River entry and migration behavior of adult coho salmon in the Klamath River Basin

Lower Klamath River – Fall 2004. Photo by author.

2004 Radio Telemetry Study
Final Progress Report

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1.0 Introduction

Coho salmon (*Oncorhynchus kisutch*) populations in the Klamath River Basin (KRB) were listed as threatened under the Endangered Species Act (ESA) in 1997 due to declining abundance trends, reduced geographic distribution, and significant risk factors (Weitkamp et al. 1995). Based on genetic analysis and continuity in habitat characteristics (Hjort and Schreck 1982, Solazzi 1986, Weitkamp et al. 1995), KRB coho are included in the southern Oregon/northern California coasts Evolutionary Significant Unit (SO/NCC ESU), which encompasses the area from Cape Blanco (Elk River) to Punta Gorda (Eel River) (Weitkamp et al. 1995). Within the KRB, coho escapement is dominated by fish produced at the Trinity Hatchery, along with Iron Gate Hatchery to lesser extent (CDFG 1994). Brown et al. (1994) compiled coho stream survey data and determined that the California portion of the SO/NCC ESU had experienced a 36% reduction in the number of tributaries that supported coho populations, most of which occurred within the Eel and Klamath River Basins. Under the current circumstances, only Tribal members can legally harvest coho and hatchery populations are still relied on for harvest production in that capacity, but otherwise serve no purpose. The remaining naturally reproducing coho populations, however, are critically important for the long term survival and recovery of the SO/NCC ESU since a broader distribution of locally adapted coho populations greatly reduces the threat of extinction from stochastic disturbance events or sudden decreases in survival (Riggs 1990, Fagen and Smoker 1989). Thus protection and restoration of naturally reproducing populations of coho is a major management goal for the SO/NCC ESU and in the KRB.

Accomplishing protection and restoration goals for such populations will be facilitated, in part, by a coherent understanding of salmonid life histories and their interactions with environmental variability (Mangle 1994). In a review of salmon recovery policies on the Columbia River, the Independent Scientific Group concluded that in order to recover declining stocks, policies needed to be guided by a foundational “salmon life history ecosystem concept”, which would involve restoration of habitats for all life history stages including adult in-river migration and spawning (Williams et al. 1999). Steps must be taken to ensure sufficient success and survivorship of all phases of the salmonid life cycle in order to prevent a bottleneck effect on maintenance and recovery efforts. This holds equally true for other salmon producing river basins.

Upriver migration and spawning are two life history stages that are critical to the success of maintenance and recovery efforts of coho salmon. Understanding these life history components and their interaction with environmental conditions and variability requires understanding how salmon life histories have evolved. There is an extensive body of literature on life history theory (see reviews by Stearns 1980; Roff 2002), including specifically for fish and salmonid migrations (see reviews by Legget 1985; Dodson 1997). A central assumption of life history theory is that natural selection produces genetically controlled traits that are adaptations for fitness (Roff 2002). Thus variations in life history traits are a product of evolution that strive to optimize reproductive success (Gross 1984). Examples of life history traits in salmonids include age and size at maturity, fecundity, egg size, and migration timing. These traits did not evolve independently from one another; rather they form location specific co-adapted complexes that represent a compromise of trade-offs between trait costs and benefits (Roff 2002).

Migration is a response to temporally (seasonal) and spatially (ocean vs. freshwater) variable habitats, which when coupled with reliable environmental cues serves to reduce the costs of environmental variability on reproductive success (Legget 1985; Dingle 1996). Evidence supports the hypothesis that the timing of salmon migrations has adapted to the long term average conditions (e.g. temperature, flow, and migration distance) experienced by populations (Gilhousen 1990; Quinn et al. 1997; Hodgson and Quinn 2002). In the case of adult salmonids, the spawning migration is timed to allow for a spawning date that will result in offspring emergence during the window of time most favorable to growth and survival (Bye 1984; Brannon 1987). The amount of time required from spawning to fry emergence is determined by egg size and water temperature (Brannon 1987), thus spawn timing can vary as a function of the thermal regime of a given tributary or spawning area (Lister et al. 1981). Optimal migration and spawn timing must be accomplished within the constraints imposed by the physical habitat in the migration corridor and spawning area, such as seasonal periods of excessively low flows or high water temperatures. Indeed, temperature and flow are two of the most important environmental variables that influence migration timing among adult salmonids (Banks 1969; Jonsson 1991; Quinn and Adams 1996; Trepanier et al. 1996; Quinn et al. 1997; Hodgson and Quinn 2002).

The exact amount of influence that temperature and flow have on the run timing of KRB coho is unknown; however, both play an important role. In the KRB (Figure 1), coho presently enter the river from August to December with the majority of the run entering from late September to late October. The high variability in run timing of KRB coho is consistent with coho run timing in other large rivers (Lister et al 1981, Weitkamp et al. 1995). Even with the high variability, KRB adult coho run timing appears to avoid the predictable period of high water temperatures (>20ºC) in the summer and also allows for continued ocean feeding and growth during the summer. Adult coho run timing is also widely believed to allow them reach tributary spawning areas which often require higher flows to access.

The subsequent rate of upriver movement and the timing of migration into spawning tributaries can be heavily influenced by flows, as KRB coho have been observed delaying in the mainstem until spawning tributary flows increase with the fall rains (personal comm. Anita Andazola). This behavior has been observed among numerous coho populations in small rivers and streams (Shapovalov and Taft 1954, Salo and Bayliff 1958, Eames et al. 1981, Lister et al. 1981). Since the timing of river entry and subsequent upriver migration to spawning areas is an adaptation to long term average conditions, increased variation in environmental conditions or artificial alteration of run timing imbues a higher risk of unsuccessful reproduction via enroute mortality, prespawn mortality, or poor offspring survival. Thus understanding adult coho run timing, migration behavior, and the influence of environmental variability is an important goal.

Individuals within a given run-timing strategy will employ a range of flexible behavioral tactics (Potts and Wooton 1984) in the face of annual and inter-annual variation from the long-term average conditions that they are presumably adapted to. These behavioral tactics serve to reduce the variance of environmental conditions actually experienced and the risks associated with adverse conditions or altered timing (Legget 1985). One important behavioral tactic is fine tuning run timing to environmental conditions on an annual basis by delaying or advancing freshwater entry.

Once salmon enter the river from the ocean and commence their in-river spawning migration, adjustments of travel rates is another important behavioral tactic. Bernatchez and Dodson (1987) concluded that only salmon stocks with exceptionally long or difficult migrations that exhaust energy reserves conform to theoretical optimums of swimming speed. Thus most salmon stocks have a sufficient energy cushion for their migration path, which combined with energy saving swimming behaviors (Hinch and Rand 2000), allows for some level of energetic flexibility with swim speeds and hence travel rates. This flexibility can be used to reduce the duration of travel in reaches of especially stressful conditions (e.g. high temperatures or high predation risk), compensate for migration delays, or shift enroute run timing (Quinn et al. 1997). Other important tactics likely exist and determining the causes of specific migration behaviors and their associated costs and benefits in specific circumstances could allow mangers to find ways to reduce the costs and maximize the benefits of management actions. Besides documenting such tactics and their relationship with environmental variables, there is a need to link such tactics to specific populations or spawning areas within the KRB.

Overall there is a desire to gain a better understanding of the spawning migration phase of KRB coho, especially in response to environmental variables such as temperature and flow so that management decisions can be made with the best available scientific understanding. Specific questions that arise as a result of the current circumstances in the KRB regarding the patterns and consequences of adult coho migration and spawning include:

1. What are the patterns of migration timing and behavior for adult coho?
2. How do adult coho respond to environmental variables such as temperature and flow during migration?
3. What spatial and temporal patterns of spawning are displayed by adult coho?
4. What are the population specific run timing and behavioral tactics for adult coho?

In an effort to provide basic data to start answering these questions the Yurok Tribal Fisheries Program (YTFP) worked with the US Fish and Wildlife Service (FWS) and the Karuk Department of Natural Resources (KDNR) on a collaborative adult coho radio telemetry research project. In 2003 we experimented with tagging techniques at the mouth of the Klamath River and at Ishi Pishi Falls. In 2004 we expanded the scope to include tagging adult coho at Iron Gate Dam and increased the sample size. This report presents and discusses results from the tagging of adult coho at the mouth of the Klamath River during 2004 by the YTFP.

1.1 Study Objectives

The primary objective of this study was to document the migration and spawning behavior of adult coho salmon in the KRB during the 2004 spawning migration season. Specific objectives were to:

1. Determine the river entry timing and migration behavior adult coho in the KRB;
2. Determine destinations and spawning site locations and their associated habitat attributes;
3. Gather data on stock specific run timing and behavior.

2.0 METHODS

2.1 Study Area

The Klamath River drains ~ 31,000 km^2 in southern Oregon and northwestern California and flows 386 km from its source at the outlet of Upper Klamath Lake, a hyper-eutrophic regulated natural lake, to its confluence with the Pacific Ocean. The Klamath River is one of only four rivers that bisect the Cascade Range, along with the Sacramento/Pit, Columbia, and Fraser Rivers. Due to this fact the Klamath River is geologically divided into two basins, which has profound affects on its hydrology, geomorphology, water quality, thermal regime, fish fauna, and ecology.

Upriver movement of anadromous fish populations are currently restricted by Iron Gate Dam at river kilometer (RKM) 310 (Figure 1) which has no fish passage facilities. The California Department of Fish and Game (CDFG) operates a mitigation hatchery at Iron Gate Dam, which has had an annual return of 1,333 adult coho on average since

1992 (Williams and Hillemeier 2005). Natural production of coho has been documented in numerous tributaries to the Klamath River and to a lesser extent in the mainstem Klamath River (personal comm. Tom Shaw).

The Klamath River's largest tributary is the Trinity River, which flows into the Klamath at Weitchpec at RKM 70. The Trinity River originates in the Trinity Alps Wilderness and was dammed in 1964 as part of the Central Valley Project which has diverted 90 – 49% of the annual flow into the Sacramento River system. There is no fish passage at Trinity or Lewiston Dams, although the CDFG operates a mitigation hatchery at Lewiston (RKM 253) that produces the majority of coho escapement in the Trinity River, which has ranged from 59,079 adult coho in 1987 to 852 coho in 1994 and averages approximately 16,000 adult coho annually (Sinnen et al. 2004).

2.2 Tagging and Telemetry

We used temperature sensitive radio transmitters to track the movements and internal body temperatures of adult coho salmon during the 2004 spawning migration in the KRB. The radio transmitters we used were Advanced Telemetry Systems - ATS F1845 esophageal transmitters with external trailing whip antennae at 148 and 150 MHz. An archival temperature device (Alpha Mach iButton, diameter 17.5 x height 6 mm, 3.3 grams dry weight) was attached to the base of each radio transmitter and recorded internal body temperature every hour. A portion of coho that we radio tagged were also tagged with spaghetti tags to aid visual identification during carcass surveys.

Adult coho were captured by the YTFP using drift gill nets or dip nets, tagged, and released at the mouth of the Klamath River from Sept 20th to Oct 22nd 2004. Each captured salmon was held and immobilized in a 250 gallon live tank on the shore with the aid of a cradle, measured (fork length cm), tagged (via force feeding with a PVC tube), and released immediately or revived first as necessary. A gas powered water pump was used to circulate river water through the live tank continuously. Efforts were taken to minimize capture stress and handling time. All successfully captured coho were tagged regardless of presence or absence of hatchery marks.

Scanning radio receivers (Lotek SRX 400s) were used for mobile tracking. After pinpointing the location of each observed tagged coho using basic triangulation, fish position was recorded using a handheld, global positioning system (GPS). Topographic maps of the river corridors complete with river kilometers (RKM) were issued to all tracking crews to aid in determining fish position. In the event of insufficient satellite contact, the nearest highway mile marker or associated landmarks were also used. For each tagged chinook observation the agency, observers, date, time, unique frequency ID, transmitter signal pulse rate (sec), meso-habitat type (i.e. pool, riffle, run), location description, UTM coordinates, river temperature (^{o}C), and fish behavior (moving versus holding) were recorded whenever possible.

The tag pulse rate was determined by using a stopwatch to measure the time interval of 10 pulses with three replicates to the nearest hundredth of a second, with the average subsequently used to determine the fish's body temperature. River temperature was measured using calibrated dissolved oxygen (DO) meters or handheld thermometers accurate to the nearest 0.2 to 0.5^{o}C respectively. An attempt was made to track tagged salmon throughout their migration path until they died. Transportation during tracking was by truck along Highways 96, 169, and 299, by jet boat, and by inflatable rafts depending on the situation. Tracking was conducted by YTFP, FWS, and KDNR trained staff. Hatchery personnel, snorkel count and carcass survey participants within the study area were notified of the study in order to assist with located tagged chinook and retrieving archival tags. A $50 reward was offered to assist in the recovery of archival tags.

A network of 14 automated radio listening stations (Advanced Telemetry Systems R4000/DCC, Grant Systems Engineering Orions, and Lotek SRXs) were placed throughout the KRB at strategic locations to continuously monitor fish presence or absence and record internal body temperatures. Listening station locations and dates of deployment are listed in Table 1. The spatial relationship of the listening stations allowed for determination of migration paths and travel rates.

2.3 Temperature and Flow Monitoring

Thermistors (Onset Optic Stowaways and Alpha Mach iBs) were used at each listening station to record the temperature of the mainstem river and of any cold water tributaries that were associated with the site. The thermistors used were rated in accuracy to the nearest 0.1°C or 0.5°C respectively. All temperature probes were tested before deployment in high and low temperature water baths and calibrated with an ASTM certified thermometer. Temperature records were not used if discrepancies in comparison to handheld measurements taken at the same location consistently occurred that were greater than the margin of error.

Ambient water temperatures at additional sites in the mainstem Klamath River were obtained from temperature recorders operated by YTFP, the US Geological Survey (USGS), and the USFS Orleans District. River flows were measured by USGS gauges and obtained from their website at http://waterdata.usgs.gov/ca/nwis/current/?type=flow Air temperature summaries from weather stations operated by the US Forest Service throughout the KRB were obtained from the National Climate Data Center website at http://www.ncdc.noaa.gov/oa/climate/stationlocator.html.

3.0 RESULTS

NOTE: The results reported herein do not include results from the 40 adult coho tagged by the FWS at Iron Gate Dam (RKM 310) or the 17 adult coho tagged by the KDNR at Ishi Pishi Falls (RKM 108). Copies of those reports should be obtained directly through the responsible agency.

3.1 Tagging and Fate Summary

A total of 21 adult coho were tagged and released at the mouth of the Klamath River (RKM 0) by the YTFP from Sept 20th to Oct 22nd 2004. Tagging data and final known fates or last observations for these 21 adult coho are summarized in Table 2.

Determination of final fates for tagged coho is problematic due to the fact that numerous fish disappeared in the estuary or nearshore ocean after tagging with the high salinities in those areas inhibiting the detection of radio transmissions. Of the 21 adult coho that were tagged in the estuary, 5 (24%) migrated after tagging while 15 (71%) disappeared in the estuary or nearshore ocean after tagging, with 1 (5%) confirmed to have been eaten by a sea lion (*Zalophus californianus*). Disappearance is defined as no further detections during manual tracking or at listening stations. Based on deductive logic the primary factors contributing to the 71% disappearance rate in the estuary/nearshore were pinniped predation, tag regurgitation, unclaimed harvest, delayed tagging mortality, and inter-basin straying or visitation. Thus in total, only 5 tagged coho, hereafter termed migrants, provided data for further analysis of end fates and migration behavior. However, the FWS and KDNR tracked additional adult coho tagged above Weitchpec which provided further data on end fates and migration behavior.

Determination of end fates and destinations for fish that did emerge from the estuary was complicated by the disappearance of fish enroute, which occurred for a variety of possible reasons. For example, a tagged coho disappearing enroute could have been due to the fish entering a tributary or river reach undetected or due to unclaimed harvest. Thus assignments to the classes of fates should be viewed as the approximate minimum. Taking this into account, of the five fish that did not disappear immediately after tagging at least one was confirmed to have died enroute (harvest, predation, or natural mortality) while the other four disappeared at some point during migration prior to reaching spawning grounds for unknown reasons. Out of these latter four fish, at least one migrated into the Klamath River above Weitchpec, at least two migrated into the Trinity River above Weitchpec, and one was never observed above Weitchpec (RKM 70). No spawning or detections of tagged coho in spawning locations were observed.

3.2 Environmental Conditions

Annual hydrographs for the 2004 migration season are presented for the Klamath and Trinity Rivers in Figures 2 through 8. All flows are reported as mean daily flow measured in cubic feet per second (cfs) and all RKMs are measured from the mouth of the Klamath River.

The 2004 water year was reclassified as “dry” for the upper Klamath River Basin, which resulted in relatively low flow releases from Iron Gate Dam (Figure 5). In contrast, the water year designation for the Trinity River sub-basin was “normal” in 2004 resulting in a flow release schedule from Lewiston Dam as dictated by the Trinity River

Record of Decision (Figure 8). Flow releases from these dams strongly influence downriver flows on the mainstem Klamath and Trinity Rivers.

Annual hydrographs throughout the lower KRB generally have three components: summer/fall base flow, rain driven high water with rain on snow flood peaks, and spring snowmelt. During 2004, summer base flow conditions were generally prevalent by early July throughout the KRB with the exception of the mainstem Trinity River due to an extended spring release from Lewiston Dam. A non-typical "pulse flow" release of approximately 2,000 cfs from Lewiston Dam occurred during the late summer (Figure 8) as part of an effort to reduce the risk of a repeat of the 2002 epizootic outbreak which killed an estimate 34,000 to 68,000 fall run chinook adults in the lower Klamath River. The first substantial increase in river flows throughout the KRB from precipitation after the summer dry season did not occur until Oct 20th, after the majority of coho had entered freshwater.

Hourly water temperatures at five representative locations (Klamath RKMs 26, 81, and 153; Trinity RKMs 102 and 187) in the KRB for the duration of the study period are presented in Figures 9 to 13 respectively. Water temperatures at these five sites are compared in relation to the timing of cessation of mean daily temperatures >20°C and 22°C in Table 3. Three of these sites contained cold-water tributary formed thermal refuges (e.g. Blue Creek RKM 26, Bluff Creek RKM 81, and Horse Linto Creek RKM 102), thus water temperatures for the creek or cold water source are reported in addition mainstem river temperatures above the thermal refuge (Figures 9 to 11). These thermal refuges are among the most significant in the lower KRB and are the only ones where radio listening stations were placed.

Mean daily air temperatures at three locations in the lower KRB are reported in Figures 14 to 16, which include mean daily flow and mean daily water temperature at approximately the same location to allow comparisons. The three locations are: Klamath Glen at RKM 10, Orleans at RKM 94, and Big Bar on the Trinity at RKM 174. Data sets from these locations were chosen because they are among the few long standing (i.e. >50 years) air temperature data sets from representative locations available in the KRB.

3.3 Migration Behavior

Run Timing

The river (freshwater) entry timing for all 20 tagged coho spanned from Sept 20th to Oct 22nd. Coho #19 was the only exception in that it held for 24.5 days in the estuary/nearshore ocean before commencing upriver migration in freshwater on Nov 14th. In comparison, the other four migrants had a mean estuary residence of 0.7 days. For the tagged coho migrants with approximate known destinations, the two that went up the Trinity River were tagged in late September (9/21 for coho #5 & 9/22 for coho #9) and the one that migrated up the Klamath River past Weitchpec was tagged in late October (10/21 for coho #17). Coho #5 had a right maxillary clip indicating it was from the Trinity River Hatchery and coho #17 had a left maxillary clip indicating it was from the Iron Gate Dam Hatchery.

Travel Rates

Travel rates are an excellent index of migration behavior because they reflect most of the behavioral tactics used by migrating adult chinook. Travel rates among the five migrants displayed consistently similar patterns within the lower Klamath River below RKM 30 after which travel rates varied considerably with some fish continuing on at the same pace while others slowed down substantially (Figure 17). Excluding the 24.5 days spent in the estuary by coho #19, the mean travel rate for all five migrants below RKM 30 was 11.6 km/day compared to a mean of 3.7 km/day above RKM 30. Travel rates are graphed along with temperature and flow for the lower Klamath River in Figure 18.

3.4 Thermal Experience

Internal Archival Temperature Data

Data from only one archival temperature tag was successfully recovered (coho #4). Archival temperature tags were attached to each radio transmitter and thus measured the internal body temperature of the fish every 60 minutes. The mean body temperature experienced by coho #4 during its migration was 15.2°C with a standard deviation of

2.9^{o}C. The maximum body temperature recorded was 19.1^{o}C with a minimum of 9.1^{o}C and a variance of 8.3^{o}C. There is no direct evidence that any behavioral thermoregulation occurred among tagged coho migrants including from the archival record of coho #4. The archival record of body temperatures, or thermal history, of coho #4 is presented in comparison to river temperature and flow in Figure 19 and in comparison to its travel rate in Figure 20.

4.0 DISCUSSION

The five tagged coho migrants yielded useful information and provided the only telemetry data in existence for KRB adult coho in the estuary and lower Klamath River. Unfortunately, the lack of tracking observations for these migrants beyond the mid-reaches of the Klamath and Trinity Rivers precludes any analysis of spawning site selection and makes linking migration behavior to specific populations approximate at best even when viewed in concert with results from the telemetry efforts of the FWS and KDNR.

Tagging adult salmonids in the Klamath River estuary greatly increases the chances of fish “disappearing” after tagging due to a variety of factors but is also the only way to capture the entire in-river migration history including the critical estuarine phase. In our previous three years of telemetry work on adult Chinook salmon the rate of disappearance for fish tagged in the Klamath estuary has ranged from 54 to 56%. The 71% rate of disappearance in the estuary/nearshore ocean among tagged coho was higher than expected and reduced the amount of data available for analysis. Factors that could have been contributed to the disappearance of tagged fish in the estuary include pinniped predation, unclaimed harvest, tag regurgitation, delayed tagging mortality, and inter-basin straying or visitation.

Determination of the contribution of each of these factors is greatly complicated by the inability to track radio tagged fish in the estuary or nearshore ocean since radio transmissions are not detectable in high salinity water. Regardless, tagged Chinook were subject to the same disappearance factors as tagged coho thus the question remains as to why there was an increase in the disappearance rate for coho. A sample size of 21 fish enhances the influence of random chance, but a higher rate of delayed tagging mortality for coho as opposed to the larger bodied Chinook is one possible explanation. However, the tags used were scaled down to fit the smaller bodies of coho, water temperatures were substantially cooler during coho tagging, and the tagging and capture methods used were the same for both species.

Sea lion activity during the end of September and into October in 2004 appeared to be substantially higher than during previous months based on the subjective observations of the tagging crew, which if true, provides an alternative explanation for the ~20% difference in the disappearance rate. This hypothesis is supported by the higher rate of disappearance observed among Chinook tagged in 2004 during the period when coho were also tagged as opposed to the period before. From Sept 20th to Oct 22nd 2004 a total of 21 adult Chinook were tagged at the mouth of the Klamath River of which 67% disappeared compared to 53% prior to that time. The answer to this question is certainly not conclusive but there is no evidence to indicate a higher delayed tagging mortality rate among coho versus chinook while there is some evidence to suggest that pinniped predation occurred at a higher rate later in the 2004 salmon season.

For adult coho tagged further upriver in the KRB, pinniped predation and inter-basin straying or visitation were not contributing factors to fish disappearance and harvest pressure was negligible. This could serve to explain the higher rate of upriver migration after tagging observed among coho tagged by the KDNR at Ishi Pishi Falls. Had their tagging site been located just above high salinity water then the “disappearance” rate would have been 23.5% (based on the number of tagged coho that fell-back and never proceeded upriver). In the case of the FWS, tagging occurred at Iron Gate Dam, the upriver terminus of migration, thus the percentage of tagged coho falling back is not comparable to that of Ishi Pishi Falls or the mouth of the Klamath River.

The river entry timing of tagged coho matched the approximate average peak entry timing of KRB coho (Weitkamp et al. 1995). Linking river entry timing to destination or population is problematic, however it should be noted that the three right maxillary clipped coho (TRH) were tagged from Sept 21st to Oct 1st and the two migrants that migrated up the Trinity River were tagged on Sept 21st and 22nd. The only left maxillary clipped coho was tagged on Oct 21st and migrated into the Klamath River above Weitchpec on Nov 26th. While all coho produced at both KRB hatcheries are marked by clipping a maxillary, IGH produces significantly fewer coho in comparison to TRH which could skew the analysis of run timing.

The peak river entry timing of coho during 2004 based on YTFP harvest monitoring data (total catch) occurred during the week beginning Sept 26th approximately two weeks after mean daily water temperatures had fallen below 20ºC for the season throughout the KRB (Table 3). Groot and Margolis (1999) reviewed studies that showed optimal water temperatures for migrating adult coho occurred below 15.6ºC. Water temperatures are typically substantially higher than 15.6ºC during late September in the lower Klamath River (Figure 9), however, it is interesting to note that the average body temperature experienced by coho #4 during its migration in the lower Klamath River from Sept 21st to Nov 5th was 15.2ºC. Coupled with the fact that the seasonal cooling that occurs in mid-September is a reliable environmental cue, this data indicates that water temperature may explain why KRB coho do not enter the Klamath River in large numbers prior to mid-September.

The Trinity River fall chinook pulse flow ceased on Sept 13th and the first natural rise in river flows after the summer base flow period occurred on Oct 20th, which corresponds to the entry timing of six of the 14 tagged coho. The Sept 26th peak coho entry timing of 2004 occurred approximately one month prior to the first fall freshet, which is typically the case. One benefit of such a strategy is that is allows migrating adult coho to conserve energy by migrating upriver during seasonal low flows while putting them in position to quickly access spawning tributaries once flows increase from fall rains.

Hatchery coho are presumably in less need of such a strategy but may be still under the influence genetically controlled run timing that evolved under such adaptive pressures. Caution should be used when making generalities about causes for adult coho run timing since it has shown to be highly variable in time and space within a given river basin, especially in large river systems (Weitkamp et al. 1995). In addition, artificial propagation has been shown to advance and condense run and spawn timing of adult coho (Flagg et al. 1995), and the nature of artificial culture tends to dilute natural selection processes which can de-link hatchery populations from natural environmental cues. An analysis of potential shifts in KRB coho run timing has not been conducted and the affect of hatchery production on such is not currently known.

When discussing run timing it is valuable to separate entry into estuaries from initiation of upriver migration in freshwater. In the case of the five tagged coho migrants, all but one proceeded through the estuary and initiated upriver migration in freshwater in under 24 hours with a mean estuary residence of 17 hours. This is approximately the minimum amount of time expected for homing and osmotic transformation mechanisms to function properly, and certainly does not indicate estuarine delays. The archival record of body temperature for coho #4 shows that this fish fell back into the nearshore ocean after tagging, presumably to recover from tagging as is common, for a period of three hours before resuming upriver movement (Figure 20). Given the cooler water temperatures in the river at that time of year and the high predation risk in the estuary, the costs of estuary residence presumably outweigh any benefits.

The one exception to this observed pattern was coho #19 which resided in the estuary/nearshore ocean for 24.5 days after tagging, after which it initiated upriver migration traveling at a rate similar other tagged coho migrants (Figure 17). Since the archival temperature tags was not recovered for this fish it is unknown how much time was spent in the estuary versus nearshore ocean (which have distinct thermal signatures). Regardless, this behavior was anomalous among the tagged coho and does not appear to be correlated with any obvious changes in or thresholds of temperature or flow (Figure 18). The destination of this fish may have suggested possible explanations for this behavior, however, that is also unknown. The possibility that the extended estuary/nearshore residence was caused by tagging stress is not considered likely since the other four tagged coho did not share this behavior and were tagged in exactly the same manner. Thus possible causes are not forthcoming, and this behavior is primarily evidence of variability in migration behavior among adult coho in the KRB.

When examining the travel rates (km/day) of the five coho migrants (Figures 17, 18, and 20), several interesting patterns become apparent. First, all five coho traveled relatively rapidly and at approximately the same rate (11.6 km/day) below RKM 30. Secondly, after RKM 30, three of the five migrants continued at approximately the same rate at least as far as Weitchpec (RKM 70), while the other two (#4 and #9) slowed down considerably. Finally, for the two migrants (#5 and #9) that were tracked beyond RKM 70, the confluence of the Trinity and Klamath Rivers at Weitchpec was an inflection point for travel rates.

While these patterns arguably raise more questions than they answer, and are illustrative rather than representative, it is worth exploring possible explanations for such behavior. Regarding the first pattern, it appears that all migrants reacted similarly to conditions in the lower Klamath River below RKM 30, which were characterized by stable trends in water temperatures and flow. One possible explanation is that this reach of the lower Klamath River has notably higher predation risk due to concentrated human fishing pressure and the presence pinnipeds, which are most active in the estuary but are observed as far upriver as RKM 26. Thus migrating coho have an incentive to “sprint” through this reach after which other variables besides predation risk become more important for determining migration behavior. Studies reviewed by Groot and Margolis (1991) have documented that adult coho will swim faster through shallow riffles in order to reduce the exposure to predation.

The second pattern cannot be explained by temperature or flow either since both were stable during the period in question. The next obvious line of inquiry would be examining the destination or stock origin of these migrants to see if it corresponded to differences in travel rates observed. For example, a coho bound for a small tributary to the lower Klamath River would be expected to travel slower in comparison to a coho bound for the upper Trinity or Klamath Rivers. Unfortunately the data for such comparisons does not exist with the exception that coho #5 had a clipped right maxillary and was presumably bound for the Trinity River Hatchery, and coho #17 had a clipped left maxillary and was presumably bound for Iron Gate Hatchery. Both of these hatchery fish traveled at a consistent and rapid rate from the estuary to Weitchpec as opposed to coho #4 and #9 which did not.

The third and final pattern, a notable change in travel rates above Weitchpec for the two migrants that were observed migrating up the Trinity River, is also perplexing. It is not surprising that travel rates would change after migrants enter into the Trinity River, but one migrant slowed down (#5) while the other sped up (#9). However, both of these fish arrived in the vicinity of the Willow Creek weir (RKM 101.75) within 3 days of each other despite considerably different travel rates employed to get there. More than leading to any likely explanations, this observed behavior seems to point out the variability in migration behavior among individuals within a run and the importance of using flexibility in swim speeds and hence travel rates to adjust migration timing at various points in the migration path.

Adjustments in travel rates can be used to compensate for migration delays caused by water temperatures in excess of the thermal threshold for migration inhibition. Often during such periods of high water temperature, salmonids will seek and reside in cold water patches, known as thermal refuges, which in the lower KRB occur primarily at cool-water tributary confluences (Belchik 1997, McIntosh and Li 1998). The temperatures at which this occurs for adult Chinook has been shown to be mean daily temperatures equal to or greater than 22ºC based on our radio telemetry research (unpublished data). The typical late September peak in river entry for KRB coho, along with timing of coho tagged in 2004, occurred after the cessation of water temperatures in excess of 22ºC and even 20ºC. Because of this fact it is not expected that use of thermal refuges by adult coho would be prevalent. Indeed there was no evidence that any of the tagged coho migrants used thermal refuges during their migration. This conclusion is based on body temperatures measurement recorded at listening stations, during manual tracking, and from the archival record of body temperature from coho #4 (Figure 19).

In summary, this study shows that radio telemetry tagging of adult coho is a viable method to begin answering questions related to migration behavior patterns and their causes, especially compared to the other applicable methods available. The high disappearance rate in the estuary/nearshore ocean, however, greatly decreases the efficiency of such an approach and requires a significantly increased sample size in order to provide a sufficient number of migrants with complete migration histories, archival tag recoveries, and data on spawning site selection. More questions were raised than answered by the results from this study, although the limited data available does provide a valuable snapshot of adult coho migration behavior in the lower Klamath River that is finer in resolution than any previous work. This snapshot shows several notable behavioral patterns with possible explanations suggested, however, no specific correlations emerged in comparison to important variables such as temperature, flow, or destination; although the peak run timing for KRB adult coho makes sense on an evolutionary scale when compared to the approximate long term average conditions. The results from this study are best viewed in conjunction with the results of the companion adult coho radio telemetry studies conducted by the FWS and KDNR in the mainstem Klamath River during 2004.

The decision as to whether to continue telemetry tagging of adult coho at the mouth of the Klamath River depends on management and funding priorities along with an evaluation of critical gaps in data on KRB coho. An ecologically based life cycle approach is a solid conceptual foundation to guide management actions for the maintenance and recovery of threatened KRB coho. With regard to the adult migration and spawning phases of their life cycle, I believe there are other more pressing research needs especially in relation to naturally reproducing populations and their interactions with hatchery produced fish and implications for hatchery operations. To quote from NOAA Fisheries' status review for coho salmon "A fundamental question in ESA risk assessments is whether natural production is sufficient to maintain the population without the constant infusion of artificially produced fish." (Weitkamp et al. 1995 p.98). Another fundamentally important question is to what extent is artificial production negatively impacting natural production? Of paramount importance is the question: what needs to be changed to ensure that natural production will be sufficient to maintain populations of SC/NCC ESU coho in the absence of artificially produced fish in order to accomplish the goal of recovery and delisting?

5.0 TABLES

Table 1. Radio listening station locations, dates of deployment, and radio telemetry equipment type.

Location	River	RKM	Date In	Date Out	Type
Wakel	Klamath	7.25	5/1/2004	12/6/2004	Orion/ATS
Blue Creek	Klamath	26.0	5/2/2004	12/6/2004	Orion
Lower Weitchpec	Klamath	67.5	5/5/2004	11/3/2004	Orion
Klamath/Trinity Confluence	Klamath	69.25	10/1/2004	12/15/2004	Orion
Bluff Creek	Klamath	80.0	5/7/2004	12/15/2004	Orion
Salmon River at Wooley Creek	Salmon	114	5/10/2004	12/1/2004	Orion
Upper Ishi Pishi Falls	Klamath	108.25	8/27/2004	12/8/2004	Lotek
Happy Camp	Klamath	177.5	8/28/2004	12/8/2004	Lotek
Blue Heron	Klamath	234.25	8/28/2004	12/8/2004	Lotek
Mouth of Shasta River	Klamath	288.5	8/29/2004	12/8/2004	Lotek
Horse Linto Creek	Trinity	101.75	5/5/2004	12/16/2004	Orion
Hawkins Bar	Trinity	132.5	10/15/2004	12/16/2004	Orion
China Slide	Trinity	146.0	5/15/2004	10/30/2004	Orion
Junction City Weir	Trinity	207.5	8/31/2004	12/16/2004	Orion

Table 2. Tagging data and final known fates or last observations for all 21 adult coho tagged at the mouth of the Klamath River by YTFP in 2004.

Tagging Date	Fish ID #	Radio Tag Frequency	FL cm	Marks	Fate or Last Observation
20-Sep	1	150.212	70	none	MIA estuary
20-Sep	2	150.293	71	none	MIA estuary
21-Sep	3	150.393	75	none	MIA estuary
21-Sep	**4**	**150.373**	**70**	**none**	**dead at RKM 56.5 on 11/5**
21-Sep	**5**	**150.403**	**72**	**right max**	**below Willow Creek weir RKM 105.7 on 10/19**
21-Sep	6	150.413	72	right max	MIA estuary
22-Sep	7	150.494	71	none	MIA estuary
22-Sep	8	150.432	75	none	MIA estuary
22-Sep	**9**	**150.623**	**68**	**none**	**passed above Hawkins Bar RKM 132.5 on 11/11**
1-Oct	10	150.673	72	none	MIA estuary
1-Oct	11	150.702	67	none	MIA estuary
1-Oct	12	150.812	72	none	MIA estuary
1-Oct	13	150.823	69	none	MIA estuary
1-Oct	14	150.893	67	none	MIA estuary
1-Oct	15	150.953	71	right max	MIA estuary
20-Oct	16	148.032	68	none	MIA estuary
21-Oct	**17**	**148.054**	**72**	**left max**	**Klamath River at Weitchpec RKM 70 on 11/4**
21-Oct	18	148.062	70	none	MIA estuary
21-Oct	**19**	**148.072**	**64**	**none**	**passed Weitchpec RKM 69 on 11/26**
21-Oct	20	148.084	70	none	seal predation
22-Oct	21	150.153	72	none	MIA estuary

Table 3. Summary of the timing of cessation of biologically important benchmarks of mean daily temperature (MDT) for five locations in the Klamath River Basin. Water temperatures were influenced by a fall chinook disease prevention pulse flow from Lewiston Dam on the Trinity River which lasted from 8/24 to 9/15/2004

Water Temperature Monitoring Location 2004	**Last Day Over MDT 22ºC**	**Last Day Over MDT 20ºC**	**Days Over MDT 20ºC**
Klamath River at RKM 26	8/24	9/16	80
Klamath River at RKM 81	9/1	9/13	81
Trinity River at RKM 102	8/22	8/24	39
Trinity River at RKM 187	NA	NA	0
Klamath River at RKM 153	9/1	9/13	88

6.0 FIGURES

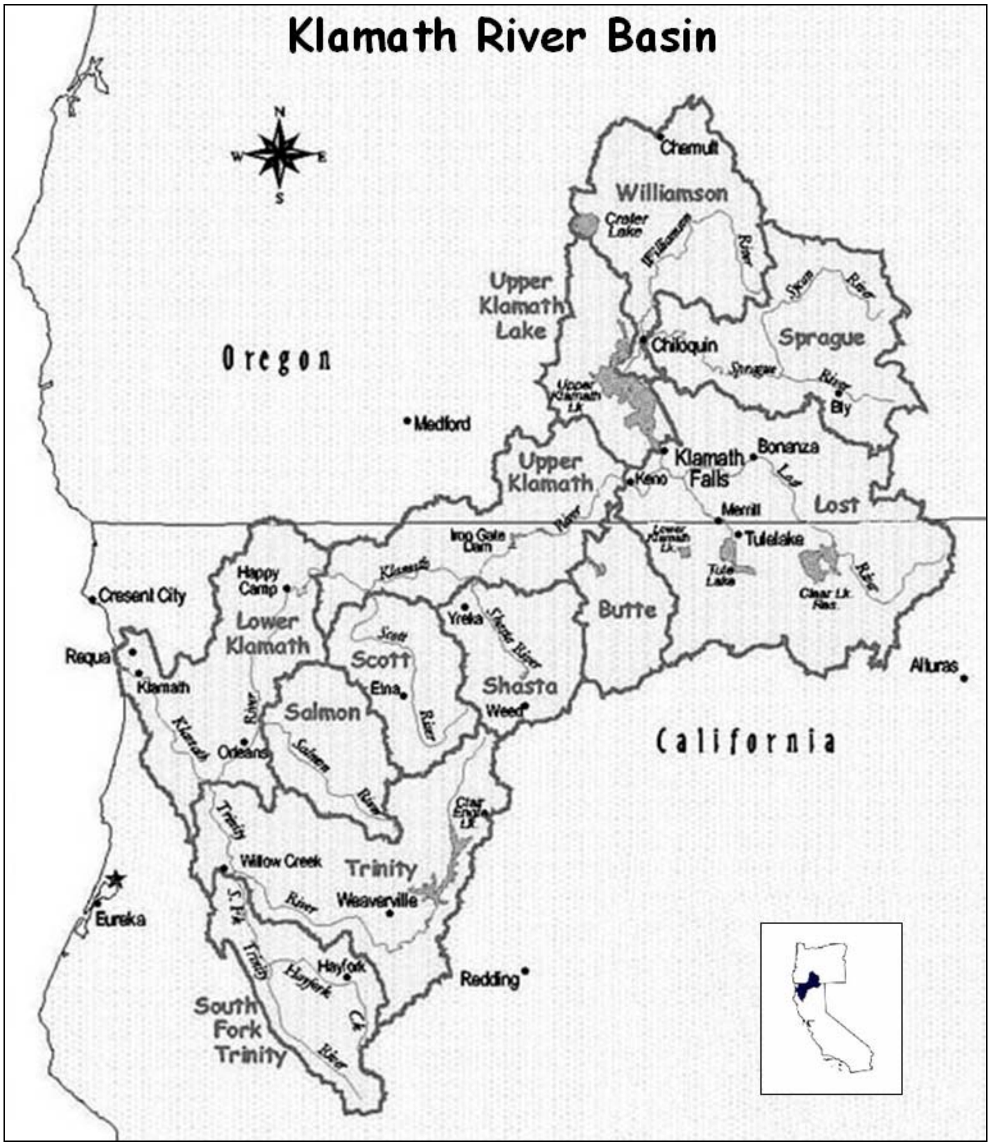

Figure 1. The Klamath River Basin of northern California and southern Oregon with sub-basins. Iron Gate Dam on the mainstem Klamath and Trinity Dam on the mainstem Trinity River both currently limit the upriver distribution of anadromous fishes within the watershed.

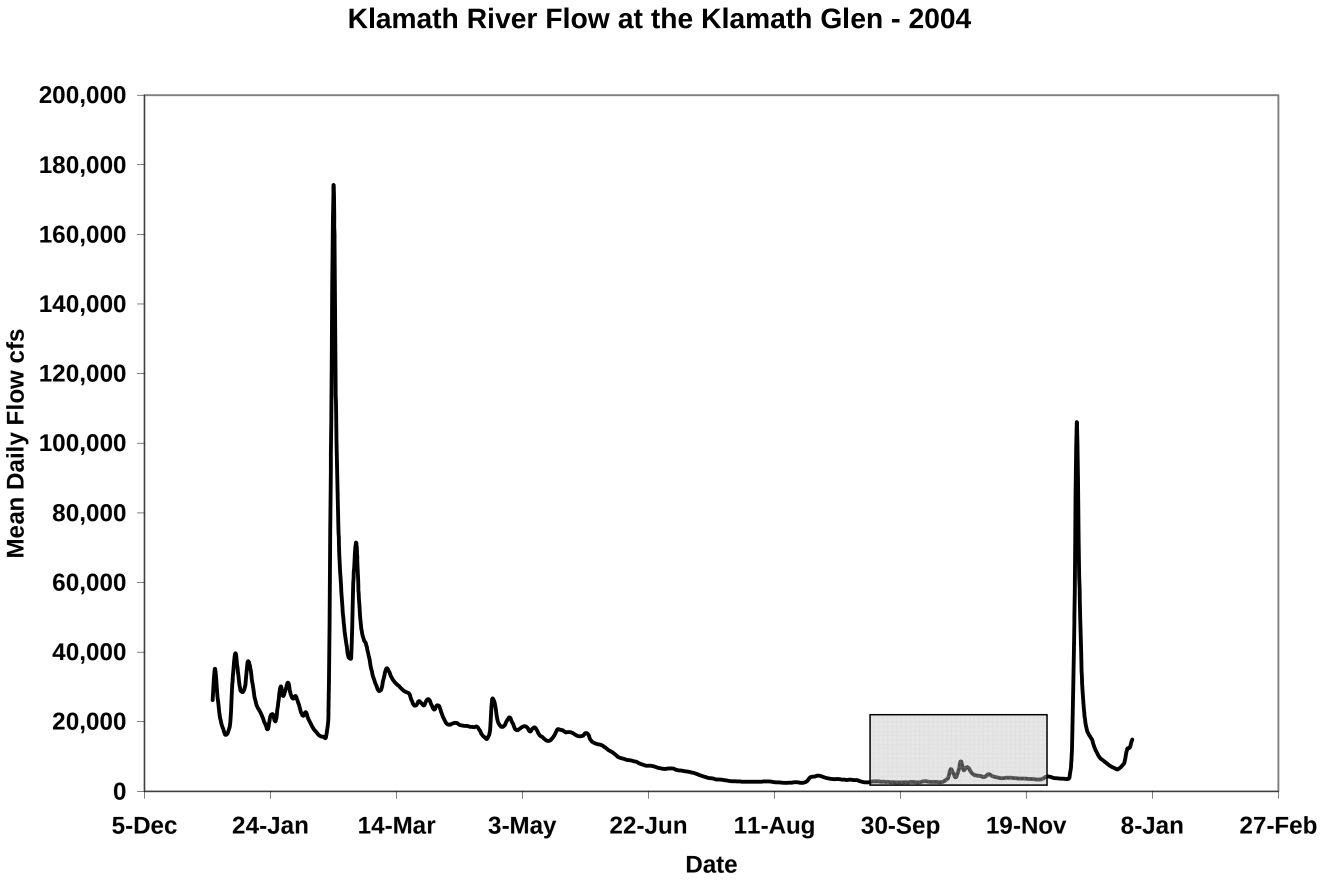

Figure 2. Flow (cubic feet per second – cfs) in the lower Klamath River during the 2004 calendar year. The shaded box highlights the months when tagged coho were holding or migrating through the lower Klamath River (defined as the reach from the estuary to the Trinity River confluence at Weitchpec RKM 69).

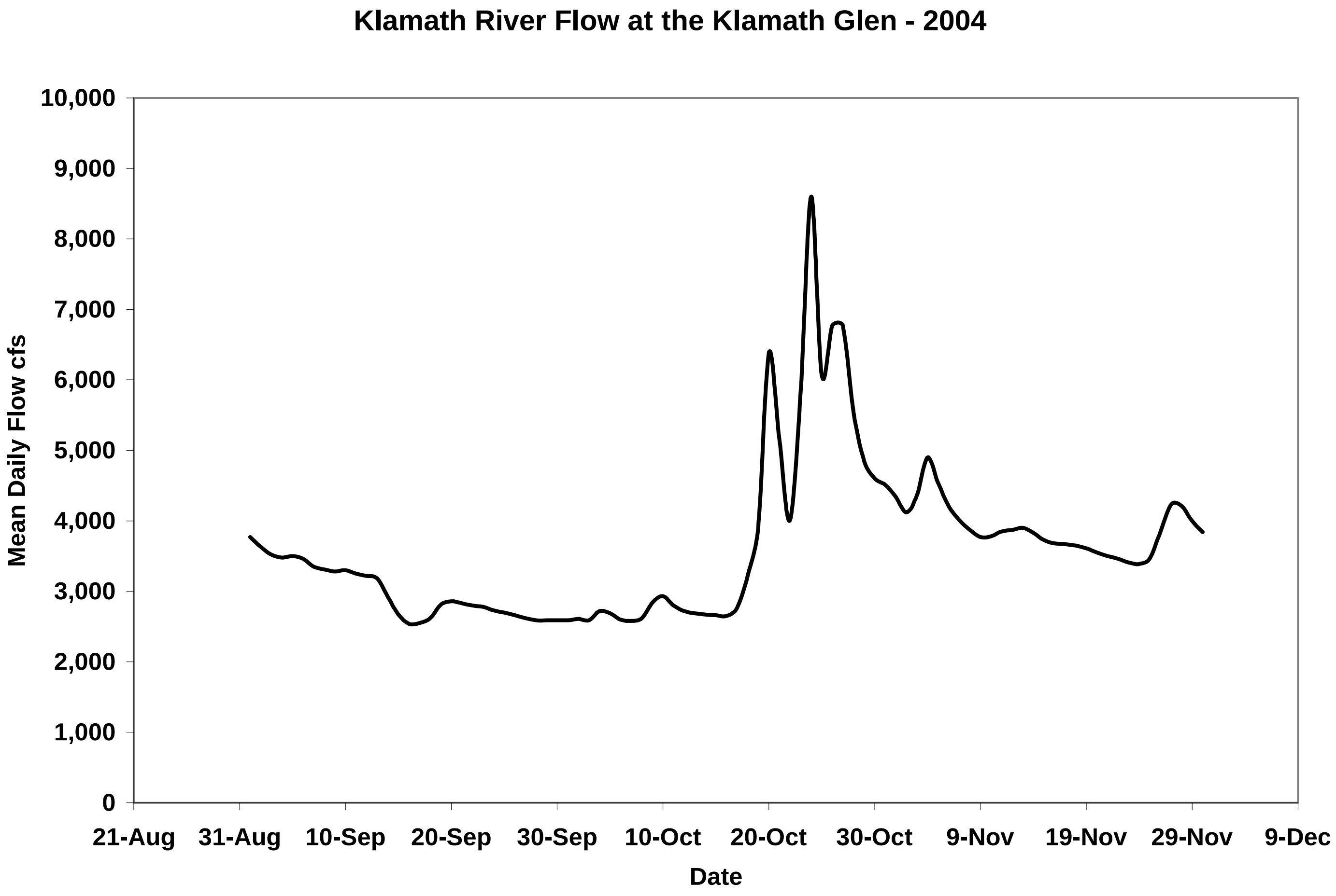

Figure 3. Flows in the lower Klamath River during the months when tagged coho were holding or migrating through the lower Klamath River. The spike in flows during late August was due to pulse flow releases from Lewiston and Iron Gate Dams.

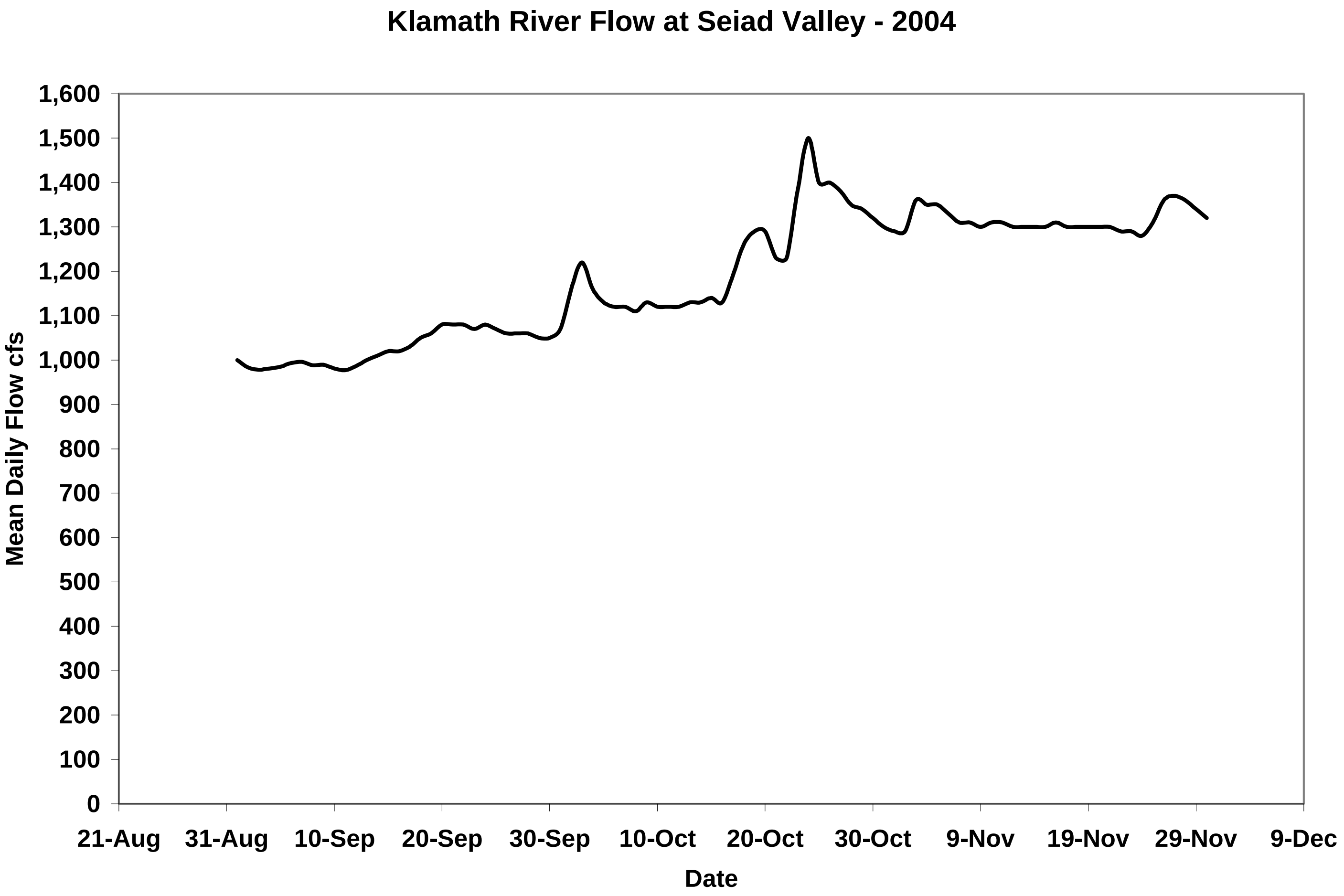

Figure 4. Flows in the mid Klamath River during the months when tagged coho were holding or migrating through in the KRB.

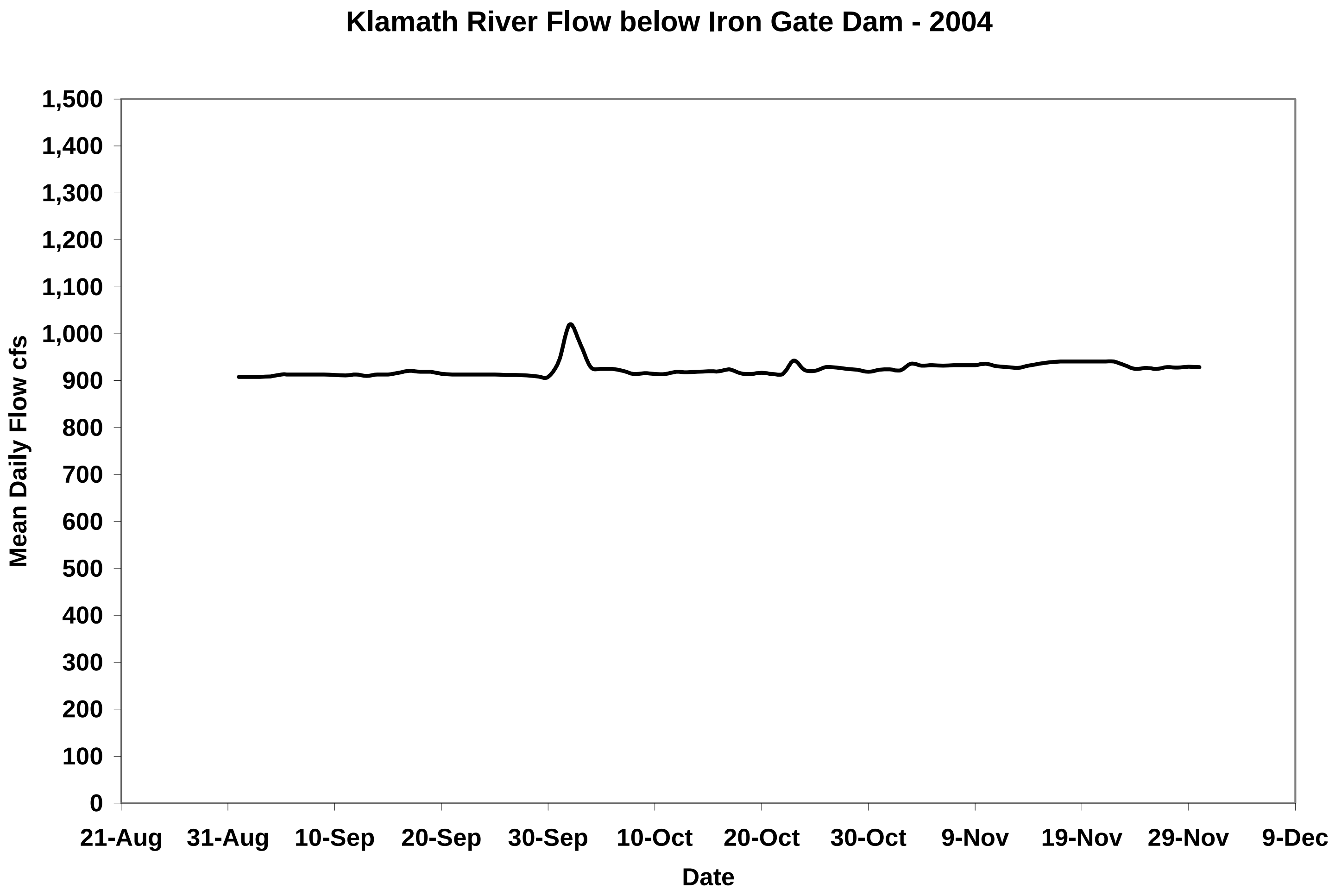

Figure 5. Flow releases from Iron Gate Dam during the period when tagged coho were migrating in the Klamath River.

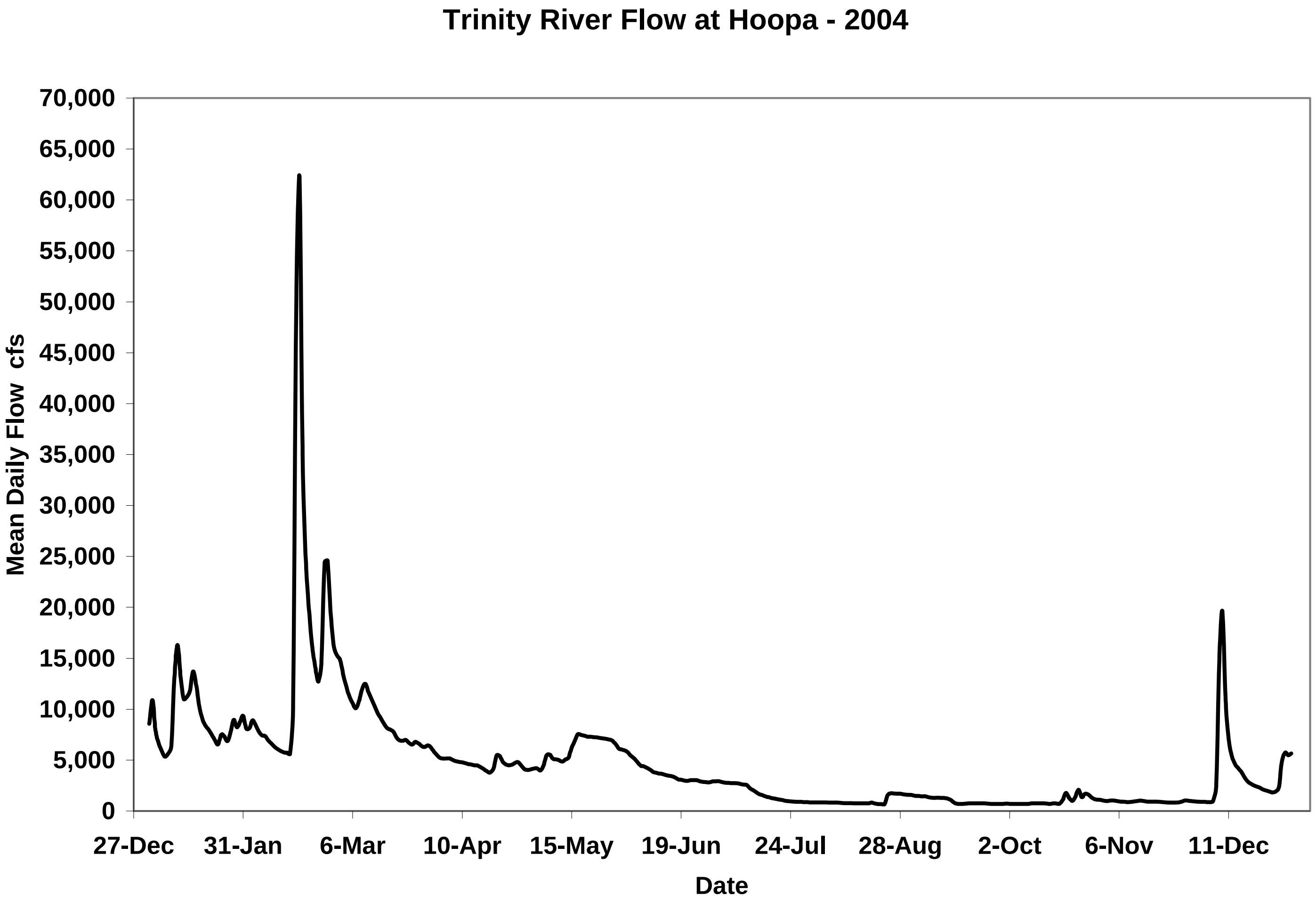

Figure 6. Flows in the lower Trinity River during the 2004 calendar year.

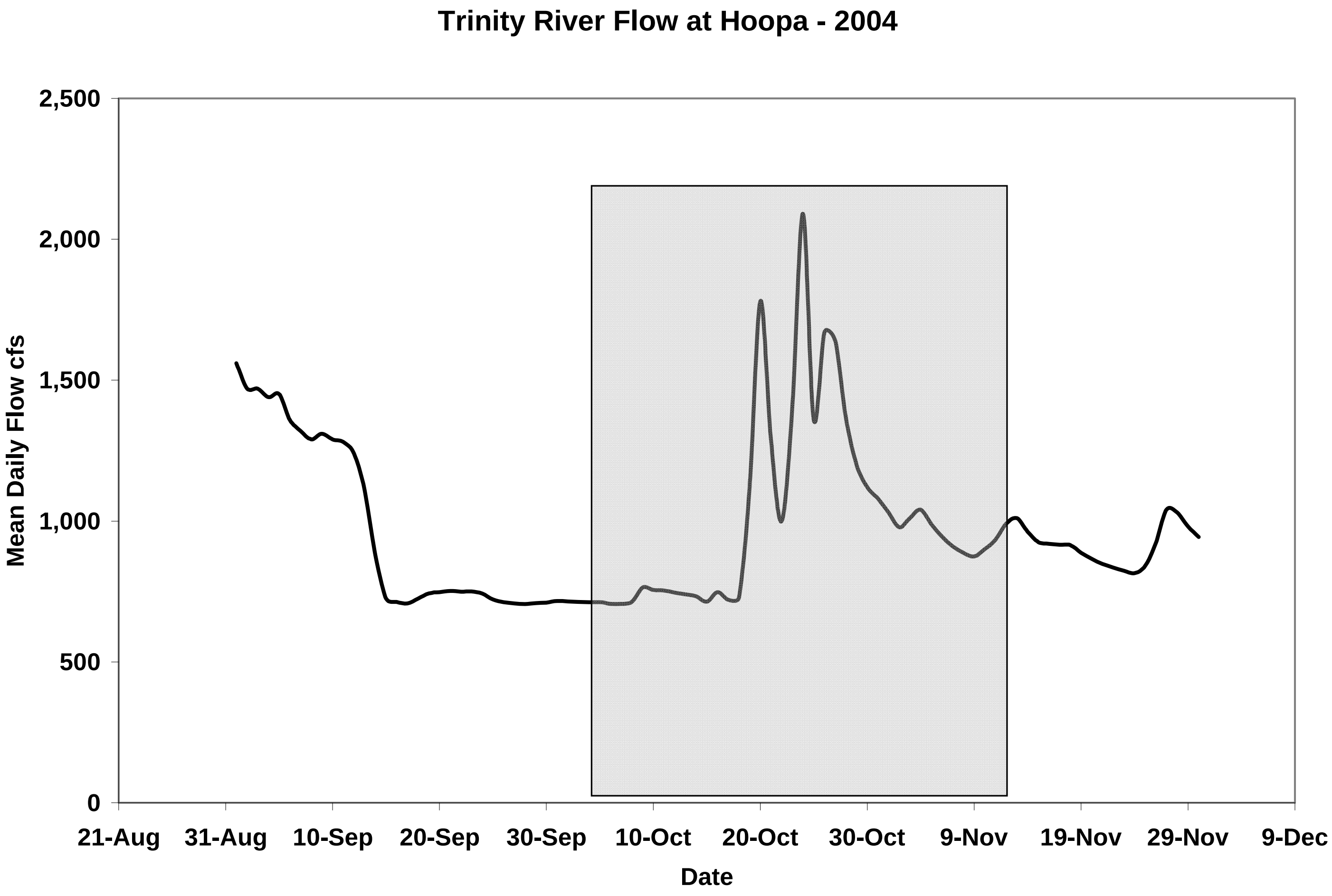

Figure 7. Flow for the lower Trinity River during the late summer and fall of 2004. The shaded box highlight the period of time when tagged coho were holding in or migration through this reach.

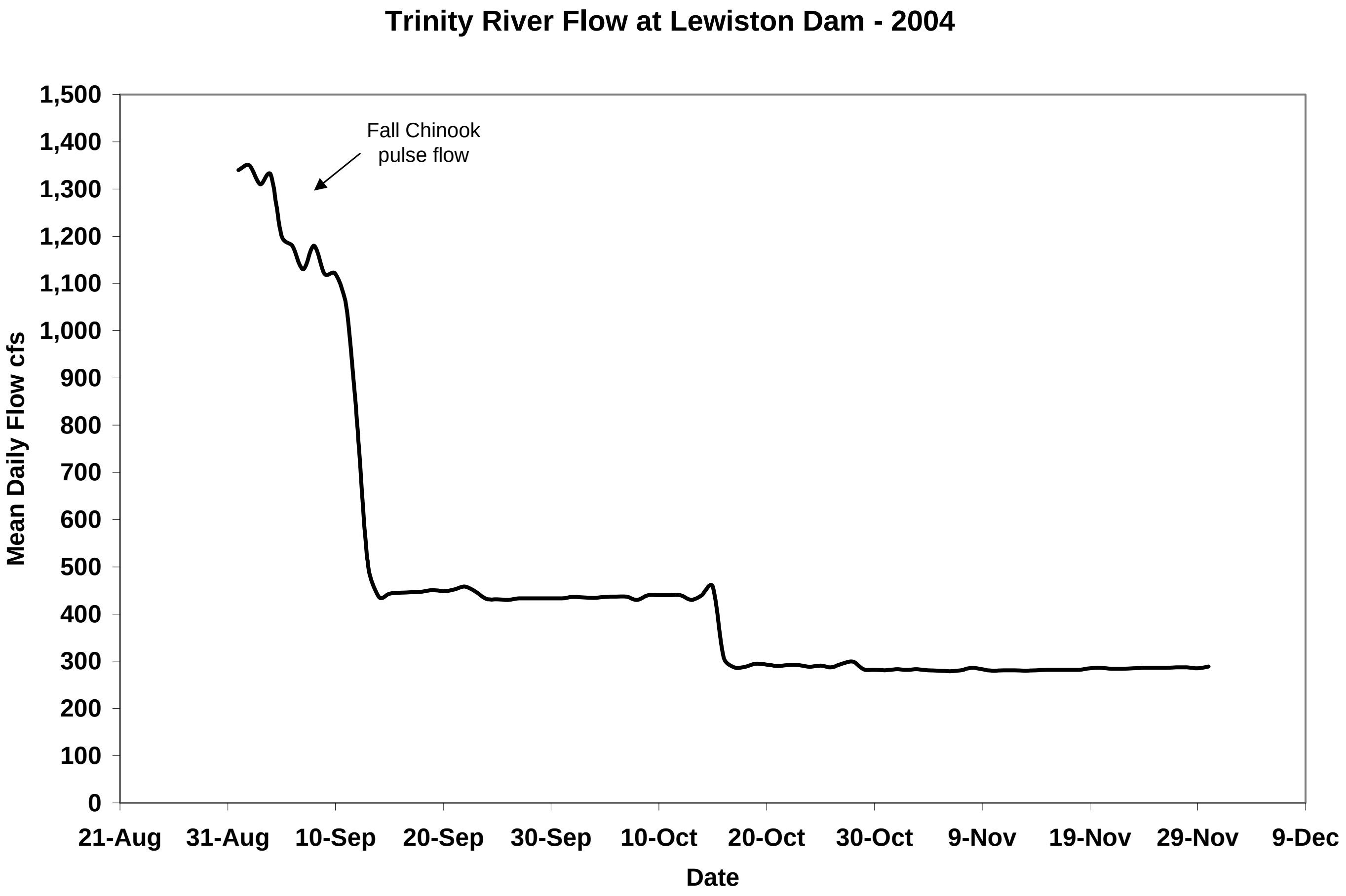

Figure 8. Flow for the lower Trinity River during the late summer and fall of 2004.

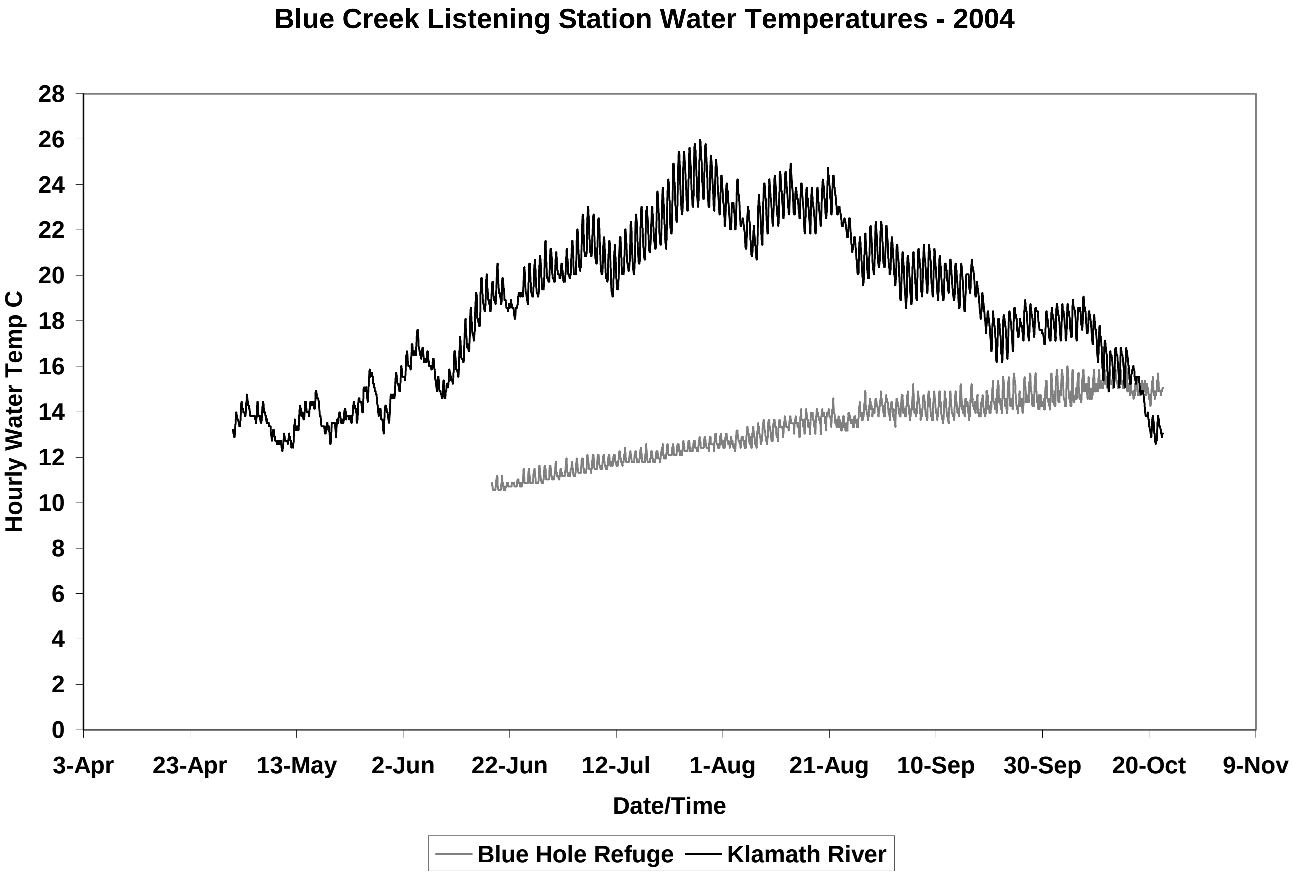

Figure 9. Hourly water temperatures for the mainstem Klamath River and the hyporheically fed Blue Hole during the study period at RKM 26, the location of the Blue Creek radio listening station.

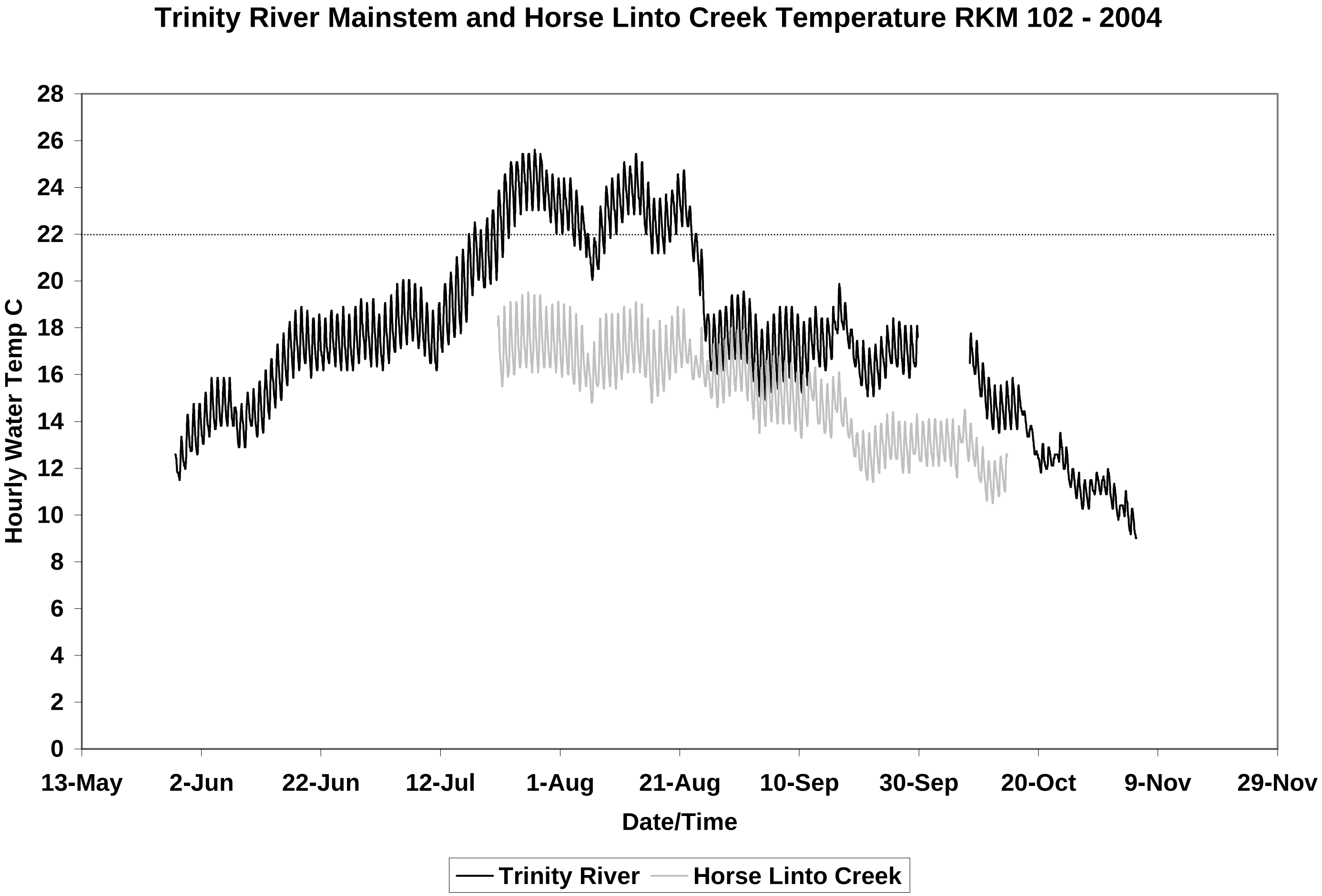

Figure 10. Hourly water temperatures for the mainstem Trinity River and the thermal refuge forming Horse Linto Creek during the study period at RKM 102, the location of the Horse Linto Creek radio listening station. The dotted line marks the 22ºC threshold.

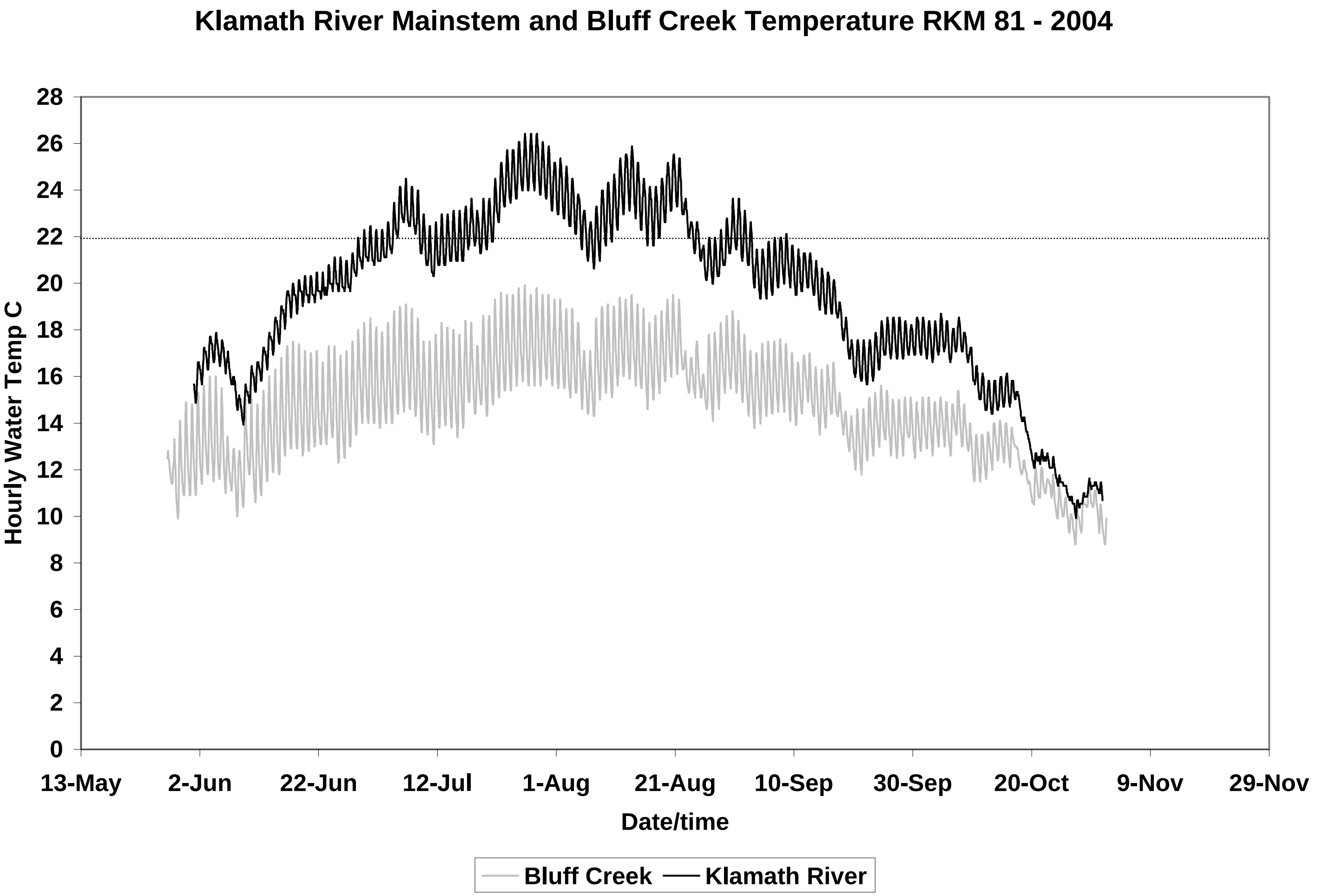

Figure 11. Hourly water temperatures for the mainstem Klamath River and the thermal refuge forming Bluff Creek during the study period at RKM 180, the location of the Bluff Creek radio listening station. The dotted line marks the 22ºC threshold.

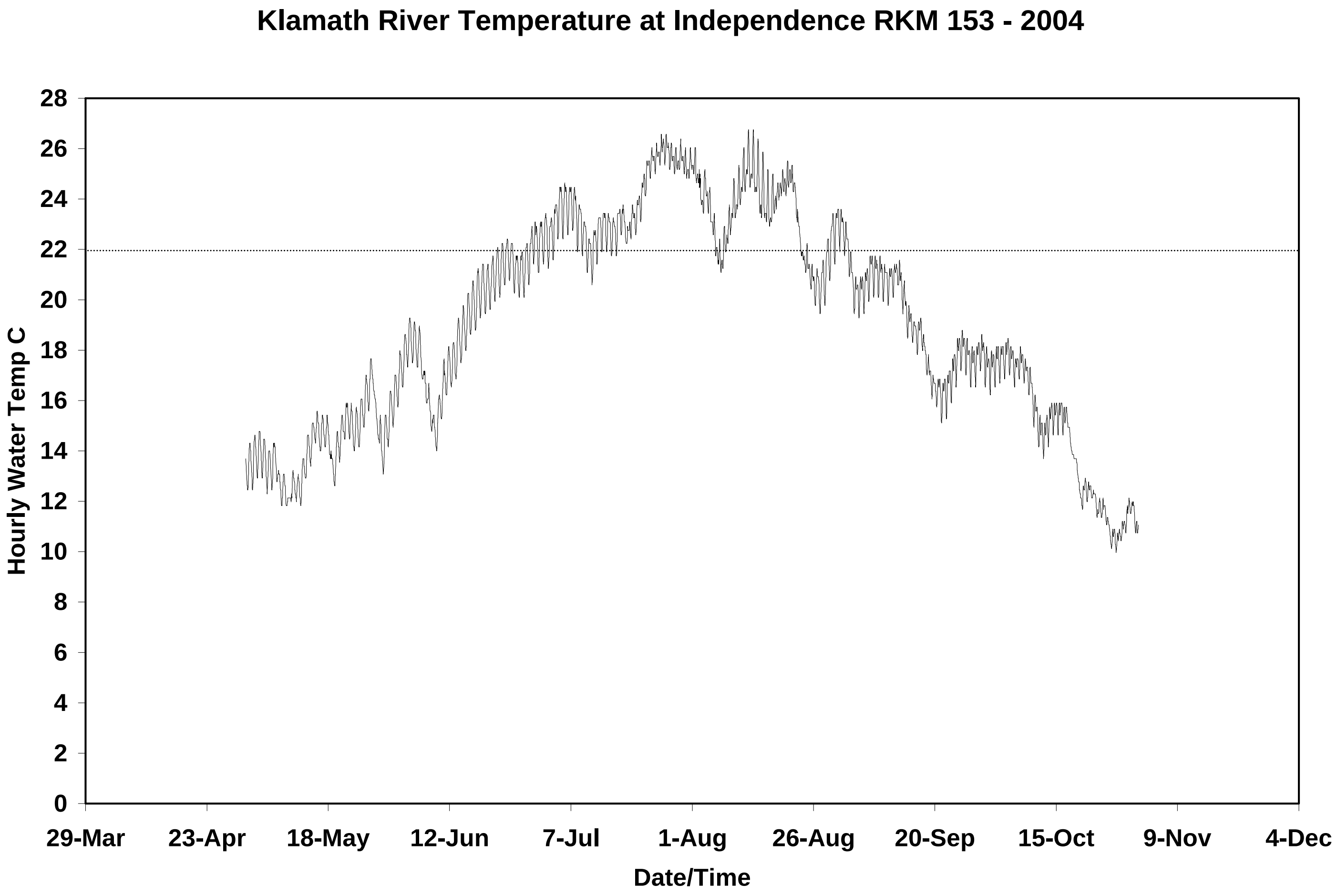

Figure 12. Hourly water temperatures for the Klamath River at Independence (RKM 153) during the 2004 study period. The dotted line marks the 22ºC threshold.

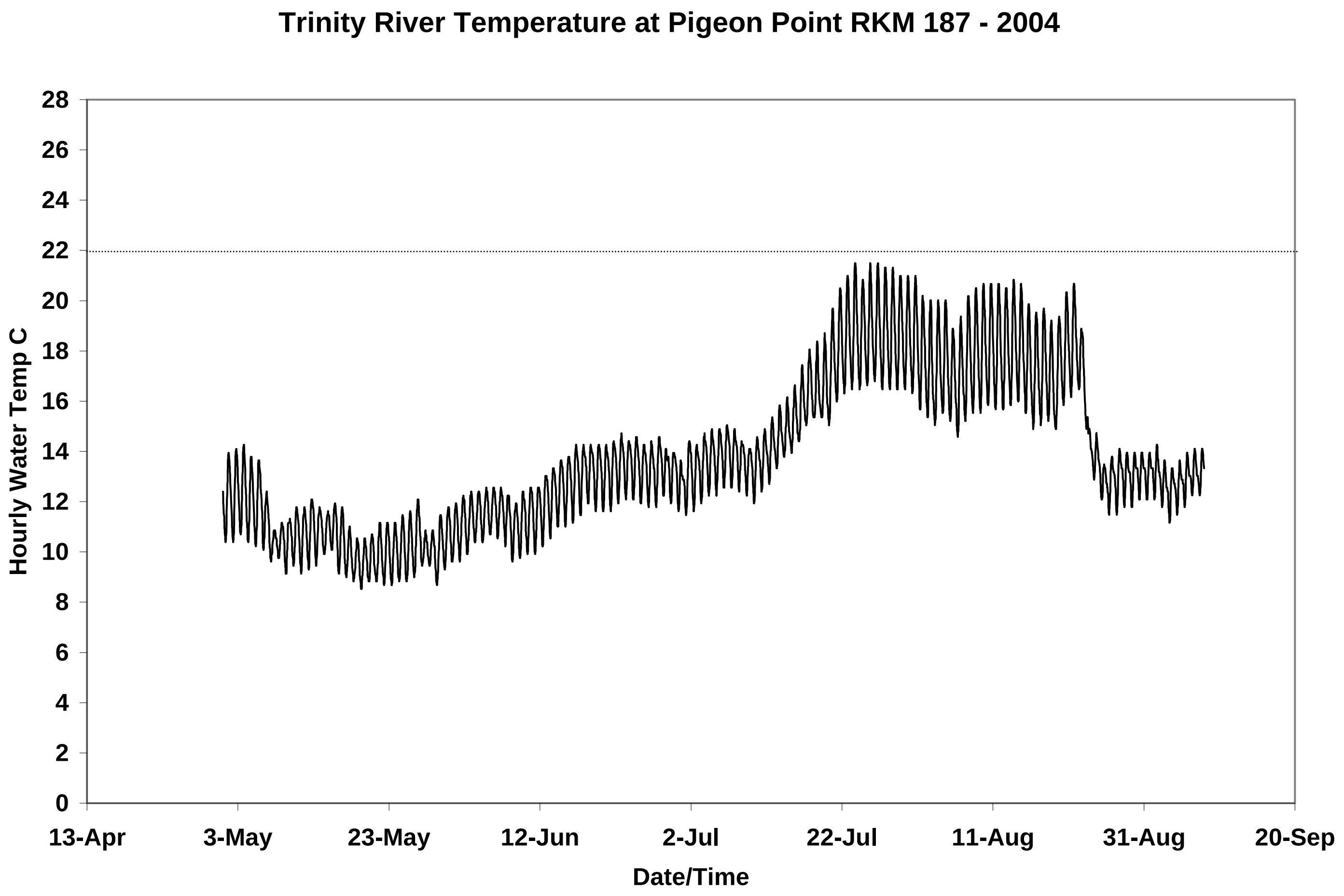

Figure 13. Hourly water temperatures for the Trinity River at Pigeon Point (RKM 187) during the 2004 study period. The dotted line marks the 22ºC threshold.

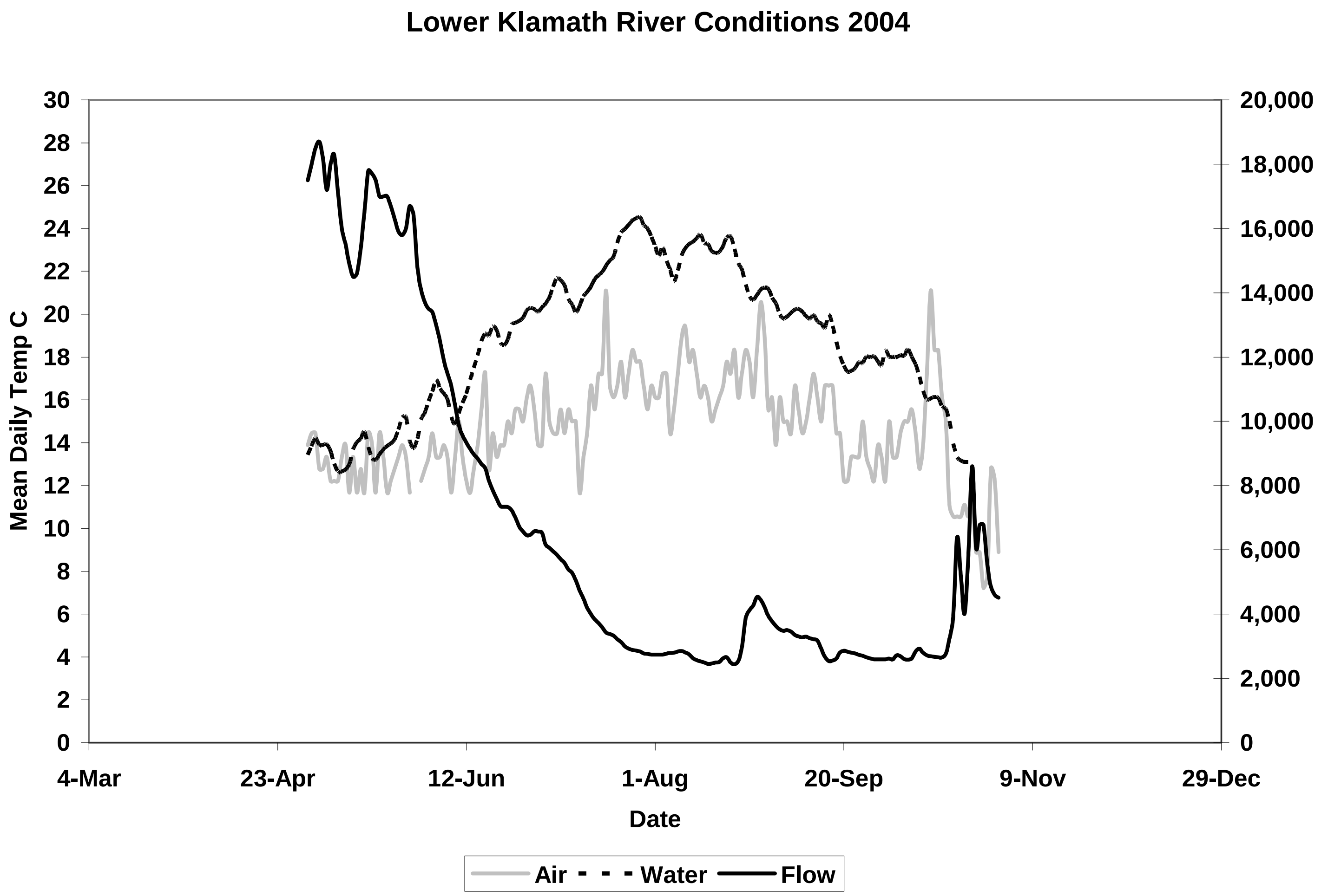

Figure 14. Comparison of mean daily air temperature (RKM 13), water temperature (RKM 26), and flow (RKM 13) for the lower Klamath River during the 2004 study period.

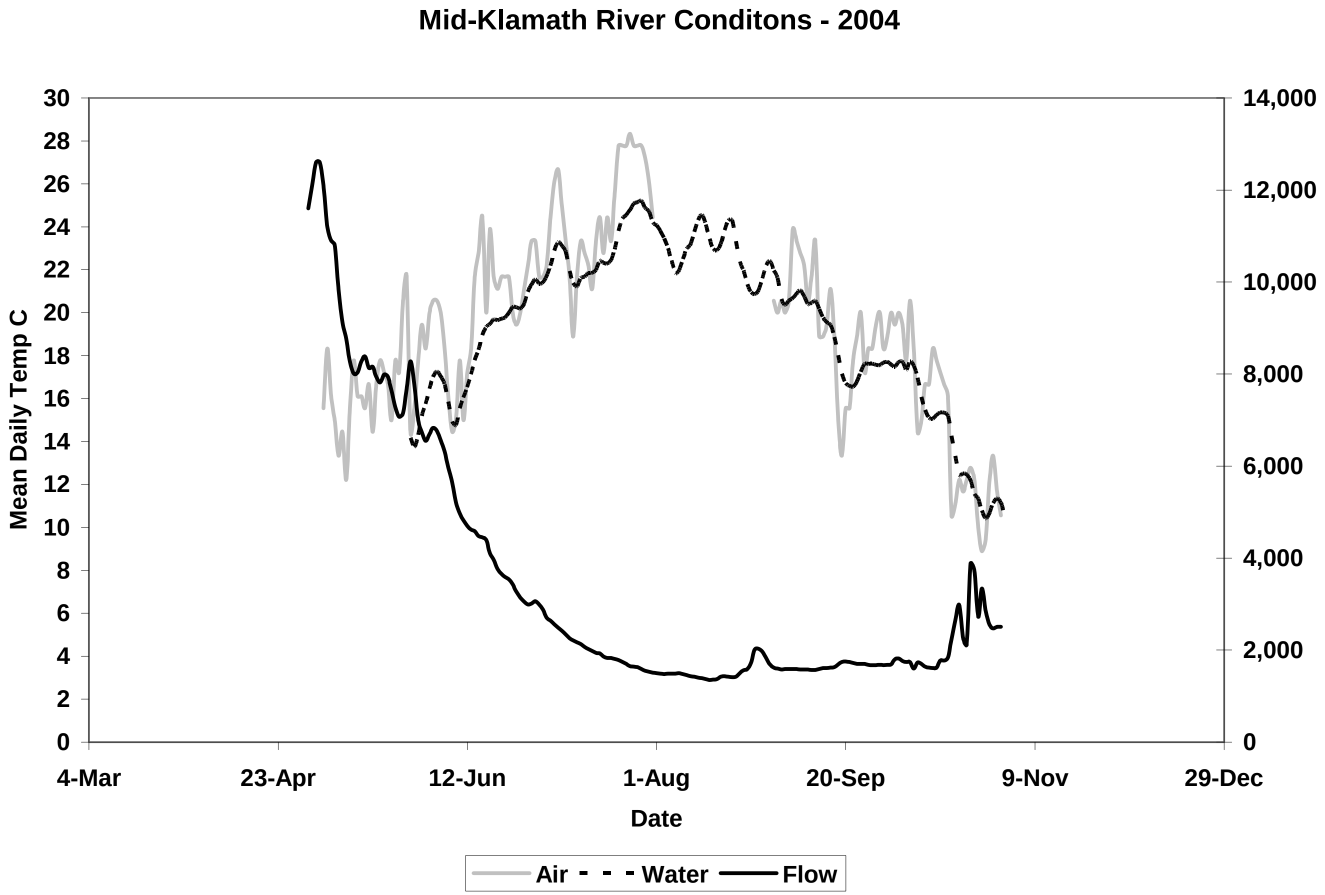

Figure 15. Comparison of available mean daily air temperature (RKM 95.5), water temperature (RKM 81), and flow (RKM 96) for the mid-Klamath River during the 2004 study period.

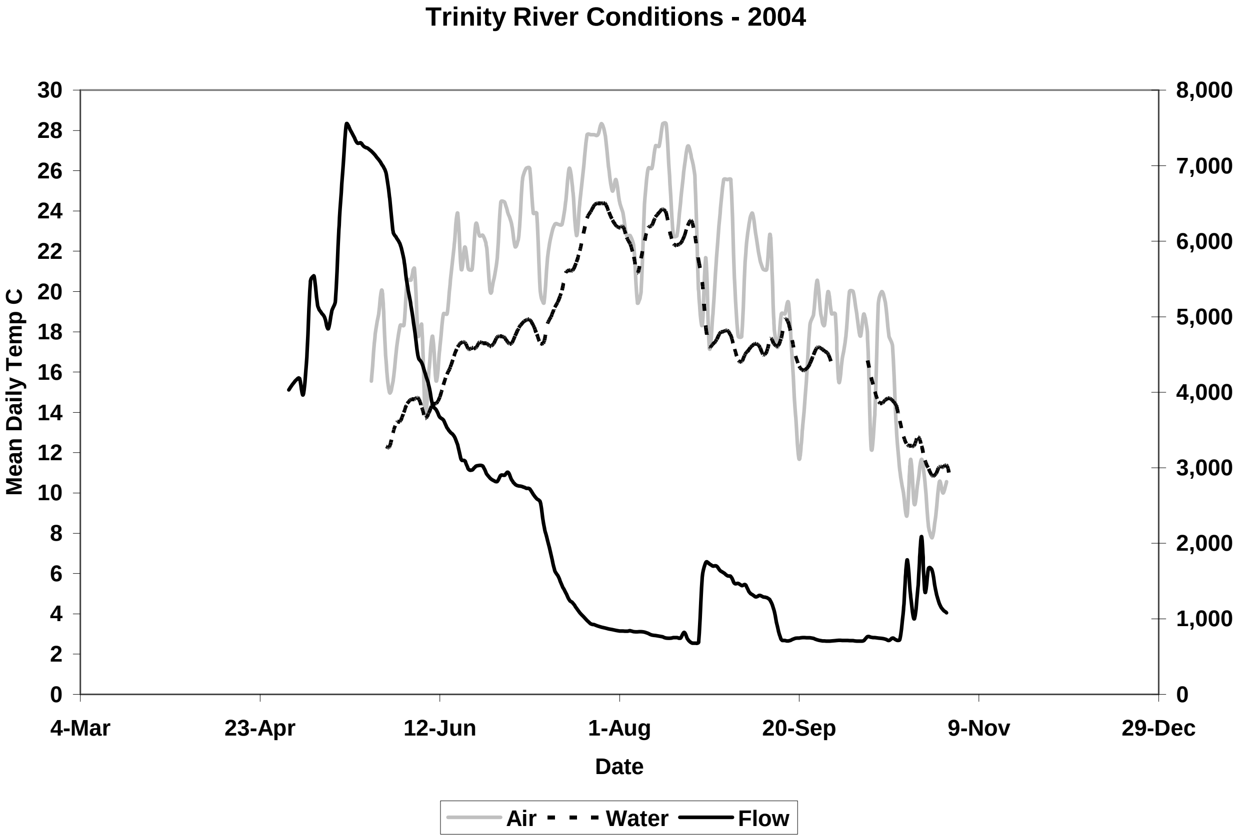

Figure 16. Comparison of mean daily air temperature (RKM 174), water temperature (RKM 102.5), and flow (RKM 90) for the lower Trinity during the 2004 study period. The air temperature record at RKM 174 was used because it was the most complete record while water temperature was used further downstream at RKM 102.5 in order to get beyond the strongest influences of cold water release from Lewiston Dam.

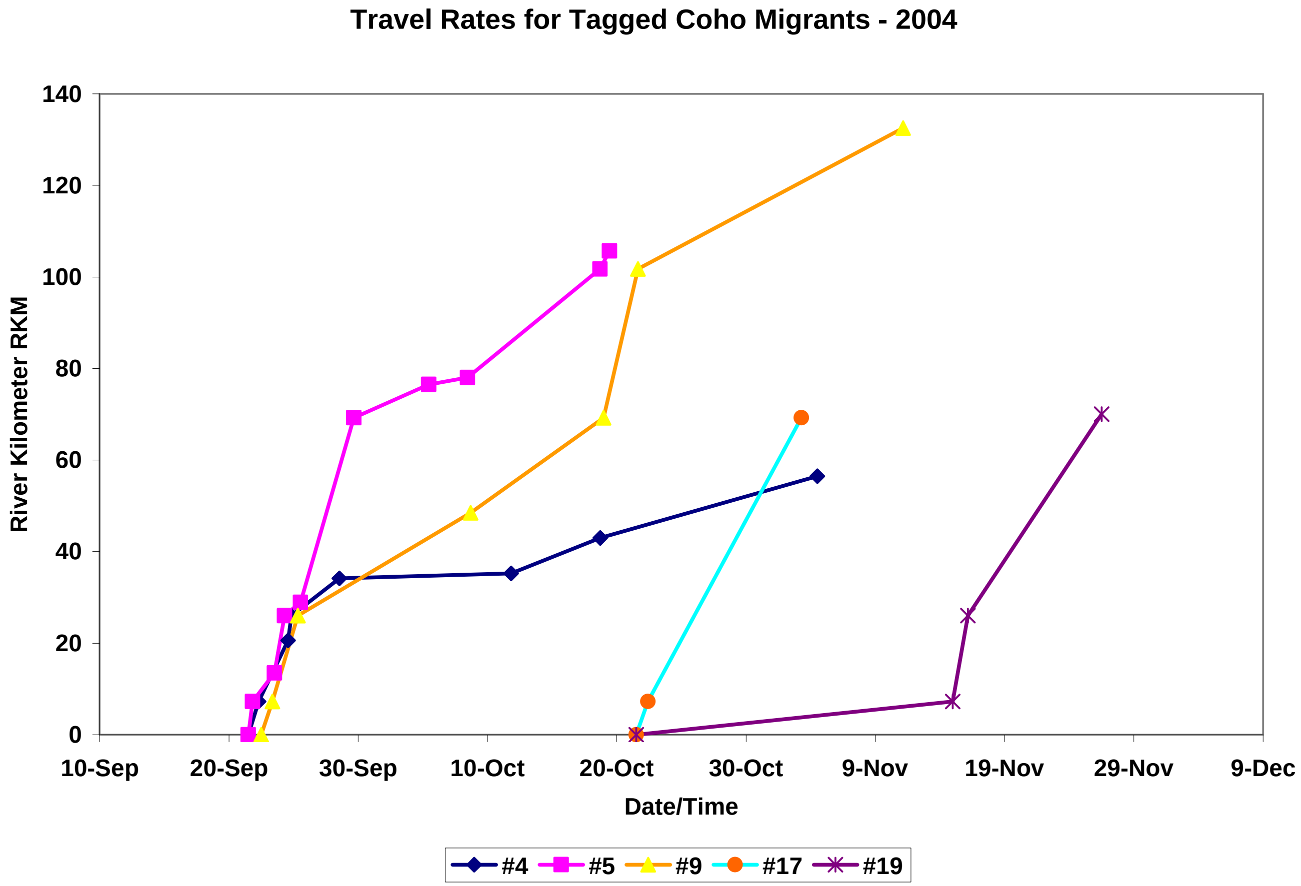

Figure 17. Travel rates of all five tagged coho "migrants" expressed as river kilometer (RKM) by date for all observations. The first data point is for the date of tagging at the mouth of the Klamath River, while the second marks the upper terminus of the estuary. Coho #5 (150.403) and #9 (150.623) both migrated up the Trinity River.

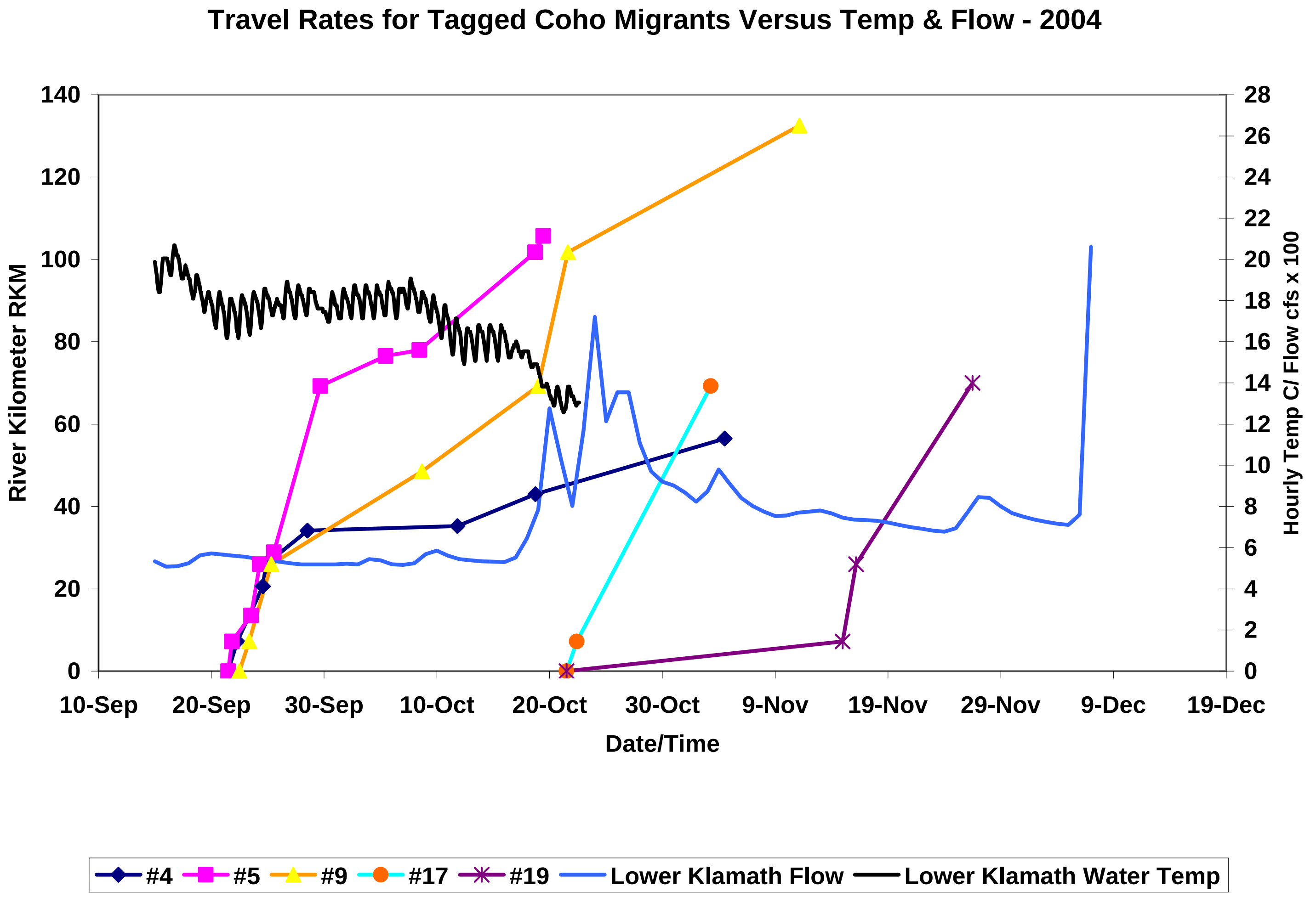

Figure 18. Water temperature and flow for the lower Klamath River compared to travel rates of all five tagged coho "migrants" expressed as river kilometer (RKM) by date for all observations.

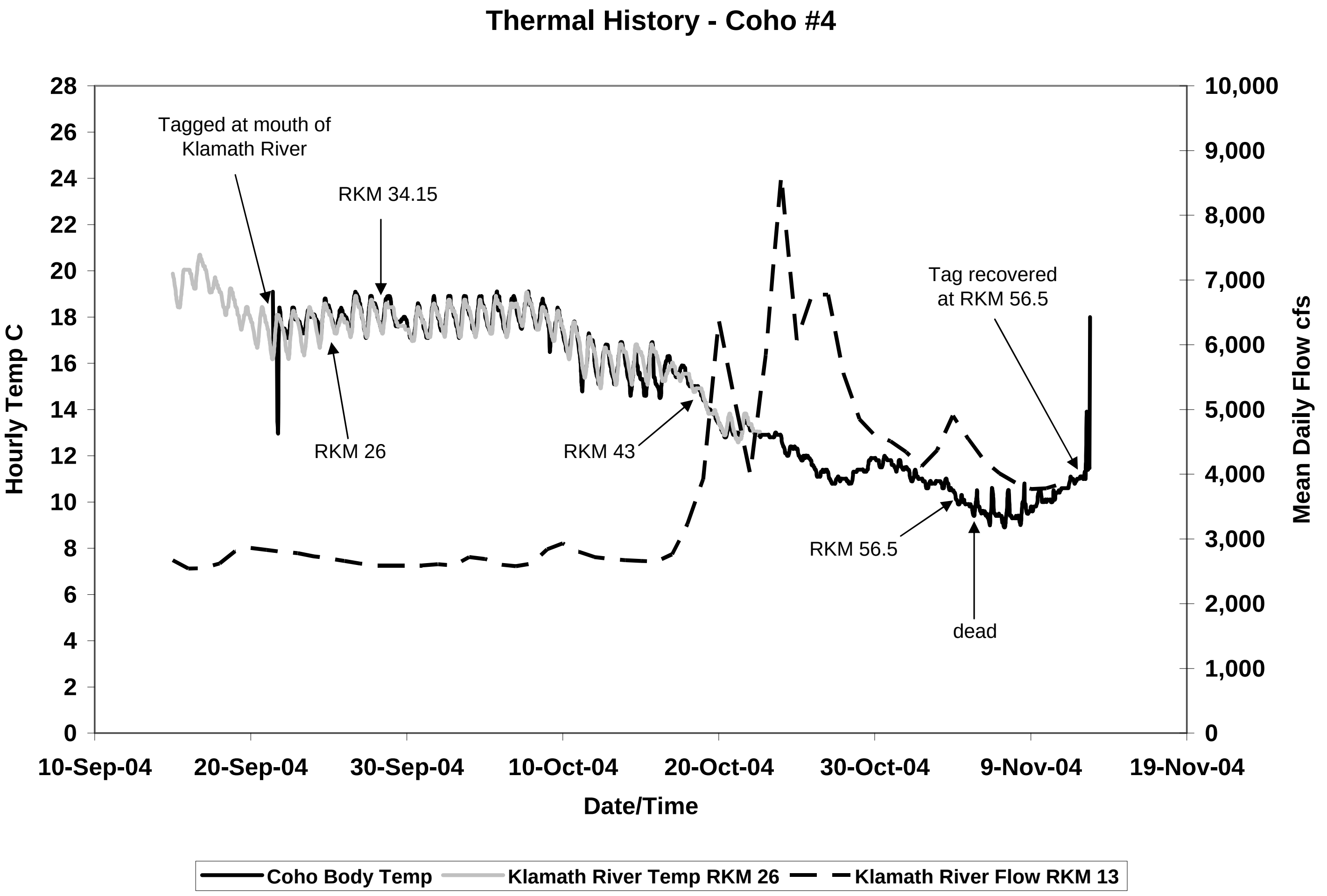

Figure 19. The thermal history of body temperatures experienced hourly by coho 150.373 in comparison to water temperature (grey line) and flow (dashed line) for the lower Klamath River. The arrows indicate observed locations (river kilometer) for this coho.

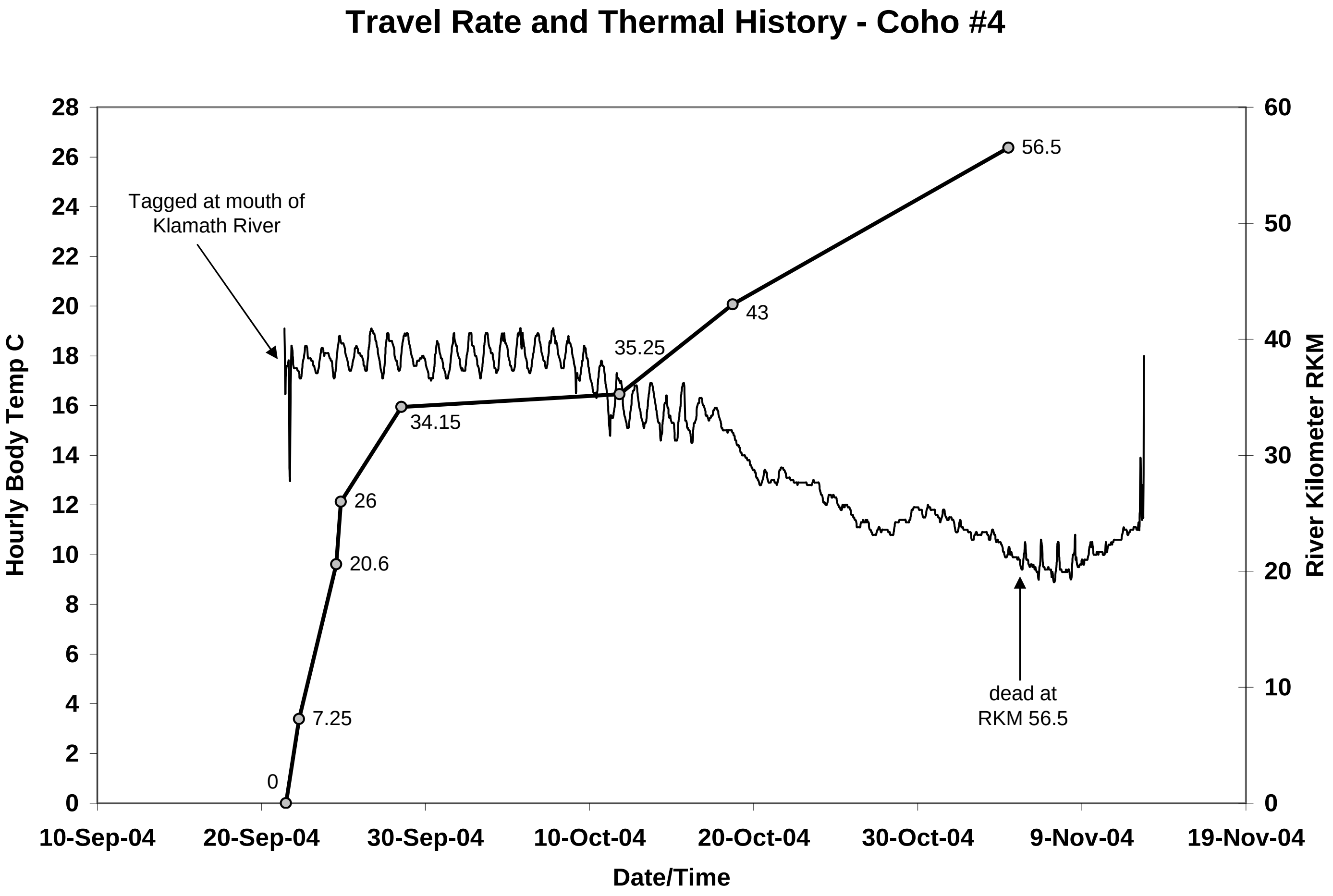

Figure 20. The thermal history of body temperatures experienced hourly by coho #4 (150.373) in comparison to its travel rate through the lower Klamath River. All observations are presented.

7.0 LITERATURE CITED

Belchik, M. 1997. Summer locations and salmonid use of cool water areas in the Klamath River: Iron Gate Dam to Seiad Creek, 1996. Yurok Tribal Fisheries Program. Klamath, CA. 13 pp.

Bernatchez, L., and Dodson, J.J. 1987. Relationship between bioenergetics and behavior in anadromous fish migrations. Can. J. Fish. Aquat. Sci. **44**: 399-407.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence timing. Can. Spec. Publ. Fish. Aquat. Sci. No. 96: 120-124.

Brown, L.R., P.B. Moyle, and R.M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. N. Am. J. Fish. Manage. 14:237-261.

Bye, V.J. 1984. The role of environmental factors in the timing of reproductive cycles. *In* Fish reproductions: strategies and tactics. *Edited by* G.W. Potts and R.J. Wotton. Academic Press, London, UK. pp. 187-205.

California Department of Fish and Game (CDFG). 1994. Petition to the California Board of Forestry to list coho salmon (*Oncorhynchus kisutch*) as a sensitive species. Calif. Dep. Fish Game Rep., 35 p. plus appendices. (Available from California Board of Forestry, 1416 Ninth, Sacramento, CA 95814.)

Dingle, H. 1996. Migration: The biology of life on the move. Oxford University Press, New York.

Dodson, J.J. 1997. Fish migration: an evolutionary perspective. *In* Behavioural ecology of teleost fishes. *Edited by* J.J. Godin. Oxford University Press, Oxford. pp. 10-36.

Eames, M., T. Quinn, K. Reidinger, and D. Haring. 1981. Northern Puget Sound 1976 adult coho and chum tagging studies. Wash. Dep. Fish. Tech. Rep. 64, 136 p.

Fagen, R., and W. W. Smoker. 1989. How large-capacity hatcheries can alter interannual variability of salmon production. Fish. Res. 8:1-11.

Gilhousen, P. 1990. Prespawning mortalities of sockeye salmon in the Fraser River system and possible causal factors. Int. Pac. Salmon Fish Comm.: Bull. No. 26: 51p.

Gross, M.R. 1984. Sunfish, salmon, and the evolution of alternative reproductive strategies and tactics in fish. *In* Fish reproduction: strategies and tactics. *Edited by* G.W. Potts and R.J. Wotton. Academic Press, London, UK. pp. 55-75.

Groot, C., and Margolis, L. 1991. Pacific salmon life histories. UBC Press, Vancouver, 564 pp.

Hinch, S.G., and Rand, P.S. 2000. Optimal swimming speeds and forward-assisted propulsion: energy-conserving behaviours of upriver-migrating adult salmon. Can. J. Fish. Aquat. Sci. **57**: 2470-2478.

Hjort, R. C., and C. B. Schreck. 1982. Phenotypic differences among stocks of hatchery and wild coho salmon, *Oncorhynchus kisutch*, in Oregon, Washington, and California. Fish. Bull., U.S. 80:105-119.

Hodgson, S., and Quinn, T.P. 2002. The timing of adult sockeye salmon migration into freshwater: adaptations by populations to prevailing thermal regimes. Can. J. Zool. **80**: 542-555.

Jonsson, N. 1991. Influence of water flow, water temperature and light on fish migration in rivers. Nordic J. Freshw. Res. **66**: 20-35.

Legget, W.C. 1985. The role of migrations in the life history evolution of fish. Contributions in Marine Science **27**: 277-295.

Lister, D. B., L. M. Thorson, and I. Wallace. 1981. Chinook and coho salmon escapements and coded-wire tag returns to the Cowichan-Koksilah river system, 1976-1979. Can. Manuscript Rep. Fish. Aquat. Sci. 1608, 168 p.

Mangle, M. 1994. Life history variation and conservation of salmonids. Conserv. Biol. **8**: 879-880.

McIntosh, B.A. and H.W. Li. 1998. Final report - Klamath Basin pilot project: coldwater refugia study and videography. Oregon State University, Corvallis, OR.

Potts, G.W., and Wooton, R.J., editors. 1984. Fish reproduction: strategies and tactics. Academic Press, London, UK.

Quinn, T.P., and Adams, D.J. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology **77**: 1151-1162.

Quinn, T.P., Hodgson, S., and Peven, C. 1997. Temperature, flow, and the migration of adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. Can. J. Fish. Aquat. Sci. **54**: 1349-1360.

Riggs, L. A. 1990. Principles for genetic conservation and production quality. Report to Northwest Power Planning Council, Portland, OR. (Available from Northwest Power Planning Council, 851 SW Sixth, Suite 1100, Portland, OR 97204-1348.)

Roff, D.A. 2002. Life history evolution. Sinauer Associates, Sunderland, MA.

Salo, E., and W. H. Bayliff. 1958. Artificial and natural production of silver salmon, *Oncorhynchus kisutch*, at Minter Creek, Washington. Wash. Dep. Fish. Res. Bull. 4, 76 p.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Dep. Fish Game, Fish Bull. 98, 375 p.

Sinnen, W., Reese, C., Currier, M., and Borok, S. 2004. Annual Report: Trinity River Basin Salmon and Steelhead Monitoring Project 2002-2003 Season. Calif. Dept. Fish and Game. 141 p.

Solazzi, M. F. 1986. Electrophoretic stock characterization of coho salmon populations in Oregon and Washington, and coastal chinook salmon populations in Oregon. Oreg. Dep. Fish Wildl., Info. Rep. 86-5, 16 p.

Stearns, S.C. 1980. A new view of life history evolution. Oikos **35**: 266-281.

Trepanier, S., Rodriguez, M.A., and Magnan, P. 1996. Spawning migrations in landlocked Atlantic salmon: time series modelling of river discharge and water temperature effects. J. Fish Biol. **48**: 925-936.

Weitkamp, L.A., Wainwright, T.C., Bryant, G.J., Milner, G.B., Teel, D.J., Kope, R.G., and Waples, R.S. 1995. Status Review of Coho Salmon from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-24. 258 p.

Williams, D., and D. Hillemeier. 2005. Yurok Tribal fisheries harvest of species listed under the Endangered Species Act. Yurok Tribal Fisheries Program. 6 p.

Williams, R.N., Bisson, P.A., Bottom, D.L., Calvin, L.D., Coutant, C.C., Erho, M.W.J., Frissell, C.A., Licatowich, J.A., Liss, W.J., McConnaha, W.E., Mundy, P.R., Stanford, J.A., and Whitney, R.R. 1999. Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries **24**: 10-19.