Adult Chinook Salmon Migration in the Klamath River Basin:

2007 Biotelemetry Monitoring Study Final Report


Sonic transmitter with archival temperature device attached and jaw tag.

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EXECUTIVE SUMMARY

Since the spring of 2002 the Yurok Tribal Fisheries Program has led a collaborative biotelemetry study of adult Chinook salmon (*Oncorhynchus tshawytscha*) migration in the Klamath River Basin (KRB). The overarching goal of this research project is to comprehensively determine and understand adult Chinook salmon migration behavior in the KRB throughout the spectrum of run-timing. Specific components include determining migration rates, thermal experience, estuary residence, run-timing, migration behavior patterns, and behavioral responses to environmental variables such as water temperature and river flow. Many of these goals have been accomplished with results from previous study years and publications are under development. This report describes and summarizes results from the 2007 study year, which was the first study year with a focus shifted from research to monitoring.

During 2007 a total of 62 adult Chinook salmon were tagged at the terminus of the Klamath River with the Pacific Ocean from 8/30/2007 to 9/26/2007 with esophageal ultrasonic transmitters, coupled with an archival temperature device that recorded fish body temperature every hour for the duration of their migration. Adipose and non-adipose fin clipped fish were tagged without bias, each fish was externally marked with a jaw tag, and rayed fin tissue samples were collected for later genetic analysis.

Out of the total sample of 62 adult Chinook, 12 (19%) eventually migrated upriver out of the estuary after tagging while 50 (81%) never migrated beyond the estuary. In previous study years this latter ratio ranged from 43 to 70%. Of the 50 fish that did not migrate upriver from the estuary, relatively little information exists to evaluate their fate. Based on previous years' results, pinniped predation and harvest were the most likely fates of these fish although some could have regurgitated their tags, died due to delayed tagging stress, or disappeared back into the ocean. On average tagged Chinook migrants spent 0.19 days in the estuary, compared to an average of 14.69 days in the ocean after tagging. Out of these same 12 tagged Chinook salmon, seven (58%) migrated into the Klamath River above Weitchpec, three (25%) migrated into the Trinity River above Weitchpec, and two (17%) were never observed migrating above the confluence of the Klamath and Trinity rivers at Weitchpec. This was the highest percentage of tagged fish that migrated into the Klamath River above the Trinity in any study years. Thus 10 tagged Chinook salmon migrated upriver beyond Weitchpec, termed migrants, served as the basis of analysis of migration behavior by run-timing and destination. Based on data from all study years, four distinct groupings or runs have emerged: spring Chinook, summer Chinook, Klamath fall Chinook, and Trinity fall Chinook. During the 2007 season, only fall Chinook salmon were targeted and tagged.

Klamath fall Chinook migrants were tagged from 8/30/2007 to 9/11/2007 and initiated migration from 9/12/2007 to 10/22/2007. Run timing of Klamath fall Chinook migrants was later than usual in 2007, which could have been due to atypically late seasonal cooling and the constricted configuration of the mouth. Given that fall Chinook salmon generally hold extensively and travel slowly through the lower Klamath River below Weitchpec as part of their apparent normative migration behavior strategy, they are especially vulnerable to infection and mortality from the ciliated protozoan

Ichthyophthirius multifiliis (*Ich*) with pathogen transmission risk increasing as flows decrease. Thus increasing base flow releases during the fall Chinook migration season is the most effective management tool for reducing the risk of *Ich* outbreaks such as occurred in September of 2002 when flows were reduced to approximately 2,000 cfs in the lower Klamath River. Flows in the lower Klamath River never dropped below 2,500 cfs in 2007, and there was no epizootic outbreak among KRB fall Chinook salmon.

Trinity fall Chinook migrants were tagged from 8/30/2007 to 9/26/2007 and initiated migration from 9/10/2007 to 9/27/2007 with fish primarily bound for the Trinity River Hatchery or nearby natural spawning areas. Trinity fall Chinook migrants also held extensively and traveled slowly through the lower Klamath River. After entering the lower Trinity River, Trinity fall Chinook encountered the California Department of Fish and Game's counting weir at Willow Creek, CA. The three Trinity fall Chinook migrants that passed the Willow Creek weir in 2007 experienced negligible migration delays with average passage duration of only 5.6 hrs. Removing a greater number of conduit rods during openings has apparently largely eliminated substantial migration delays at the Willow Creek weir.

No behavioral thermoregulation was observed by fall Chinook migrants at en route thermal refuges (i.e. cold creek confluences). Results from 2007 supported the conclusion from previous study years that the thermal threshold for migration inhibition for KRB adult Chinook occurs at mean daily water temperatures above 23.0ºC during periods of falling water temperatures, 21.0ºC during rising water temperatures, and 22.0ºC during stable water temperatures.

1.0 Introduction

Accomplishing protection and restoration goals for Pacific salmon and steelhead populations will require, in part, 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 migration (Williams et al. 1999). This holds equally true for other salmon producing river basins. The adult in-river spawning migration is one salmon life history stage that has received relatively little research attention in comparison to other stages, especially in regards to the effects of increased environmental variability and adversity, from both natural and human induced causes (Rand et al. 2004).

Understanding the spawning migration life history component and interactions 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 traits that are adaptations for fitness (Roff 2002). Thus variations in life history traits are a product of evolution that 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), and 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). Hodgson and Quinn (2002) undertook a regional examination of adult sockeye salmon (*Oncorhynchus nerka*) migration timing and found that in the absence of adverse environmental conditions (defined as water temperatures >19°C) sockeye timed their migrations to arrive on the spawning grounds about one month prior to spawning. In the face of adverse environmental conditions adult sockeye timed their migration to avoid high summer water temperatures by migrating before (i.e. spring) or after (i.e. autumn) the onset of high temperatures (Hodgson and Quinn 2002).

This pattern would be expected to hold true for other salmonid species due to the similarity in thermal selective pressures, which appears to be the case with spring and fall run Chinook salmon (*O. tshawytscha*) for example. With spring Chinook salmon, their run timing avoids the predictable period of high water temperatures in the summer and is also widely believed to allow them to reach headwater spawning areas, which require higher flows to access but also results in foregoing summer ocean feeding opportunities. With fall Chinook salmon, their run timing avoids high water temperatures and also allows for continued ocean feeding and growth during the summer. The problem with this tidy story are the outliers such as summer run Chinook salmon.

In the Klamath River Basin (KRB) of northern California and southern Oregon (Figure 1), Chinook salmon historically (Snyder 1931) and presently enter the river throughout the year including the hot summer months of July and August when river temperatures typically continuously exceed 19°C. Understanding if the run timing of KRB Chinook salmon violates the hypothesis advanced by Hodgson and Quinn (2002) requires an evaluation of the historical environmental conditions (e.g.. lotic thermal regime) under which they evolved. It may be that historically water temperatures were not as high during the summer in the KRB, indeed data from the last several decades shows trends of increasing water temperatures throughout the Pacific Northwest (Beschta et al. 1987; Quinn and Adams 1996), including the KRB specifically (Bartholow 1995, 2005). Since run-timing in salmonids has been shown to be under considerable genetic control (Gharrett et al. 1987; Stewart et al. 2002), it could be that run-timing has not yet genetically shifted in adaptation to the new conditions, especially given the maturation constraints of salmon (Quinn and Adams 1996). Another possible explanation is that behavioral flexibility within the summer run-timing strategy compensates for the adverse environmental conditions or a combination thereof.

Individuals within a run-timing strategy will employ a range of flexible behavioral tactics (Potts and Wooton 1984) in the face of annual and inter-annual variations 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 (Legget 1985). One form of this is the fine-tuning of run-timing to annual variability; indeed run-timing has been show to be influenced by environmental conditions (e.g. temperature and flow) (Banks 1969; Jonsson 1991; Smith et al. 1994; Quinn and Adams 1996; Trepanier et al. 1996; Quinn et al. 1997; Hodgson 2000). Run-timing is fine tuned in part on an annual basis by delaying or advancing freshwater entry. Salmon have been shown to delay freshwater entry by holding in the estuaries (including nearshore) of their natal rivers (Gilhousen 1960; Brawn 1982; Potter 1988), which presumably allows them to undergo the process of reverting to an hyposmotic environment, ensure time for homing mechanisms to work, and monitor the river for optimal or adequate migratory conditions, while using passive tidal transport and thermal stratification to conserve energy (Groot et al. 1975; Aprahamian et al. 1998). While there are advantages to such behavior, Wertheimer (1984) showed that gamete viability was poor when advanced maturation occurred in high salinity water among chum and coho salmon. Pinnipeds and fisheries tend to concentrate at estuaries, potentially resulting in acute predation risk. Holding in estuaries may present a compromise between the need to delay until after adverse riverine conditions have ceased while avoiding predation, versus the need for continued maturation in a low salinity environment.

Once salmon enter the river from the estuary and commence their fresh water spawning migration, adjustments of travel rates is another behavioral tactic employed. 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. In contrast, most stocks have an apparent energy cushion, 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 (ex. high temperatures), compensate for migration delays, or shift en route run-timing (Quinn et al. 1997).

In the face of extremely severe environmental conditions adult salmon are unable to survive or migrate due to physiological and bioenergetic constraints (Brett 1979; McCullough 1999). In the case of temperature, behavioral thermoregulation in the form of seeking and residing in cold water patches, or thermal refuges, is the primary option available for poikilothermic salmonids when they encounter excessively stressful temperatures during migration. Thermal refuges typically take the form of thermally stratified pools, groundwater or hyporheic seeps and springs, cold tributary confluences, or cool stream reaches (Bilby 1984; Torgersen et al. 1999). Numerous researchers have documented thermal refuge use by salmonids for behavioral thermoregulation (Kaya et al. 1977; Belchik 1997; Nielsen et al. 1994; Kaeding 1996; Ebersole et al. 2001), and thermal refuges play an important role for adult Chinook in the KRB and other similar basins, such as the Yakima (Berman and Quinn 1991) and John Day (Torgersen et al. 1999). The presence and use of thermal refuges may allow for the persistence and increase the carrying capacity of stocks in thermally marginal streams and habitats (Burns 1971; Kaya et al. 1977; Torgersen et al. 1999; Ebersole et al. 2001).

Use of thermal refuges can occur at a wide range of temperatures, but becomes more probable with rising temperatures until it becomes the norm as thermal thresholds are exceeded (Armour 1991; Bjornn and Reiser 1991; Bartholow 1995). A threshold of particular importance to salmonids is the upper thermal limit for migration. In the case of both adult sockeye and Chinook salmon, 21°C had emerged as the accepted thermal limit to migration (Quinn et al. 1997; McCullough 1999). Data from previous study years for KRB Chinook has shown that threshold to be much higher (i.e. mean daily temperature of 23.5°C) during periods of declining river temperature. When the threshold is exceeded the majority of fish will stop migrating and use available thermal refuge habitat even if it means retreating considerable distances.

Flow is another major factor that influences migration behavior and can cause migration delays. The degree to which either water temperature or flow exerts control over migration appears to be location and circumstance specific (Banks 1969; Alabaster 1990; Jonsson 1991; Trepanier et al. 1996). However, studies reviewed by Jonsson (1991) suggest that large rivers, such as the mainstem Klamath River, are less susceptible to delays caused by low flows. Obviously periods of temperature greater than the thermal limit to migration will result in delays regardless of flow.

Migration delays result in a trade-off between the associated costs (e.g. increased predation or energy expenditures) and benefits (e.g. avoiding lethal conditions), and can be thought off as making the "best of bad situation" (Gross 1984). The nature and severity of costs depends on multiple factors, especially the quality, quantity, and distribution of holding habitat. High quality thermal refuge holding habitat in sufficient availability and distribution can greatly reduce the costs of holding (Berman 1990; Torgersen et al. 1999). Unfortunately holding habitat can often be sub-optimal given the low flow and high temperature conditions typically associated with migration delays in addition to other forms of human induced habitat degradation. One of the most predominant and serious cost associated with migration delays is disease mortality. Salmonids holding in poor quality habitat can become stressed and crowded (Schreck and Li 1991; Matthews and Berg 1997), perfect conditions for outbreaks of diseases such as *Flexibacter columnaris* (Holt et al. 1975; Wakabayashi 1991) and *Ichthyophthirius multifiliis (Ich)* (Bodensteiner et al. 2000). Such conditions were implicated for causing large fish kills from these pathogens for sockeye salmon holding prior to admittance into engineered spawning channels in British Columbia during 1994 and 1995 (Traxler et al. 1998) and adult Chinook salmon in the Klamath River (32,533 to 65,066 in the lower 40 km; personal communication, George Guillen FWS) during September of 2002 (Guillen 2003; Belchik et al. 2004; Turek et al. 2004).

Determining the causes of specific migration behaviors and their associated costs in specific circumstances has both practical management applications and value in analyzing the adaptive merit of behavioral tactics from an evolutionary perspective (Legget 1985; Hyatt et al. 2003). Specific questions that arise as a result of the current circumstances in the KRB regarding the patterns and consequences of adult Chinook salmon migration include:

1. How do adult Chinook salmon cope with high water temperatures during their spawning migration?
2. What temperatures are adult Chinook salmon experiencing during their migration in comparison to river temperatures?
3. How do adult Chinook salmon respond to environmental variables such as temperature and flow during upriver migration?
4. What spatial and temporal patterns of thermal refuge use (behavioral thermoregulation) are displayed during their spawning migration?
5. What is the run-timing distribution of Chinook salmon stocks in the Klamath Basin?

In an effort to provide data to answer these questions the Yurok Tribal Fisheries Program (YTFP) initiated a collaborative radio telemetry research project on adult Chinook salmon migration behavior beginning with a pilot study in 2002 and followed by an expanded study in 2003 and 2004 in cooperation with the US Fish and Wildlife Service's Arcata Field Office, the Karuk Tribe's Department of Natural Resources, and the US Forest Service Orleans District Office. In 2005 and 2006 we continued this approach in cooperation with Hoopa Valley Tribal Fisheries (HVTF), but switched from radio to sonic transmitters in order to also determine adult Chinook salmon behavior in the estuary and nearshore ocean. The overarching goal of this research project was to comprehensively determine adult Chinook salmon migration behavior in the KRB throughout the spectrum of run-timing. There is an imperative need to gain a comprehensive understanding of adult Chinook salmon migration in the KRB, especially in response to environmental variables such as temperature and flow so that management decisions can be made with the best available scientific understanding. In 2007 the focus shifted from this overarching goal to a narrower goal of providing migration movement data in the event of a disease outbreak or other unusual mortality event.

1.1 Study Objectives

The primary objective of this study was to document the migration behavior and thermal experience of adult fall-run Chinook salmon in the KRB during the 2007 spawning migration season. Specific objectives were to:

1. Determine the migration behavior and thermal experience of adult fall-run Chinook salmon in the KRB;
2. Analyze behavioral responses to environmental variables such as temperature and flow;
3. Determine the spatial and temporal patterns of thermal refuge use;
4. Determine the spatial and temporal patterns of estuarine residence;
5. Gather data on stock specific run timing.

2.0 METHODS

2.1 Study Area

The Klamath River drains approximately 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, although a mitigation hatchery for the construction of Iron Gate Dam is operated by the California Department of Fish and Game (CDFG) at Iron Gate. [Note: All river kilometers used in this report are measured from the mouth of the Klamath River]. The upper basin formerly supported large numbers of Chinook salmon and other anadromous fishes such as steelhead (Hamilton et al. 2005), but these runs were extirpated with the construction of Copco Dam in 1917. Both dams are part of a series of five hydroelectric dams owned by PacifiCorp that are currently undergoing the Federal Energy Regulatory Commission relicensing process.

The Klamath River's largest tributary is the Trinity River which originates in the Trinity Alps Wilderness and flows into the Klamath at Weitchpec (RKM 70). Dams were constructed on the Trinity River at Trinity Center and Lewiston (RKM 253) in 1964 as part of the Central Valley Project, which has diverted 49-90% of the annual flow into the Sacramento River system. There are no fish passage facilities at Lewiston or Trinity Dams, although the CDFG operates a mitigation hatchery at Lewiston. The Trinity River's largest tributary, the South Fork, joins at RKM 121 and originates in the Yolla Bolly Mountains.

From the Salmon River to the Klamath River estuary, major thermal refuges have been previously observed at the mouths of Camp (RKM 92), Red Cap (RKM 85), Bluff (RKM 80), Aikens (RKM 78.5), Hopkins (RKM 75), Pine (RKM 65.5), Tully (RKM 61.5), Ka'pel (RKM 53), Roaches (50.5), Pecwan (RKM 40), and Blue Creeks (RKM 26). On the Trinity River starting at Weitchpec (RKM 70) major thermal refuges are found at the mouths of Bull (RKM 73), Mill (RKM 84), Tish Tang (RKM 97), Horse Linto (RKM 102), and Willow Creeks (RKM 111) with no significant thermal refuges upstream on the mainstem Trinity for quite a distance, although river temperatures begin to cool rapidly above Burnt Ranch Gorge (RKM 138 to 146) due to the influence of the cold hypolimnetic release from Trinity Dam. In the lower Klamath and Trinity Rivers, the furthest distance from one thermal refuge to the next is 26 km between the estuary and Blue Creek. The thermal refuge at Blue Creek is unique because it consists of the typical creek confluence refuge, but at times it also contains a lateral scour bedrock pool that is fed by cold (10-15ºC) hyporheic inflow with a partially connection to the mainstem Klamath River thus providing access for fish. Locally called Blue Hole, the degree of fish access to this large thermal refuge pool depends on the configuration of the gravel bar at its outlet and on the height of flow in the Klamath River. During the winter of 2005/2006, the mainstem Klamath River shifted course to flow directly into Blue Hole thus creating a well mixed pool, which remained into 2007.

2.2 Tagging and Telemetry

Ultrasonic esophageal transmitters (Vemco, V16T-3L-S256 or V16T-3L; W16 x L73 mm, 28 g in air) were used to track the movements of adult fall Chinook salmon during the 2007 spawning migration in the KRB. Thirty-eight of these transmitters had temperature sensors while the remaining 24 transmitters did not. An archival temperature device (Alpha Mach iB22L; W22 x L12 mm, 9.5 grams; accuracy ±0.5ºC, resolution ±0.0625ºC) was attached to the base of each transmitter to record internal body temperature every hour. All tags were tested prior to use. Each fish was externally marked with a jaw tag.

Adult Chinook salmon were captured using drift gill nets, and tagged at the mouth of the Klamath River from 8/29/2007 to 9/26/2007. Tagged fish were released either in the estuary close to the capture site or directly into the Pacific ocean across the sand spit from the tagging site. Each captured salmon was held in a 250 gallon live tank on the shore and immobilized with the aid of a cradle, measured (fork length cm), tagged, and released immediately or revived first as necessary. A gas powered water pump was used to circulate river water through the live tank continuously. Obtaining a water cooling system for use at the tagging location was impractical, thus no anesthesia was used to facilitate a more rapid recovery and prompt release whereupon fish could immediately seek thermal refuge in the cold estuarine salt wedge or ocean. Tissue samples were taken from rayed fins and stored in 100% ethanol to allow for genetic analysis of racial origin at a later date. Efforts were taken to minimize capture stress and handling time. All Chinook salmon that were caught were tagged regardless of the presence of an adipose fin or not, unless severe injury or shock was apparent.

A network 35 sonic listening stations (Vemco VR2s and VR2Ws) were placed throughout the KRB at strategic locations to continuously monitor fish presence or absence and to record internal body temperatures as applicable. Listening station locations are listed in Table 1. The spatial relationship of the listening stations allowed for determination of migration paths and travel rates. No mobile tracking was undertaken.

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 salmon and retrieving archival tags. Flyers were posted throughout the study area to alert anglers of the study and a $50 reward was offered to assist in the recovery of archival tags. YTFP harvest monitoring personnel also assisted with recovering tags from Tribal and sport fishers in the Klamath River.

2.3 Temperature and Flow Monitoring

Ambient water temperature data at various sites in the mainstem Klamath and Trinity rivers were obtained from temperature recorders operated by the US Forest Service, Orleans District Office. River flows were measured by USGS gauges and obtained from their website at http://waterdata.usgs.gov/ca/nwis/current/?type=flow.

2.4 Data Analysis Approach

Telemetry studies are often not representative in a statistical sense given the exorbitant costs of achieving a representative sample size for large populations, as is often the case with fish. Regardless of the exact degree of representation, the results of this and other similar studies provide valid illustrative results that allow a window of observation into an otherwise elusive subject.

Telemetry studies can determine behavioral patterns and provide a basis for understanding the underlying causes for those patterns. Inferential statistical testing to determine statistically significant relationships in the measurements of animal behavior is one method to help determine patterns and their underlying causes. Statistical analysis can determine the level of statistical significance of the relationships tested, however, determining the level of biological or behavioral significance requires comparing telemetry data with the pertinent independent (and often autocorrelated) variables. Appropriate interpretation of animal behavior also requires applying existing biological knowledge within the context of the specific habitat. Thus analysis of results from this study to determine Chinook salmon behavioral patterns and their underlying causes will primarily consist of graphically presenting data at appropriate resolution on commonly scaled axes.

3.0 RESULTS AND DISCUSSION

3.1 Tagging and Fate Summary

Tagging data and the final known fate or last observation of all 62 tagged Chinook salmon is summarized in Appendix 1. Out of the total sample of 62 adult Chinook, 12 (19%) migrated upriver from the estuary after tagging while 50 (81%) never migrated beyond the estuary. In previous study years this latter ratio ranged from 43 to 70%. Pinniped predation, tag regurgitation, unclaimed harvest, delayed tagging mortality, and inter-basin straying are factors that potentially contributed to the disappearance rate in the estuary. Determination of the relative contribution of these factors in 2007 was not possible due to complications resulting from the lack of temperature sensors in the majority of sonic tags and the relatively low chances of tag recoveries from the Yurok Tribal commercial fishery due to the fast pace of fish gutting, including at night. In 2007, the Yurok Tribe allocated Chinook salmon from their total allowable catch for a commercial fishery in the estuary, which resulted in especially heavy fishing pressure from the start of the fall Chinook salmon run to the commercial closure in October of 2007.

In 2006, the relative contribution of these tag loss factors was largely determined through use of sonic transmitters, which are detectable in high salinities, along with sonic receivers placed in the estuary and nearshore ocean. Results showed that pinniped predation was the primary known cause of 'disappearance' with 11 of 80 (or 26% of the 43 fish that disappeared in the estuary/ocean) tagged Chinook salmon known to have been eaten by pinnipeds, most likely California sea lions (*Zalophus californianus*). Pinniped predation was determined by temperature data from the sonic transmitters, which would suddenly rise from a cool temperature consistent with that of a poikilothermic fish to that of an endothermic marine mammal, which in the case of California sea lions is 37.5ºC.

Due to the seemingly large numbers of pinnipeds that gather at the mouth of the Klamath River annually and the purportedly excessive predation, the YTFP undertook a visual observation and scat analysis study of seal and sea lion predation beginning with a pilot study in 1997 and full-scale studies in 1998 and 1999 (Williamson and Hillemeier 2001). Predation rates for the entire fall Chinook salmon run during 1998 and 1999 ranged from 2.3 to 2.6% with California sea lions being responsible for 89.8 to 93.5% of this predation. The rate of pinniped predation observed on tagged Chinook salmon should not be inferred to reflect the predation rate on the Chinook salmon run as a whole. Tagged Chinook salmon can be assumed to be temporarily disoriented and/or fatigued when released in comparison to a non-tagged fish and are therefore more vulnerable to predation. Indeed, most tagged Chinook salmon that have been preyed upon were eaten relatively quickly after release (hours). Various efforts were tried to minimize pinniped predation, such as seal bombs and different release locations, without noticeable success.

Out of the 12 tagged Chinook salmon that did migrate upriver from the estuary in 2007 at least 5 (42% of 12) successfully reached spawning grounds (2) or a hatchery (3); 5 (42%) appeared to be still migrating at the time of their last observation; and 2 (16%) disappeared in the lower Klamath River. There was no documented harvest of these 12 fish although some could have occurred. Out of these same 12 tagged Chinook salmon, 7 (58%) migrated into the Klamath River above Weitchpec, 3 (25%) migrated into the Trinity River above Weitchpec, and 2 (17%) were never observed migrating above Weitchpec (RKM 70) for unknown reasons. This was the highest proportion of tagged fish to migrate up the Klamath above the Trinity out of all study years, although the relatively small sample size may have biased this distribution. Chinook #65 migrated into the Shasta River, which was the only tagged fish detected in any tributaries to the Klamath or Trinity Rivers. Determination of percentages of end fates for tagged Chinook salmon that did migrate upriver from the estuary was complicated by the disappearance of fish en route, which could have occurred for a variety of reasons (i.e. disease or other non-harvest mortality, unclaimed harvest, tag regurgitation, migration into an unmonitored tributary, or additional movement after the conclusion of the study).

Thus a total of 10 tagged Chinook salmon migrated past the confluence of the Klamath and Trinity Rivers at Weitchpec and reasonable assumptions can be made about their approximate destinations and likely stock origins. Hereafter termed migrants, their tagging data and fates are displayed excluding all other tagged Chinook salmon in Table 2. These migrants served as the basis of analysis of adult Chinook salmon migration behavior by run-timing and destination/stock groups.

Sonic receivers preformed flawlessly with the exception of several receivers that were placed in excessively turbulent locations, which if combined with the sound refraction caused by extremely high densities of Mycrocystis toxic blue-green algae, resulted in poor detection probabilities. These stations were located at Pecwan, Happy Camp, and China Slide and had maximum detection probabilities, respectively, of 90, 33, and 33%. By comparison the rest of the sonic receivers had an average detection probability of 100%. The sonic receiver located at the mouth of the Klamath River (the lips) was buried in sand and has not yet been recovered. The ocean receivers were excluded from this analysis because it could not be determined how many fish swam within their detection range; however, in combination they recorded 38 fish out of the total sample of 62 (61%). Of these 38 tagged fish, 22 were last detected in the ocean and no where else (35% of 62). Receiver detection probabilities can be easily improved by careful attention to their exact placement, although there is no effective remedy for the *Mycrocystis* problem short of dam removal. With regards to the high fish loss associated with tagging fish at the mouth of the Klamath River, it is still the best location because it provides a complete migration history within both the estuary and freshwater along with thermal and osmotic refuge in the ocean and salt wedge. Most importantly, high water temperatures combined with a lack of thermal refuge make tagging at other locations biologically infeasible during the majority of the adult Chinook salmon migration season.

3.2 Environmental Conditions

River Flow

Annual hydrographs for the 2007 study period are presented for the Klamath River (Figure 2) and Trinity River (Figure 3) plus select tributaries (Figure 4). All flows are reported as mean daily flow measured in cubic feet per second, and all RKMs are measured from the mouth of the Klamath River.

Based on the Natural Resource Conservation Service (NRCS) April 1, 2007 hydrological forecast for inflow into Upper Klamath Lake, the US Bureau of Reclamation (USBR) classified the water year type as "below average" for Upper Klamath Lake level and Klamath River discharge operations planning. The water year designation for the Trinity River sub-basin was “dry” in 2007, which resulted in flow releases from Lewiston Dam as dictated by the Trinity River Record of Decision. Flow releases from these dams are the primary drivers of downriver flows in the mainstem

Klamath and Trinity Rivers during the summer and fall. Summer and fall flows in the lower Klamath River for 2000 through 2007 are presented in Figure 5. Annual hydrographs throughout the lower KRB generally have three components: summer/fall base flow, rain driven winter high water with rain on snow flood peaks, and spring snowmelt. Unregulated snowmelt flows are compared to the regulated Lewiston Dam releases for 2007 in Figure 6.

The only exception to the summer/fall base flow component of hydrographs in the KRB are special flow release events during the summer or fall for the purpose of disease risk management (e.g. 2002, 2003, and 2004) or to meet ceremonial obligations to local Tribal nations (e.g. 2001, 2005, 2006, and 2007) (Figure 5). The only special flow release in 2007 was a two-day pulse flow released from Lewiston Dam with a peak of 1,760 cfs on 8/27/2007 for the purpose of meeting ceremonial obligations to the Hoopa Valley Tribe (boat dance flow). The first substantial natural increase in river flows throughout the KRB from precipitation after the summer dry season occurred on 10/20/2007.

Water Temperature

Hourly water temperatures at various locations in the KRB during the adult fall Chinook salmon migration season are presented in Figures 7 to 9. Water temperatures in the lower Klamath River at Weitchpec (RKM 69) reached a maximum of 26.0ºC on 7/10/2007. Water temperatures at RKM 69 are compared to river flow and periods when Chinook were tagged in Figure 7. Seasonal cooling began especially late in 2007, with water temperatures ≥22ºC for the last time on 9/11/2007 and ≥20ºC on 9/16/2007 (Figure 7). This pattern was generally consistent throughout the lower KRB with the exception of the upper Trinity River, which is heavily influenced by cold hypolimnetic releases from Trinity and Lewiston Dams. Water temperatures of the Klamath and Trinity Rivers at their confluence are generally equivalent (with the Trinity slightly cooler in 2007) except during periods of large releases from the Trinity Dams such as during the boat dance flow at the end of August 2007 (Figure 8). Substantial weather-induced cooling events have occurred during late July or early August during all study years with the exception of 2005 (substantial defined as a decrease of mean daily water temperatures

>2ºC; i.e. mid-July 2007). Dams on the mainstem Klamath River heavily influence river temperature, delaying the onset of seasonal autumn cooling (Bartholow et al. 2005) and thereby affecting spawning temperatures. Surface water temperatures in the nearshore ocean at RKM -0.5, which is an extension of the Klamath River estuary, are presented in Figure 9.

3.3 Migration Behavior and Experience

Run-Timing

Before reporting and discussing run-timing it is important to define the terms used herein. As properly used in fisheries biology the term 'run' typically denotes a specific group of fish ascending a river to spawn. A given run of fish is distinct but could be comprised of mixed stocks or populations of varying degrees of genetic similarity with one or multiple destinations. Thus the term 'run-timing' denotes the timing of migration of a specific group of fish and generally has four main components: river entry from the ocean into the estuary, initiation of upriver migration from the estuary, arrival at a subjective point along the migration path, and arrival to pre-spawn holding areas or spawning grounds. For example the phrase 'summer run' as used herein denotes a group of migrating adult Chinook salmon that are distinct in their run-timing (all components) and migration behavior from other groups (i.e. spring run, Klamath fall run, and Trinity fall run). Summer run Chinook appear to be comprised primarily of TRH spring Chinook salmon based on CWT recoveries during the summer in the lower Klamath River and estuary (Figure 10). It is unclear whether the summer run are just a random late run component of Trinity River spring Chinook or if they are a genetically distinct group. Determining the actual genetic origins and relationships of run-timing groups requires performing the appropriate genetic analysis from tissue samples in addition to examining coded wire tag (CWT) recoveries. Such genetic analysis is possible but has not yet been conducted for KRB Chinook salmon populations and is beyond the scope of this report. Stream-type Chinook salmon generally have a spring or summer run-timing and ocean-type Chinook salmon generally have a fall run-timing (Healey 1991), but variation can occur such as spring run Chinook salmon in the Salmon River giving rise to both stream and ocean-type offspring (personal communication, Al Olson, USFS).

For tagged Chinook salmon with known destinations (termed migrants), run-timing based on tagging date (i.e. approximate river entry), and date of initiation of upriver migration matched their destinations and likely stock origins. In previous study years, four major distinct groups or runs had been identified in this manner. In 2007, only two runs were targeted and subsequently tagged and identified: Klamath fall Chinook and Trinity fall Chinook salmon (Figure 11).

Klamath fall Chinook salmon were tagged from 8/30/2007 to 9/11/2007, and initiated upriver migration from the estuary from 9/12/2007 to 10/22/2007 (Figure 12). The earliest initiation of upriver migration among Klamath fall migrants coincided with the onset of seasonal cooling (Figure 12). Another important factor that appeared to trigger upriver migration from the ocean was the breaching of the estuarine sand bar and the creation of a new mouth on October 3, 2007. Previously the old mouth was long, shallow, and extremely narrow, creating an ideal arrangement for pinniped predation. The new mouth was much wider and deeper (Figure 13), which apparently triggered river entry among Chinook salmon waiting in the nearshore for a change in conditions. Included in this mass river entry were three of the seven Klamath fall Chinook migrants (Figure 12). Klamath fall Chinook migrant run-timing in 2007 was distinctly later than all other study years (Figure 14) and in comparison to the average for IGH fall Chinook salmon based on CWT recoveries from 1988 to 1999 in the estuary (Figure 10), which usually peaks during late August to early September. The especially late seasonal cooling combined with the constricted mouth configuration, likely along with other unidentified factors, contributed to the apparent late entry of Klamath fall Chinook salmon in 2007.

Trinity fall Chinook salmon were tagged from 8/30/2007 to 9/26/2007 and initiation of upriver migration occurred from 9/10/2007 to 9/27/2007 (Figure 15). Only three tagged Chinook salmon migrated up the Trinity River in 2007, thus conclusions about run-timing are tenuous. However, Trinity fall Chinook migrant run-timing in 2007 was comparable to all other study years (Figure 16) and consistent with the average for TRH fall Chinook salmon based on CWT recoveries from 1988 to 1999 (Figure 10), which usually peaks during late September. The first initiation of upriver migration did not occur until seasonal cooling was imminent (Figure 15). There are no obvious explanations for why Trinity fall Chinook migrants entered the river before the sand bar broke open, but again the small sample size confounds conclusions regarding behavior of Trinity fall Chinook salmon in general.

The run-timing of tagged migrants could potentially be biased due to handling induced delays prior to initiation of upriver migration. In all study years, many but not all Chinook salmon retreated downriver after tagging regardless of tagging location. After a period of recovery, tagged Chinook salmon are assumed to revert back to normal behavior. The length of this recovery period is not know with precision and likely varies among individuals. Bernard et al. (1999) identified a distinct post-tagging retreat (at least 3 km) and delay (4-5 days) effect for adult Chinook salmon in several Alaskan Rivers and concluded that it was due to handling and not tagging per se. Other researchers conducting telemetry tagging studies on adult salmonids have assumed recovery periods ranging from hours (Candy and Quinn 1999) to up to three weeks (Walker et al. 2000). It should be noted that some studies, including this one, used esophageal tags only while others used external tags that required piercing the body (e.g. Walker et al. 2000) with presumably greater trauma. The extent of post-tagging delays have been highly variable including individuals with no delay in this and other studies (Bernard et al. 1999). This author considers the recovery period to range from several hours to several days but cannot rule out the potential for longer delays triggered by handling, thus estimates of run-timing based on tagged Chinook salmon should be interpreted cautiously with the possibility of artificial delays taken into consideration. After tagged Chinook salmon initiated upriver migration past RKM 7 there has been no evidence of handling effects in all study years.

Even without handling effects variation in run-timing among individuals within a run is expected. If run-timing for a given population follows a normal distribution, then some portion of the run would initiate upriver migration relatively early and some relatively late (e.g. Figure 10). Such spread in run-timing enhances persistence on an evolutionary scale by spreading mortality risks over time (Stearns 1976) and can be caused by numerous factors. Run-timing can influence migration behavior directly by influencing the amount of time left before the end of the spawning season or indirectly via river conditions. Individual fish that are at a more advanced state of maturation may be forced to initiate upriver migration at an earlier time or migrate at a faster rate.

Movement Histories

Migration rates (i.e. ground speeds) were highly variable among all migrants and for a given migrant over the course of its migration path (again the term migrant refers to a tagged Chinook with a known approximate destination). Migration rates ranged from zero during periods of holding up to 46.6 km/d during rapid upriver migration in certain reaches. Migration appeared to occur primarily in alternating bouts of upriver movement and restful holding periods as evidenced by the substantially higher ground speeds observed in short distances as compared to longer reach-scale distances. This intermittent movement pattern was also observed during manual tracking in previous study years and is consistent with studies conducted in the Fraser River for adult sockeye salmon (Rand and Hinch 1998; Hinch and Bratty 2000).

Location via river kilometer versus date for Klamath fall Chinook migrants (*n*=7) is presented with applicable landmarks and compared to river temperature and flow in Figure 12. Klamath fall Chinook migrants have previously displayed consistent movement patterns characterized by rapid travel from the estuary to the vicinity of Blue Creek, followed by slow movement and extended periods of holding at various locations from Blue Creek to Weitchpec. Travel rates have increased markedly above Weitchpec with rapid and steady migration to spawning grounds in the IGD area. In 2007, four migrants showed this general movement pattern but the other three moved steadily from river entry to arrival on spawning grounds. It is possible the these fish were delayed (in relation to their individual maturation schedule) due to the especially late seasonal cooling combined with the constricted mouth configuration and therefore migrated steadily to make up for lost migration time.

Location via river kilometer versus date for Trinity fall Chinook migrants (*n*=3) is presented with applicable landmarks and compared to river temperature and flow in Figure 15. Holding occurred at more variable locations but all Trinity fall Chinook migrants held or substantially slowed their migration for an extended period somewhere between Blue Creek (RKM 26) and Hoopa (RKM 90). For migrants that exhibited slowed migration in the lower Klamath River, travel rates usually increased markedly immediately after passing Weitchpec or Hoopa. The high gradient Burnt Ranch Gorge presents a challenging obstacle for all Trinity River salmonids destined for the upper Trinity River.

Another obstacle encountered by Trinity River Chinook migrants was the Willow Creek weir at RKM 105, which is a counting facility operated by the CA Department of Fish and Game. In 2005, Chinook migrants appeared to be substantially delayed by the Willow Creek weir, with transit time from the station below the weir (RKM 104.0) to above the Willow Creek weir (RKM 105.5) ranging from 3.5 to 31.1 days. While some delay still occurred in 2006 (0.1 to 10.4 days), the removal of substantially more conduit rods from every other weir panel on weekend openings appeared to greatly reduce the average and maximum passage time of tagged Chinook salmon past the Willow Creek weir. In 2007, the average transit time for the three migrants was 0.2 days (5.6 hours), which is consistent with results from 2006 and suggests that the new weir operating protocols have significantly reduced fish delays at the weir.

A potential obstacle encountered by all migrating salmon in the KRB are shallow riffles such as found in the lower Klamath River, of which the riffle just below Pecwan Creek is especially notable. In 2006, sonic receivers where placed immediately above and below the Pecwan riffle to determine if there was a slowing in migration rates at the riffle. No evidence was found among tagged Chinook salmon in 2006 for substantial slowing of migration rates or migrational delays at the Pecwan riffle. In 2007, this receiver deployment was repeated and again there was no evidence for substantial slowing of migration rates or migrational delays at the Pecwan riffle (Figure 17). There was also no consistent relationship between river flow and passage rate at Pecwan riffle in 2007 (Figure 18).

Thermal Experience

Data from the archival temperature tag of Chinook #88 was successfully recovered and provided a complete thermal experience of this migrant from the time of tagging to spawning at the Trinity River Hatchery (Figure 19). Unfortunately this was the only archival temperature tag recovered from migrants in 2007. The recovery rate of archival tags was greatly diminished by the use of sonic transmitters that, in contrast to radio transmitters used in previous study years, are not efficiently located using manual tracking.

Estuary and Nearshore Ocean Residence and Behavior

In previous study years, archival temperature data revealed highly variable thermal experience during estuary/nearshore residence prior to upriver migration in freshwater characterized by cold temperatures (e.g. <15ºC) with occasional to regular warmer spikes. This pattern could have been caused by nearshore ocean residence with visits into the warmer estuary, or by holding a stationary position in the estuary while the cold salt wedge moved back and forth on a tidal cycle.

Based on 2005 data, it was determined that this pattern of thermal experience was created while residing entirely within the nearshore ocean and not in the estuary (defined herein as the mouth of the Klamath River to the upriver extent of tidal influence at Wakel RKM 7). The same overall result occurred in 2006 and in 2007. Residence times in the estuary and/or nearshore ocean are reported for all tagged Chinook salmon that migrated above the estuary (n=12) in Table 3. Residence times in the estuary were very brief (e.g. mean of 0.19 d, max of 0.91 d) in comparison to residence times in the ocean (e.g. mean of 14.88 d, max of 40.67 d) after tagging.

In sum, the behavior exhibited by tagged Chinook salmon in 2005, 2006, and 2007 showed minimal residency and use of the estuary with a substantial portion of migrants retreating back to the ocean for extended periods prior to upriver migration. Extended post-tagging residency in the ocean could be caused by an artificial factor such as handling induced fallback and delay as has been observed with adult Chinook in other river systems (Bernard et al. 1999), or due to multiple natural factors such as behavioral thermoregulation and predator avoidance. Both explanations and combinations thereof are plausible but the important conclusion is that adult Chinook salmon of all run groups have some flexibly to delay upriver migration, with holding occurring almost exclusively in the ocean, and still successfully arrive at spawning grounds within the appropriate spawning window. There are limits to extent of the delay in upriver migration in terms of river conditions, sexual maturation, and bioenergetics but delays of up to 22 d (Chinook #65) were observed in 2007 while holding in the ocean with subsequent successful migration to spawning grounds.

The lack of use of the estuary as a holding habitat by tagged Chinook salmon is not considered to be an artifact of tagging and handling because of the consistency of results for all tagged Chinook salmon over multiple years including those that spent extensive time in the ocean, whom can be considered to have fully recovered from any plausible handling effects. The presence of highly active predators in the estuary, especially California sea lions, provides a readily apparent natural explanation for this behavior. Besides the obvious concentration of sea lions in the estuary and their documented predation on tagged and non-tagged adult Chinook salmon (Williams and Hillemeier 2001), the extremely rapid travel rates of adult Chinook salmon while in the estuary provide additional supporting evidence. The fastest observed travel rates for any river reach or segment usually occurred in the estuary. For example, the overall maximum ground speed observed in 2006 occurred in the estuary (Chinook #88, 81.7 km/d for a distance of 4.3 km, equal to 3.4 km/hr, 0.9 m/sec or 1.3 body lengths/sec). This ground speed is approximately equal to the maximum observed for sustained swimming in adult salmonids (Rand and Hinch 1998).

Adult Chinook salmon must accomplish many tasks in estuaries such as proper detection of homing cues, osmotic transformation, behavioral thermoregulation, and detection of environmental cues signaling upriver migratory conditions (Healey 1991). In an ideal scenario for adult Chinook salmon, they would be free to choose from available habitats and locations in the estuary and/or nearshore ocean to accomplish these tasks in a manner and timing best suited to their physiological and behavioral needs. In the Klamath River, the reality is that the estuary is a physical bottleneck in comparison to the open ocean that logically gives predators such as humans and pinnipeds a significant advantage. Thus adult Chinook salmon face tradeoffs between behaviors that will accomplish estuarine related tasks in an optimal manner and behaviors that will give the best chances of surviving the concentration of predators. The general lack of substantial residence times in the estuary and reliance on staging in the nearshore ocean indicate that avoiding predation is likely the primary driver of adult Chinook migration behavior (i.e.

short residence times) in the Klamath River estuary. While humans are likely the top predator in the estuary in terms of numbers of salmon caught, California sea lions appear to be the top predator in terms of forcing Chinook behavior due to their active hunting, duration of residence, and numbers. While pinniped predation is one of the factors that reduces Chinook salmon escapement and influences behavior, it is important to remember that these species coevolved before reaching conclusions regarding the seriousness of pinniped predation or negative consequences thereof.

Behavioral Thermoregulation

Use of the nearshore ocean and estuarine salt wedge before commencing upriver migration, which has been observed in all study years, could serve a thermoregulating purpose. One of the benefits of holding in the nearshore ocean and/or estuarine salt wedge prior to commencing upriver (freshwater) migration is reduced exposure to warm river temperatures. This could be considered behavioral thermoregulation since such a fish is choosing to delay freshwater entry and thereby reducing exposure to warmer waters, however, estuary/nearshore residence is driven by potentially interacting factors besides thermoregulation as previously discussed. Combined with the readily accessible nearshore ocean, the Klamath River estuary is the largest thermal refuge in the entire KRB with the exception of cold water reaches below Lewiston Dam on the mainstem Trinity River and in the headwaters of mountainous tributaries. Predation pressure reduces the survival benefit of making long term use of the estuarine salt wedge as a thermal refuge, while in comparison the ocean offers less risk of pinniped predation, colder temperatures, and greater feeding opportunities. This logic is borne out in the average proportion of time spent in the estuary versus the nearshore ocean (1.25%) for tagged Chinook salmon in 2007. Regardless of the reasons for the proportion of time spent in the estuary versus the nearshore ocean, the availability of large volumes of cold water for pre-migration holding is critical to the migration behavior strategies for all migrant groups.

Once upriver migration is underway, cool to cold tributary confluences provide thermal refuge for Chinook salmon en route. Use of en route thermal refuges has been documented in previous study years and is a behavior analogous to a quick recovery break. While inconsequential in terms of cumulative thermal experience, such short term behavioral thermoregulation is likely beneficial to physiological performance. Based on data from all study years, extended en route thermal refuge use occurs for a minor but important portion of the spring and summer Chinook salmon runs. In contrast, no fall Chinook migrants have been observed using en route thermal refuges in 2007, as has been true during all study years, including when fish were holding in the lower Klamath River in the vicinity of cool tributary confluences (e.g. Blue Creek) for extended periods. The lack of thermal refuge use observed by fall Chinook migrants is expected given that river temperatures are typically below 22ºC when they are migrating in freshwater. Fall Chinook salmon are believed to hold in the lower Klamath River for reasons other than immediate behavioral thermoregulation.

Understanding behavioral thermoregulation requires understanding the thermal threshold for migration inhibition which is a critical trigger for thermal refuge use. Values for this threshold reported in relevant literature are typically 21ºC (e.g. see review by McCullough 1999). However, unpublished results from the 2002 study year indicated that adult Chinook migration in the KRB was inhibited when mean daily water temperatures ≥22ºC, at which point adult Chinook would seek out and reside in thermal refuges or delay migration and continue to hold in the nearshore ocean. Since 2002 this relationship has been determined to be dependent on the trend in river temperatures, with tagged Chinook observed migrating and ignoring thermal refuges at mean daily water temperatures up to 23.6ºC during periods of falling temperature, and observed ceasing migration and retreating to thermal refuges at mean daily water temperatures of 20.9ºC once river temperatures started to rise again. During the 2005 study year this relationship held true with the initiation of migration occurring when mean daily water temperatures where as high as 23.5ºC. Results from 2007 did not serve to refute previous conclusions regarding the threshold for migration inhibition, nor did it provide much supporting evidence given that only fall Chinook salmon were tagged. Thus in the absence of evidence to the contrary, it can be still concluded that the thermal threshold for migration inhibition for KRB adult Chinook occurs at mean daily water temperatures above 23.0ºC during periods of falling water temperatures, 21.0ºC during rising water temperatures, and 22.0ºC during stable water temperatures.

4.0 TABLES AND FIGURES

Table 1. Sonic listening station locations for the 2007 adult Chinook salmon telemetry study. All river kilometers (RKM) are measured from the mouth of the Klamath River.

ID	Site Location	RKM	River	Type
1	ocean north	-0.50	Ocean	sonic
2	ocean south	-0.50	Ocean	sonic
3	ocean offshore	-1.50	Ocean	sonic
4	Estuary 1 - Lips	0.00	Klamath	sonic
5	Estuary 2 - Requa	1.00	Klamath	sonic
6	Estuary 3 - Jet Tours	3.00	Klamath	sonic
7	Wakel	7.25	Klamath	sonic
8	Blue Creek	26.00	Klamath	sonic
9	lower Pecwan Riffle	39.50	Klamath	sonic
10	upper Pecwan Riffle	40.00	Klamath	sonic
11	Moore's Rock	43.00	Klamath	sonic
12	Coon Creek Falls	57.50	Klamath	sonic
13	Weitchpec Klamath	71.00	Klamath	sonic
14	Weitchpec Trinity	71.00	Trinity	sonic
15	Hoopa gauge	90.00	Trinity	sonic
16	Riverdale screw trap	104.00	Trinity	sonic
17	Willow Creek weir	105.00	Trinity	sonic
18	Ogorman's	105.50	Trinity	sonic
19	Salyer	133.00	Trinity	sonic
20	China Slide	147.00	Trinity	sonic
21	Junction City	190.25	Trinity	sonic
22	Steiner Flat	215.00	Trinity	sonic
23	Bucktail	242.00	Trinity	sonic
24	Trinity River Hatchery	252.50	Trinity	sonic
25	Salmon River at Oak Flat	108.00	Salmon	sonic
26	Big Bar	82.00	Klamath	sonic
27	Dolan's Bar	97.50	Klamath	sonic
28	Green Riffle	114.00	Klamath	sonic
29	Happy Camp	176.50	Klamath	sonic
30	Blue Heron	233.25	Klamath	sonic
31	Scott River	233.50	Scott	sonic
32	Shasta River	289.00	Shasta	sonic
33	Hornbrook	293.00	Klamath	sonic
34	Bogus Creek Weir	309.50	Bogus	sonic
35	Iron Gate Hatchery	310.00	Klamath	sonic

Table 2. Tagging and fate summary for all 10 adult fall Chinook salmon migrants in 2007. All Chinook salmon were tagged at the mouth of the Klamath River and released either in the estuary or across the sand spit into the ocean. FL = fork length. TRH = Trinity River Hatchery. IGH = Iron Gate Hatchery.

Date	Time	Jaw Tag	Tag Code	FL cm	ad clip	release	Fate
30-Aug-07	11:50	197	**6480**	76	no	estuary	Iron Gate Hatchery 10/10
30-Aug-07	12:40	193	**6460**	75	no	estuary	China Slide 10/21 rkm 147
11-Sep-07	14:33	94	**6472**	77	no	ocean	Big Bar 11/1 rkm 82
11-Sep-07	14:42	92	**58**	74	no	ocean	Green Riffle 10/22 rkm 114
11-Sep-07	14:48	91	**65**	76	no	ocean	Shasta River 10/20 rkm 292
11-Sep-07	15:07	199	**72**	96	no	ocean	Green Riffle 10/11 rkm 114
11-Sep-07	15:13	197	**88**	72	no	ocean	Trinity River Hatchery 11/8
11-Sep-07	15:20	195	**89**	79	no	ocean	Green Riffle 10/16 rkm 114
11-Sep-07	17:40	183	**86**	77	no	estuary	Hornbrook 11/4 rkm 293
26-Sep-07	14:03	164	**59**	72	no	estuary	Trinity River Hatchery 11/2

Table 3. Estuary and nearshore ocean residence times (d) for all 12 Chinook salmon that migrated above the estuary in 2007, arranged by run timing group in order of tagging date. The amount of time spent in the estuary was defined as the total amount of time spent between the mouth (RKM 0) and Wakel (RKM 7). Ocean residence was defined as the total amount of time spent in the ocean after tagging. Lkfall = fall migrants of unknown destination. iB = recovery of archival temperature data from iButton tag.

Fish ID	Tagging Date	Estuary (d)	Ocean (d)	Total (d)	% in Est.	Group	iB
6480	30-Aug-07	0.14	13.24	13.38	1.0%	Kfall	n
6460	30-Aug-07	0.91	10.39	11.30	8.1%	Tfall	n
6472	11-Sep-07	0.23	40.44	40.67	0.6%	Kfall	n
58	11-Sep-07	0.09	21.89	21.98	0.4%	Kfall	n
65	11-Sep-07	0.09	21.90	21.99	0.4%	Kfall	n
72	11-Sep-07	0.09	21.87	21.96	0.4%	Kfall	n
88	11-Sep-07	0.07	15.84	15.91	0.4%	Tfall	y
89	11-Sep-07	0.09	7.94	8.03	1.1%	Kfall	n
86	11-Sep-07	0.11	15.81	15.91	0.7%	Kfall	n
70	11-Sep-07	0.11	1.94	2.05	5.4%	LK	n
6470	12-Sep-07	0.20	0.85	1.05	19.0%	LK	n
59	26-Sep-07	0.10	4.21	4.31	2.3%	Tfall	n
mean		**0.19**	**14.69**	**14.88**	**1.25%**		

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 limit the upriver distribution of anadromous fishes within the watershed. Historically spring Chinook were distributed throughout large areas, presently however, spawning populations of spring Chinook are found only in the Salmon River, South Fork Trinity, and mainstem Trinity sub-basins.

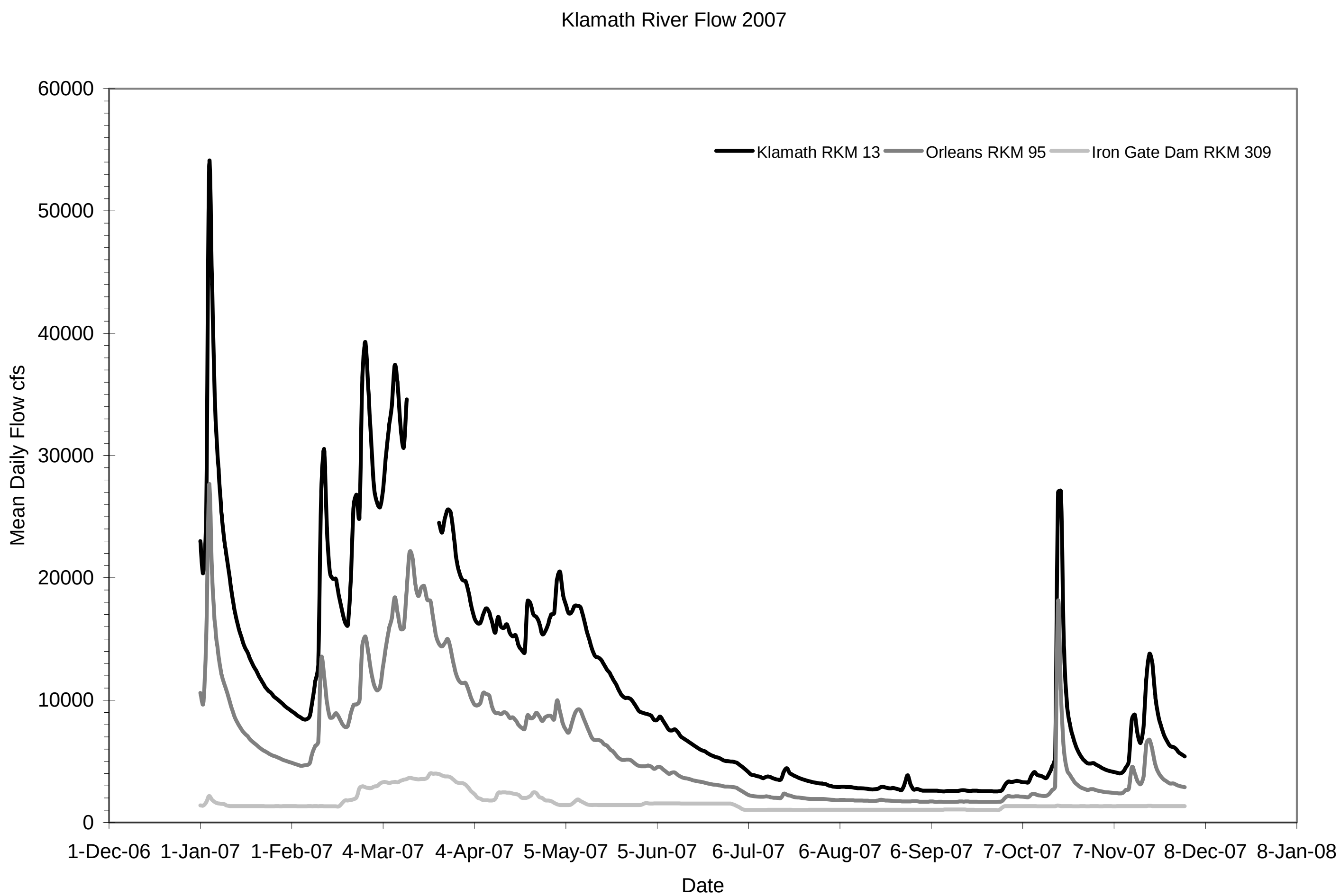


Figure 2. Flows for the Klamath River mainstem at representative locations during 2007 (USGS data).

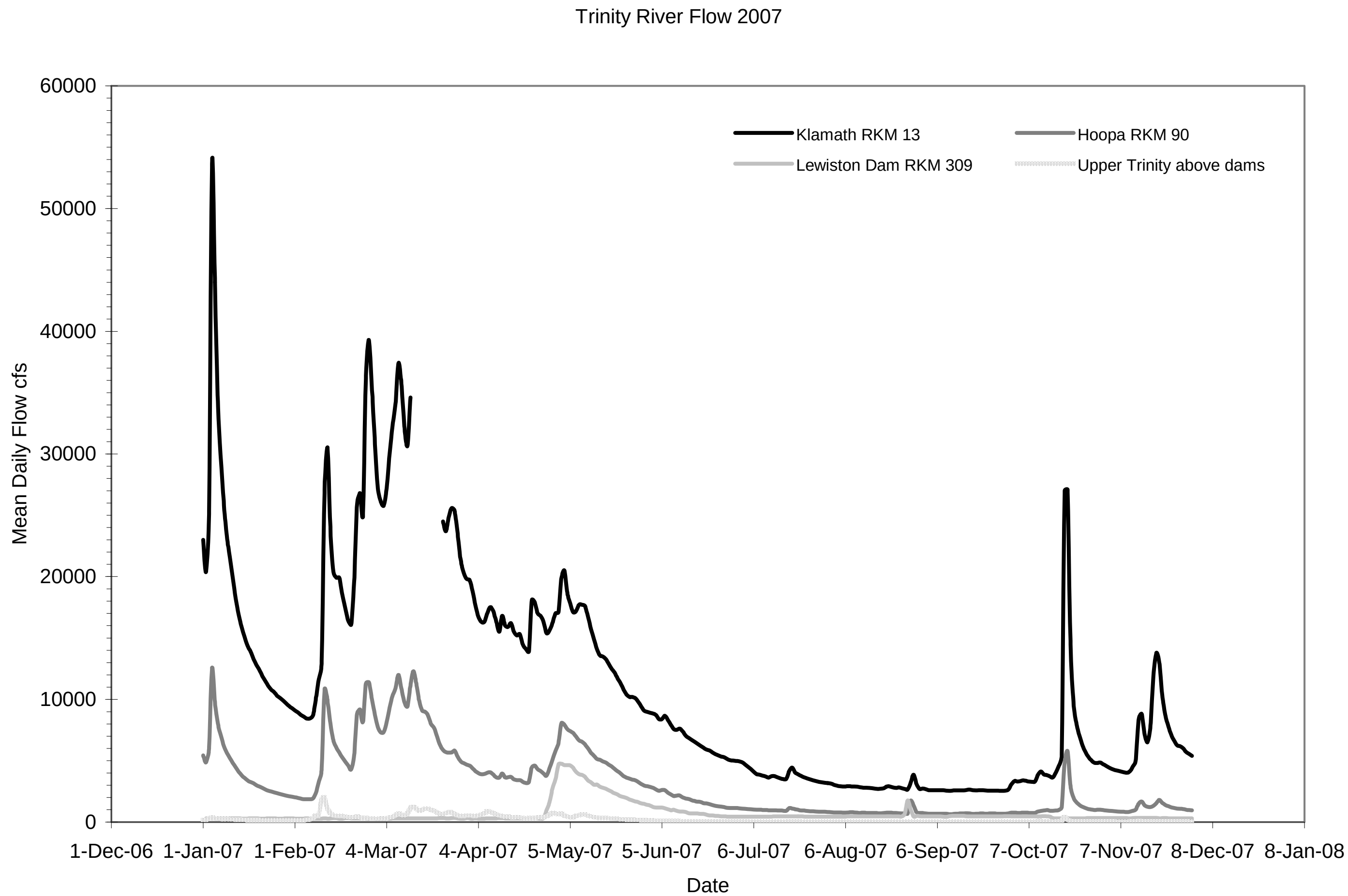


Figure 3. Flows for the Trinity River mainstem at representative locations during 2007 (USGS data).

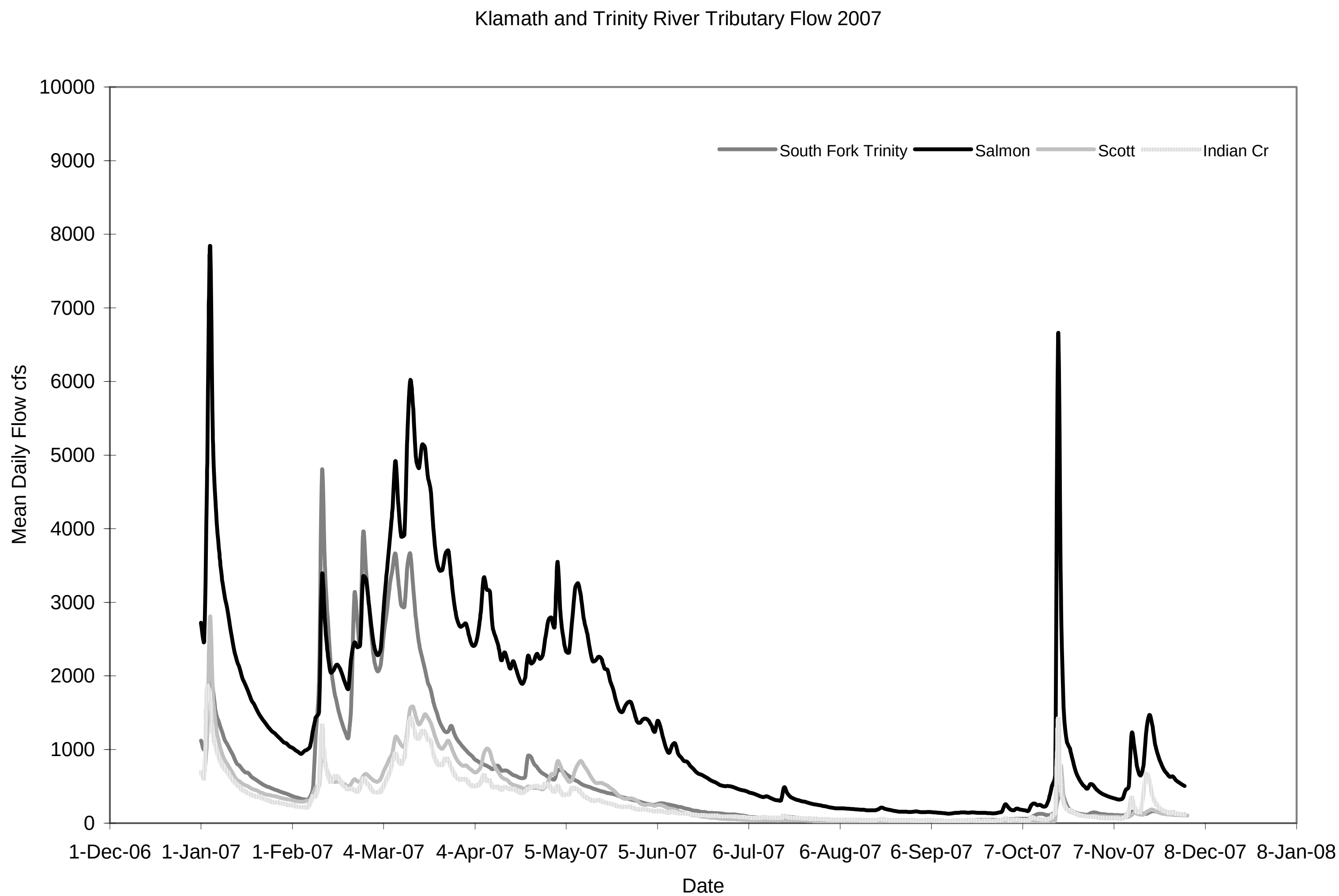


Figure 4. Flows for select major tributaries to the Klamath and Trinity Rivers during 2007 (USGS data).

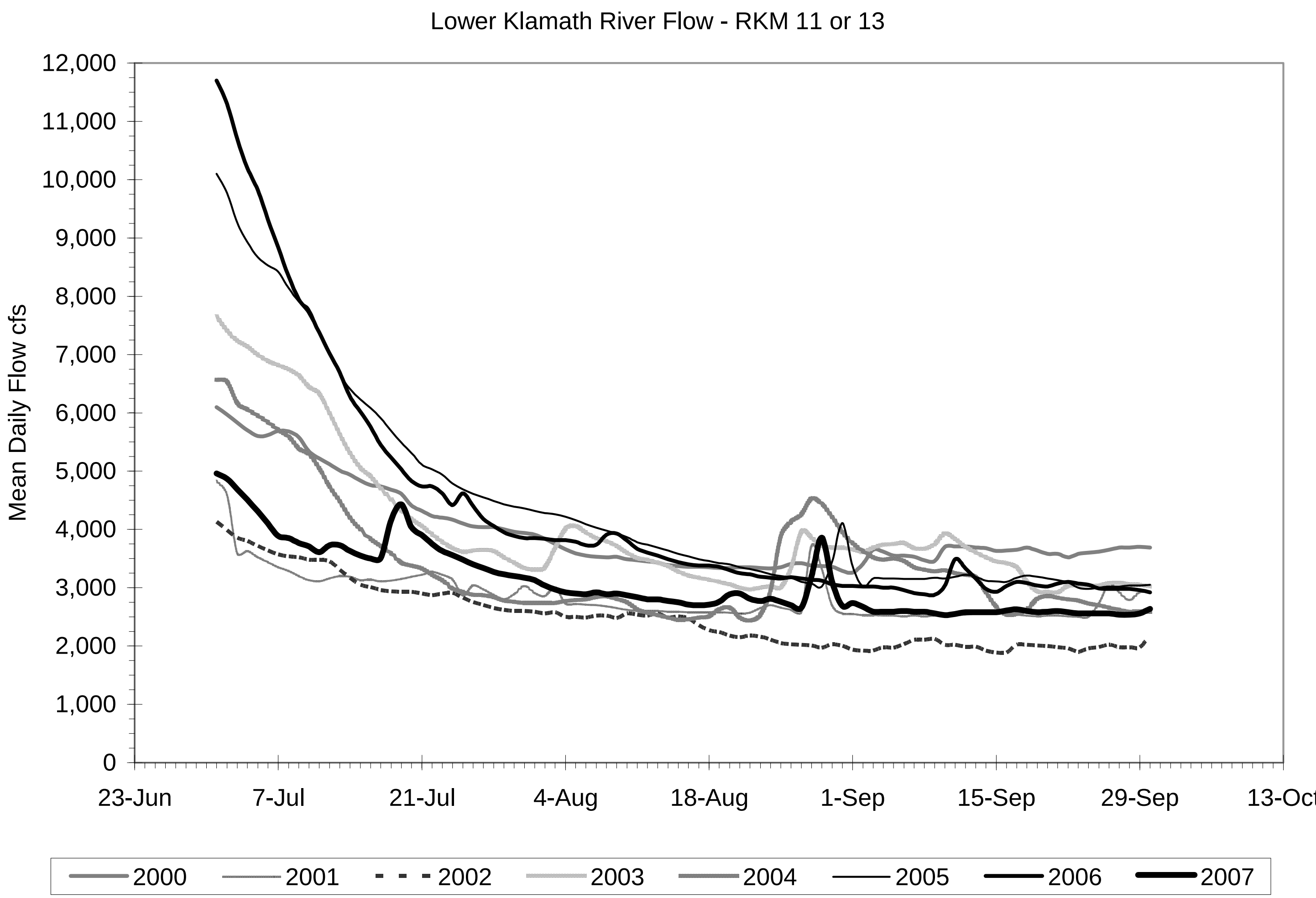


Figure 5. Summer and fall flows for the Klamath River from 2000 to 2007 (USGS final data 2000 to 2007l).

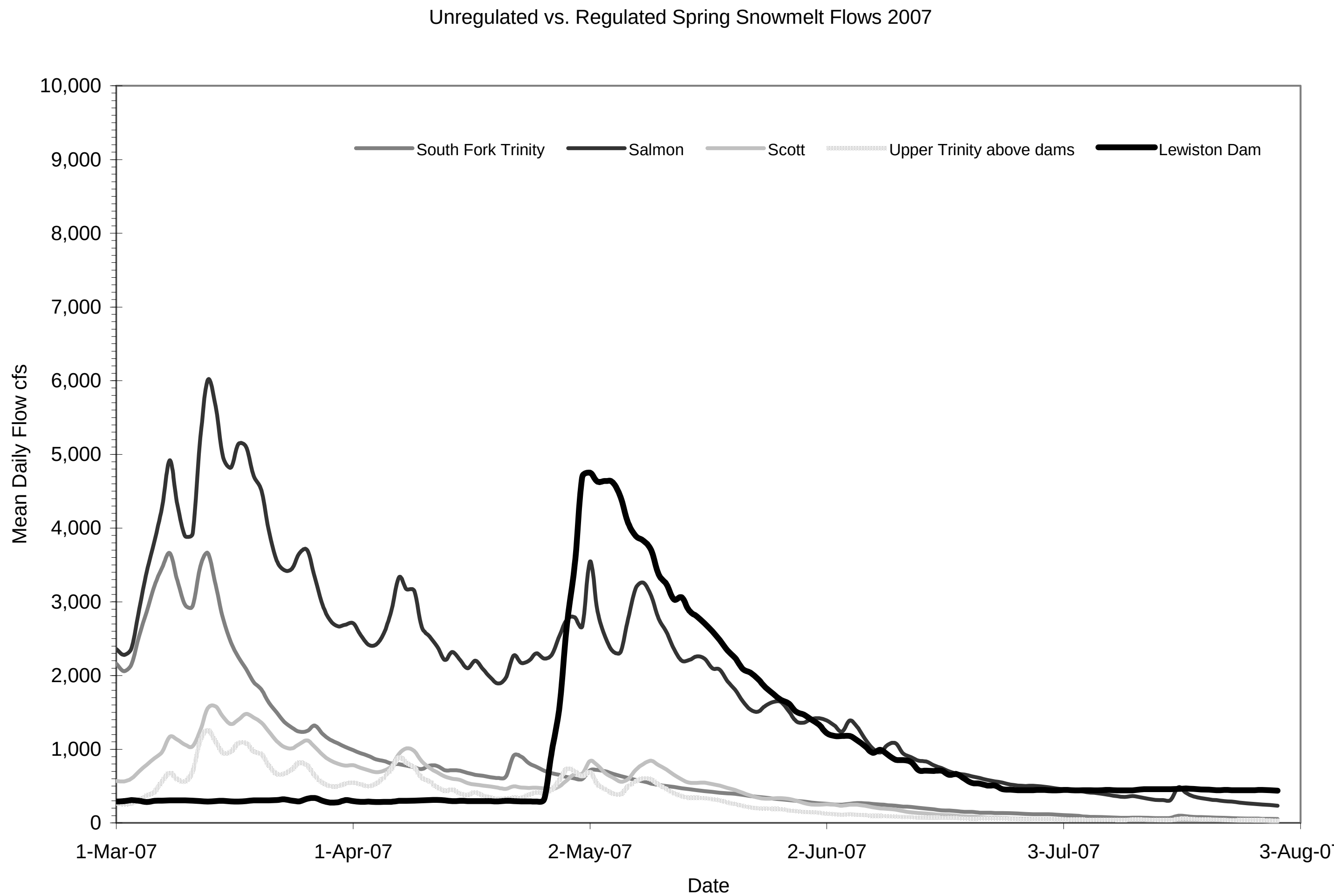


Figure 6. The regulated spring hydrograph for the Trinity River at Lewiston versus the unregulated spring hydrographs for several KRB tributaries in 2007 (USGS data).

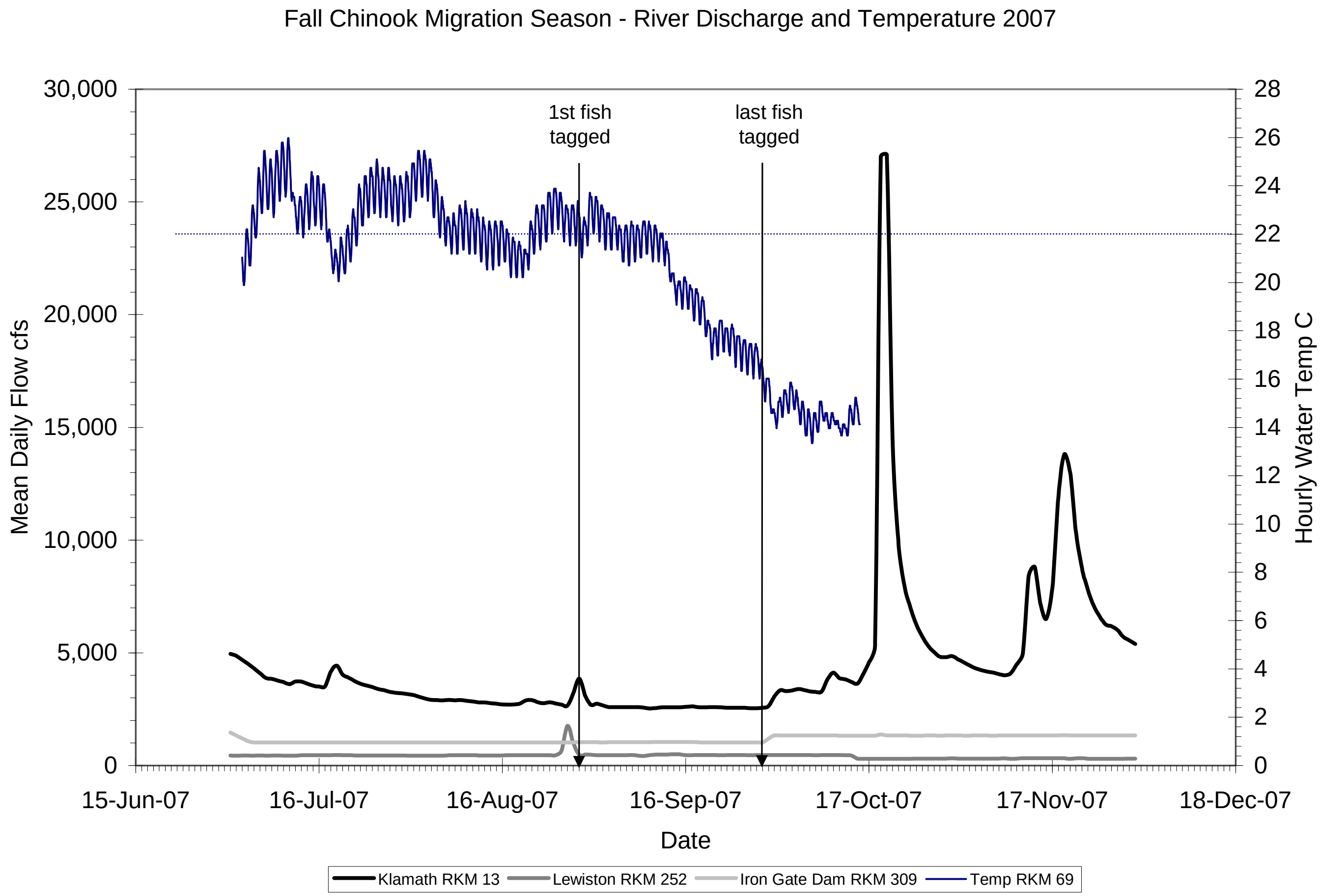


Figure 7. Water temperature (hourly) of the lower Klamath River below Weitchpec at RKM 69 plus flow at representative locations during the adult Chinook migration season in 2007 (USGS data). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold. Periods when adult fall Chinook salmon were tagged are indicated by the arrowed lines.

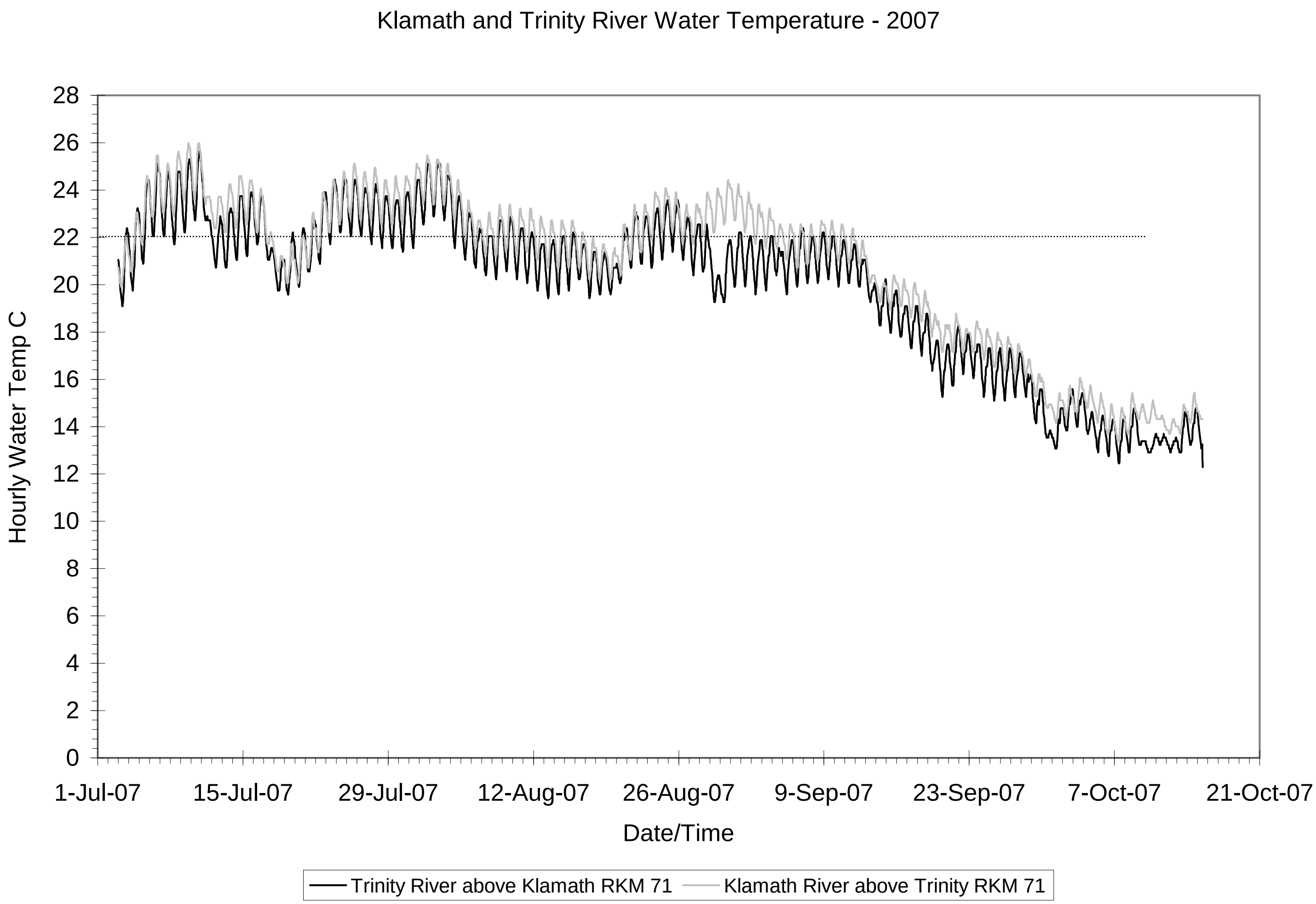


Figure 8. Available water temperature data at Weitchpec RKM 71 for the Klamath and Trinity Rivers above their confluence during 2007 (USFS). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

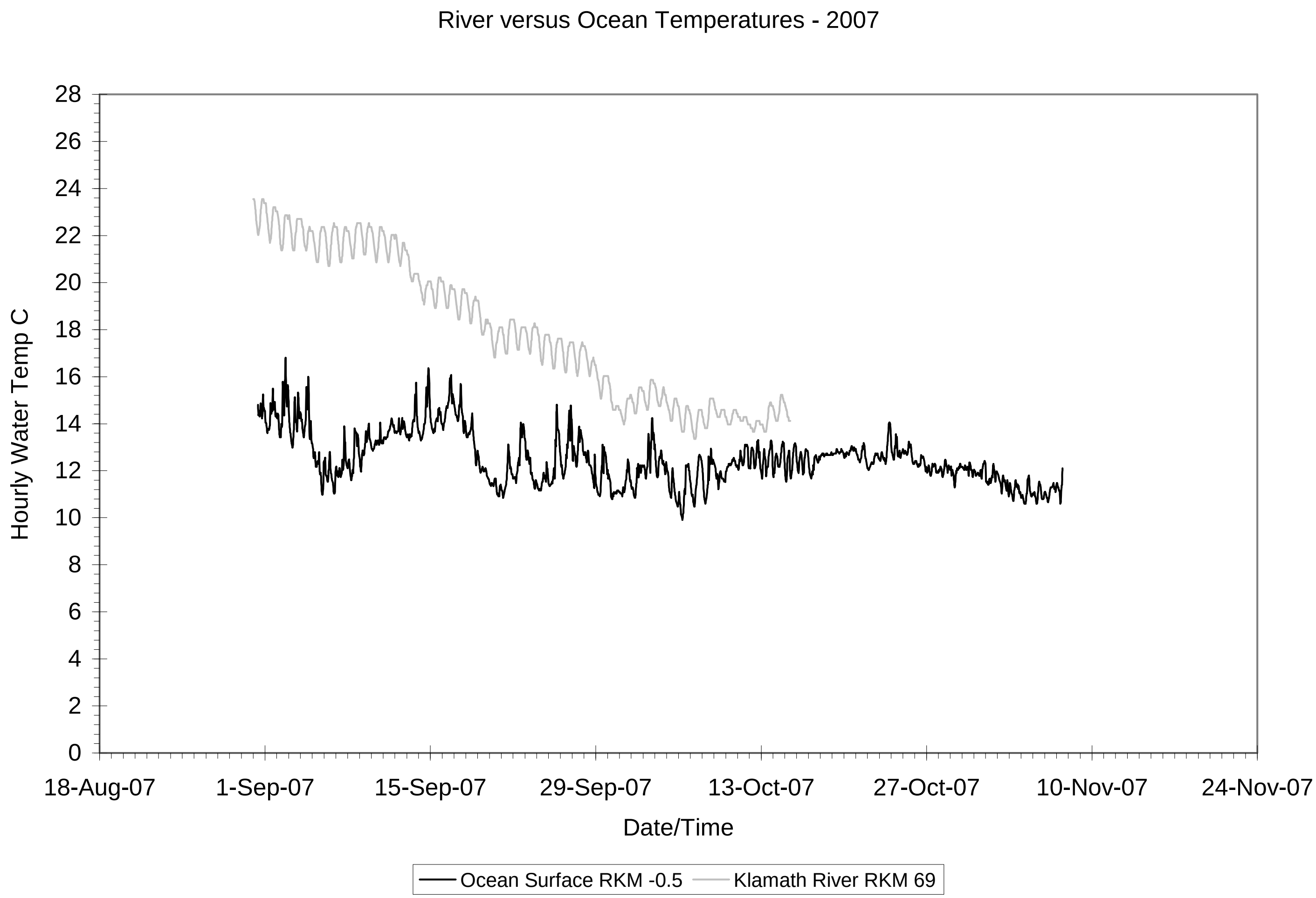


Figure 9. Available water temperature records (at surface) in Pacific Ocean 0.5 km (YTFP) northeast of the mouth of the Klamath River (nearshore estuary) versus mainstem water temperatures below the Trinity River confluence at RKM 69 (USFS).

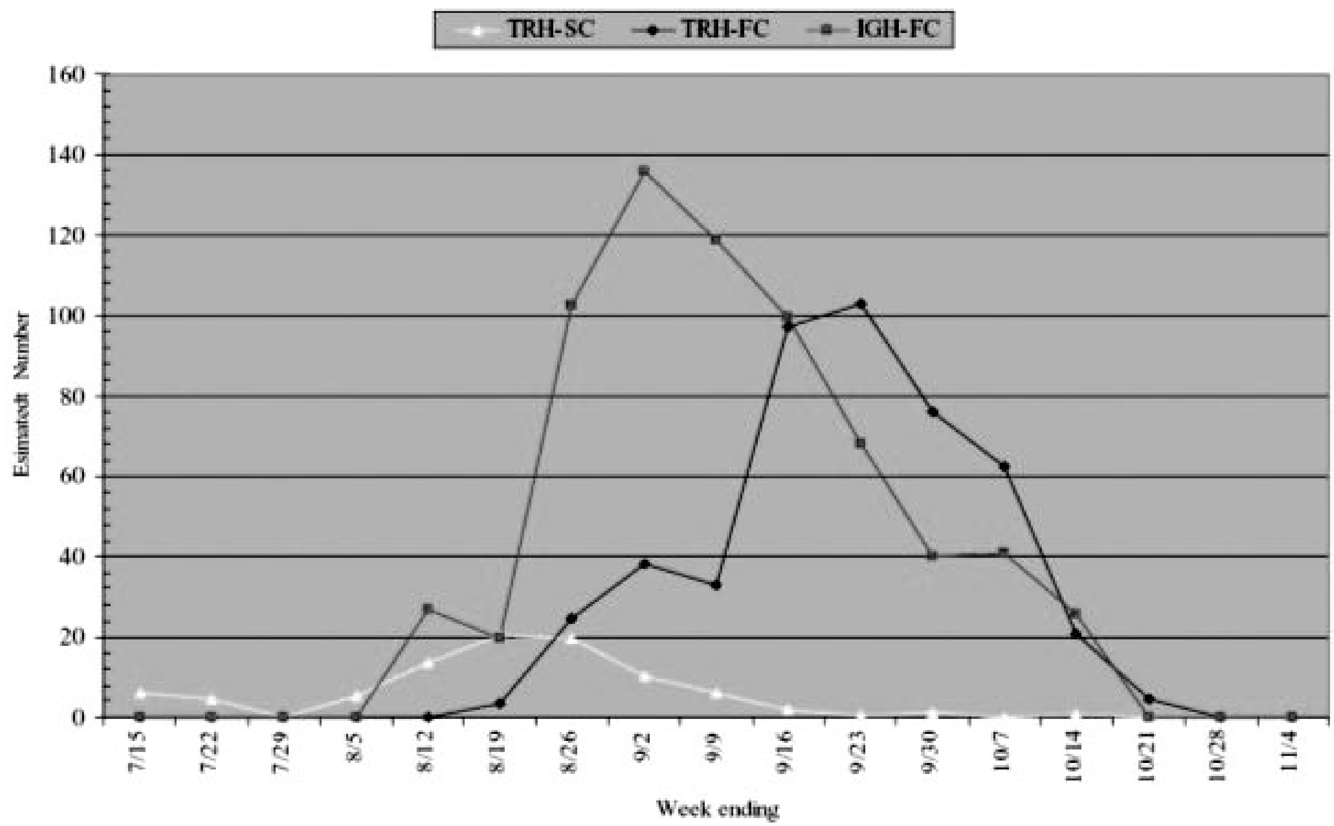


Figure 10. Average run-timing by week for adult Chinook salmon in the lower Klamath River (primarily below RKM 26) based on coded wire tag recoveries form the sport fishery from 1988 to 2001. Trinity River Hatchery spring Chinook (TRH-SC) have bimodal run-timing with the larger peak in the late June (not shown). Iron Gate Hatchery fall Chinook (IGH-FC) consistently run earlier than Trinity River Hatchery fall Chinook (TRH-FC). Source CDFG

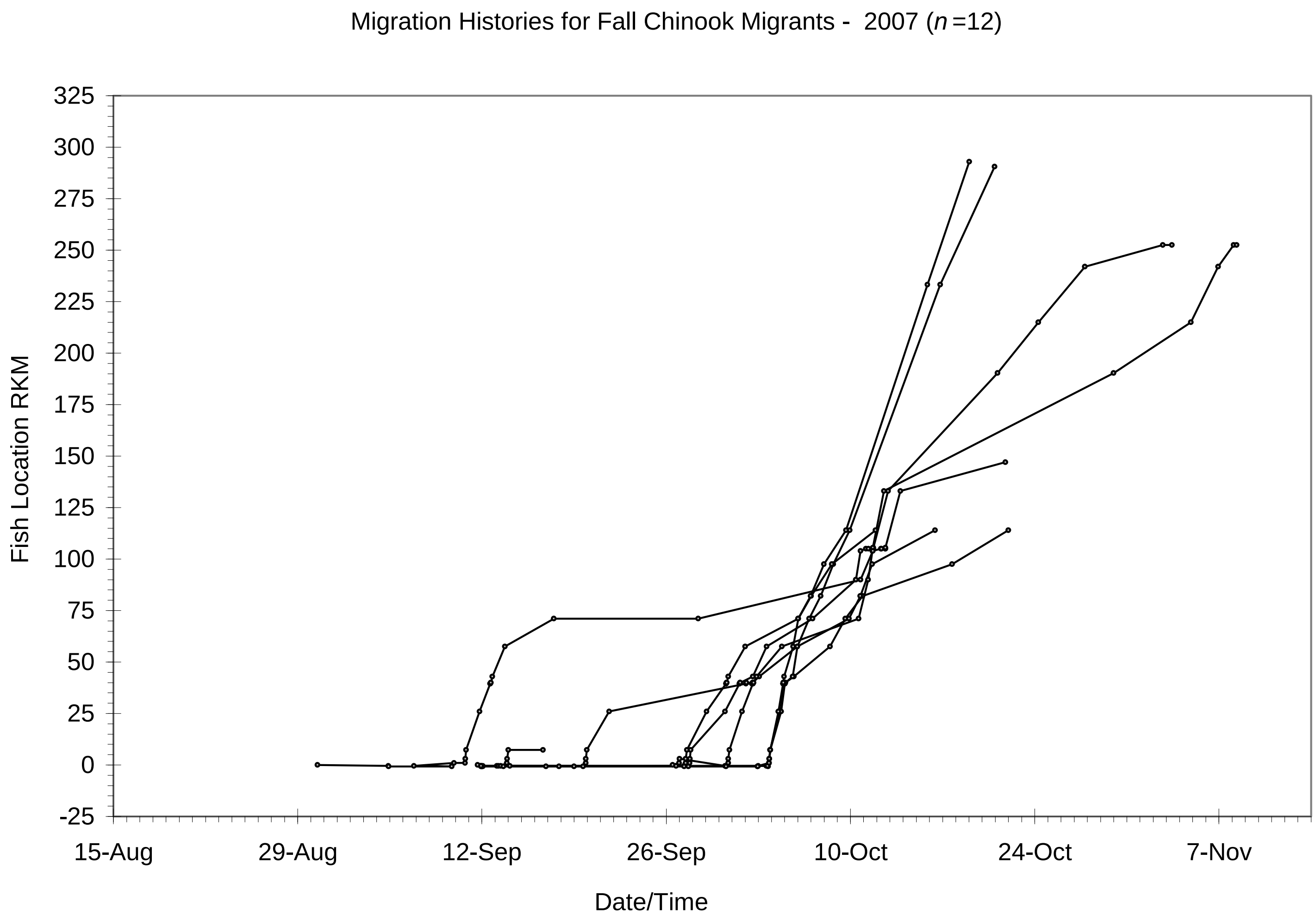
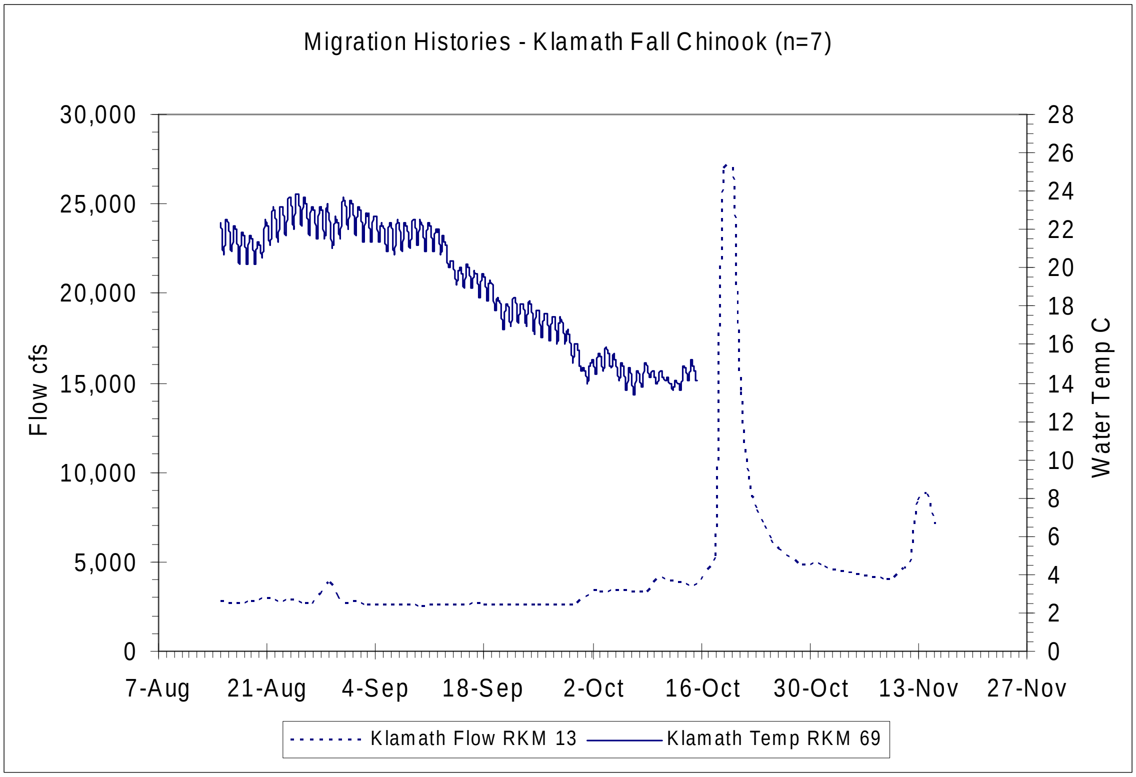


Figure 11. Migration histories for all 12 fall Chinook salmon tagged in 2007 that migrated upriver from the estuary. All river kilometers are measured from the mouth of the Klamath River



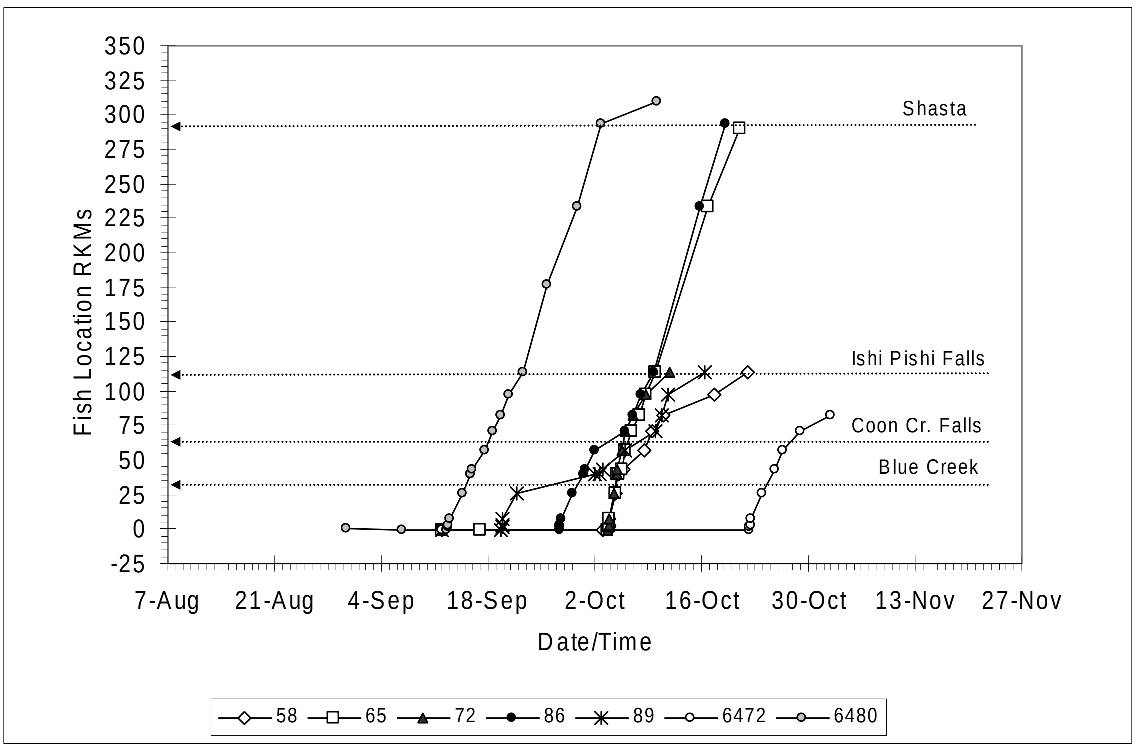


Figure 12. Migration histories for Klamath fall Chinook migrants in comparison to temperature and flow using commonly scaled axis. Dotted lines designate major landmarks.

Figure 13. Photograph of the mouth of the Klamath River on October 3, 2007 showing the old (top) and new (bottom) mouths.

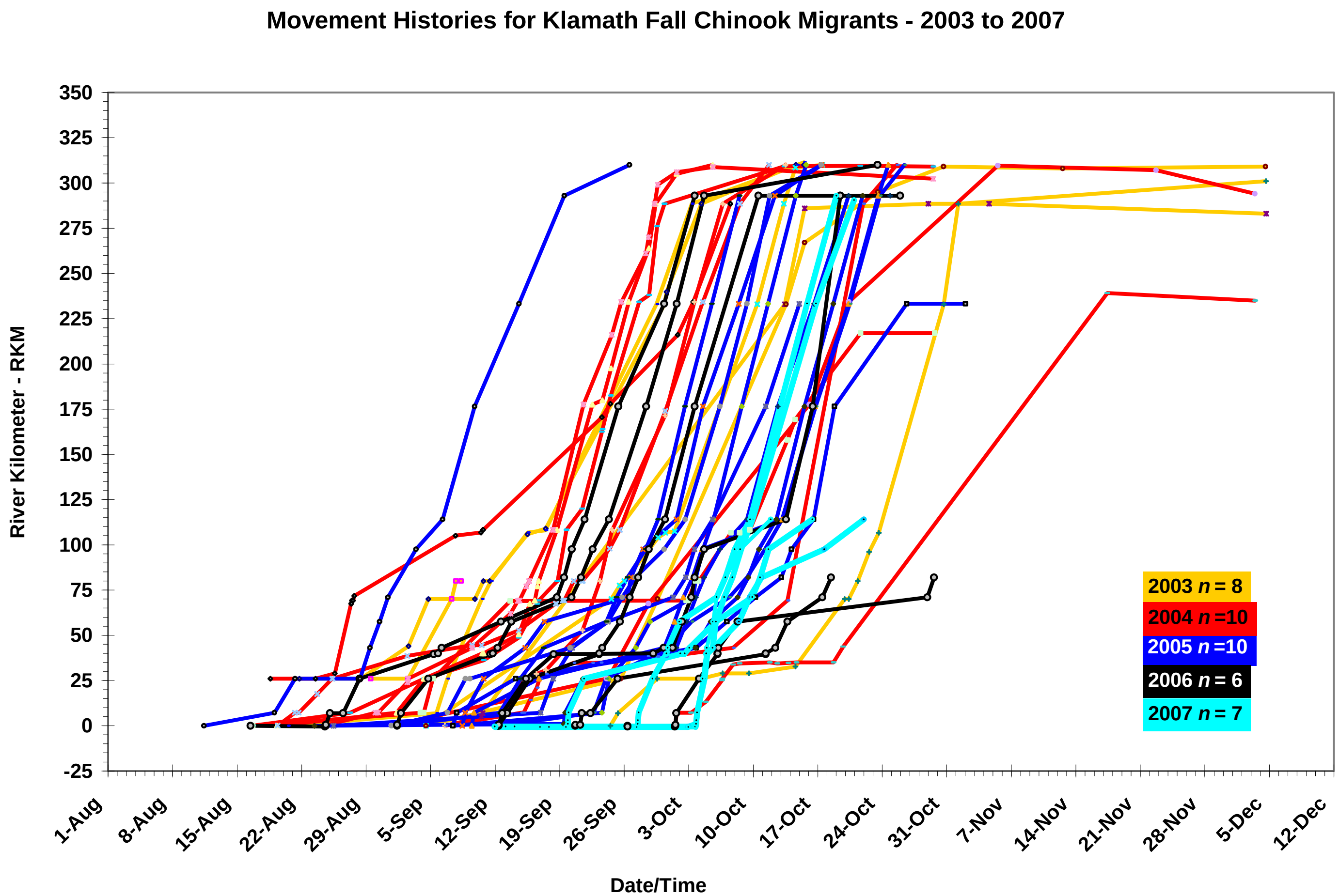
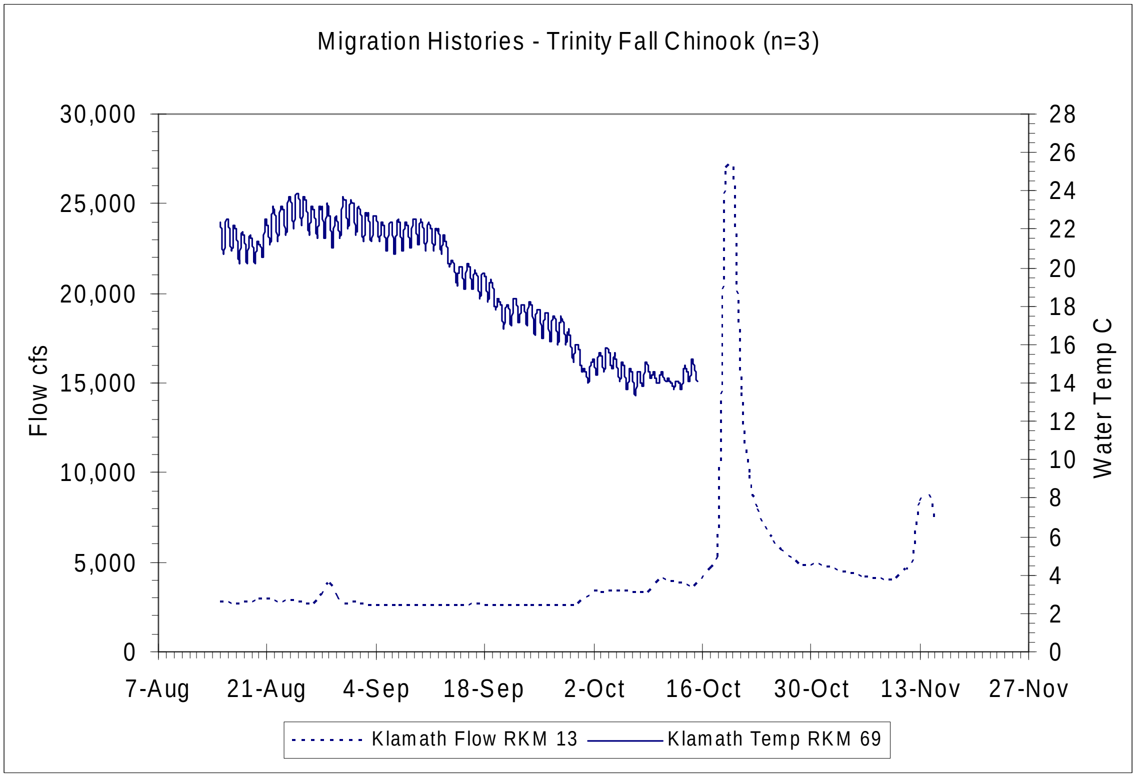


Figure 14. Movement histories for Klamath fall Chinook migrants tagged from 2003 to 2007 color coded by year including the three fish tagged above the estuary in the Blue Creek thermal refuge and an exceptionally early fish in 2005.



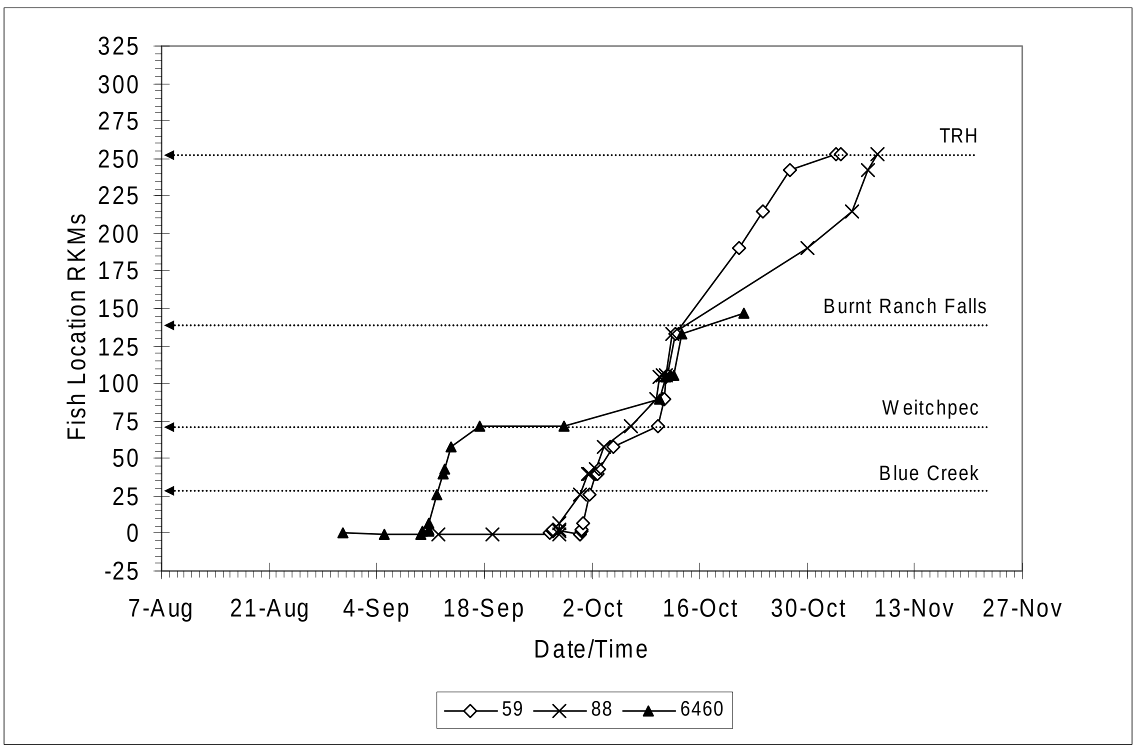


Figure 15. Migration histories for Trinity fall Chinook migrants in comparison to temperature and flow using commonly scaled axis. Dotted lines designate major landmarks.

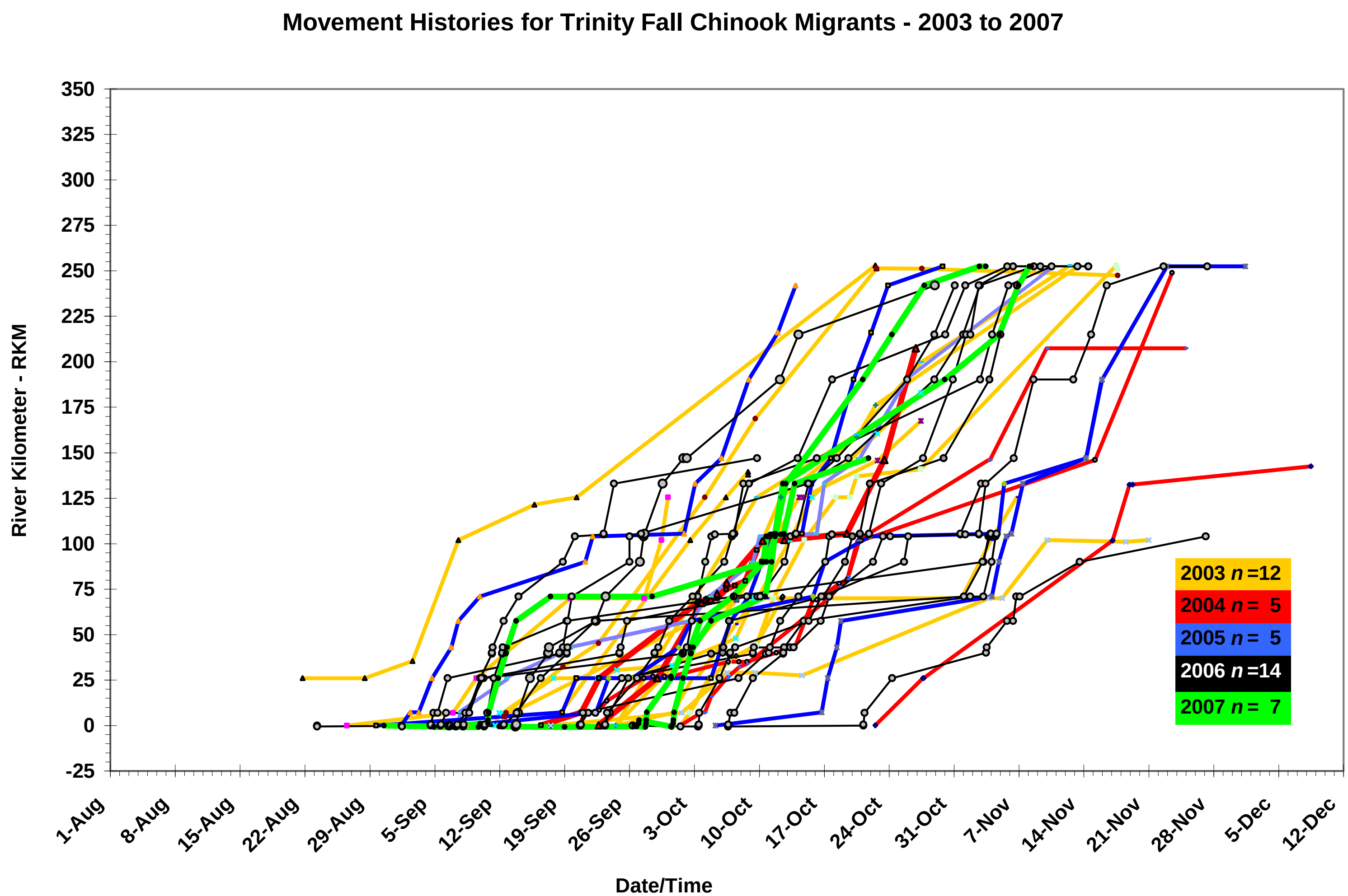


Figure 16. Movement histories for all Trinity fall Chinook migrants tagged from 2003 to 2007 color coded by year.

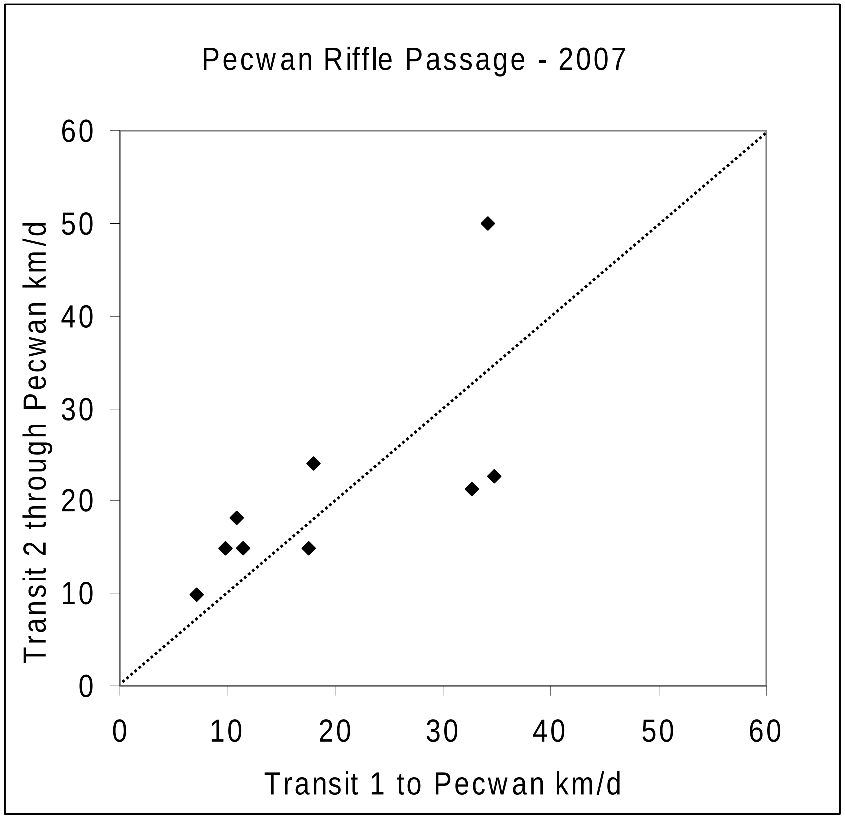


Figure 17. Migration rates for fall Chinook salmon (*n*=9) to the Pecwan Riffle (Transit 1 RKM 7.0 to 39.5) versus migration rates through the Pecwan Riffle (Transit 2 RKM 39.5 to 40.0). The dotted line marks the 1:1 ratio with all points above the line indicating faster migration rate through the Pecwan Riffle than up to it. The majority of tagged Chinook salmon (6 of 9, 67%) were above the 1:1 ratio line.

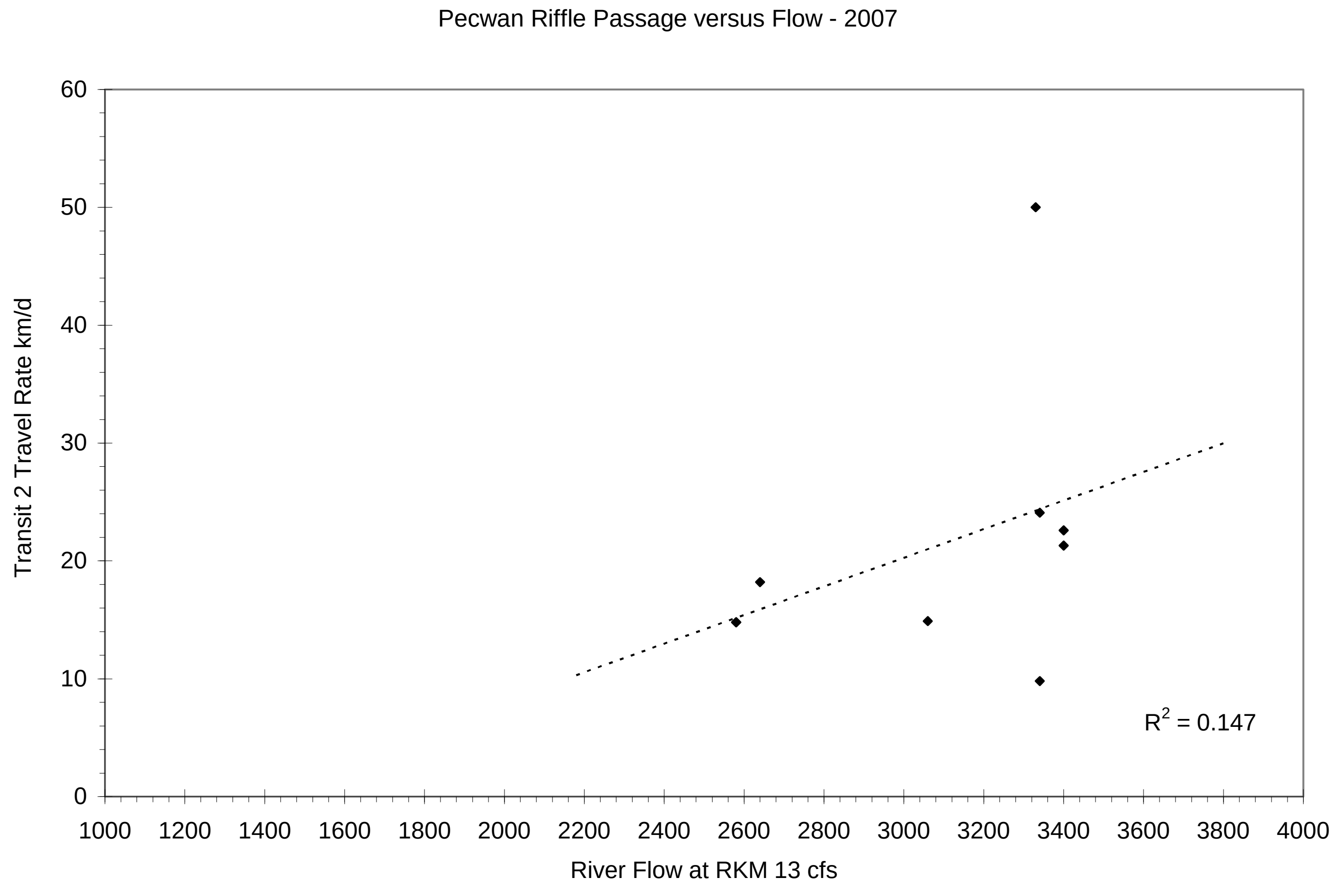


Figure 18. Migration rates for fall Chinook salmon (*n*=9) at the Pecwan Riffle (from RKM 39.5 to 40.0) versus flow (RKM 13). Given the low r squared value, the high amount of variation at flows of approximately 3,400 cfs, and the equivalent migration rates documented among some fish at lower and higher flows, there appears to have been no consistent relationship between flow and tagged Chinook salmon migration rates past the Pecwan Riffle at the flows observed during the fall of 2007.

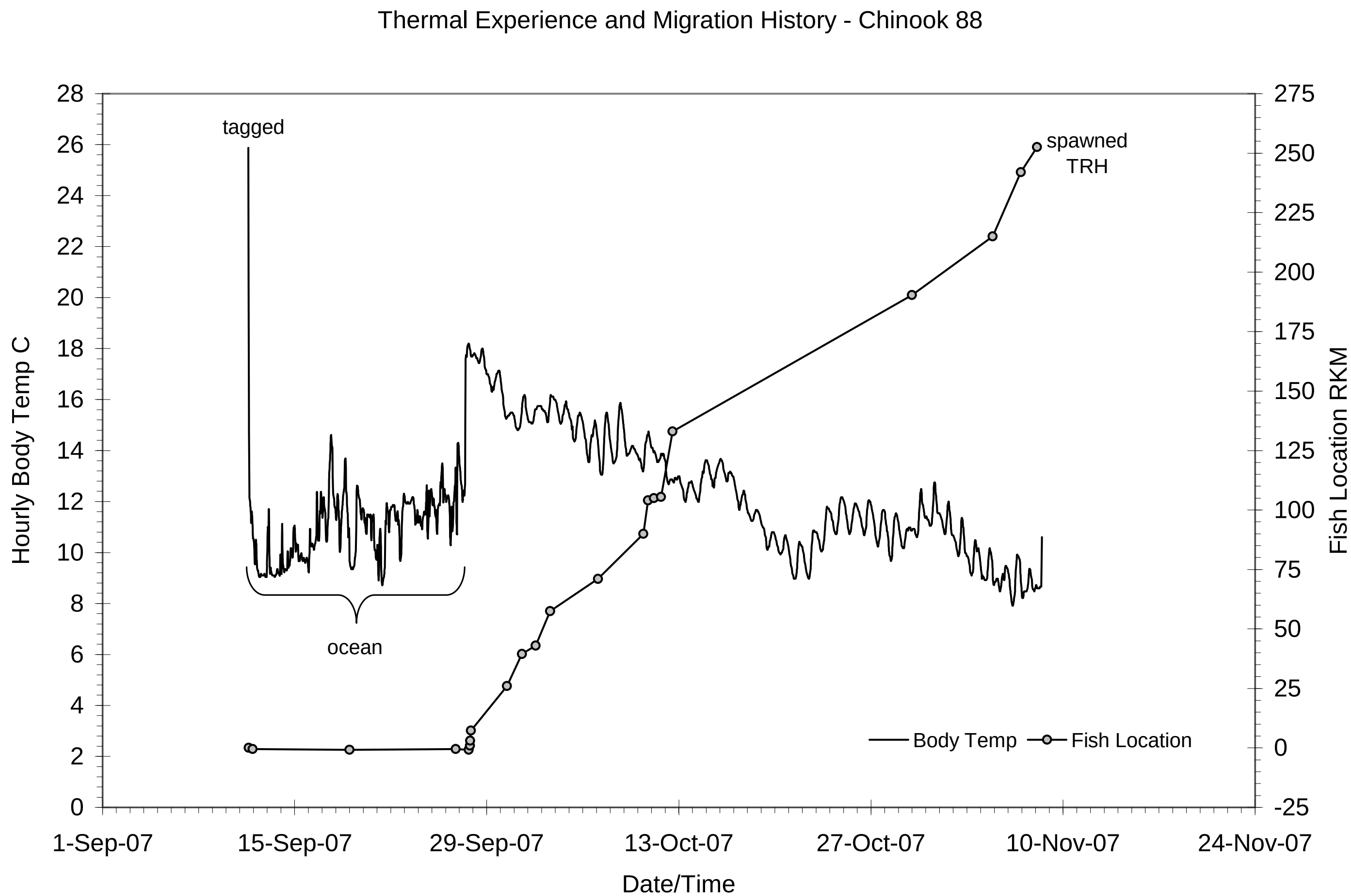


Figure 19. The thermal experience and migration history of Trinity fall Chinook 88 as determined from archival body temperature and sonic telemetry data. This female was spawned at the Trinity River Hatchery (TRH) on 11/8/2007.

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6.0 APPENDIX 1. Tagging data and fate or last observation summary for all 62 adult Chinook salmon tagged in 2007. All fish were tagged at the mouth of the Klamath River.

Tagging Date	Fish #	Jaw Tag #	Tag Code	Fork Length cm	Adipose Fin Clip	Archival Data	Fate or Last Observation	Last River or Reach
29-Aug-07	1	200	6463	77	yes		no observations	na
30-Aug-07	2	199	6477	65	no		no observations	na
30-Aug-07	3	198	6475	87	no		no observations	na
30-Aug-07	**4**	**197**	**6480**	**76**	**no**		**Iron Gate Hatchery 10/10**	**Klamath**
30-Aug-07	5	196	6478	82	no		Requa 10/8 rkm 1	estuary
30-Aug-07	6	195	6467	82	no		no observations	na
30-Aug-07	7	194	6461	85	no		Jet Tours 10/23 rkm 3	estuary
30-Aug-07	**8**	**193**	**6460**	**75**	**no**		**China Slide 10/21 rkm 147**	**Trinity**
30-Aug-07	9	188	6459	77	no		ocean 10/9	ocean
30-Aug-07	10	187	6458	99	no		ocean 9/13	ocean
30-Aug-07	11	186	6476	95	no	y	tribal harvest	estuary
4-Sep-07	12	184	6471	76	no		no observations	na
4-Sep-07	13	183	6479	73	no		ocean 9/5	ocean
4-Sep-07	14	182	6464	69	no		ocean	ocean
4-Sep-07	15	181	6474	73	no		requa 10/22 rkm 1 dead	estuary
7-Sep-07	16	100	6473	69	no	y	tribal harvest	estuary
7-Sep-07	17	99	6466	83	no		requa 9/8	estuary
7-Sep-07	18	98	6457	68	no		no observations	na
11-Sep-07	19	97	6468	62	no		no observations	na
11-Sep-07	20	96	6465	96	no		jet tours 10/15 rkm 1	estuary
11-Sep-07	21	95	6481	95	no		ocean 9/11	ocean
11-Sep-07	**22**	**94**	**6472**	**77**	**no**		**Big Bar 11/1 rkm 82**	**Klamath**
11-Sep-07	23	93	6469	89	no		ocean 9/22	ocean
11-Sep-07	**24**	**92**	**58**	**74**	**no**		**Green Riffle 10/22 rkm 114**	**Klamath**
11-Sep-07	**25**	**91**	**65**	**76**	**no**		**Shasta River 10/20 rkm 292**	**Shasta**
11-Sep-07	26	90	78	83	no		ocean	ocean

11-Sep-07	27	89	67	81	no		ocean	ocean
11-Sep-07	28	200R	73	73	no		ocean	ocean
11-Sep-07	**29**	**199**	**72**	**96**	**no**		**Green Riffle 10/11 rkm 114**	**Klamath**
11-Sep-07	30	198	87	79	no		no observations	na
11-Sep-07	**31**	**197**	**88**	**72**	**no**	**y**	**Trinity River Hatchery 11/8**	**Trinity**
11-Sep-07	32	196	75	79	no		ocean	ocean
11-Sep-07	**33**	**195**	**89**	**79**	**no**		**Green Riffle 10/16 rkm 114**	**Klamath**
11-Sep-07	34	194	61	84	no		no observations	na
11-Sep-07	35	193	90	84	no		ocean 10/6	ocean
11-Sep-07	36	192	68	78	no		ocean	ocean
11-Sep-07	**37**	**191**	**70**	**80**	**no**		**Wakel 9/16 rkm 7**	**lower Klamath**
11-Sep-07	38	190	77	91	no		ocean	ocean
11-Sep-07	39	189	64	81	yes		no observations	na
11-Sep-07	40	188	62	87	yes		no observations	na
11-Sep-07	41	187	76	94	no		ocean 10/8	ocean
11-Sep-07	42	186	71	85	no		Requa 10/6 rkm 1	estuary
11-Sep-07	43	185	74	92	no		no observations	na
11-Sep-07	44	184	80	82	no		no observations	na
11-Sep-07	**45**	**183**	**86**	**77**	**no**		**Hornbrook 11/4 rkm 293**	**Klamath**
11-Sep-07	46	182	79	77	no		ocean	ocean
11-Sep-07	47	181	81	70	no		no observations	na
11-Sep-07	48	180	84	72	no		ocean	ocean
12-Sep-07	49	179	57	76	no		ocean	ocean
12-Sep-07	50	178	66	85	no		no observations	na
12-Sep-07	51	177	91	76	yes		ocean	ocean
12-Sep-07	52	176	59	81	no		caught	estuary
12-Sep-07	53	175	82	77	no		ocean	ocean
12-Sep-07	54	174	85	83	no		Requa 10/21 rkm 1	estuary
12-Sep-07	55	172	63	73	no		ocean	ocean
12-Sep-07	56	171	69	71	yes		Requa rkm 1	estuary
12-Sep-07	**57**	**169**	**6470**	**77**	**no**		**Wakel 9/13 rkm 7**	**lower Klamath**
12-Sep-07	58	168	83	73	no		ocean	ocean

26-Sep-07	59	167	32	87	no	ocean	ocean
26-Sep-07	60	166	150	65	no	no observations	na
26-Sep-07	61	165	96	84	no	no observations	na
26-Sep-07	**62**	**164**	**59**	**72**	**no**	**Trinity River Hatchery 11/2**	**Trinity**

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