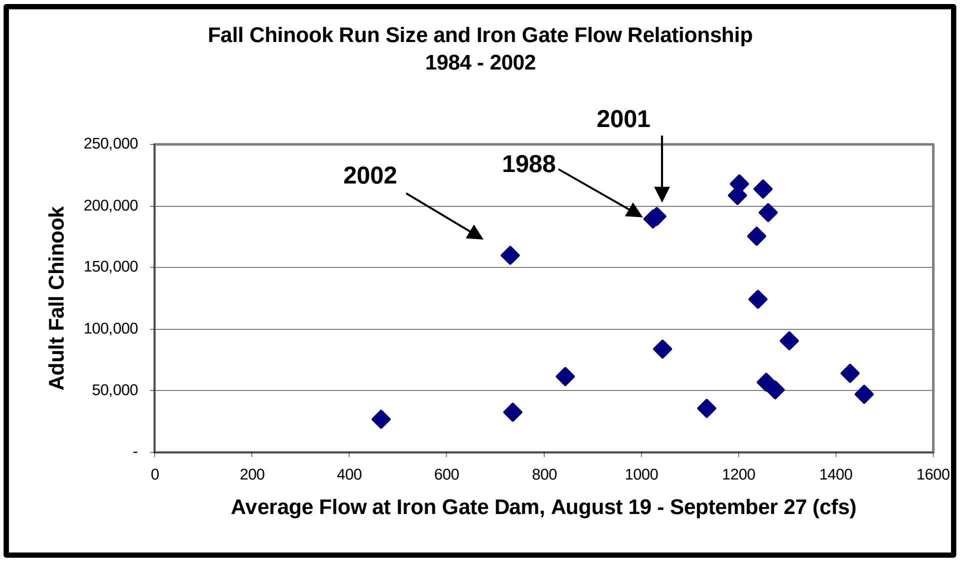


Figure 8: Scatter plot comparing values of average September Iron Gate Dam flow releases and total adult fall Chinook ocean escapement.[23]

Table 1: Low flow years from Figure 5 with run sizes by year from Figure 6, the low flow years with the highest ocean escapements (1988, 2001, and 2002) were selected for comparative analysis. The other low flow years had relatively smaller ocean escapements.

Average September Iron Gate Flow and Run Size for Low Flow years		
Year	**Run Size**	**Iron Gate Flow**
1992	26,700	538 cfs
1991	31,700	749 cfs
2002*	**160,000**	**760 cfs**
1994	61,600	906 cfs
1981	77,300	916 cfs
2001*	**189,300**	**1000 cfs**
1997	83,600	1035 cfs
1988*	**191,300**	**1038 cfs**

[23] Klamath River Technical Advisory Team 2002. Ocean Abundance Projections and Prospective Harvest Levels for Klamath River Fall Chinook, 2002 Season

<u>Intermediate Conclusion on Years to Compare</u>: From 1985 – 2002, of the eight lowest flow years 1988, 2001, and 2002 had the highest ocean escapements of adult fall Chinook. Those three years were chosen for comparative analysis.

<u>Flow:</u>

Of the environmental variables examined in this report, flow showed the most variation. In general, compared to the past 18 years, the flows of 2002 were among the lowest. At Iron Gate Dam, 2002 flow releases for the period of August 19 through September 27 were the second lowest for the past 18 years (Figure 9).

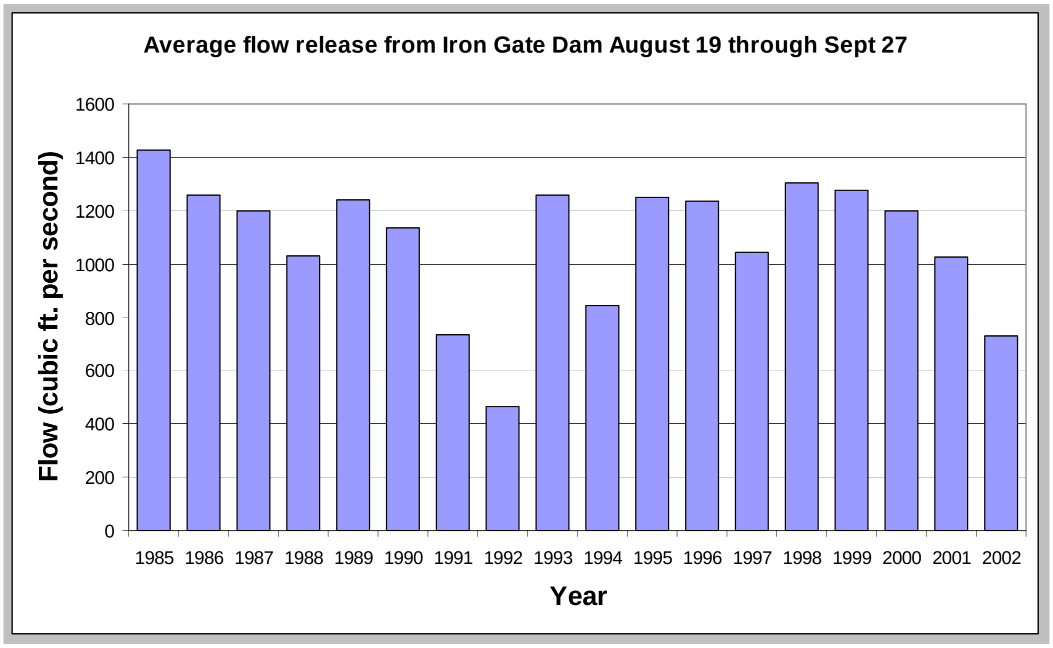


Figure 9: Average August 19-September 27 flow releases at Iron Gate Dam for the past 18 years[24]. The 2002 releases for that time period were the second lowest on record.

<u>Iron Gate Flow Comparisons</u>

Flows released at Iron Gate Dam have a profound influence on the magnitude of flow downstream in low water years. In 2002 in response to the fish kill PacifiCorp released additional flows from Iron Gate Dam raising the flow rate from 757 cfs to 1350 cfs. Figure 10 shows the percent of Iron Gate contribution to flows passing select down stream gauge sites. At the onset of the fish kill on September 19, the flows at the estuary are estimated to have been 2010 cfs. After the release of extra water from Iron Gate the flows increased to an estimated 2580 cfs; an increase in volume of about 28 percent.

As the chart shows, at the Seiad Gauge, which is 60 miles below Iron Gate Dam, Iron Gate flows, after the release increased to 1350 cfs, made up 88% of the flows running

[24] USGS flow data from USGS website. 2002 data is provisional.

past the gauge; Iron Gate Dam flow also comprised 73% of the flow past Orleans which is 130 miles below the Dam, and 52% of the flows at the estuary about 190 miles downstream of the Dam.

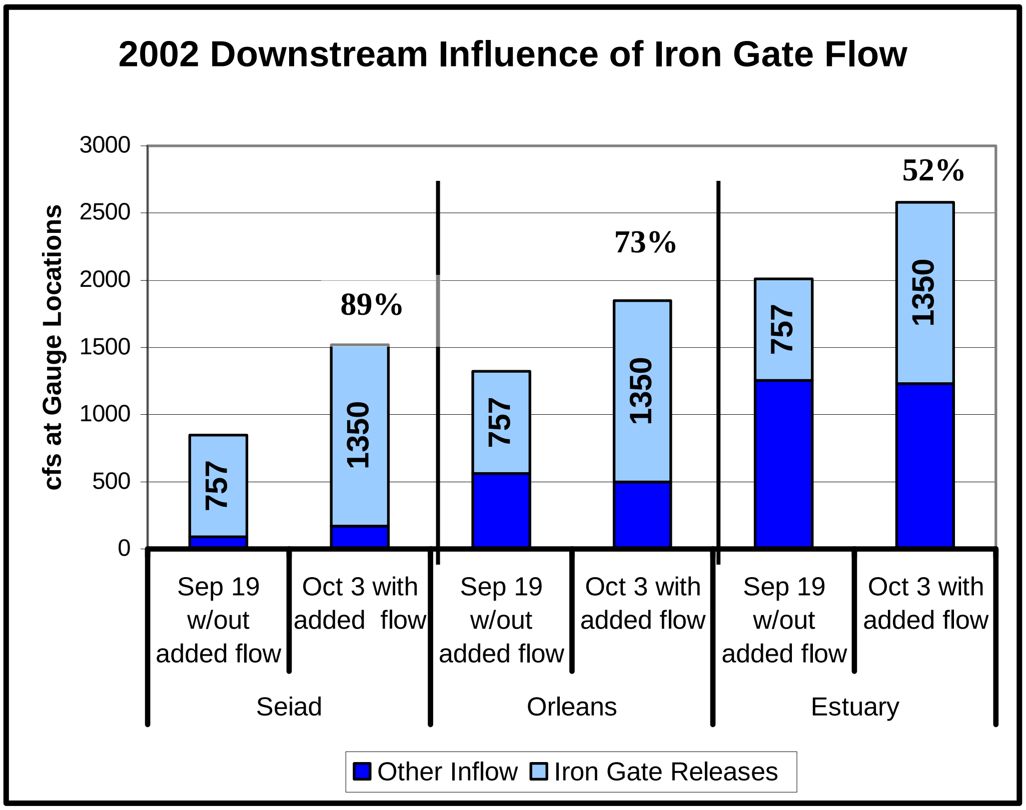


Figure 10: Chart showing the relative contribution of Iron Gate flow at select gauge sites down stream of the Dam before and after PacifiCorp increased Iron Gate releases from 757 to 1350 cfs in response to the 2002 fish kill (i.e. at Orleans Iron Gate flow made up 73% of the flow past that point after the increase.

As Iron Gate flow releases have a direct effect on the magnitude of flow downstream of the Dam, a comparison of the Iron Gate releases in the selected years of 1988, 2001, and 2002 are shown below in Figures 11 and 12. As shown, of the three years, 2002 was the only year in which the flow rates from Iron Gate Dam were less than 1000 cfs in August and September.

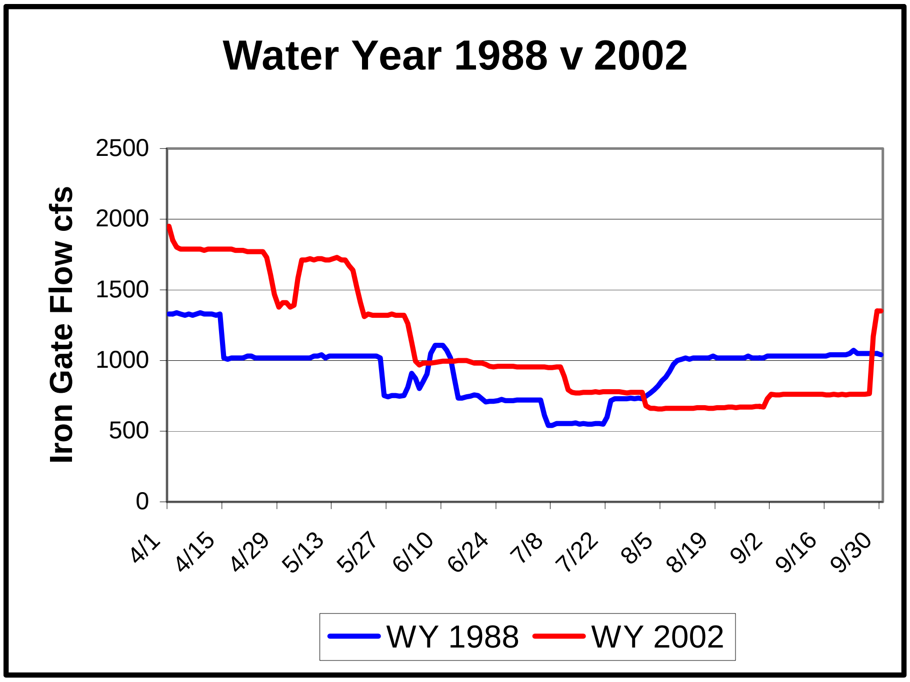


Figure 11: Daily flow releases from Iron Gate Dam during 1988 and 2002 shows increases in flow up to 1000 cfs on August 9, 1988 compared to decrease in flow down to 660 cfs on August 2, 2002.

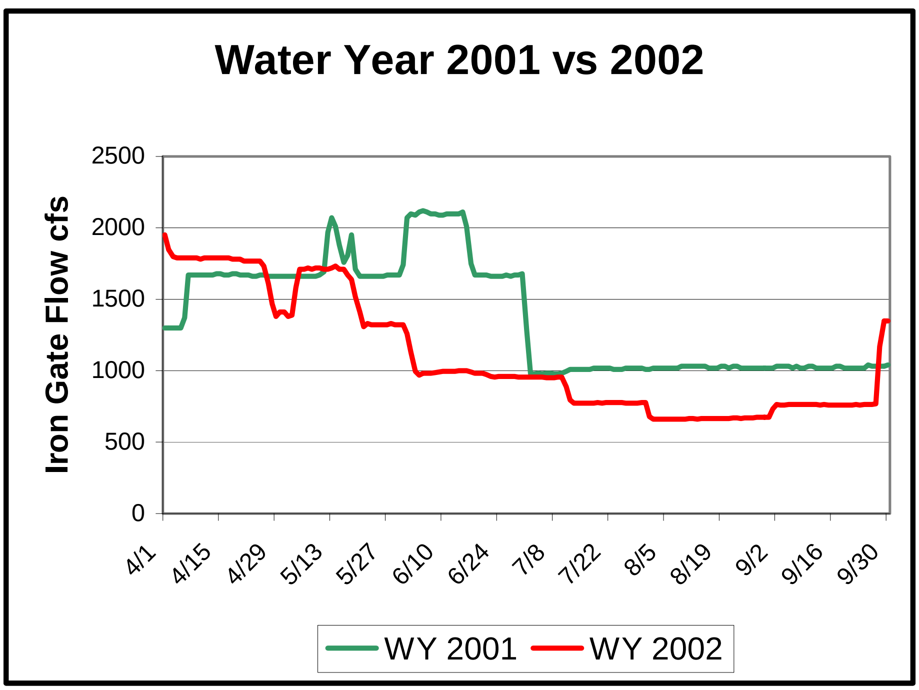


Figure12: Daily flow releases from Iron Gate Dam during 2001 and 2002 shows flow was held at approximately 1010 cfs from July 14 through September, 2001 compared to decrease in flow down to 660 cfs on August 2, 2002 increasing to 762 cfs on September 5.

<u>Intermediate Conclusion on Iron Gate flow</u>: August and September Iron Gate flow releases (from 659-767 cfs) in 2002 were significantly lower than 1988 or 2001 which were at or near 1000 cfs. Increased flow in September 2002 prior to the fish kill (to 1300 cfs) would have increased flow in the lower river by approximately 25% and relieved crowding.

<u>Mid-Klamath Gauge Comparisons:</u>

Reported September flows measured at Orleans (river mile 59) were slightly less in 2001 (1,220 cfs) than in 2002 (1,290 cfs). Recorded flow at Orleans being lower in 2001 than 2002 seems to reflect a gauging inaccuracy as gauged releases at Iron Gate and flows near Seiad (river mile 130) were both significantly higher in 2001 than in 2002.

Flow records at the Orleans gauging stations in 2001 and 2002 were rated as having a 10 percent level of accuracy (Friebel and others, 2002).[25] The magnitude of error could account for the minimal measured difference between 2001 and 2002. With a plus or minus 10 percent margin of error, the September 2002 value reported as 1,290 cfs at Orleans is known to be between 1,160 and 1,420 cfs (260 cfs spread) with a 95 percent confidence.[26]

As an estimate of flow entering the area of the fish kill, flows at the Orleans gauge on the mainstem Klamath and flows at the Trinity gauges were summed. Without consideration of the margin of error, the August flows in 2002 were lower than 1988 and slightly higher in the early part of August compared to 2001. Flows for 1988, 2001, and 2002 were within about 200 cfs of each other for the majority of September. USGS analysis of the summed flows placed September 1-24, 2002 as the sixth lowest since 1961.[27]

The year 2001 was unique in that an extra pulse flow from the Trinity River, to accommodate the Hoopa Boat Dance ceremony, spiked flow entering the Lower Klamath to 2800 cfs on August 28 (Figure 13). This pulse flow may have triggered upriver movement of the spawning run in 2001. There was no Trinity pulse flow in 2002 or 1988.

[25] Lynch, Dennis B. and Risley, John C., Klamath River Basin Hydrologic Conditions Prior to the September 2002 Die-Off of Salmon and Steelhead, USGS 2002.
[26] Ibid. at page 5.
[27] Ibid. at page 6

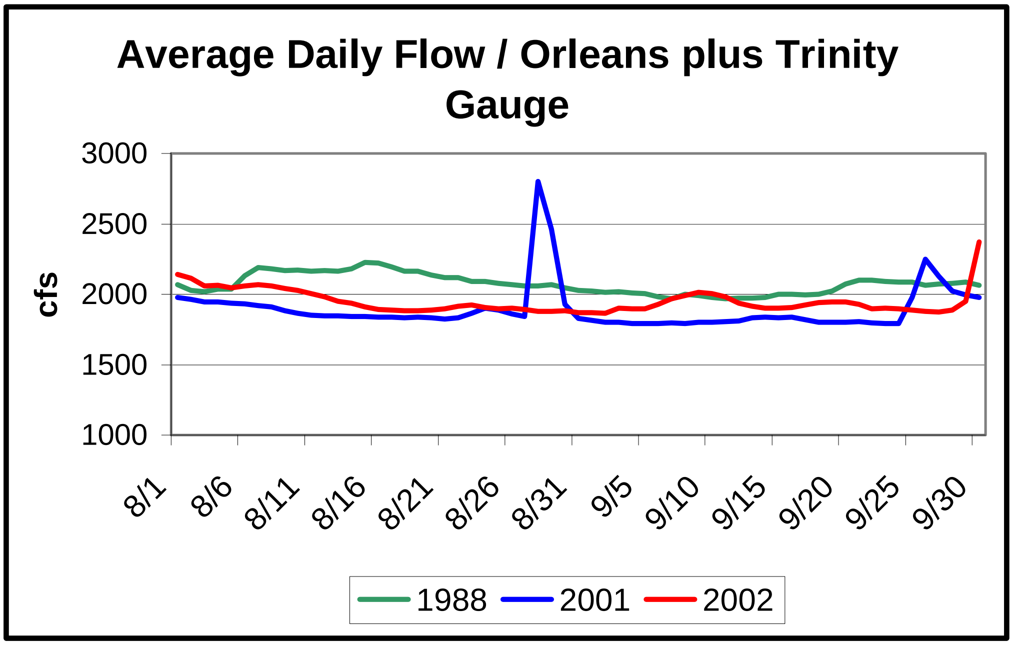


Figure 13: Average daily flows in the River above the area of the fish kill is indicated by the combined flow of the Trinity and Orleans gauges for 1988, 2001, and 2002. (The spike in late August in 2001 was an increase in flows in the Trinity to accommodate the Hoopa Boat Dance Ceremony.)

Intermediate Conclusions on Mid-Klamath Flow: The summed Orleans and Trinity gauge data as an indicator of the flows entering the fish kill area include an unrectified gauge error at Orleans. USGS estimates the flows as being the sixth lowest since 1961. There was an August 28, Trinity pulse flow in 2001 that was not present in 1988 and 2002 that may have stimulated migration and relieved over crowding of fish in the Lower River in 2001.

Lower Klamath Gauge Comparisons

Average flow releases recorded at Terwer[28] gauge for the past 18 years for the period of August 19 through September 27, show the 2002 flows were the third lowest of that period with 1992 and 1994 being the only lower years (Figure 14). Gauge data shows that 1988 estuary flows were markedly higher than 2002, and that 2001 was higher throughout August and approximately the same in early September of 2002 (Figure 15).

Flows near the mouth of the Klamath at Terwer are difficult to assess for several reasons. In low flow years, partial sand spit closures can cause water level backups that affect the stage height, and make flows impossible to measure. In these years, flow is either not reported, or is estimated by using upstream gages and applying a correlation equation. In this case, the USGS reported flows at the estuary should be considered an estimate. Furthermore, the channel near the Terwer gauge is highly mobile, and can shift even during low flow months. These shifts can change the stage-discharge relationship in a non-linear fashion. Therefore, flows reported for the Terwer gage should be used with caution.

[28] This location is spelled as "Terwer", "Turwar", or "Terwar" in various maps, and documents.

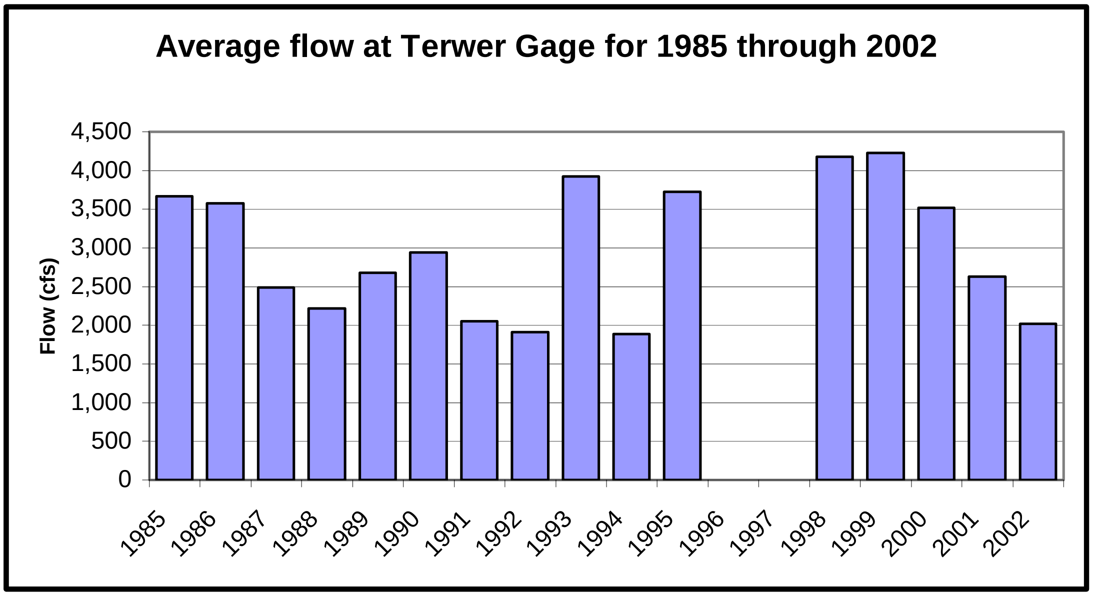


Figure 14: Average flow releases at Terwer gage for the past 18 years for the period of August 19 through September 27. The 2002 flows were the third lowest of that period with 1992 and 1994 being the only lower years. There were no records for 1996 and 1997. As explained in the text, the accuracy of the flow measurements at Terwer is questionable.

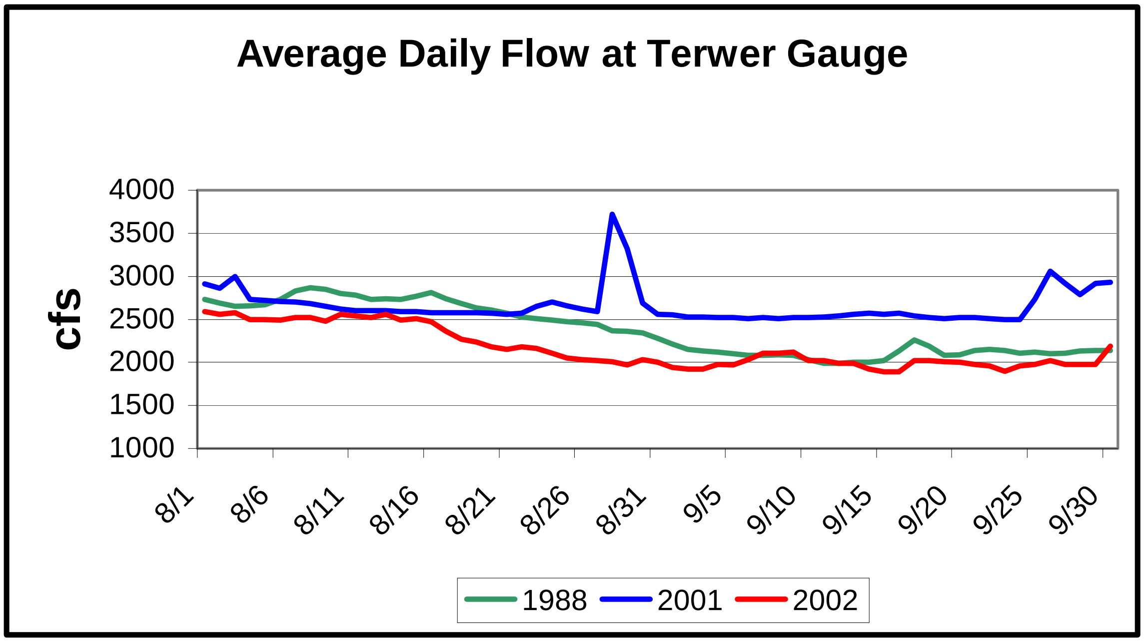


Figure 15: Flow at the Klamath near Klamath gauge for 1988, 2001, and 2002.

<u>Intermediate Conclusions regarding Flows in the Area of the Fish Kill</u>: Data shows that 2001 flows in the lower river were higher than 2002 and 1988 flows were higher than 2002 through August until September 6. Due to tidal influence Terwer gauge data must be used with caution.

<u>Water temperature</u>:

The fish kill occurred primarily in the lower 30 miles of the Klamath River. Water temperatures records for this area are not as complete as air temperature records, as noted in the CDFG report, but water temperatures for the past seven years are available at Weitchpec (rm 44), and Terwer / Omagaar (rm 5 and 10.5).

Using temperature logging devices, the United States Forest Service collected hourly water temperatures on the mainstem Klamath below Weitchpec from 1996 through 2002. One of the sites monitored was located just below the confluence with the Trinity River, and this site was selected for more intensive analysis. Temperatures were taken at 15 minute intervals during 1996 and 1997, at 24 minute intervals in 1998, and from then until the present were taken at 1 hour intervals. This temperature monitoring site was located approximately 8 river miles above the largest concentration of the fish kill. However, because the river is at or near atmospheric equilibrium, temperatures in the vicinity of the fish kill would have been similar to those measured near Weitchpec. Additional water temperatures were obtained from YTFP data at Omagaar Creek (river mile 10.5), and Yurok Environmental Program Data near Terwer Creek (river mile 5). At this location, hourly water temperature data is available from 1996 through 2002 with the exception of the year 2000.

In order to examine the possibility that unusually high water temperatures, or an unusual pattern of water temperatures caused the fish kill, the past six years of daily maximum and minimum temperatures at Weitchpec, and in the Lower Klamath at Omagaar and Terwer, were plotted. The data shows that 2002 was not unusual compared to recent years, and that there were no unusual temperature "spikes" that might have precipitated the fish kill. Temperatures for 1988 are not available for comparison to 2001 and 2002 (Figure 16, 17, 18).

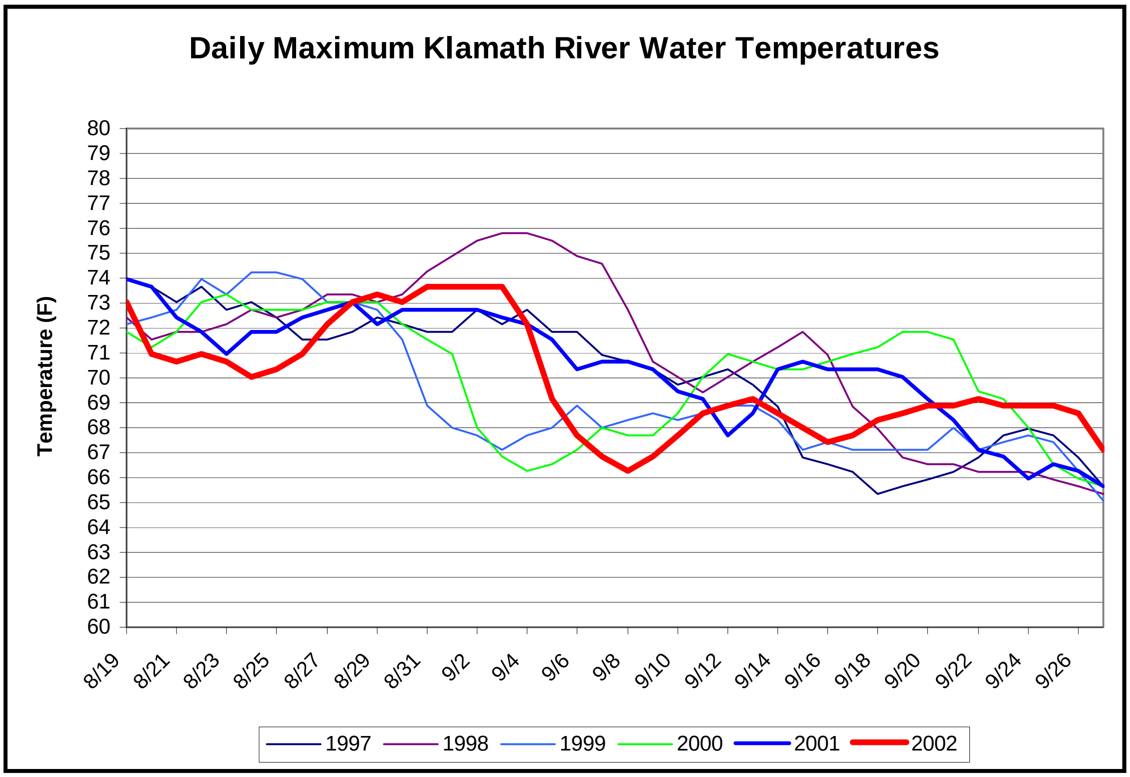


Figure 16: Daily MAXIMUM water temperatures just below Weitchpec (river mile 43).

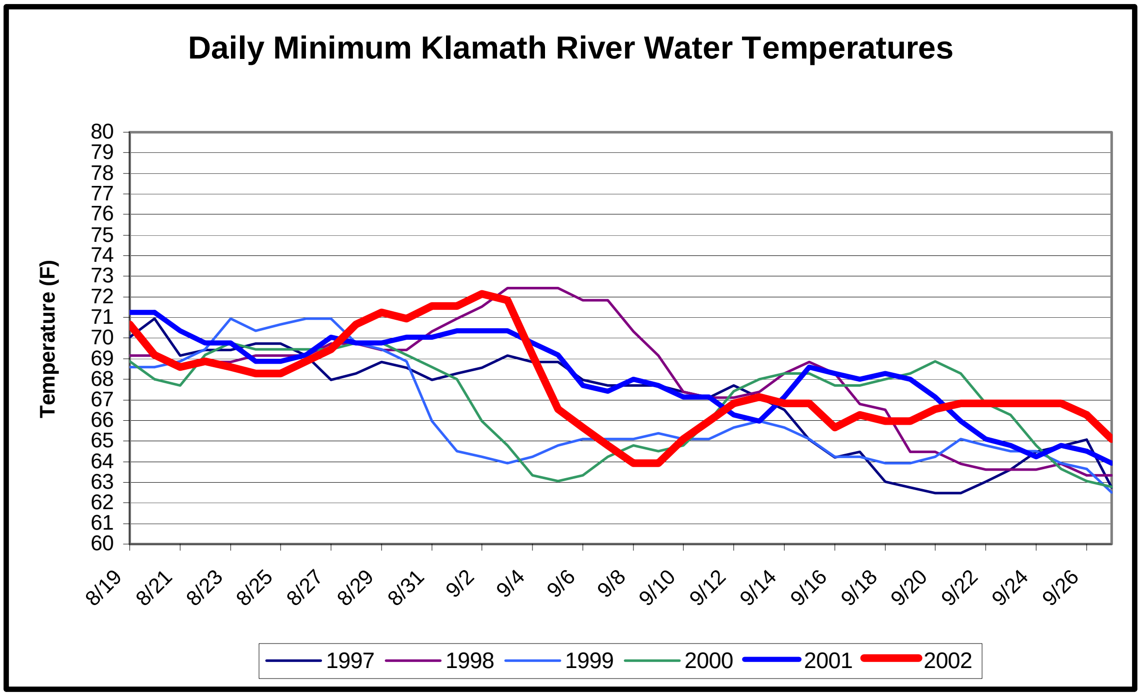


Figure 17: Daily MINIMUM water temperatures just below Weitchpec (river mile 43).

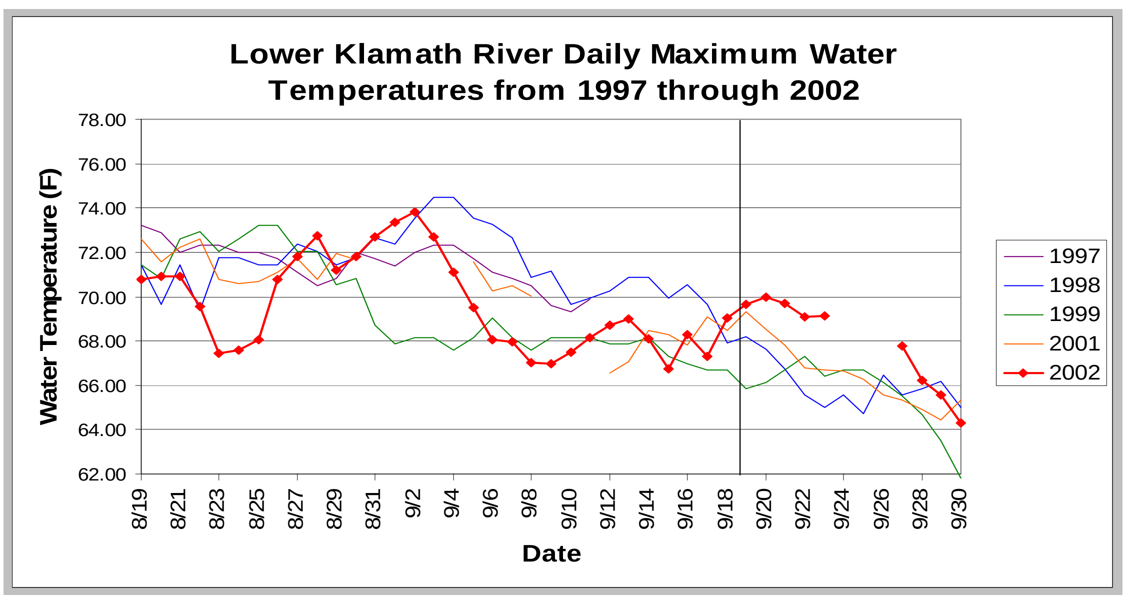


Figure18: Lower Klamath River Daily maximum temperatures measured at Omagaar Creek (river mile 10.5) and at Terwer Gage (river mile 5.6). Temperatures at Omagaar are similar to those at Terwer.

Some have speculated that a sharp drop in water temperatures lead to the fish kill by luring fish into the river where they perished following a subsequent temperature rise. However, figures 16 and 17 show that the pattern of cooling and warming temperatures has happened before in the recent past with no resultant fish kills. Figure 16 shows that during the year 2000, the same type of temperature variation occurred, and during that year water temperatures rose to even higher levels following that drop. The run size in 2000 was over 200,000 fish (larger than the run size of 2002), with very similar temperatures to 2002, yet there was no fish kill that year. The temperatures for 2000 are missing from the Terwer temperature data, however 1999 shows a similar pattern. In general, temperatures from the very lowest portion of the river (such as near Terwer), show a moderating influence of the marine coastal fog layer.

The sharp drop in water temperatures experienced in early September is typical for the lower Klamath. As the photoperiod decreases, and the weather pattern is transitioning from summer to winter climate, the lower Klamath usually experiences several cold fronts, that do not necessarily result in precipitation, but result in cool, cloudy weather during September. These fronts cause water temperature drops such as experienced on the Klamath in 2000 and 2002.

In addition to daily maximum temperatures daily minima must also be considered. In order to investigate the previous years of temperature data in a different manner, an hourly temperature analysis was performed. In this analysis, all temperature records from a single site corresponding to a certain hour of the day were analyzed together, and an average daily temperature trace was produced. For example, the 13:00 (1 pm) temperature represented in the analysis for a given year is obtained by averaging all of the 13:00 temperatures over the August 19-September 27 period of analysis. In this way, a unique daily temperature trace was produced for each year, and these traces were overlain and compared.

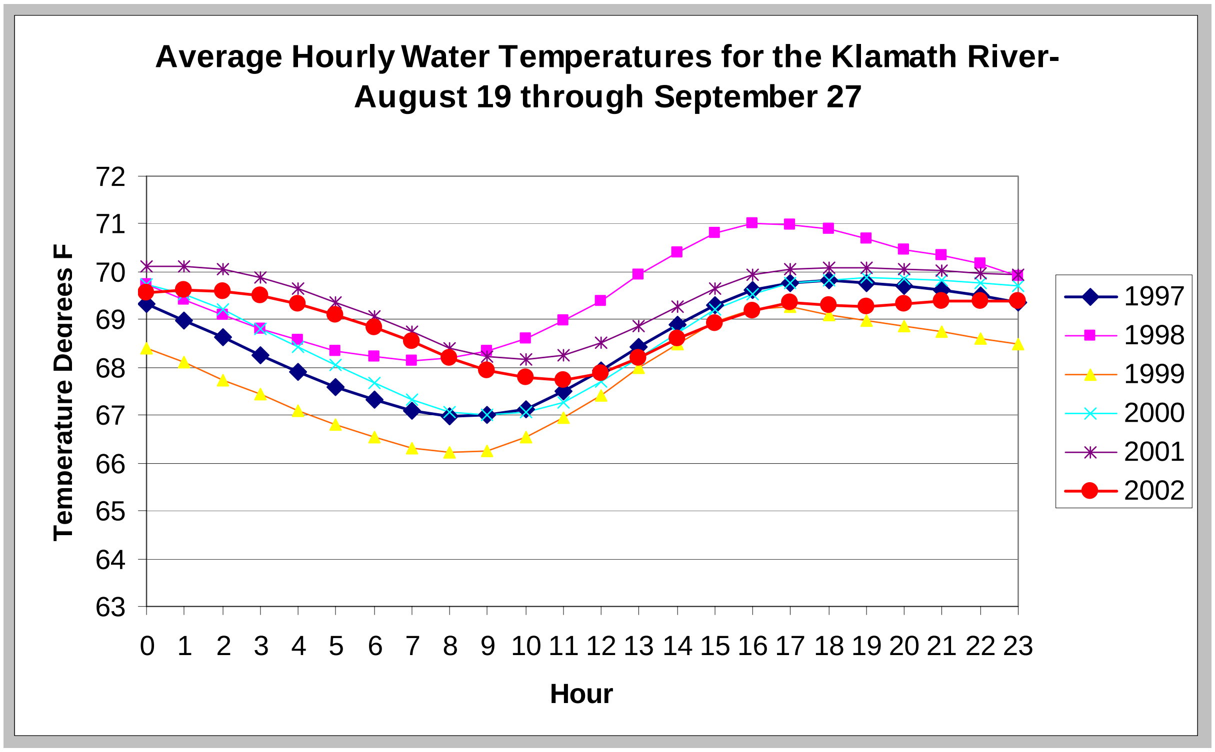


Figure 19: Daily temperature traces for the six previous years for the Klamath River mainstem just below the confluence with the Trinity River (river mile 43).

From figure 19, we can see that 2002 was well within the range of previous years for which water temperature information is available. Night time minima were slightly warmer during 2002 than for 1997, 1999 or 2000 and were slightly cooler than during 1998 and 2001.

To further substantiate that 2002 did not have unusually warm temperatures, all of the temperatures for the period of analysis (August 19 through September 27) were averaged to obtain an overall average temperature. Figure 20 shows that average water temperatures in 2002 were actually significantly cooler than 2001.

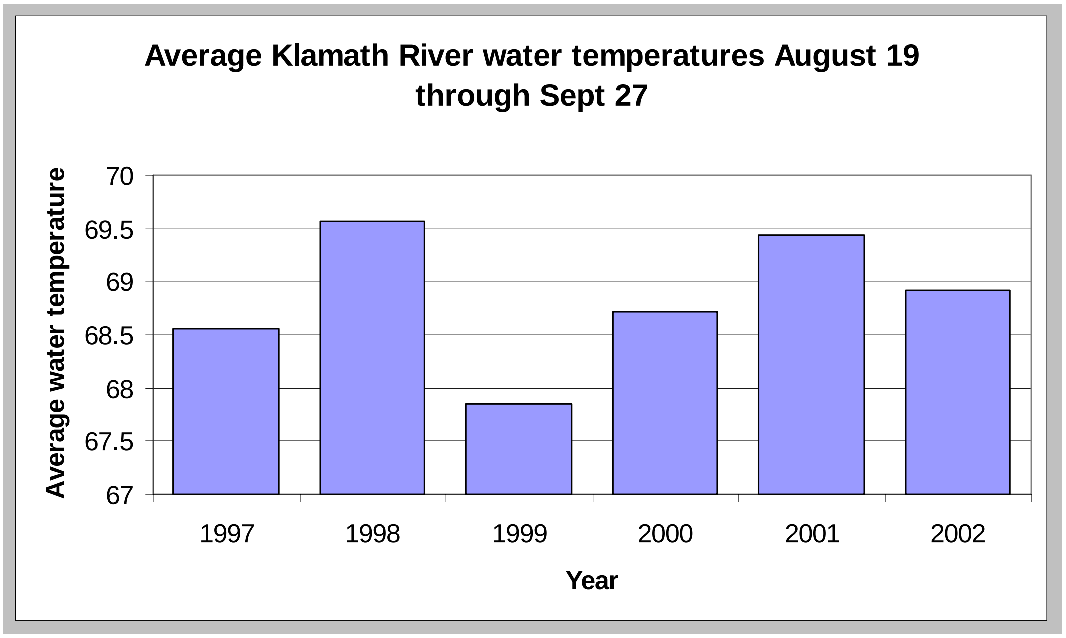


Figure 20: August 19 through September 27 average river temperature at river mile 43 near Weitchpec, CA for the past 6 years.

Figure 20 indicates that average water temperatures were not unusually warm during 2002 when compared to other recent years that did not have fish kills. 1999 featured unusually cool water temperatures due to heavy smoke from a major nearby wildfire. A similar analysis was performed on maximum daily temperatures (Figure 21).

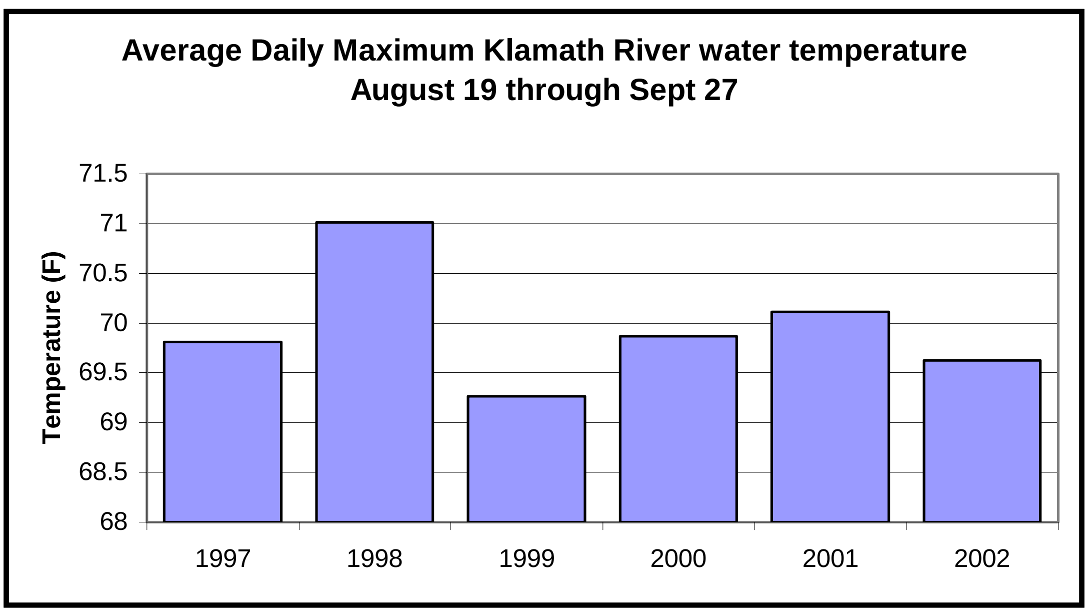


Figure 21: Average daily maximum water temperatures in the Klamath River near Weitchpec for analysis period for past 6 years.

Again, Figure 21 demonstrates that 2002 was not an unusually warm year with regard to average maximum water temperature, and was actually cooler than 2000 and 2001, which had large salmon runs. Average daily maximum temperatures were the coolest of the past 6 years, with the exception of 1999 which was affected by wildfire smoke.

Some parties have claimed that temperatures in the Klamath were lethal to salmon at the time of the fish kill, but the data clearly shows that salmon have migrated through identical and sometimes higher temperatures, before without experiencing high mortalities.

During the time of the fish die-off, concerns were raised by some that the release of additional water from Upper Klamath Lake in September 2002 might worsen the water-temperature problem in the Lower Klamath River. But, USGS found that the:

> "2002 water-temperature data from Upper Klamath Lake and the Klamath River at Orleans suggest that these concerns were unwarranted: Water temperatures in the lake were considerably cooler than in the river at Orleans. Daily maximum and minimum water temperatures in Upper Klamath Lake averaged 65.3 and 61.9 o F, respectively, for the period September 1–24, 2002, as compared to 68.6 and 67.4 o F in the Klamath River at Orleans. A similar temperature differential existed throughout the summer between Upper Klamath Lake and the lower Klamath River, largely owing to the fact that Upper Klamath Lake has a surface elevation of about 4,140 feet, where the nights are much cooler.[29]

Intermediate Conclusions on Temperature: **While temperature may have contributed to the severity of the outbreak by providing stressful conditions for adult salmon and favorable conditions for ich, available water temperature data show that temperatures in 2002 were well within the range of normal recent environmental variability. There is no evidence that this fish kill event was primarily caused by unusually warm water temperatures, or by an uncharacteristic cooling and warming trend.**

[29] Lynch, Dennis B. and Risley, John C., Klamath River Basin Hydrologic Conditions Prior to the September 2002 Die-Off of Salmon and Steelhead, USGS 2002.

Run Size:

The fall Chinook ocean escapement of 2002 was not unusually large. CDFG records show that the ocean escapement of 2002 adult Chinook was the eighth largest run since 1978. Figure 22 shows the run sizes since 1978. The run size in 2002 is best described as somewhat above average, rather than exceptional.

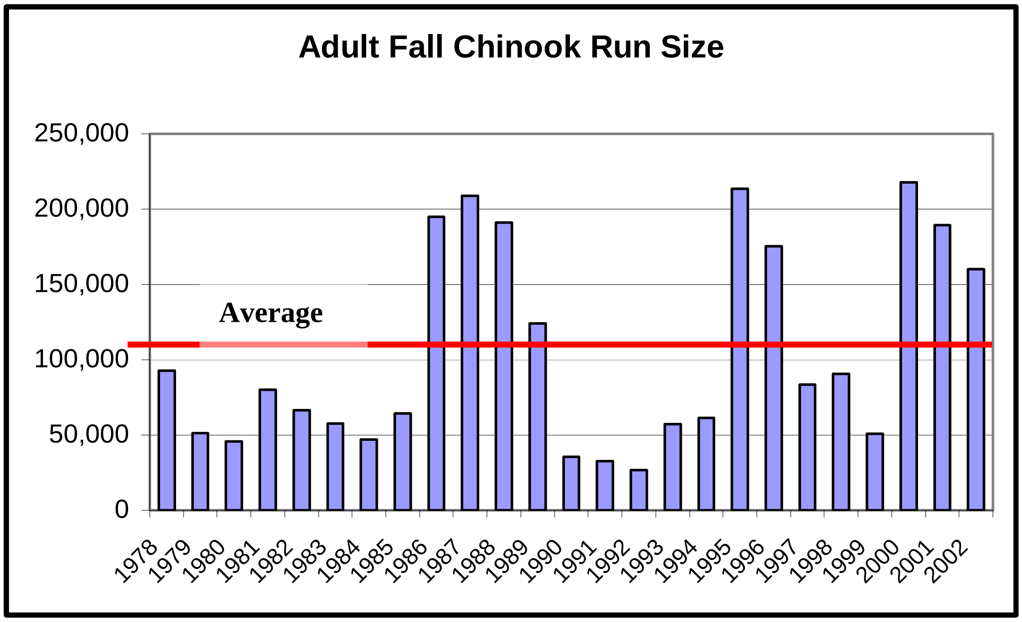


Figure 22: Ocean escapements (in-river run) since 1978[30]. The average ocean escapement was over the time period was 104,770 adult Chinook.

<u>Comparison of 1988, 2001, and 2002 Run Size:</u> The estimated ocean escapement of adult fall Chinook for the comparative years of 1988, 2001, and 2002 were 191,300, 189,300 and 160,000 respectively. The total ocean escapement estimates are calculated with the estimated in-river harvest included. To approximate the numbers of adult fall Chinook escaping the estuary to enter into the area of the fish kill, Tribal and sport harvests must be deducted from the ocean escapement. The estimated estuary escapements of adult fall Chinook after harvest for 1988, 2001, and 2002 were 151,019, 153,519, and 136,014 respectively (Figure 23). Using estuary escapement rather than ocean escapement as comparison reduces the magnitude of difference in run size between years. The estuary escapement in 2002 was approximately 90 percent of the escapements in 1988 and 2001. It should be noted that the 2002 ocean escapement estimate may be underestimated based on the conservative estimate of the number of adult Chinook mortalities in the fish kill. The USFWS calculated that the 2002 ocean escapement may have been as high as 203,000 adult fall Chinook.[31]

---

[30] CDFG, Klamath River Basin Fall Chinook Salmon Spawner Escapement, In-river Harvest and Run-Size Estimates, Nov. 2003.

[31] USFWS Klamath River Fish Die-Off September 2002: Causative Factors of Mortality. Report Number AFWO-F-02-03. November 7, 2003 (at pg 9)

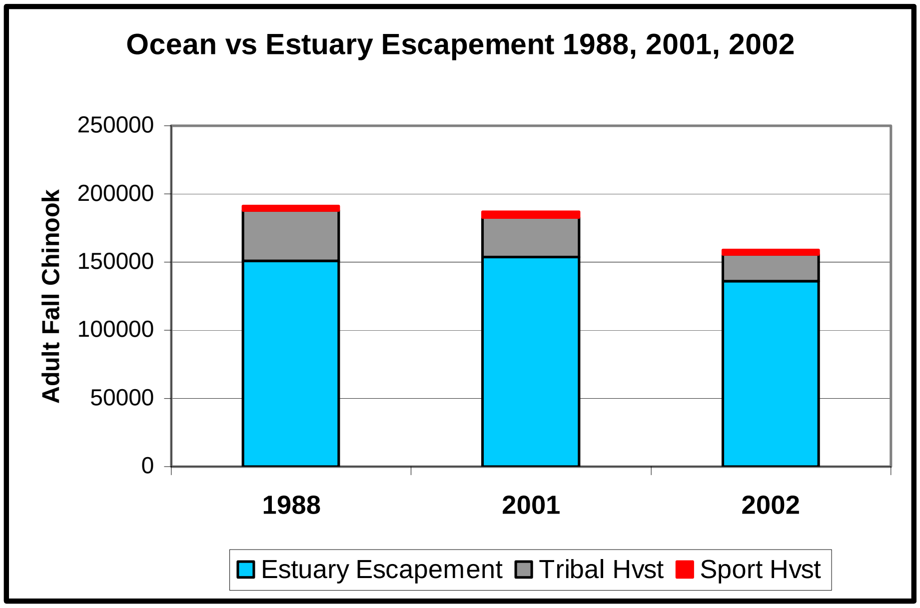


Figure 23: Comparison of 1988, 2001, and 2002 ocean escapement and estuary escapement of adult fall Chinook. Estuary escapement is the total estimated in-river run minus the Tribal and sport estuary harvest.

<u>Intermediate Conclusion on Run Size:</u> The 2002 total estimated ocean escapement of adult Chinook salmon was the eighth largest of the past 24 years. After deducting estuary harvest, the 2002 estuary escapement entering the fish kill area was within 10% of 1988 and 2001. However, the 2002 ocean escapement may have been much larger than calculated due to underestimates of fish that died due to parasitic infection. Run size alone cannot be considered a primary causative factor of the fish kill.

<u>Run timing:</u>

Analysis of run timing also indicates that the run timing of 2002 was not unusual compared to the years of available record (1994-2002). Using catch per unit effort (CPUE) of Yurok Tribal gillnetters and CDFG creel census data as an indication of run timing, 2002 does not appear unusual in any way. As shown in Figure 24, the run began in earnest in the latter part of August, which was well within the normal range of variation.

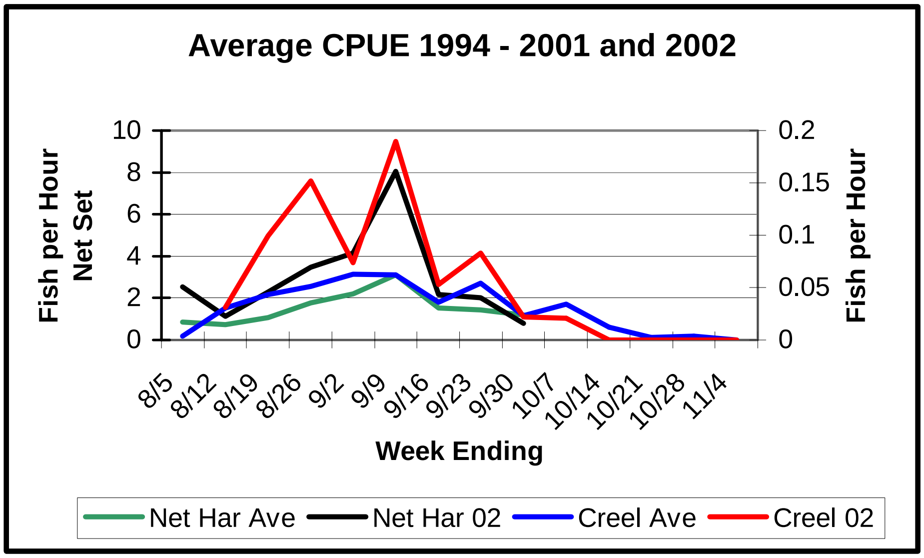


Figure 24: The 2002 run timing of adult salmon compared to the 1994 to 2001 average as indicated by CPUE data from the estuary Tribal gillnet harvest and the CDFG creel census (Chart adapted from CDFG).

The Klamath River portion of the fall Chinook run, those fish bound for Iron Gate Dam and the Shasta River, are the first to enter the River on their spawning migration. The Trinity River segment of the run typically peaks a few weeks later as shown by the average coded wire tag (CWT) recovery data from 1988 through 2001 in Figure 25. Klamath side salmon also tend to stay in the estuary longer than the Trinity stock before migrating upriver.[32]

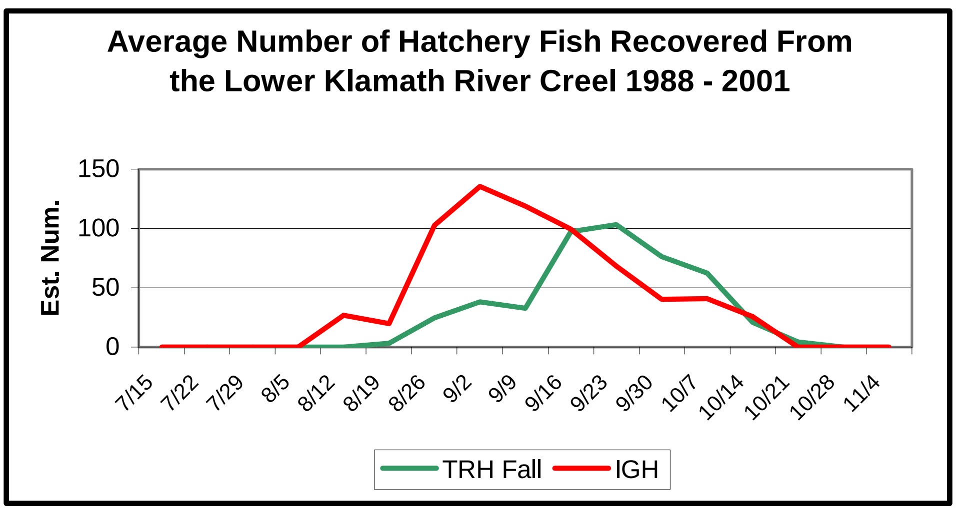


Figure 25: Average coded wire tag recoveries in the Lower Klamath River from 1988 through 2001. This graph shows that, on average, the Trinity River Hatchery run peaks about three weeks after the Iron Gate Hatchery run.

[32] USFWS 1988. Klamath River Fisheries Assessment Program. Annual Report 1987 No. FRI/FAO-88-14.

Figure 26 Catch Per Unit of Effort (CPUE) data indicated that the 2002 Klamath side Chinook entered the River in significant numbers earlier than in 1988 or 2002. The peak of the run, with Klamath and Trinity stocks combined occurred in early September. Data indicate that in 1988 and 2001 the peak of the run occurred more towards late September. The relatively low recreational CPUE in 1988 may be due to the fact that there was a relatively large commercial gill net harvest in the estuary that year.

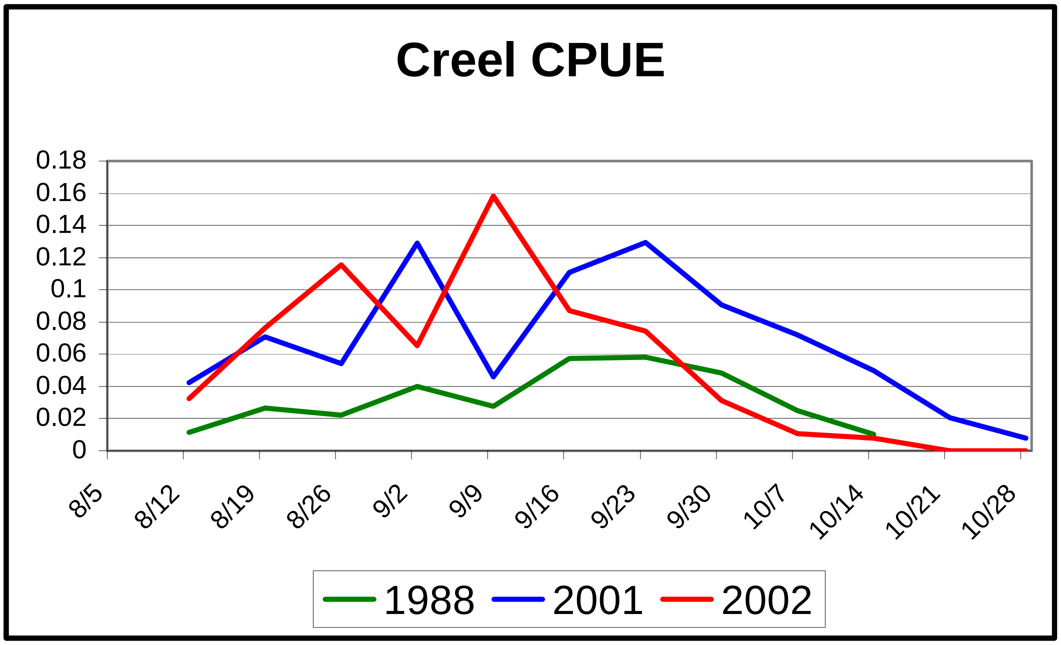


Figure 26: Adult Fall Chinook catch per unit of effort 1988, 2001, and 2002.

In 2000, with the largest ocean escapement in the period of record since 1978, there was an earlier bimodal peak run to the River (Figure 27). The extremely large run did not result in a fish kill. Flows from Iron Gate Dam were average 1030 cfs in August and 1300 cfs in September in 2000, compared to 666 cfs and 813 cfs respectively in 2002.

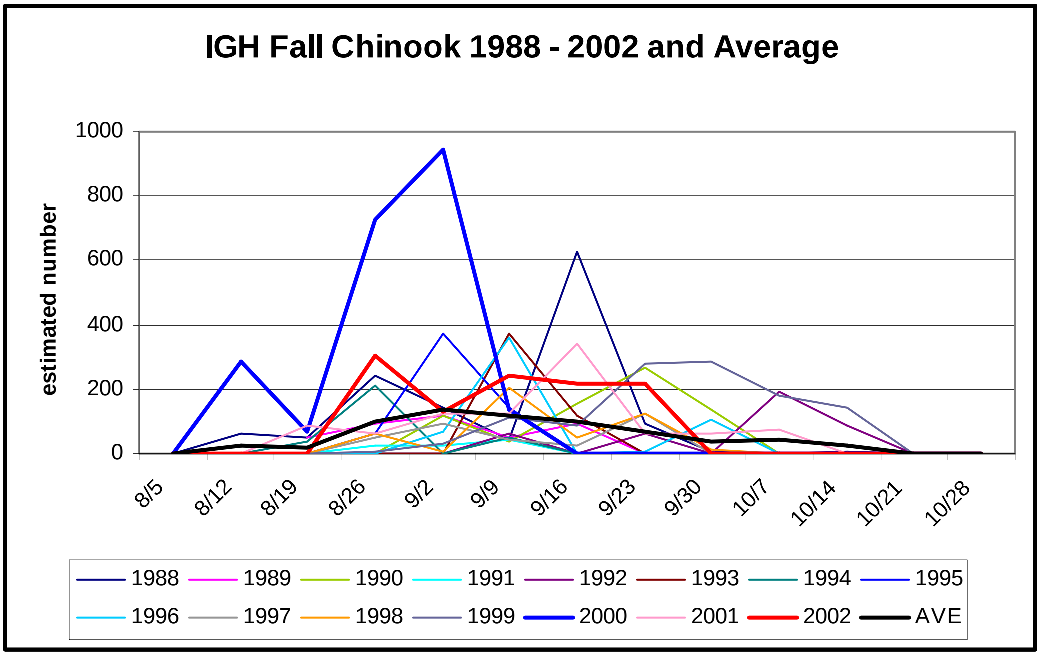


Figure 27: Fall Chinook 1988 – 2002 estimated run timing based on CWT data.

<u>Intermediate Conclusions on Run Timing:</u> The 2002 adult fall Chinook in-river run entered the River about one week earlier than during 1988 or 2001. The majority of the run consisted of Klamath Basin stocks which hold longer in the lower River than Trinity Basin stocks.

<u>Estuary Water Levels</u>:

Because of wave energy and longshore transport, river mouths along the north coast of California tend to close during low flow periods. For smaller rivers, such as Redwood Creek or the Mad River, the ocean can close the estuaries completely with a physical sand barrier. For the Klamath, the estuary does not completely shut off, but sand bar formation constricts the mouth of the River enough to raise the water level and total volume of the estuary, primarily in low flow years. The degree of water backup depends on flow, ocean wave energy, and the physical location of the river mouth which can vary substantially between years. With the annual variation in sandbar formation at the mouth, the actual location of the River mouth can shift from north to south.

The year 2002 was unusual for low flow years of the recent past, in that the estuary did not backup and there was no subsequent increase in the volume of the estuary (Figure 28). This was probably due to the fact that the mouth of the river during 2002 was against the extreme northern edge of the river valley, which allowed increased channel scouring because of bedrock control. This northern location also protects the mouth from northerly ocean swell, resulting in less sand bar formation.

Although water level as expressed by gauge height at the Terwer is not absolutely related to the volume of water in the estuary[33], it does indicate of water surface elevation in the

[33] Greg Susich, USGS; personal communication 2003.

estuary and thus is a relative indicator of estuary volume. Any conclusions drawn about run size and volume of the estuary that are drawn from these data must acknowledge the uncertainty when using Terwer gage height as a surrogate for estuary water level. However, with differences of the magnitude between 1988, 2001, and 2002, relative estuary volume can be ascertained.

In 2001 the mouth of the River was constricted due to the formation of a sand spit. The Turwar gauge is located six miles upstream of the mouth of the River, therefore an increase in gauge height of the magnitude indicated during 2001 represents a significant increase in the volume of water present in the Lower River, which results in increased habitat area and decreased fish density.

In 1988, while the River bar did not create a barrier to flow, gauge stage height records show a significantly higher level, 6 feet, as opposed to approximately 4 feet in 2002. It is uncertain whether water levels were different in the estuary in 1988 than they were in 2002.

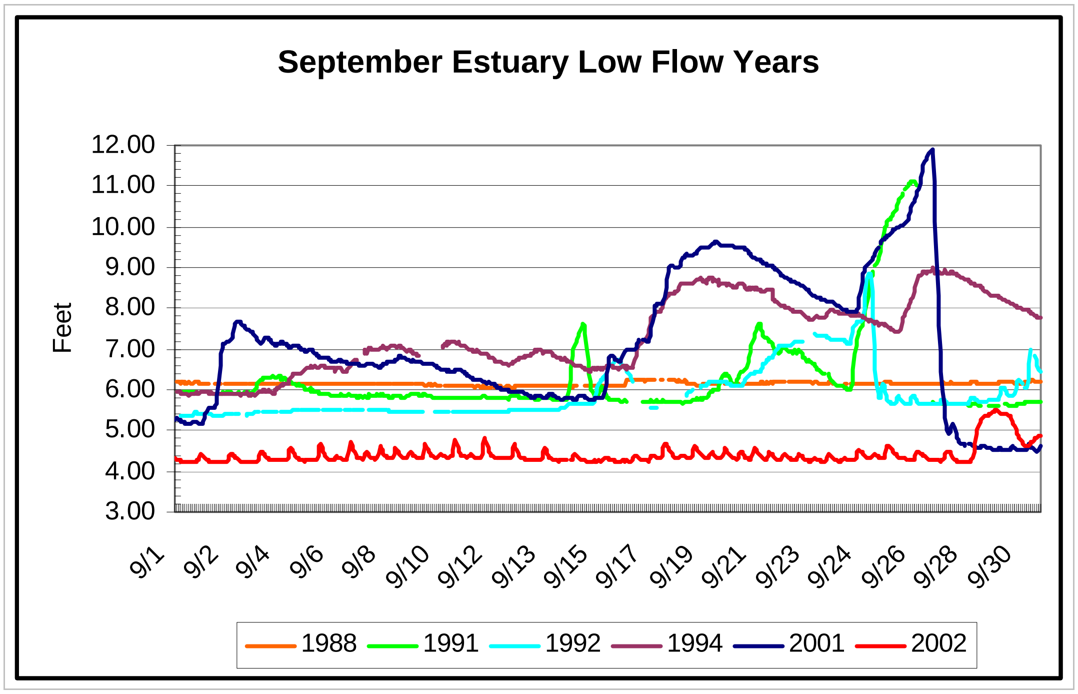


Figure 28: Estuary water levels during low flow years from 1988 to 2002 as measured by gage height at the Terwer River Gage near Klamath, CA[34]. 2002 was the lowest of the low flow years, and showed little sign of water back up due to sandbar formation. (The abrupt drop in heights, as on 9/28 2001, is indicative of the sand bar flushing open resulting in an immediate drop in volume.)

[34] Figure courtesy of CDFG. Data collected from USGS website.

<u>Intermediate Conclusions of Estuary Water Levels:</u> The mouth of the River was constricted by a sand bar in 2001 causing water to backup in the lower River with a resultant increase in overall volume. In 1988 the mouth was not constricted, however the gauge at Terwer was two feet higher than during 2002. In 2002 the mouth was not constricted and the relative volume of the lower river was substantially lower than in 2001.

<u>Indicators of Delayed Migration:</u>

<u>CWT Recovery Time</u>:
The two primary hatcheries in the Klamath-Trinity Basin, Iron Gate (IGH) and Trinity River (TRH) Hatcheries, typically implant coded wire tags in (CWTs) and clip the adipose fin of (for later identification as a fish with a CWT) a portion of the their Chinook salmon production. Recovery of these clipped fish bearing CWTs allows identification to their hatchery of origin, and subsequent expansion to estimate the total number of hatchery fish represented by the recovered CWTs. Analysis of CWT recoveries in a fishery over time can be used to indicate the temporal presence of fish from IGH and TRH. In general, the increased recoveries of CWTs from a hatchery indicate an increase in the presence of fish from that hatchery.

The recovery of CWTs can be an indicator of run timing. If the up-river migration run is delayed, resulting in fish holding in the estuary and lower River, they then remain vulnerable to lower river fishing. Therefore, the recovery of CWTs can remain high, even though the entry of fish from the ocean to the river may have diminished.

Data from the Lower River Creel indicates a migratory delay of Iron Gate Hatchery fall Chinook during 2002, as is shown in Figure 29. The number of CWTs from the Klamath portion of the run (IGH CWTs), soared during the week beginning August 19th, but then instead of gradually descending, it remained unusually high throughout most of September relative to previous years. This is indicated by the red series line in Figure 29, which remains high through the third week of September instead of the typical waning earlier in the month. These data suggest that there was a migration delay from the lower River of the Klamath portion of the fall Chinook run.

As stated previously, a primary pathogen the fish died from was ich. Ich is only present in freshwater and fish must be exposed to a heavy infection of ich for 20-26 days prior to dying from the disease. Therefore, the fish that died from ich had to have been in the lower river at least three weeks, indicating they had undergone a migration delay.

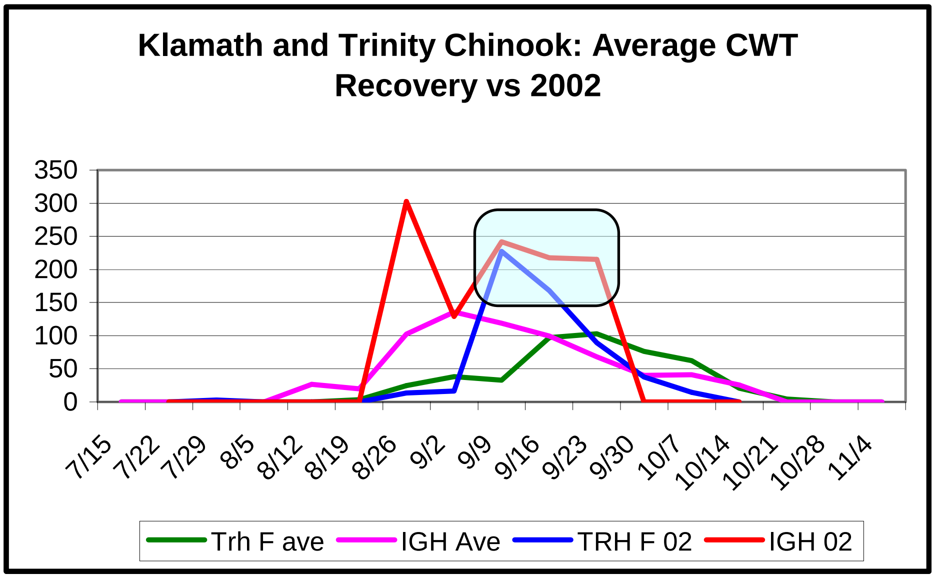


Figure 29: Coded wire tag returns for the lower Klamath in 2002 as compared to the average from 1988 to 2001. The blue window shows where the tag recoveries of Iron Gate Hatchery fish remained unusually high through the first three weeks of September instead of the typical decline earlier in the month. This pattern is also shown in Figure 27. (TRH F = Trinity hatchery fall Chinook; IGH = Klamath side fall Chinook from Iron Gate Hatchery.)

Shallow water considerations: There is no specific data on the depths that fish encountered during their upstream migration during 2002. Personal observation of the river, and the fish killed, indicated that the fish were large, the water was very clear, and the riffles were often shallow. Some[35] have hypothesized that the 1997 flood may have modified channel shape in the lower river, which contributed to shallower riffle depths. Although jetboat operators observed what they considered unusually shallow depths at several locations in the lower river, no direct measurements were taken.

Up River Migration as Indicated by Catch Rate: The Karuk Tribal dipnet fishery for salmon takes place at Ishi-Pishi Falls at Somes Bar above Orleans. In 2002, prior to the release of additional flows from Iron Gate Dam in response to the fish kill, catch of adult salmon had been extremely low. After the additional flow reached the Ishi Pishi area (as measured by the flow gauge near Orleans) catch dramatically increased (Figure 30). This relationship between catch, as an indicator of Chinook migration, with flows from Iron Gate Dam, indicates that migration was being delayed by low Iron Gate Dam flows.

[35] CDFG Preliminary Fish Kill Report 2002

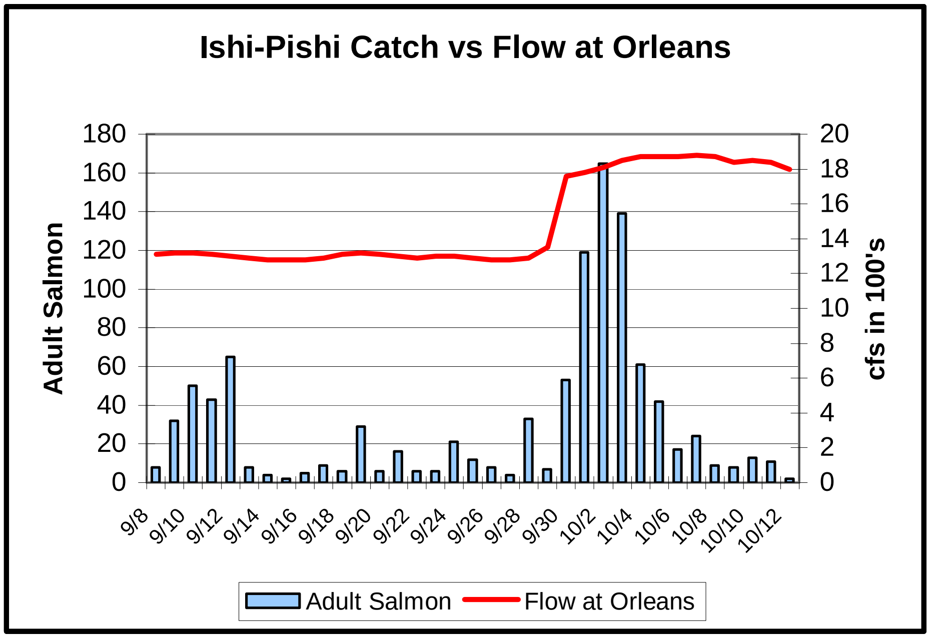


Figure 30: The reported catch from the Karuk dip net fishery at Ishi Pishi Falls, upstream of the Orleans gauge versus the daily average flow at the gauge. Flow releases from Iron Gate Dam were increased from 757 to 1350 cfs on September 27; the flow increase reached the Orleans gauge on September 29. (Data is courtesy of the Karuk Tribe.)

Intermediate Conclusions on Migration Delay: Coded wire tag data shows that the Klamath stock (IGH fall Chinook) held for a longer time in the lower river compared to other years. The September 27 release of additional flow from Iron Gate Dam shows a corresponding increase in the Karuk dip net fishery at Ishi Pishi Falls, which leads to the conclusion that increased flows stimulated up river migration.

Potential Factors Considered but Eliminated

Toxic Spill Hypothesis:

Some have speculated that the fish kill must have been caused by an unknown toxic spill, or the presence of toxic chemicals. However, based on data, evidence, and observation, this possibility can be ruled out. There are at least four reasons why toxicity does not appear to have been a factor:

1) The fish kill affected mostly adult salmon, while thousands of juvenile fish in the same vicinity were unaffected.[36] Poisoning would have affected different species and lifestages indiscriminately[37]. Photographic evidence collected by the Yurok Tribal Fisheries Program verifies this[38].

[36] Yurok Tribal Fisheries Program unpublished data, 2002.

[37] AFS (American Fisheries Society). 1992. Investigation and valuation of fish kills. AFS Special Publication 24. AS. Bethesda, MD.

[38] Yurok Tribal Fisheries Program photograph 1 (attached)

2) The fish themselves clearly showed that they had expired from disease, not poisoning, as two separate independent fish pathology reports verify[39]. Additionally, photographic evidence gathered by the Yurok Tribal Fisheries Program during the fish kill[40], shows that the fish succumbed to disease rather than poison (Figure 3).

3) Samples taken during the time when fish were still dying indicated that no toxic substances were present in the Klamath at that time[41].

4) Finally, fish that were sent to laboratories for toxic screening analysis came back negative for toxic substances[42]. Ammonia levels during the latter part of the fish kill were far below chronic or acute thresholds for fish. Thus, multiple lines of evidence point to the fact that this fish kill was not caused by some sort of toxic substance.

Dissolved Oxygen:

Dissolved oxygen was not regularly monitored on the lower Klamath River prior to 2001. Because of this, dissolved oxygen levels were examined to see if they were low enough to be identified as a major stressor to the migrating adult salmon. Analysis of dissolved oxygen levels in the Klamath River at the Terwer Gage shows that dissolved oxygen levels were similar in 2001 and 2002 (Figure 31).

Dissolved oxygen fluctuates daily in the Klamath (and other biologically active water bodies) due to its consumption and production from algae and other aquatic vegetation. It can also be depleted by the decomposition of dead organisms, or the presence of many living organisms. However, dissolved oxygen "sags" were not noted prior to the fish kill. The dissolved oxygen reduction (usually experienced in the early morning hours) can affect aquatic organisms, such as adult salmon. Salmon will show initial oxygen distress if the amount of dissolved oxygen falls below 6.0 milligrams per liter (mg/L) for extended periods of time, and will show widespread oxygen impairment if the level falls below 4.25 mg/L[43] . Dissolved oxygen levels did not fall below 6.0 prior to or during the fish kill, therefore dissolved oxygen does not appear to explain the catastrophic fish kill.

It has been hypothesized that stratified pools could have low dissolved oxygen levels in their lower levels which could have contributed to the fish kill. No direct measurements of pool bottoms were made, but several years of extensive searching for stratification (as evidenced by differences in temperatures), has not revealed any stratification[44]. Even low flows during the summer period in the Lower Klamath prevent stratification. One exception to this can be found at Blue Creek. The backwater of the confluence (known as Blue Hole) has exhibited stratification during certain conditions, and could have become stratified. However, only a small proportion (a couple thousand at most) of the

---

[39] State of California, The Resources Agency Department of Fish And Game. 2003. September 2002 Klamath River Fish Kill: Preliminary Analysis of Contributing Factors Special Report
[40] Yurok Tribal Fisheries Program photograph 2 (attached)
[41] Peter Otis, North Coast Water Quality Control Board, unpublished data transmitted to YTFP via personal communication.
[42] George Guillien, USFWS personal communication to Yurok Tribal Fisheries Program Director. February 6, 2003.
[43] Davis, J.C. 1975 as cited in Deas, 1999. Klamath River Modeling Project.
[44] Yurok Tribal Fisheries Program unpublished data.

fish run can be found in that location at any given time. Because of these considerations, it is highly unlikely that low dissolved oxygen in the deeper portions of pools near Blue Creek was responsible for the fish kill of 2002. (Monitoring of dissolved oxygen levels in pools near Blue Creek commenced in 2003).

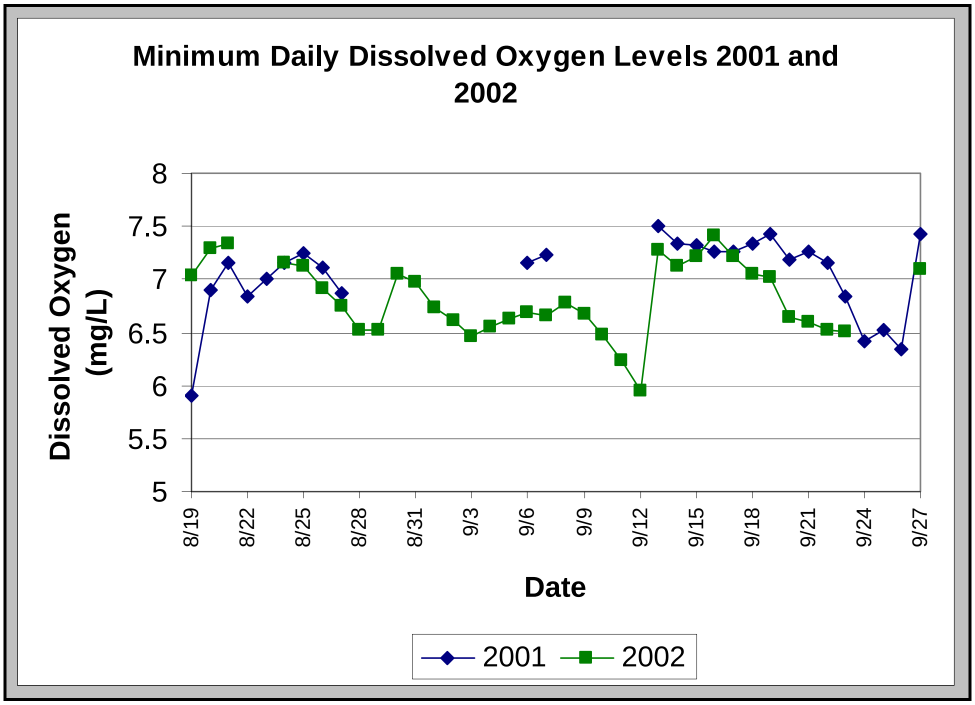


Figure 31: Minimum daily dissolved oxygen levels at Terwer in 2001 and 2002. (Weekly shifts in minimum dissolved oxygen levels are attributable to membrane fouling and recalibration after the instrument was changed i.e. values immediately prior to 9/12 and 9/26 may read too low. Partial daily records were excluded from this analysis as they would skew results.)

Acidity:

Because long-term records of pH do not exist, pH cannot be analyzed to see if 2002 was unusual compared to other years. Instead, pH was examined to see if it exceeded literature values considered harmful to anadromous fish. pH (level of acidity) fluctuates daily, mostly in response to plant growth in the water. Plant growth affects the amount of dissolved carbon dioxide, which in turn affects the pH of the water. A pH level of 7.0 is neutral, lower is acidic, and higher is basic. There is a close relationship between pH level, water temperature, and ammonia toxicity to fish. As water temperature and pH increase, the amount of toxic (un-ionized) ammonia also increases. A hydrolab© continuously monitored pH of the mainstem Klamath River both preceding and during the fish kill. Ammonia concentrations were also analyzed within the fish kill zone on September 20 (in the early stage of the fish kill), and on September 27 by way of grab samples collected by the U.S. Fish and Wildlife Service[45] and Regional Water Quality Control Board[46] . Given the temperatures and pH levels in the Lower Klamath River prior to and during the fish kill, ammonia levels were approximately an order of magnitude below what is considered chronic for salmonids and two orders of magnitude below what is considered acute for salmonids. Therefore, pH and ammonia levels were not primary factors contributing to the 2002 fish kill.

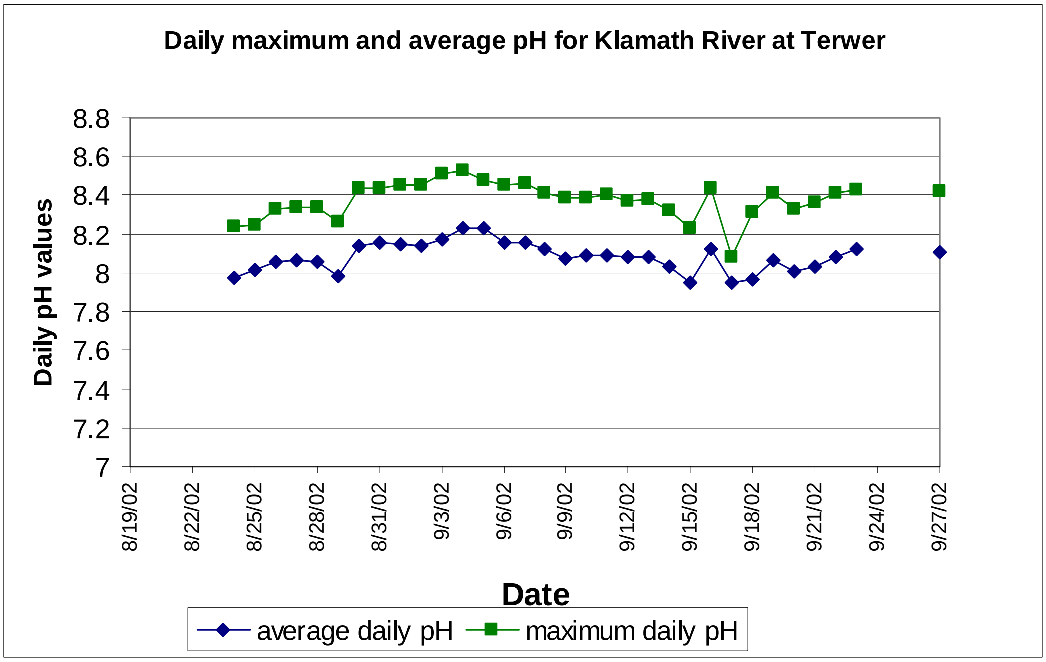


Figure 32: Daily maximum and average pH values for 2002. Partial daily records were excluded from this analysis.

Fish Kills in Other Systems

Fish kill events involving adult salmon have happened in other systems, including the Rogue, Butte Creek, the Elwah, the Fraser River, and the Skeena River; all caused by diseases of various types. A common theme in these fish kill events is high densities of fish in less than optimal water quality conditions, resulting in epidemics and mass mortality. Such was also the case in the Klamath.

Of these fish kill events, the Skeena River in British Columbia is the most relevant, because it involved adult salmon (sockeye salmon) that perished from massive ich infections, such as happened on the Klamath[47]. The Skeena River fish kill was first documented report of high prespawning mortality in wild salmonids due to ich. In the Skeena River fish kill, migration delay was caused by the installation of barrier gates

[45] USFWS Personal communication, February 13, 2003

[46] North Coast Water Quality Control Board, Personal communication; September 2002.

[47] Traxler et al, Ichithyophthirius multifiliis (Ich) Epizootics in Spawning Sockeye Salmon in British Columbia, Canada. Journal of Aquatics Animal Health 10:143-151, 1998.)

intended to control spawning escapement to artificial spawning channels. The resulting buildup of fish below these gates in warm, but not unusually warm water temperatures, eventually resulted in an epidemic of ich, and the death of at least 10-15,000 sockeye salmon. Migration delay was a primary factor in the ich-related kill of sockeye salmon on the Skeena River in British Columbia. Evidence of the same phenomenon (migration delay or blockage) on the Klamath is considered as a primary factor contributing to the Klamath River 2002 fish kill.

Summary and Conclusions

Review of Intermediate Conclusions:

Intermediate Conclusion on Conditions for Ich: The presence of ich in the system was not unique to 2002, as ich has been endemic to the River. Temperature conditions within the area of the fish kill were conducive to the ich reproductive cycle in all years for which we have temperature records, 1997 through 2001, with no epidemic occurrences. Fish that died from ich must have held in the lower Klamath River for at least 20-26 days, which appears to indicate that a migration delay was a unique contributing factor in 2002 that increased fish density in the lower River. (Reference page 5)

Intermediate Conclusion on Years to Compare: From 1985 – 2002, of the eight lowest flow years 1988, 2001, and 2002 had the highest ocean escapements of adult fall Chinook. Those three years were chosen for comparative analysis. (Reference page 12)

Intermediate Conclusion on Iron Gate flow: August and September Iron Gate flow releases (from 659-767 cfs) in 2002 were significantly lower than 1988 or 2001 which were at or near 1000 cfs. Increased flow in September 2002 prior to the fish kill (to 1300 cfs) would have increased flow in the lower river by approximately 25% and relieved crowding. (Reference page 15)

Intermediate Conclusion on Mid-Klamath Flow: The summed Orleans and Trinity gauge data as an indicator of the flows entering the fish kill area include an unrectified gauge error at Orleans. USGS estimates the flows as being the sixth lowest since 1961. There was an August 28, Trinity pulse flow in 2001 that was not present in 1988 and 2002 that may have stimulated migration and relieved over crowding of fish in the Lower River during 2001. (Reference page 17)

Intermediate Conclusions regarding Flows in the Area of the Fish Kill: Data show that 2001 flows in the lower river were higher than 2002 and 1988 flows were higher than 2002 through August until September 6. Due to tidal influence Terwer gauge data must be used with caution. (Reference page 18)

Intermediate Conclusions on Temperature: While temperature may have contributed to the severity of the outbreak by providing stressful conditions for adult salmon and favorable conditions for ich, available water temperature data show that temperatures in 2002 were well within the range of normal recent environmental variability. There is no evidence that this fish kill event was primarily caused by unusually warm water temperatures, or by an uncharacteristic cooling and warming trend. (Reference page 24)

Intermediate Conclusion on Run Size: The 2002 total estimated ocean escapement of adult Chinook salmon was the eighth largest in the past 24 years. After deducting estuary harvest the 2002 run entering the fish kill area was within 10% of 1988 and 2001. However, the run may have been much larger than calculated due to underestimates of fish that died due to parasitic infection. Run size alone cannot be considered a primary causative factor of the fish kill. (Reference page 26)

Intermediate Conclusions on Run Timing: The 2002 adult fall Chinook inriver run entered the River about one week earlier than during 1988 or 2001. The majority of the run consisted of Klamath Basin stocks which hold longer in the lower River than Trinity Basin stocks. (Reference page 29)

Intermediate Conclusions of Estuary Water Levels: The mouth of the River was constricted by a sand bar in 2001 causing water to backup in the lower River with a resultant increase in overall volume. In 1988 the mouth was not constricted, however the gauge at Terwer was two feet higher than during 2002. In 2002 the mouth was not constricted and the relative volume of the lower river was substantially lower than in 2001. (Reference page 31)

Intermediate Conclusions on Migration Delay: Coded wire tag data shows that the Klamath stock (IGH fall Chinook) held for an longer time in the lower river compared to other years. The September 27 release of additional flow from Iron Gate Dam shows a corresponding increase in the Karuk dip net fishery at Ishi Pishi Falls, which leads to the conclusion that increased flows stimulated up river migration. (Reference page 33)

Conclusion

Consideration of all pertinent data led to the conclusion that in 2002 a relatively robust run of adult fall Chinook entered the Klamath River approximately one week earlier than usual. Environmental conditions in the River at the time of the 2002 fall-run Chinook salmon run were characterized by low flow rates and volume, and an apparent lack of migration cues to proceed upriver. The resultant migration delay, crowded conditions, and warm water temperatures provided an ideal environment for the proliferation of the parasite *Ichthyopthirius multifilis* (ich) and the bacterial pathogen *Flavobacter columnare* (columnaris).

Isolation and identification of causative factors of fish kills in general, is a complex task that generally does not lead to the identification of a single independent “cause,”. Rather, the cause of this fish kill was a unique combination of factors that led to a severe epizootic outbreak. Despite the complexity of this fish kill, once the interdependent causative factors have been identified, one can formulate data-supported conclusions regarding likely contributing factors, and from those, determine what management actions could have been undertaken to prevent such an outbreak.

In this instance, low flows from Iron Gate Dam were a substantial causative factor in the fish kill of 2002. It is also the only factor that is controllable by human action. Had the flows from Iron Gate Dam in August and September been at or above approximately 1000 cfs, as they were in all other years of above average escapements, it is likely that the fish kill would not have occurred.