Adult Chinook Salmon Migration in the Klamath River Basin:

2006 Telemetry Study Final Report

Radio telemetry equipment for installation on the Trinity River. Photo by author.

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EXECUTIVE SUMMARY

Since the spring of 2002 the Yurok Tribal Fisheries Program has led a collaborative telemetry 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. This report describes and discusses results from the 2006 study year.

During 2006, a total of 80 adult Chinook salmon were tagged at the terminus of the Klamath River with the Pacific Ocean from 6/8/2006 to 10/6/2006 with esophageal radio or temperature sensitive 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 80 adult Chinook salmon, 37 (46%) eventually migrated upriver out of the estuary after tagging while 43 (54%) never migrated beyond the estuary. In previous study years this latter ratio ranged from 43 to 70%. Of the 43 fish that did not migrate upriver from the estuary, 1 (2% of 43) was definitively harvested, 6 (14%) regurgitated their tags or were killed, 2 (5%) were last detected in the ocean, 23 (53%) disappeared with no further detections, and 11 (26%) were confirmed to have been eaten by pinnipeds, in particular California sea lions. Pinniped predation appeared to be a major driver of estuary behavior among tagged Chinook salmon contributing to minimal estuary residence. On average tagged Chinook salmon spent 0.47 days in the estuary, compared to an average of 8.5 days in the ocean for the 45% (of 14 of 31) of fish that retreated back to the ocean. While some fallback and initial delay in the ocean was likely related to handling effects, the behavior and resulting thermal experience of tagged Chinook salmon while in the ocean was consistent with continued feeding. Additional benefits of ocean residency include reduced cumulative thermal experience and predator avoidance. Of the 37 tagged Chinook salmon that did migrate upriver from the estuary, at least 15 (41% of 37) successfully arrived to spawning grounds (9) or a hatchery (6), at least 6 (16%) were harvested, at least 1 (3%) died en route prematurely, and 15 (41%) disappeared or were last observed during active migration. Out of these same 37 tagged Chinook salmon, 6 (16%) migrated into the Klamath River above Weitchpec, 24 (65%) migrated into the Trinity River above Weitchpec, and 7 (19%) were never observed migrating above the confluence of the Klamath and Trinity rivers at Weitchpec.

Thus the 30 tagged Chinook salmon that 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 2006 season, no summer Chinook were tagged that survived to migrate beyond Weitchpec. The term 'run' denotes a distinct group of fish ascending a river to spawn and can be homogeneous or comprised of mixed stocks or populations of varying degrees of genetic similarity or differentiation with one or multiple destinations.

Spring Chinook migrants, as defined by their spring and early summer run-timing and unique migrational patterns, were tagged from 6/8/2006 to 7/6/2006 and initiated upriver migration from 6/19/2006 to 7/19/2006 prior to water temperatures >22ºC and during the descending limb of the snowmelt peak with relatively steady and rapid upriver migration.

Klamath fall Chinook migrants were tagged from 8/15/2006 to 9/26/2006 and initiated migration from 8/26/2006 to 10/1/2006, primarily bound for the Iron Gate Hatchery or nearby natural spawning areas. Klamath fall Chinook migrants in the non-pulse flow years of 2006 and 2005 displayed equivalent movement patterns as Klamath fall Chinook migrants in the 2003 and 2004 Trinity fall pulse flow years; both before, during, and after the pulse flows. This relationship was especially apparent for Klamath fall Chinook migrants but also held true for Trinity fall Chinook migrants. Consistent movement patterns with and without pulse flows over multiple years is compelling evidence that these flows do not stimulate upriver movement or otherwise substantially alter migration behavior. The Klamath ceremonial boat dance flow of September 2006 also did not noticeably affect adult Chinook salmon migration behavior. Given that fall Chinook salmon 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 salmon migration season is the most effective management tool for reducing the risk of *Ich* outbreaks such as occurred in September of 2002.

Trinity fall Chinook migrants were tagged from 8/23/2006 to 10/6/2006 and initiated migration from 9/4/2006 to 10/21/2006, 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. Tagged Chinook salmon that passed the Willow Creek weir experienced migration delays ranging from 0.1 to 10.4 d with a median of 0.6 d. Telemetry data showed that adult Chinook salmon primarily used the daily and weekend openings to pass the weir and that a substantial reduction in delays as compared to 2005 (median of 10.2 d) was achieved by removing a greater number of conduit rods during openings in 2006.

No behavioral thermoregulation was observed by fall Chinook migrants at en route thermal refuges (i.e. cold creek confluences) and no substantial (>12 hrs) thermal refuge use was observed for spring Chinook migrants. Results from 2006 supported the conclusion from previous study years that the thermal threshold for migration inhibition for KRB adult Chinook salmon occurs at mean daily water temperatures above 23.5^{o}C during periods of falling water temperatures, 21.0^{o}C during rising water temperatures, and 22.0^{o}C 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 salmon 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 salmon 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 salmon respond to environmental variables such as temperature and flow during upriver migration?
3. What spatial and temporal patterns of thermal refuge use (behavioral thermoregulation) are displayed during their spawning migration?
4. 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 behavior in the estuary and nearshore ocean. The overarching goal of this research project is 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.

1.1 Study Objectives

The primary objective of this study was to document the migration behavior and thermal experience of adult Chinook salmon in the KRB during the 2006 spawning migration season. Specific objectives were to:

1. Determine the migration behavior and thermal experience of adult Chinook salmon in the KRB throughout the spectrum of run-timing;
2. Analyze behavioral responses to environmental variables such as temperature and flow;
3. Determine the spatial and temporal patterns of thermal refuge use by adult Chinook during their spawning migration;
4. Determine the spatial and temporal patterns of estuarine residence by adult Chinook salmon;
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 also contains a lateral scour bedrock pool that is fed by cold (10-15°C) hyporheic inflow and is partially connected 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 created a well mixed pool.

2.2 Tagging and Telemetry

Radio and sonic esophageal transmitters were used to track the movements of adult Chinook salmon during the 2006 spawning migration in the KRB. Radio transmitters (Lotek MBFT-3A pulsed at 151 MHz; W16 x L47 mm, 15.5 g in air) were used in the spring and early summer due to their superior performance in high flow conditions (turbidity and turbulence), and temperature sensitive sonic transmitters (Vemco, V16T-3L-S256; W16 x L73 mm, 28 g in air) used were in the late summer and fall due to their otherwise superior performance including detectability in high salinity water. 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, tagged, and released at the mouth of the Klamath River from 6/8/2006 to 10/6/2006. No effort was made to capture and tag Chinook salmon at the Blue Creek/Blue Hole thermal refuge during 2006, partly due to the changed configuration of Blue Hole. 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 dorsal or anal 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 of 10 automated radio listening stations (Grant Systems Engineering Orions) and 31 sonic listening stations (Vemco VR2s) were placed throughout the KRB at strategic locations to continuously monitor fish presence or absence and for sonic receivers, to record internal body temperatures. Listening station locations are listed in Table 1. The spatial relationship of the listening stations allowed for determination of

migration paths and travel rates. Limited mobile tracking occurred for radio tagged Chinook salmon and none was undertaken for sonic tagged fish.

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

Thermisters (Onset Optic Stowaways and Alpha Mach iBs) were used at each listening station to record ambient water temperature. The thermisters used were rated in accuracy to the nearest 0.1ºC (Onset) or 0.5ºC (Alpha Mach). All temperature probes were tested before deployment in high and low temperature water baths and calibrated with an ASTM certified thermometer.

Ambient water temperatures at additional sites in the mainstem Klamath River were obtained from temperature recorders operated by the YTFP, the US Forest Service, and the US Geological Survey (USGS). 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. However, efforts were made to increase the representativeness of this study by attempting to tag at least several adult Chinook salmon each week throughout the study period. 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

NOTE: The results and discussion herein will undergo further analysis, including a comprehensive analysis of multi-year data sets in preparation for peer reviewed publications.

3.1 Tagging and Fate Summary

Tagging data and the final known fate or last observation of all 80 tagged Chinook salmon is summarized in Appendix 1. One coho salmon migrant was opportunistically tagged, which migrated to the Trinity River Hatchery with migration data presented in Appendix 2. All Chinook salmon were tagged at the mouth of the Klamath River (north and south shore) where the chute empties river into the ocean. After tagging, not all Chinook salmon migrated beyond the estuary. Out of the total sample of 80 adult Chinook salmon, 37 (46%) migrated upriver from the estuary after tagging while 43 (54%) never migrated beyond the estuary. In previous study years this latter ratio ranged from 43 to 70%, however the non-detectability of radio transmitters in high salinities precluded the determination of fates of tagged fish that ‘disappeared’ in the estuary or nearshore ocean (disappearance is defined as no further detections). 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.

In 2006, the relative contribution of these factors was largely determined through use of sonic transmitters, which are detectable in high salinities, along with two sonic receivers placed in the estuary plus one in the nearshore ocean. Results showed that pinniped predation was the primary known cause of 'disappearance' with 11 (14% of 80, 26% of 43) 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 Chinook salmon to that of an endothermic marine mammal, which in the case of California sea lions is 37.5ºC. This method only detected tagged Chinook salmon that were eaten whole or nearly so, thus it can be assumed that more than 11 tagged Chinook salmon were killed by pinnipeds. Of the remaining tagged Chinook salmon that disappeared in the estuary/nearshore, 1 (2% of 43) was harvested (claimed), 6 (14%) likely regurgitated their tags (although predation cannot be ruled out), 2 (5%) were last detected headed back to the ocean, and 23 (53%) disappeared after tagging with no known fate.

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 pinniped predation rates observed by Williamson and Hillemeier (2001) were substantially lower than the minimum 14% pinniped predation rate observed for tagged Chinook salmon in the estuary/nearshore during 2006. However, 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 were 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.

The level of pinniped predation and activity observed in 2006 is significant on two notable levels. First, the current rate of pinniped predation could be higher than was documented by Williamson and Hillemeier (2001) in the late 1990's and annual variability could be substantial. Specifically, Williamson and Hillemeier (2001) compared their results to studies conducted ten to twenty years earlier and concluded that the temporal presence and associated predation pressure from California sea lions was on the increase. If this trend continued since the 1990s then the predation rate by the 2000's would be expected to be higher although potentially still relatively low. The minimum level of pinniped predation was substantially higher in 2005 (33%), which suggests the possibility of high annual variability in the numbers of salmon consumed by pinnipeds in the estuary. Second, pinniped predation pressure appears to be a major driver of adult Chinook salmon behavior in the estuary. This is discussed in more detail later, but the fact that the estuary is a physical bottleneck with actively hunting pinnipeds, in particular cooperatively hunting male California sea lions (personal observation), is a substantial deterrent to residing in the estuary more than the minimum necessary for adult Chinook salmon.

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 still migrating when receivers were pulled). Taking this into account, of the 37 tagged Chinook salmon that did migrate upriver from the estuary in 2006 at least 15 (41% of 37) successfully reached spawning grounds (9) or a hatchery (6); at least 6 (16%) were harvested; 15 (41%) disappeared during migration or were still migrating when receivers were pulled; and at least one (3%) died en route. Out of these same 37 tagged Chinook salmon, 6 (16%) migrated into the Klamath River above Weitchpec, 24 (65%) migrated into the Trinity River above Weitchpec, and 7 (19%) were never observed migrating above Weitchpec (RKM 70) due to harvest (4) or disappearance (3). Based on a process of elimination, up to nine migrants that disappeared during migration could have

migrated into unmonitored tributaries, primarily the South Fork Trinity River or tributaries to the Klamath River above Weitchpec. No tagged Chinook salmon were detected in the Salmon River.

Thus a total of 30 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 will serve as the basis of analysis of adult Chinook salmon migration behavior by run-timing and destination/stock groups.

Sonic receivers preformed without failure and with only three missed detections total at all stations (with the exception of the ocean receiver) resulting in a 99.3% detection probability. Radio stations also did not fail but had a slightly lower detection probability of 97.7%. Based on this performance, it is recommended that sonic transmitters remain the featured tag for future studies assuming that manual tracking isn't required and turbidity is not excessively high. It is also recommended that an additional receiver be placed in the ocean to provide complete coverage, and the primary tagging location should remain at the mouth of the Klamath River due its unique advantages despite the proximity of pinnipeds. Tagging adult Chinook salmon in the uppermost reach of the estuary during 2003 did not yield a reduced 'disappearance' rate over fish tagged at the mouth and all four test fish tagged around RKM 21 in 2003 retreated back to the vicinity of the estuary. Most importantly, besides the estuary and Blue Creek, 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 2006 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 meters per second (cms; 35.31 x cms = cfs), and all RKMs are measured from the mouth of the Klamath River.

Based on the Natural Resource Conservation Service (NRCS) April 1, 2006 hydrological forecast for inflow into Upper Klamath Lake, the US Bureau of Reclamation (USBR) classified the water year type as "above average" for Upper Klamath Lake level and Klamath River discharge operations planning. The water year designation for the Trinity sub-basin was “extremely wet” in 2006 due to overall higher precipitation and snow pack, 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 2006 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.

During 2006, spring snowmelt from unregulated tributaries generally occurred from mid-March to late-June with peaks in May. After peaking, the descending limb occurred uninterrupted except for a smaller peak on 6/2/2006 with summer base flow conditions generally prevalent by mid-July. The mainstem Trinity River, however, experienced a later peak due to flow releases from Lewiston Dam that peaked at approximately 283 cms on 5/24/2006 followed by extended bench releases with ramp down completed by 7/19/05 (Figure 6). The timing, duration, and magnitude of spring snowmelt flows are important for numerous biota including migrating adult Chinook salmon, however, the timing of the ramp down and the ramping rate of the Trinity bench release did not match that of snowmelt hydrographs for unregulated tributaries in the KRB (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, and 2006) (Figure 5). The only special flow release in 2006 was a four-day pulse flow released from Iron Gate Dam with a peak of 42 cms on 9/9/2006 for the purpose of meeting ceremonial obligations to the Yurok Tribe (boat

dance flow). The first substantial natural increase in river flows throughout the KRB from precipitation after the summer dry season did not occur until approximately 11/14/2006.

Water Temperature

Hourly water temperatures at various locations throughout the KRB during the adult Chinook salmon migration season are presented in Figures 7 to 12. Water temperatures in the lower Klamath River at Blake's (RKM 13) first ≥20ºC on 6/24/2006 and ≥22ºC on 7/9/2006 with a maximum of 26.8ºC on 7/24/2006. Water temperatures at RKM 13 are compared to river flow and periods when Chinook were tagged in Figure 7. After the annual peak, water temperatures declined sharply until 8/1/2006 where after mean daily water temperatures were relatively stable. Seasonal cooling began in late August with water temperatures ≥22ºC for the last time on 8/28/2006 and ≥20ºC on 9/15/2006 (Figure 7). This pattern was generally consistent throughout the lower KRB with the exception of the upper Trinity River (Figure 8), 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 2006) except during periods of large releases from the Trinity Dams such as during June and July of 2006 (Figure 9). 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). Water temperature changes substantially over the longitudinal profile of the Klamath River from the vicinity of Iron Gate Dam (Hornbrook RKM 293) to the vicinity of the estuary (Blakes RKM 13) (Figure 10), with a coastal cooling effect from Weitchpec to the estuary during the summer (Figure 11). Dams on the mainstem Klamath River heavily influence river temperature, specifically delaying the onset of seasonal autumn cooling (Bartholow et al. 2005) and thereby affecting spawning temperatures (Figure 10). Estuarine water temperatures are presented in Figure 12. The salt wedge was already established at the time of thermister deployment in late July.

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 or differentiation with one or multiple destinations. Thus the term 'run-timing' denotes the timing of migration of a 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). 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 2006, only three runs were tagged and identified: spring Chinook, Klamath fall Chinook, and Trinity fall Chinook. Based on harvest data (Figure 13), a summer run still occurred in 2006 (i.e. Julian week 32, starting 8/6/2006) but no tagged migrants were classified as summer run. Given on the timing of tagging, only two potential summer run Chinook were tagged (7/19/2006 and 8/1/2006) but neither migrated above the estuary, in contrast

to all other study years. 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 14). It is unclear whether the summer run are just a random late run component of Trinity River spring Chinook salmon or if they are a genetically distinct group.

Chinook salmon tagged from 6/8/2006 to 7/6/2006 initiated upriver migration from 6/19/2006 to 7/19/2006 exhibiting a unique combination of migration behaviors consistent with spring run Chinook. The exceptionally late and high spring flows in 2006 could have contributed to a later run-timing for spring Chinook in 2006 as compared to other study years. All spring Chinook migrants initiated migration during the receding limb of the snowmelt peak and were tagged prior to river temperatures exceeding 22ºC for the first time for the year.

Klamath fall Chinook were tagged from 8/15/2006 to 9/26/2006, and initiated upriver migration from the estuary from 8/26/2006 to 10/1/2006. This peak of upriver migration initiation matched the timing of recoveries of CWTs from IGH fall Chinook harvested in the lower Klamath River during the 2006 sport fishing season (Figure 20), although more Klamath fall Chinook migrants initiated upriver migration earlier and later in the migration season as compared to CWT recoveries. Klamath fall Chinook migrant run-timing in 2006 was consistent with 2003 and 2004, and slightly earlier than 2005; but all study years have been comparable with the average for IGH fall Chinook salmon based on CWT recoveries from 1988 to 1999 (Figure 14), which usually peaks during late August to early September.

Trinity fall Chinook were tagged from 8/23/2006 to 10/6/2006 and initiation of upriver migration occurred from 9/4/2006 to 10/8/2006 (one fish on 10/21/2006). In 2006, the timing of initiation of upriver migration for Trinity fall Chinook migrants displayed a bi-modal peak (Figure 13), which is typically the case with CWT recoveries for TRH fall Chinook salmon (Figure 14). This was not the case with CWT recoveries for TRH fall Chinook salmon in the sport creel (Figure 13), which could have been due to low numbers of CWT recoveries from adult Chinook salmon in 2006 as a result of fishing restrictions.

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). I consider 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.

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 14). 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 salmon with a known approximate destination). Migration rates ranged from zero during periods of holding up to 91.8 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).

Another important aspect of upriver migration in fish, and locomotion in animals in general, is the timing of movement in relation to the diel day-night cycle. The first detection of a migrant at a fixed site station was assumed to represent active migration since upriver movement is required to move within detection range. Arrival timing of all Chinook migrants at all fixed site stations is compared to date of arrival in Figure 15a. Visual inspection of this scatter plot revealed that migration movement occurred during both day and night with a possible preference for movement during dusk and dawn. The only notable exception was a predominance of movement during the daylight hours for spring Chinook, especially during the month of June. Arrival timing was also compared to fish location (RKM) to determine if movement timing changed as a function of location with the river basin (Figure 15b). Visual inspection revealed no distinct patterns with movement at almost all stations occurring during both day and night hours, with the exception of the estuary stations and stations at or near hatcheries, which showed a predominance of movement during daylight hours. The diel timing of migration among adult salmonids varies by location and circumstance, which seems to represent trade-offs between the need for light to see and avoid obstacles and the need for cover to avoid visual-based predators (Banks 1969). For example, the daylight preference for movement exhibited by spring Chinook in 2006 is likely explained by the relatively high turbidity at that time of year that provided visual cover from predators. By comparison, fall Chinook salmon migrating during base flow conditions had very little turbidity cover consequently increasing the importance of cover in the form of low light levels. Further

analysis of the diel timing of movement among tagged Chinook migrants in the KRB would likely reveal further clues as to the specific causal variables involved.

No easily discernable universal movement patterns emerged when all tagged Chinook salmon that migrated above the estuary were viewed in total (Figure 16). However, when separated into groups by run-timing and destinations, consistent movement patterns did emerge as a function of river kilometer or reach. Migrant groups displayed consistent and distinct patterns in their rates of travel and timing of movement along their migration path. Movement patterns for all migrant groups exhibited generally consistent inflection points at notable landmarks in their migration paths where changes in conditions prompted changes in behavior. Starting at the mouth of the Klamath River and proceeding upriver to IGD the landmarks that demarcated behavioral reaches were Wakel (head of estuary), Blue Creek (major thermal refuge), Moore's Rock (deepest pool in Klamath River), Weitchpec (Klamath/Trinity River confluence), Ishi Pishi Falls (highest gradient in Klamath migration path), and the Shasta River confluence (start of primary spawning area). Proceeding up the Trinity River, landmarks were Weitchpec, Willow Creek Weir (if installed and only for some fish), Burnt Ranch Gorge (highest gradient in Trinity migration path), and the North Fork Trinity confluence (start of primary pre-spawn holding and spawning area). Which landmarks influenced Chinook salmon migration behavior and the nature of that influence depended on the run-timing/stock origin of the particular migrant. This fact emphasizes the context sensitivity of adult Chinook migration salmon behavior.

Specifically, spring Chinook migrants (as defined by run-timing and migration behavior) exhibited similar movement patterns characterized by relatively rapid and steady migration. Location via river kilometer versus date for the spring Chinook migrant group (n=6) is presented with applicable landmarks and compared to river temperature and flow in Figure 17. Essentially the migration strategy of this group is to: 1) enter the estuary during the spring before the onset of temperatures in excess of the upper thermal limit to migration; 2) steadily and relatively rapidly migrate upriver during the receding limb of the snowmelt component of the hydrograph to pre-spawn holding pools in the cool-water reach starting at the North Fork Trinity confluence (RKM 187) near Junction City or in the Salmon River; and 3) use thermal refuges (e.g. Blue Creek) if

caught en route by rising temperatures ≥21ºC. One exception to the steady and relatively rapid upriver movement of spring Chinook migrant was the slow movement of Chinook 151.500 in the lower Klamath River, which was likely caused by extended thermal refuge use during excessively high water temperatures in July and August. This cannot be confirmed with certainty since no archival tag was recovered for this fish.

Chronologically the next group of migrants after spring Chinook were Klamath fall Chinook, which displayed a distinctly unique movement pattern. Location via river kilometer versus date for the Klamath fall Chinook migrant group (*n*=6) is presented with applicable landmarks and compared to river temperature and flow in Figure 18. Klamath fall Chinook migrated as an especially cohesive group with 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 from Blue Creek to Weitchpec. Travel rates increased markedly above Weitchpec with rapid and steady migration to spawning grounds in the IGD area. The general migration strategy of this group is: 1) estuary/nearshore entry and residence followed by initiation of upriver migration early in the fall migration season in conjunction with the cessation of water temperatures ≥22ºC; 2) rapid travel to holding areas in the lower Klamath River from Blue Creek to Weitchpec; followed by, 3) resumption of rapid and steady upriver migration to spawning grounds in response to physiological and possibly environmental cues. The migration strategy described above held true for all Klamath fall Chinook migrants although the specific locations (i.e. RKM 26 to 71) and dates (i.e. 8/28/2006 to 10/28/2006) of holding and slow movement in the lower Klamath River varied.

The reasons for the slow movement and extended holding observed in the lower Klamath River, which has been observed in all previous study years for this group, are not yet known with certainty but several potential causative factors can be eliminated. First, the possibility of a thermal block can be eliminated. Even though water temperatures are typically warm during the beginning of this holding period, they have always been below the thermal threshold for migration inhibition (i.e. 23.5 to 21.0ºC) and have been relatively cold (i.e. 13-16ºC) during the end of this period. Furthermore, no thermal refuge use has been observed or documented among any tagged fall Chinook salmon that displayed slow movement and extensive holding in the lower Klamath River.

Second, physical impedance by relatively low or high summer/fall flow can be eliminated. The slow movement and extensive holding displayed by tagged Klamath fall Chinook in the lower Klamath River has occurred at a wide range of flows (i.e. 71 to 128 cms at RKM 13), during stable flows, and during, after, and in the absence of a fall pulse flow from Lewiston Dam. If low flow impeded migration, distinct delays or slowed movement would be expected to occur at the shallowest riffles in the lower Klamath River. Receivers placed at the top and bottom of one such riffle immediately below the mouth of Pecwan Creek allowed a test of this hypothesis. Results showed no consistent relationship between flow and passage rate of tagged Chinook at the Pecwan riffle in 2006 (Figure 19) with most fish moving past the Pecwan riffle at a faster rate (median 30.2 km/d) than they did from the estuary to the Pecwan riffle (median 4.4 km/d, Table 3; Figure 20). Flows in the lower Klamath River (at RKM 13) when tagged Chinook salmon passed the Pecwan Riffle in 2006 were rising, falling, and stable and ranged from 83 to 99 cms (Table 3). In comparison, mean monthly flow during September of previous study years was 56 cms in 2002, 96 in 2003, 85 in 2004, 88 in 2005, and 86 in 2006 (Figure 5). Since summer/fall flows were substantially higher in all study years as compared to 2002, the possibility of flow induced impedance to migration during the exceptionally low flows of 2002 cannot be eliminated. However, the slow movement and extensive holding observed by fall Chinook salmon in the lower Klamath River during study years was not caused by low flow impedance. Finally, if the cue(s) that trigger resumed upriver migration were strictly environmental then the locations and/or dates of holding in the lower Klamath River would be expected to be consistent for all Klamath fall Chinook migrants in a given year. This is not the case however, which indicates that a physiological cue is involved such as the level of gonadal maturity and body energy content.

In 2003 and 2004, multiple Klamath fall Chinook migrants initiated upriver migration immediately upon cessation of water temperatures ≥22ºC. In contrast, no Klamath fall Chinook migrants initiated upriver migration during 2005 until several days after water temperatures cooled below 22ºC and generally exhibited a slightly later run-timing compared to other study years (Figure 21). Some degree of variation in migration timing is expected, but one possible explanation for the later run-timing in 2005 was the

exceptionally poor ocean feeding conditions during the spring and early summer. Significant upwelling usually occurs by early spring (Schwing at al. 1996) but was delayed until mid-July to mid-August in 2005 along Oregon, Washington, and northern California (Hickey et al. 2005; PFEL 2006). During 2006, upwelling was not substantially delayed and run-timing of adult fall Chinook salmon was consistent with the 2003 and 2004 study years, which supports the hypothesis of delayed entry in 2005 due to poor ocean feeding conditions. There are two primary limits placed on extending ocean residence for the purpose of feeding prior to migration: 1) initiation of upriver migration in freshwater must occur in time to allow for arrival on the spawning grounds within the spawning window; and, 2) advanced gonadal maturation needs to occur in freshwater (Wertheimer 1984). Thus adult Chinook salmon face tradeoffs between maximizing body energy content and the need to begin freshwater migration with the appropriate window of environmental and physiological opportunity.

During the fall of 2003 and 2004 a pulse of water was released from Lewiston Dam (Figure 5) with the goal of avoiding another epizootic fish kill such as occurred in September of 2002. Scientists and river managers convened by the USBR's Trinity River Restoration Program hypothesized these pulse flows would stimulate adult Chinook salmon to migrate upriver out of the lower Klamath River below Weitchpec, thereby reducing fish densities and the risk of disease transmission and mortality. Based on telemetry data from tagged Chinook salmon in 2003 and 2004, upriver movement was not triggered except for the few Chinook salmon that were already holding in en route thermal refuges (e.g. Blue Creek). This conclusion is further supported by results from 2005 and 2006, years with no fall pulse flows aside from brief and relatively minor ceremonial flows.

Klamath fall Chinook migrants in 2005 and 2006 displayed equivalent movement patterns as Klamath fall Chinook migrants in the pulse flow years; both before, during, and after the pulse flows. This relationship was especially apparent for Klamath fall Chinook (Figure 21) but also held true for Trinity fall Chinook (Figure 22). Since the migration timing of Klamath fall Chinook migrants was slightly later in 2005 than in 2003 or 2004, the argument could be made that the fall pulse flows induced this group of Chinook salmon to enter the river early. Besides the extremely late nearshore upwelling

of 2005 (Hickey et al. 2005; PFEL 2006), this argument is refuted by the fact that the run-timing of Klamath fall Chinook in 2006 matched that of 2003 and 2004 and was within the normative range (Figure 14). Simply stated, consistent movement patterns with and without pulse flows over multiple years is compelling evidence that these flows do not trigger upriver movement or substantially alter migration behavior among adult Chinook salmon. The Klamath boat dance flow also did not noticeably affect adult Chinook salmon migration behavior as both holding and rapid movement was exhibited by fall Chinook migrants during this brief pulse flow (Figures 18 and 23). The majority of fall Chinook migrants initiated migration after the cessation of this three-day pulse flow, which did not reach the lower Klamath River (at RKM 13) until 9/10/2006 (Figure 2). Understanding why there was virtually no response to any of the fall pulse flows among fall Chinook salmon requires remembering the evolutionary axiom of adaptation to long term average conditions (Gilhousen 1990; Quinn et al. 1997; Hodgson and Quinn 2002). The fall pulse flows were unprecedented in their magnitude and duration for that time of year and thus well outside the range of long term average conditions to which KRB adult Chinook salmon have adapted. The only natural equivalents are ephemeral and inconsistent flash floods in mountainous tributaries.

In the absence of dispersal of adult Chinook salmon in reaction to a pulse flow, higher flows (pulsed or base flows) can still substantially reduce the risk of pathogen transmission and disease mortality by increasing river flow volume and secondarily by reducing water temperatures (thermal effects are location and release specific). Most importantly for ciliated protozoan such as *Ich*, higher flows increase turnover rates and water velocities, which serve to flush out pathogens and decrease fish-to-fish horizontal pathogen transmission. Using a controlled fish culture environment and channel catfish (*Ictalurus punctatus*) as the laboratory animal, Bodensteiner et al. (2000) evaluated fundamental dynamics controlling *Ich* infections and concluded that increasing turnover rates and water velocities are the most effective measure to prevent and stop *Ich*. Furthermore, Bodensteiner et al. (2000) found that fish density did not affect *Ich* infection or mortality rates, which suggests that fish density has an on-or-off threshold relationship (e.g. necessary condition) and not a linear relationship with *Ich*. Thus once the fish density threshold is crossed for a given setting, flow via turnover rates and water

velocities are the primary determinants of *Ich* infection and mortality rates (e.g. controlling factors). Given that fall Chinook primarily hold and travel slowly through the lower Klamath River as part of their apparent normative migration behavior strategy, they are especially vulnerable to *Ich* infection and mortality with pathogen transmission risk increasing as flows decrease. These relationships are consistent with the combination of large run size and low flows that occurred before and during the September 2002 fish kill as compared to the absence of epizootic outbreaks in years with larger runs but higher flows (Guillen 2003; Belchik et al. 2004; Turek et al. 2004). However, these relationships are not field testable in a controlled experimental manner, thus it is incumbent on river mangers to take risk averse actions in the face of uncertainty about the turnover rate, water velocity, and fish density thresholds for the lower Klamath River; for which there is only one affirmative data point – 2002.

The final migrant group tagged in 2006 was Trinity fall Chinook, which were interspersed with Klamath fall Chinook migrants and demonstrated subtly but importantly different movement patterns with a greater amount of variability. Location via river kilometer versus date for the Trinity fall Chinook migrant group (n=18) is presented with applicable landmarks and compared to river temperature and flow in Figure 23. 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 presented an obstacle for Trinity fall Chinook migrants but travel times through the Gorge were faster than for true spring Chinook migrants observed in other study years.

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 were substantially delayed by the Willow Creek weir, with transit time from the station below the weir (RKM 104.0) to the station above the Willow Creek weir (RKM 105.5) ranging from 3.5 to 31.1 days. In contrast during 2006, transit times ranged from 0.1 to 10.4 days with six of 13 migrants experiencing essentially no delay (i.e. <12 hrs) (Table 4). Delays experienced at the

Willow Creek weir and the ratio of that delay to the travel time from the estuary to the vicinity of the Willow Creek weir are reported for each fish in Table 3 for 2005 and 2006. Only one of the 13 tagged Chinook salmon that passed the Willow Creek weir in 2006 could have been trapped and counted; the rest passed during its daily (31%) or weekend (61%) openings. This was similar to 2005 and shows that adult Chinook salmon take advantage of the openings, which serve to reduce delays but not sufficiently so in 2005. While some delay still occurred in 2006, 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. The exact mechanisms that lead to delay at the Willow Creek weir are unclear, but fish that delayed the longest (i.e. Chinook 37, 44, 112, 131) apparently first arrived at the weir location when it was closed suggesting that first impressions may have an influence on subsequent passage behavior. Chinook migrants passing the Willow Creek weir that were in the highest quartile of travel time from the estuary to RKM 104 (mean = 45.7 d) had the quickest passage times at the Willow Creek weir (mean = 0.25 d). This indicates slower migrants were more motivated to pass the Willow Creek weir quickly. There did not appear to be any relationship between tag date and passage times at the Willow Creek weir.

Thermal Experience

Data from six archival temperature tags were successfully recovered allowing determination of the thermal experience during migration for these tagged Chinook salmon. 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. Archival temperature tags were attached to each sonic transmitter and measured internal body temperature every hour. All available archival data is graphed in Figures 24 to 29 arranged in order of tagging date.

All six archival tags were recovered from adult Chinook salmon classified as migrants (6 of 30 migrants or 20%), including at least one per migrant group. Summary statistics are reported for a migrant from each migrant group in Table 5 for the lower Klamath River and for their entire migration to spawning grounds.

Estuary and Nearshore Ocean Residence and Behavior

Combined with the network of three sonic receivers in the estuary and nearshore ocean, archival temperature data allowed for a determination of adult Chinook salmon behavior during residence in the estuary and/or nearshore ocean. 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 result occurred in 2006. Not all fish displayed this highly variable pattern of thermal experience during ocean and estuarine residence. For example Chinook 43 displayed a distinct thermal experience while residing in the ocean characterized by body temperatures with a stable minimum of approximately 9.5ºC (Figure 30). The pattern in thermal experience displayed by Chinook 43 suggests two important conclusions. First, this fish must have swum further off-shore to colder, deeper waters since water temperatures as low as 9.5ºC do not generally occur in the shallow nearshore. Second, the consistency of body temperatures during this period could have only been achieved via behavioral selection and is indicative of continued feeding. This stable pattern of selection of water temperatures of approximately 9ºC has been repeatedly observed in immature adult Pacific salmon feeding in the open ocean (personal communication, Kate Myers, High Seas Salmon Research Program; Hinke et al. 2005) but also among pre-spawn holding sockeye salmon in a stratified lake (Newell and Quinn 2005).

Residence times in the estuary and/or nearshore ocean are reported for all tagged Chinook salmon that migrated above the estuary (n=37) in Table 6. Definitive data to determine the proportion of time spent in the estuary versus the ocean after tagging was

available for 32 of these 37 Chinook salmon. Residence times in the estuary were brief (e.g. mean of 0.47 d, max of 1.52 d). Fourteen (45%) Chinook salmon fell back to the ocean after tagging with an average ocean residence of 8.47 d. Of these 14 Chinook salmon, 95% of their time after tagging and prior to arrival at RKM 7 was spent in the ocean on average.

In sum, the behavior exhibited by tagged Chinook salmon in both 2005 and 2006 showed minimal residency and use of the estuary with a minor but 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 salmon 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, while still successfully arriving 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 17.2 d (Chinook 35) were observed in 2006 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 and 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 121, 91.8

km/d for a distance of 6.5 km, equal to 3.8 km/hr, 1.1 m/sec or 1.5 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 which 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 salmon 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 salmon 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 continued feeding opportunities. This logic is borne out in the average amount of time spent in the estuary (0.47 d) versus the nearshore ocean (8.5 d) for tagged Chinook salmon in 2006. 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. During the 2006 season, no tagged Chinook salmon were documented behaviorally thermoregulating to any substantial extent while en route. Based on migration behavior and river temperatures, Chinook 151.500 likely used en route thermal refuge(s) in the lower Klamath River, but validation is not possible since the archival tag was not recovered. Use of en route thermal refuges has been documented in previous study years and is a behavior analogous to a quick break to rest and recover 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 salmon migrants have been observed using en route thermal refuges during all study years, including during extended holding in the lower Klamath River in the vicinity of cool tributary confluences (e.g. Blue Creek). 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. As previously

discussed, fall Chinook salmon 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 salmon migration in the KRB was inhibited when mean daily water temperatures ≥22ºC, at which point adult Chinook salmon 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 salmon 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. During 2006, temperature dynamics in relation to when Chinook salmon were tagged and migrating did not create a situation wherein mean daily water temperatures were above 22 to 23.5ºC. Results from 2006 did not serve to refute previous conclusions regarding the threshold for migration inhibition, nor did it provide much supporting evidence. Thus in the absence of evidence to the contrary, it can be concluded that the thermal threshold for migration inhibition for KRB adult Chinook salmon occurs at mean daily water temperatures above 23.5ºC during periods of falling water temperatures, 21.0ºC during rising water temperatures, and 22.0ºC during stable water temperatures.

3.4 Summary of Major Conclusions

- Four distinct major runs of adult Chinook salmon occur in the KRB: spring Chinook, summer Chinook, Klamath fall Chinook, and Trinity fall Chinook.
- Pinniped predation, in particular by California sea lions, was the single biggest known factor resulting in loss of adult Chinook salmon after tagging and before commencement of upriver migration out of the estuary. Pinniped predation also

appears to be a major driver of adult Chinook salmon behavior in the estuary contributing to minimal estuarine residence. However, it is important to remember that these species coevolved before reaching conclusions regarding the seriousness of pinniped predation or negative indirect consequences thereof.

- Residing in the ocean until riverine conditions are acceptable or an individual fish is physiologically ready to commence upriver migration is a fundamental behavior that serves to reduce the probability of predation and also provides continued feeding opportunities and the lowest available water temperatures.
- Fall pulse flows exert minimal influence over adult Chinook salmon migration behavior in the KRB and have not stimulated upriver movement by tagged Chinook migrants with the exception of fish already residing in en route thermal refuges.
- The slow movement and extended holding observed during all study years among fall Chinook migrants in the lower Klamath River appears to be part of their normative migration strategy and was not caused by physical blockages of water temperature or flow. This behavior increases the vulnerability of fall Chinook salmon to disease pathogen infection and mortality, especially for the ciliated protozoan *Ich*. This vulnerability can be reduced by higher minimum flows because increasing flows results in higher turnover rates and water velocities, which have been shown to be the most effective measure for preventing and stopping *Ich* outbreaks (Bodensteiner et al. 2000).
- The thermal threshold for migration inhibition for KRB adult Chinook salmon occurs at mean daily water temperatures above 23.5ºC during periods of falling water temperatures, 21.0ºC during rising water temperatures, and 22.0ºC during stable water temperatures.
- Use of en route thermal refuges occurs for a minor but important portion of the spring and summer Chinook runs with negligible use by fall Chinook salmon.
- Migration delays of tagged Chinook salmon at the Willow Creek weir were substantially reduced in 2006 as compared to 2005, likely due to the greatly increased removal of conduit rods in 2006 during weekend openings.
- Critically important migration behaviors used by all major runs of adult Chinook salmon in the KRB include: staging in the nearshore ocean, quick reaction to

changing river conditions, reach and river condition specific adjustment of travel rates, and use of en route thermal refuges only when acutely needed.

3.5 Summary of Major Recommendations

- Ensure adequate flows during the fall Chinook salmon migration season in the lower Klamath River starting in late August in order to provide turnover rates and water velocities sufficiently high enough to significantly reduce the probability of *Ich* infection and mortality. Water managers should take a disease risk averse approach to setting river flows in the face of uncertainty in the exact fish density threshold in the lower Klamath River necessary for an *Ich* outbreak and the turnover rates and water velocities that would prevent an outbreak once this threshold is exceeded.
- Emphasize a management strategy of using flow to manipulate disease pathogen behavior and ensure the ecological health and integrity of the mainstem Klamath and Trinity Rivers, while any proposed strategy of attempting to manipulate adult Chinook salmon behavior with flow should be discontinued.
- Improve upon the timing and rates of flow ramping events to more closely mimic natural hydrographs in order to provide ecologically accurate migration cues.
- Determine the degree of genetic segregation of spring and fall Chinook salmon in the Trinity River, the genetic origins of summer run Chinook salmon, and implications and management options arising thereof.
- Continue to improve operational protocols at the Willow Creek weir to further reduce migration delays.
- Protect thermal refuges and their tributary watersheds from excessive land-use disturbances to ensure continued high value water quality, quantity, and morphology.
- Protect fish using thermal refuges from harassment and fishing pressure.
- Continue adult Chinook salmon telemetry research to obtain data for all water year types and to provide behavior data in the event of an unforeseen mortality event. Continue using sonic transmitters as the featured tags and the mouth of the Klamath River as the tagging location.

4.0 TABLES AND FIGURES

Table 1. Sonic listening station locations for the 2006 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	nearshore ocean	-0.50	Ocean	sonic
2	Estuary 1 - Lips	0.00	Klamath	sonic
3	Estuary 2 - Requa	1.00	Klamath	sonic
4	Wakel	7.25	Klamath	sonic
5	Blakes	13.00	Klamath	radio
6	Blue Creek	26.00	Klamath	both
7	lower Pecwan Riffle	39.50	Klamath	sonic
8	upper Pecwan Riffle	40.00	Klamath	sonic
9	Moore's Rock	43.00	Klamath	both
10	Coon Creek Falls	57.50	Klamath	sonic
11	Weitchpec Klamath	71.00	Klamath	both
12	Weitchpec Trinity	71.00	Trinity	both
13	Hoopa gauge	90.00	Trinity	sonic
14	Riverdale screw trap	104.00	Trinity	sonic
15	Willow Creek weir north	105.00	Trinity	sonic
16	Willow Creek weir south	105.00	Trinity	sonic
17	Ogorman's	105.50	Trinity	sonic
18	Hawkin's Bar	133.00	Trinity	both
19	China Slide	147.00	Trinity	both
20	Junction City	190.25	Trinity	both
21	Steiner Flat	215.00	Trinity	sonic
22	Bucktail	242.00	Trinity	sonic
23	Trinity River Hatchery	252.50	Trinity	both
24	Salmon River at Oak Flat	108.00	Salmon	both
25	Big Bar	82.00	Klamath	sonic

26	Dolan's Bar	97.50	Klamath	sonic
27	Green Riffle	114.00	Klamath	sonic
28	Happy Camp	176.50	Klamath	sonic
29	Blue Heron	233.25	Klamath	sonic
30	Hornbrook	293.00	Klamath	sonic
31	Bogus Creek Weir	309.50	Bogus	sonic
32	Iron Gate Hatchery	310.00	Klamath	sonic

Table 2. Tagging and fate summary for all 30 adult Chinook salmon migrants in 2006. All Chinook salmon were tagged at the mouth of the Klamath River. FL = fork length. iB data = archival body temperature data. TRH = Trinity River Hatchery. IGH = Iron Gate Hatchery.

Date	Tag Code	Jaw Tag #	Sex	FL (cm)	Fate or Last Observation	iB Data	Ad Clip
6/8/2006	**151.740**	101		92	above Junction City 7/23		N
6/14/2006	**151.480**	103		81	Bucktail 7/26		Y
6/20/2006	**151.320**	104		70	above Junction City 7/24		N
6/26/2006	**151.500**	106		75	caught Weitchpec 8/7		N
7/6/2006	**151.360**	108		79	caught in Weitchpec Gorge on 7/14	y	N
7/6/2006	**151.340**	109	female	86	moribund near Pigeon Point on 8/18		N
8/15/2006	**41**	115		91	hornbrook 10/3		N
8/23/2006	**43**	116	female	79	TRH 11/8	y	N
8/23/2006	**54**	117		79	Weitchpec Trinity 9/11		N
9/1/2006	**48**	119	male	80	IGH spawned 10/23	y	N
9/1/2006	**37**	121		89	china 10/9		N
9/5/2006	**49**	123		92	bucktail 10/31		N
9/6/2006	**33**	126		80	bucktail 10/28		N
9/6/2006	**35**	128		87	bucktail 11/6		N
9/6/2006	**40**	131		82	ogorman’s 11/3		N
9/7/2006	**44**	135		78	TRH 11/10		N
9/7/2006	**53**	136		80	Weitchpec 9/19		N
9/12/2006	**92**	137		72	ogoramn's 11/3		N
9/12/2006	**103**	138		73	hornbrook 10/10 to 10/26		N
9/12/2006	**106**	160		79	hornbrook 10/19		N
9/15/2006	**94**	151		79	caught below hoopa on 9/23	y	N
9/20/2006	**96**	150		75	orgorman’s 11/4		N
9/20/2006	**107**	145		71	big bar 10/18		N
9/20/2006	**112**	144		79	TRH 11/4 to 11/14		N
9/23/2006	**123**	167	female	78	spawned TRH 11/14	y	N
9/26/2006	**127**	168		81	Weithcpec Trinity 10/24 MIA		N
9/26/2006	**121**	170		70	Hawkins bar 11/2		N
9/26/2006	**132**	171		81	big bar 10/29		N
10/6/2006	**131**	161	female	79	spawned at TRH 11/27	y	N
10/6/2006	**129**	189		83	hoopa 11/6		?

Table 3. Summary of passage timing and migration rates at the Pecwan Riffle with transit time to the Pecwan Riffle shown for comparison along with mean daily flow at RKM 13 and mean daily water temperature at RKM 39.5. A larger ratio of transit1:transit2 equals slower passage at Pecwan Riffle in comparison to previous migration rate. A stable trend in flow was defined as less than 5 cms variation.

Fish ID	Group	Transit1 to Pecwan Riffle (RKM 7 to 39.5)		lower Pecwan RKM 39.5	upper Pecwan RKM 40.0	Transit2 at Pecwan Riffle (RKM 39.5 to 40)		Ratio Transit1/ Transit2	Flow		Mean Daily Temp.
		days	km/d	date & time	date & time	days	km/d		cms	trend	ºC
41	Kfall	9.827	**3.3**	9/5/2006 8:09	9/5/2006 19:07	0.457	**1.1**	**3.0**	85	stable	20.2
48	Kfall	9.712	**3.3**	9/11/2006 11:45	9/11/2006 18:01	0.261	**1.9**	**1.8**	99	rising	20.1
54	Tfall	1.807	**18.0**	9/6/2006 1:40	9/6/2006 20:26	0.782	**0.6**	**28.1**	84	stable	20.5
43	Tfall	13.111	**2.5**	9/18/2006 9:57	9/18/2006 10:10	0.009	**58.3**	**0.0**	87	stable	17.8
44	Tfall	23.452	**1.4**	10/1/2006 18:04	10/1/2006 18:15	0.008	**63.9**	**0.0**	82	stable	16.3
37	Tfall	2.636	**12.3**	9/11/2006 3:56	9/11/2006 4:05	0.006	**77.1**	**0.2**	99	rising	20.1
38	Lkfall	22.276	**1.5**	9/30/2006 19:26	9/30/2006 19:59	0.023	**21.9**	**0.1**	83	stable	16.4
49	Tfall	16.214	**2.0**	9/24/2006 21:58	9/24/2006 22:13	0.010	**48.6**	**0.0**	86	stable	17.0
40	Tfall	1.594	**20.4**	9/12/2006 6:16	9/12/2006 6:33	0.012	**42.8**	**0.5**	94	falling	20.4
53	Tfall	2.955	**11.0**	9/14/2006 5:41	9/14/2006 6:04	0.016	**30.5**	**0.4**	84	falling	20.0
106	Kfall	5.570	**5.8**	9/18/2006 8:25	9/29/2006 3:46	10.806	**0.05**	**126.1**	84	stable	16.5
103	Kfall	9.984	**3.3**	9/23/2006 6:42	9/23/2006 7:06	0.017	**30.1**	**0.1**	87	stable	17.5
92	Tfall	5.404	**6.0**	9/19/2006 5:32	9/19/2006 5:52	0.014	**37.0**	**0.2**	86	stable	17.7
33	Tfall	3.233	**10.1**	9/17/2006 5:16	9/17/2006 5:29	0.009	**58.5**	**0.2**	88	stable	17.9
94	Tfall	2.025	**16.1**	9/18/2006 5:06	9/18/2006 5:15	0.007	**76.5**	**0.2**	87	stable	17.8
99	Lkfall	15.957	**2.0**	10/3/2006 1:37	10/3/2006 6:48	0.216	**2.3**	**0.9**	91	rising	16.0
112	Tfall	19.723	**1.6**	10/10/2006 16:33	10/11/2006 0:21	0.325	**1.5**	**1.1**	96	stable	14.7
96	Tfall	16.991	**1.9**	10/9/2006 6:59	10/9/2006 7:21	0.015	**32.9**	**0.1**	97	stable	15.3
107	Kfall	18.998	**1.7**	10/11/2006 8:06	10/11/2006 8:27	0.014	**35.0**	**0.0**	95	stable	14.7
123	Tfall	5.112	**6.4**	9/28/2006 16:40	9/28/2006 16:54	0.009	**54.2**	**0.1**	84	stable	16.6
35	Tfall	10.924	**3.0**	10/4/2006 19:06	10/6/2006 1:16	1.256	**0.4**	**7.5**	94	rising	15.7
132	Tfall	4.477	**7.3**	10/6/2006 2:54	10/6/2006 3:18	0.016	**30.3**	**0.2**	97	rising	16.0
121	Tfall	3.281	**9.9**	10/6/2006 19:24	10/6/2006 20:30	0.046	**10.9**	**0.9**	97	rising	16.0
125	Tfall	6.054	**5.4**	10/11/2006 8:47	10/11/2006 18:46	0.416	**1.2**	**4.5**	95	stable	14.7
131	Kfall	5.264	**6.2**	10/12/2006 13:29	10/12/2006 14:13	0.030	**16.5**	**0.4**	95	stable	14.5
127	Tfall	11.351	**2.9**	10/19/2006 18:37	10/20/2006 7:10	0.523	**1.0**	**3.0**	97	falling	14.2
median			**4.4**				**30.2**	**0.3**			

Table 4. Summary of delays at the Willow Creek weir (RKM 105) for all relevant Trinity Chinook migrants in 2005 and 2006. Delay is defined as the travel time from the sonic station below the Willow Creek weir (at RKM 104) to the sonic station above the Willow Creek weir (at RKM 105.5). Ratio is defined as and the ratio of that delay to the travel time from the estuary terminus (RKM 7) to the site of the lower Willow Creek weir station (RKM 104); i.e. delay at weir/travel time to weir. The Willow Creek weir was operational from 8/21/2006 to 11/12/2006. While in operation the weir was fished (closed) from Sunday night to Friday afternoon (1300), with the exception of daily openings from 1300 to half an hour after sunset. During openings in 2005 the two trap boxes were left open along with the boat passage gate. In 2006, an additional step was taken during openings on weekdays to pull up 10 of 45 conduit rods on every other panel and 25 of 45 conduit rods from every other panel on weekends.

Fish ID	Year	Tag Date	Delay (d)	Ratio	Weir Status
140	2005	10-Aug	31.1	1.08	open-weekend
147	2005	11-Aug	10.4	0.95	open-daily
102	2005	29-Aug	6.1	0.16	trapped
117	2005	1-Sep	9.9	0.48	open-weekend
47	2005	7-Sep	3.5	0.19	open-weekend
52	2005	8-Sep	13.9	0.47	open-weekend
43	2006	23-Aug	0.2	0.01	trapped?
37	2006	1-Sep	3.1	0.27	open-weekend
49	2006	5-Sep	0.6	0.02	open-weekend
33	2006	6-Sep	0.1	0.01	open-daily
35	2006	6-Sep	0.8	0.03	open-weekend
40	2006	6-Sep	0.2	0.00	open-weekend
44	2006	7-Sep	2.5	0.09	open-weekend
92	2006	12-Sep	0.1	0.00	open-daily
112	2006	20-Sep	4.3	0.16	open-weekend
96	2006	20-Sep	0.1	0.00	open-weekend
123	2006	23-Sep	0.1	0.01	open-weekend
121	2006	26-Sep	5.6	0.25	open-daily
131	2006	6-Oct	10.4	0.62	open-daily

Table 5. The thermal experience as determined by archival body temperature records for three tagged Chinook salmon from each migrant group tagged in 2006. The summary statistics reported include estuary and/or nearshore residence but excluded pre-spawn holding in the vicinity of spawning grounds.

	Thermal Experience ºC		
Group	Spring	K Fall	T Fall
Fish ID	151.360	48	123
	Tagging to RKM 71		
Mean	20.6	20.0	17.3
Max	22.4	22.1	18.8
Min	17.0	16.8	16.0
Std. Dev	0.9	1.3	0.6
	Tagging to spawning area		
Mean	na	18.8	13.1
Max	na	22.1	18.8
Min	na	15.7	7.6
Std. Dev	na	1.7	3.2

Table 6. Estuary and nearshore ocean residence times (d) for all 37 Chinook that migrated above the estuary in 2006, 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. The mean ocean residence and % of time in estuary excludes Chinook migrants that did not go to the ocean after tagging (55%). Lkfall = fall migrants of unknown destination.

Fish ID	Tagging Date	Estuary (d)	Ocean (d)	Total (d)	% in Est.	Group
151.740	8-Jun			5.03		spring
151.480	14-Jun			4.96		spring
151.320	20-Jun			14.23		spring
151.280	26-Jun			6.30		spring
151.500	26-Jun			17.80		spring
151.340	6-Jul			8.77		spring
151.360	6-Jul	0.17	0	0.17		spring
mean				**8.18**		
41	16-Aug	0.45	8.17	8.63	5.2%	Kfall
48	1-Sep	0.41	0	0.41		Kfall
106	12-Sep	0.43	0	0.43		Kfall
103	12-Sep	0.90	0	0.90		Kfall
107	20-Sep	0.70	0	0.70		Kfall
132	26-Sep	0.10	5.18	5.28	1.9%	Kfall
mean		**0.50**	**6.68**	**2.73**	**3.6%**	
43	23-Aug	0.29	12.25	12.54	2.3%	Tfall
54	23-Aug	0.18	11.23	11.41	1.6%	Tfall
37	1-Sep	0.44	6.65	7.09	6.2%	Tfall
49	5-Sep	0.65	0	0.65		Tfall
33	6-Sep	0.22	7.23	7.45	3.0%	Tfall
35	6-Sep	0.55	16.67	17.23	3.2%	Tfall
40	6-Sep	0.31	3.68	3.99	7.8%	Tfall
44	7-Sep	0.98	0	0.98		Tfall
53	7-Sep	0.75	3.17	3.92	19.1%	Tfall
92	12-Sep	1.52	0	1.52		Tfall
94	15-Sep	0.31	0	0.31		Tfall
96	20-Sep	0.90	0	0.90		Tfall
112	20-Sep	0.27	0	0.27		Tfall
123	23-Sep	0.22	0	0.22		Tfall
127	26-Sep	0.10	12.02	12.11	0.8%	Tfall
121	26-Sep	0.08	7.10	7.18	1.1%	Tfall
129	6-Oct	0.14	14.59	14.72	1.0%	Tfall
131	6-Oct	0.24	0	0.24		Tfall
mean		**0.45**	**9.46**	**5.71**	**4.6%**	
56	30-Aug	0.91	0	0.91		Lkfall
38	6-Sep	0.31	0	0.31		Lkfall
105	12-Sep	0.38	8.29	8.68	4.4%	Lkfall
99	14-Sep	0.38	2.28	2.66	14.3%	Lkfall
97	20-Sep	0.37	0	0.37		Lkfall
108	20-Sep	0.84	0	0.84		Lkfall
mean		**0.53**	**5.29**	**2.30**	**9.3%**	

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 salmon were distributed throughout large areas, presently however, spawning populations of spring Chinook salmon are found only in the Salmon River, South Fork Trinity, and mainstem Trinity sub-basins.

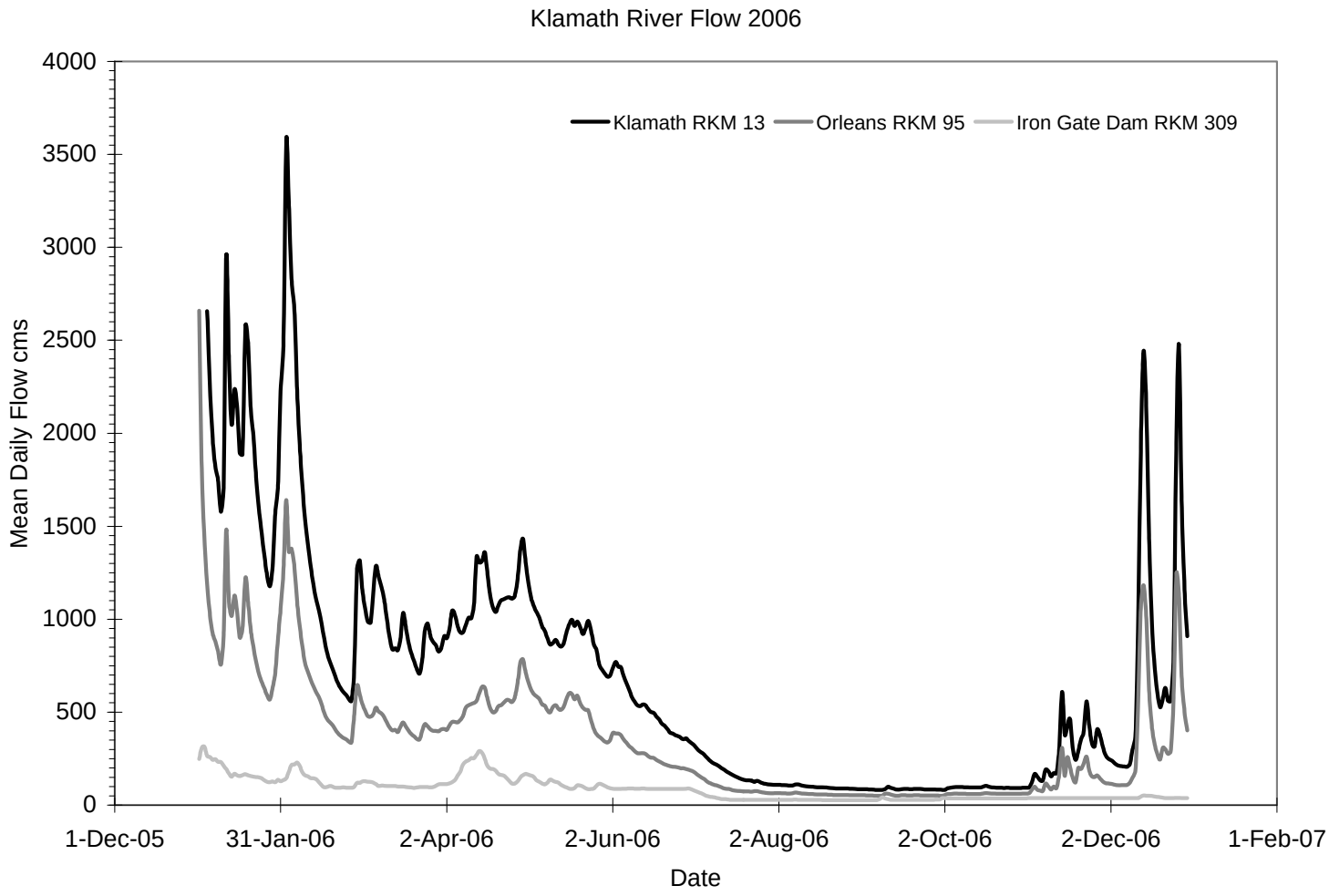


Figure 2. Flows for the Klamath River mainstem at representative locations during 2006 (USGS data).

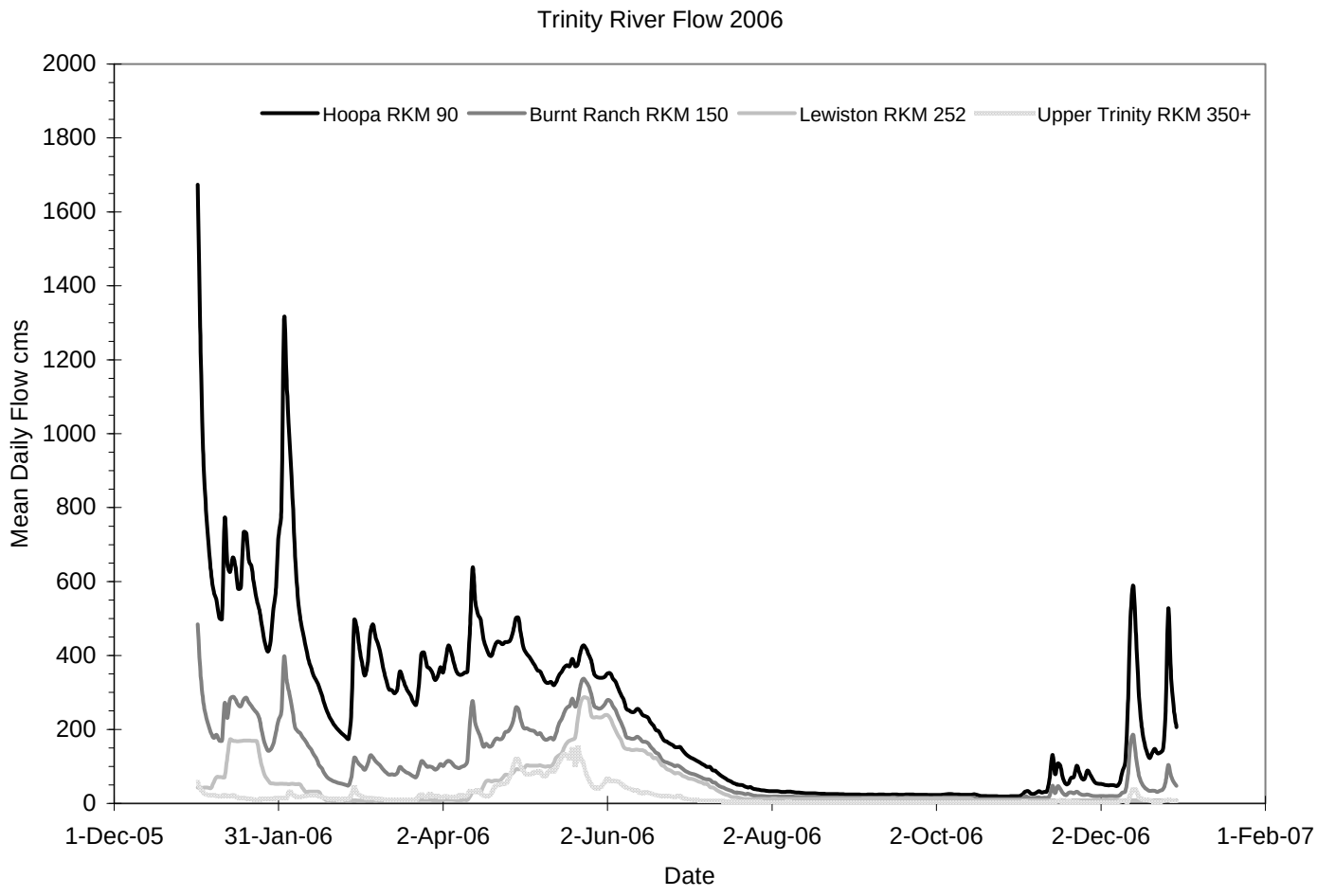


Figure 3. Flows for the Trinity River mainstem at representative locations during 2006 (USGS data).

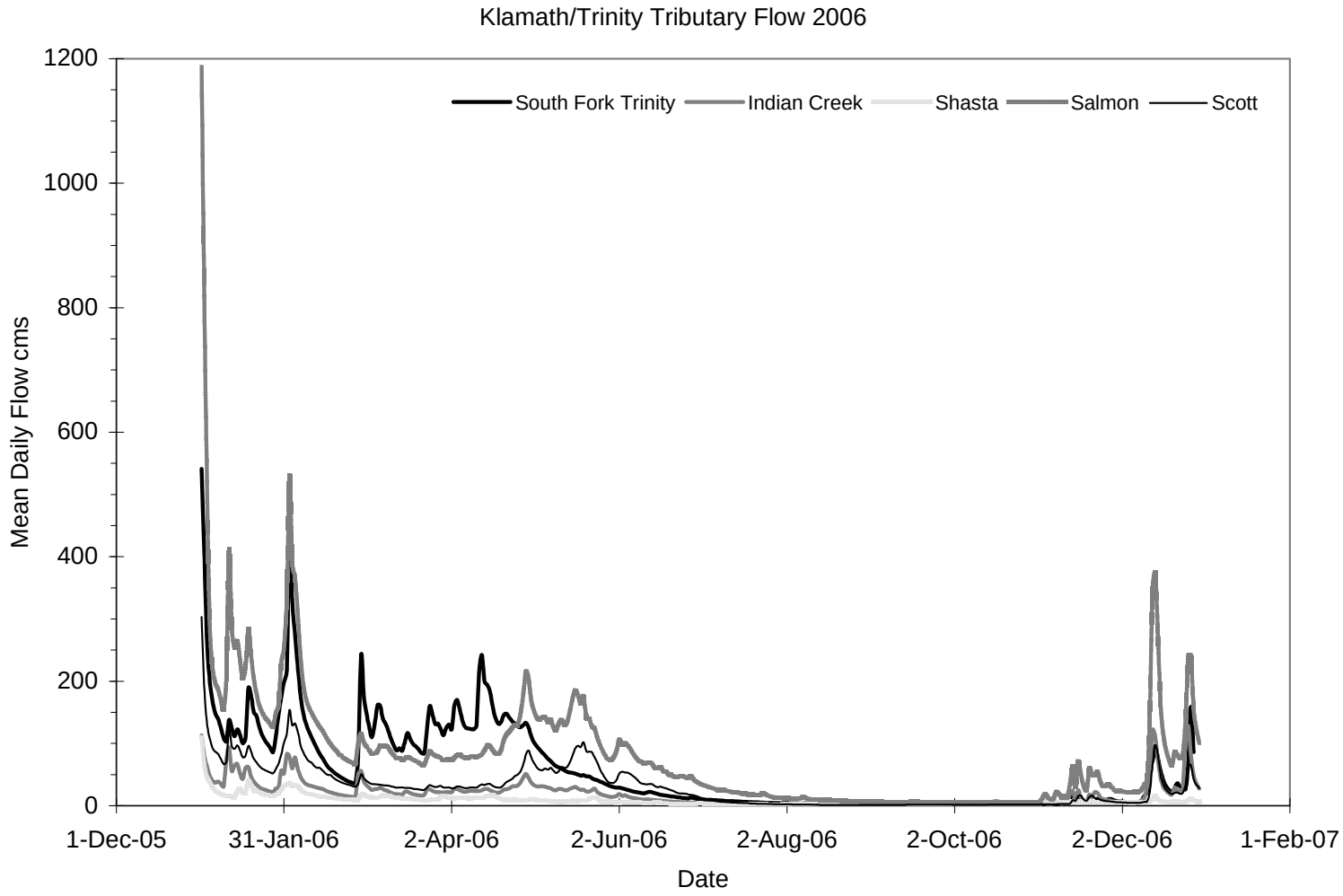


Figure 4. Flows for select major tributaries to the Klamath and Trinity Rivers during 2006 (USGS data).

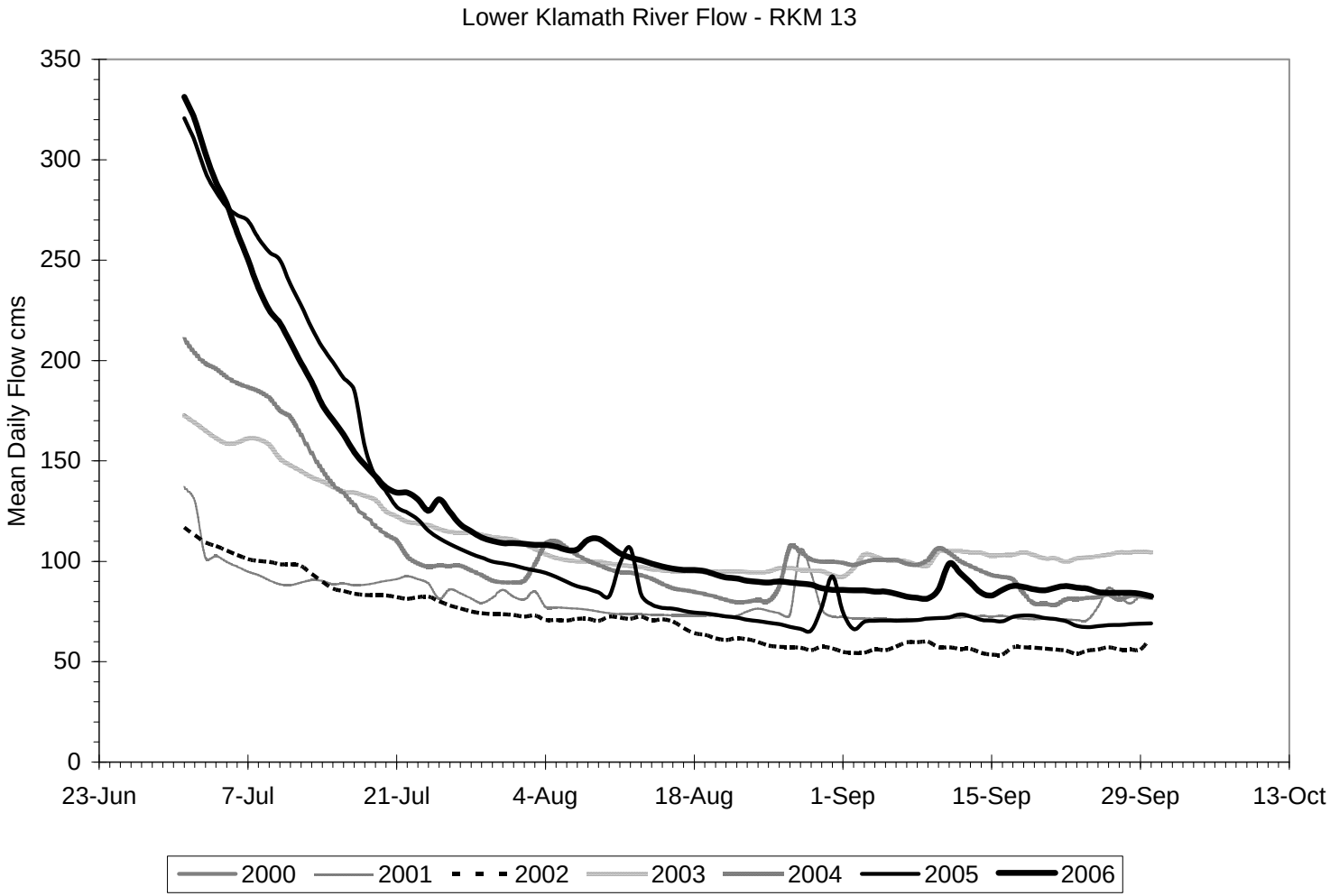


Figure 5. Summer and fall flows for the Klamath River from 2000 to 2006 (USGS data).

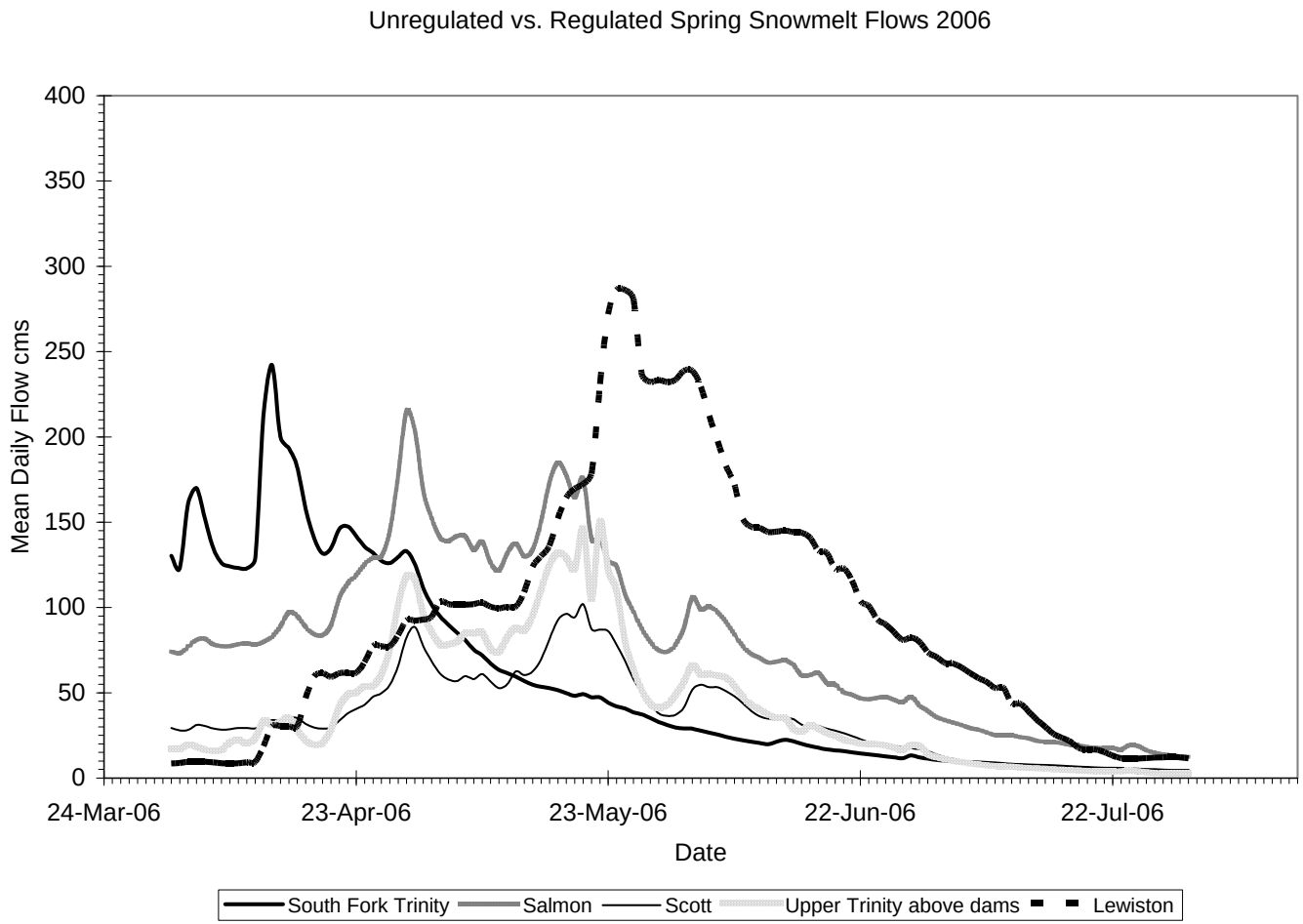


Figure 6. The regulated spring hydrograph for the Trinity River at Lewiston versus the unregulated spring hydrographs for several KRB tributaries showing the discontinuity between the timing and rate of the descending limb for 2006 as typically occurs (USGS data).

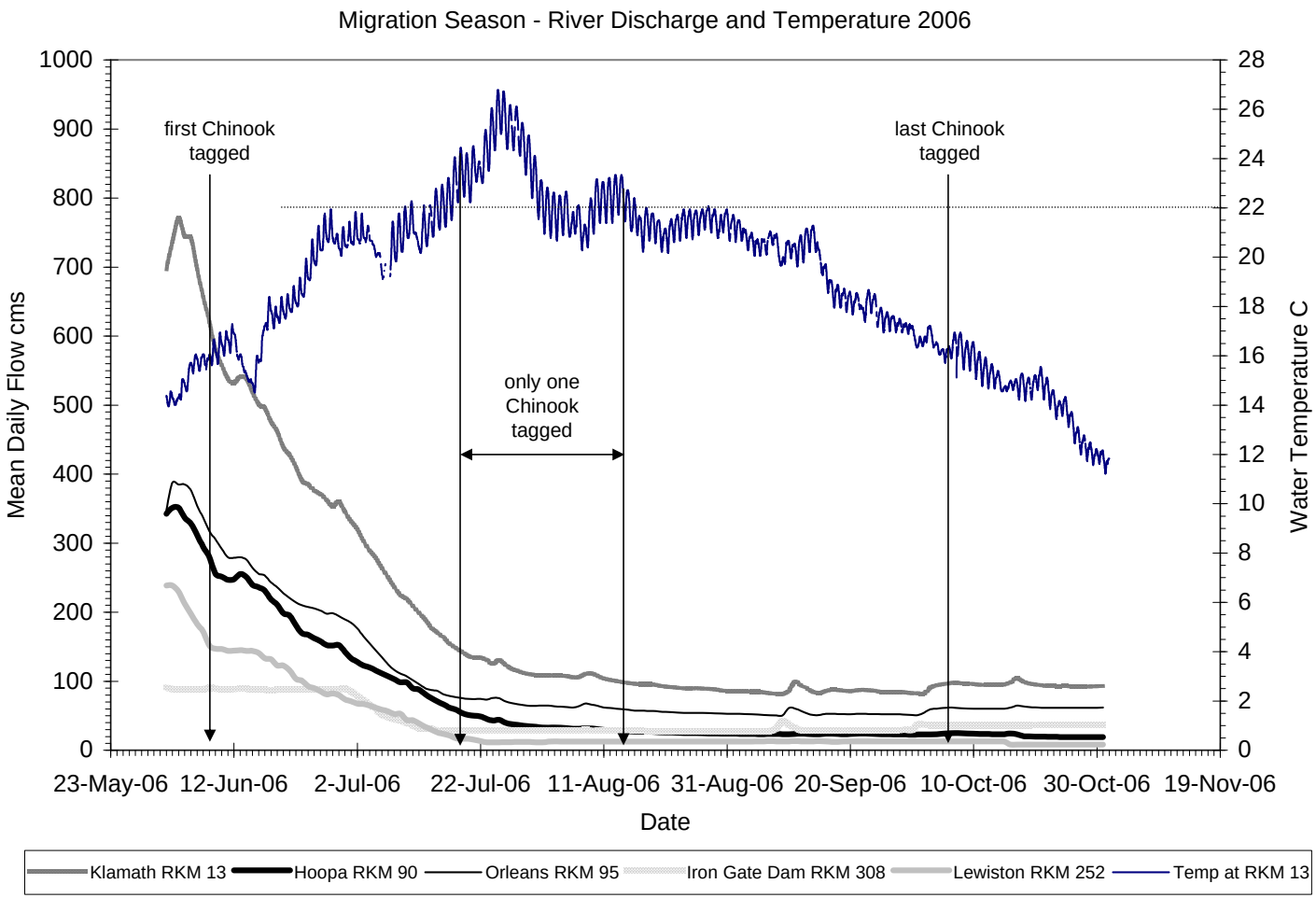


Figure 7. Water temperature (15-min intervals) of the lower Klamath River at Blake's RKM 13 plus flow at representative locations during the adult Chinook salmon migration season in 2006 (USGS data). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold. Periods when fish were tagged are indicated by the arrowed lines.

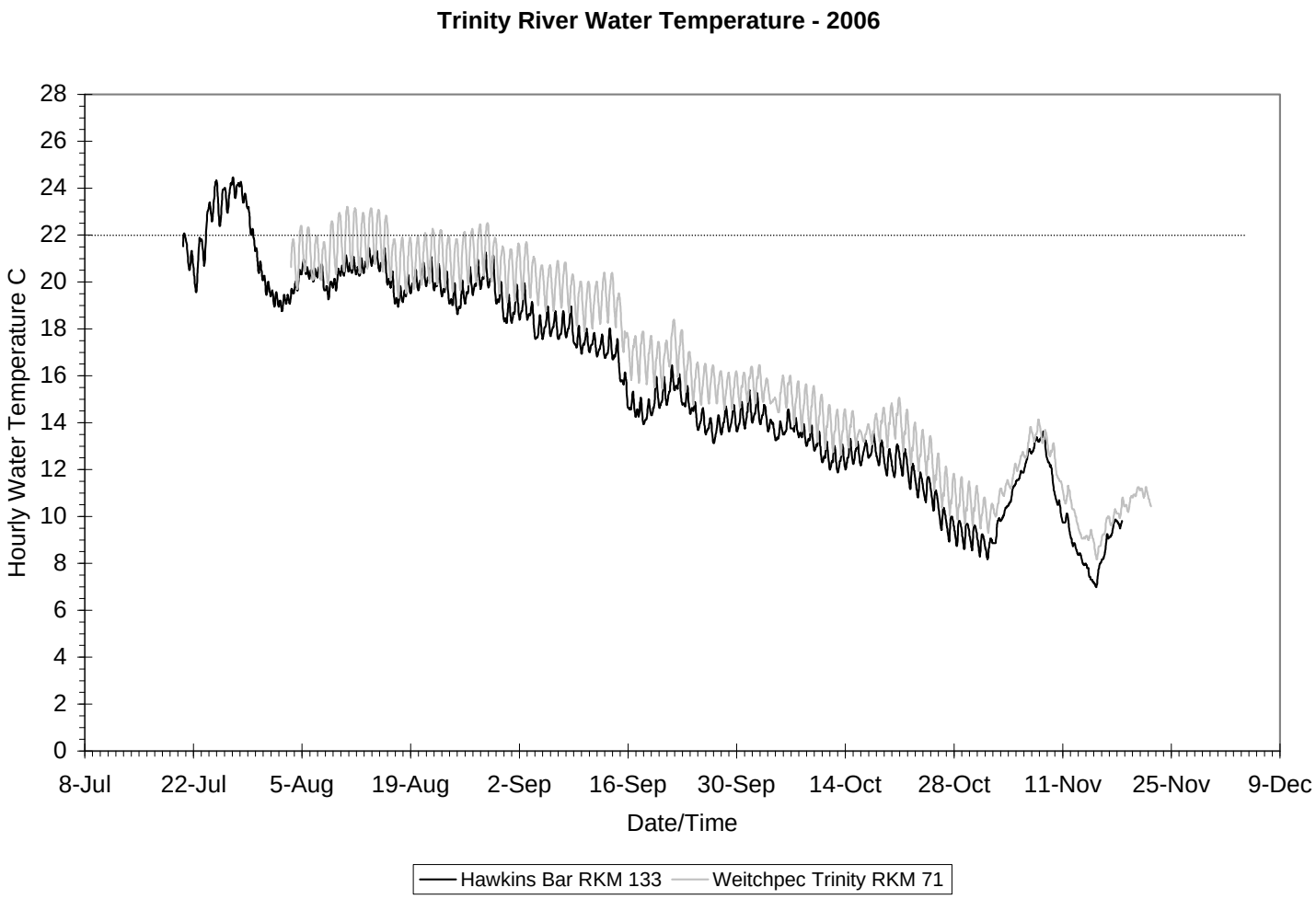


Figure 8. Water temperatures in the Trinity River just above its confluence with Klamath River (at RKM 71) and above its confluence with its South Fork (RKM 133) (iB). The dotted line at 22ºC provides an approximate visual reference for the migration inhibition threshold.

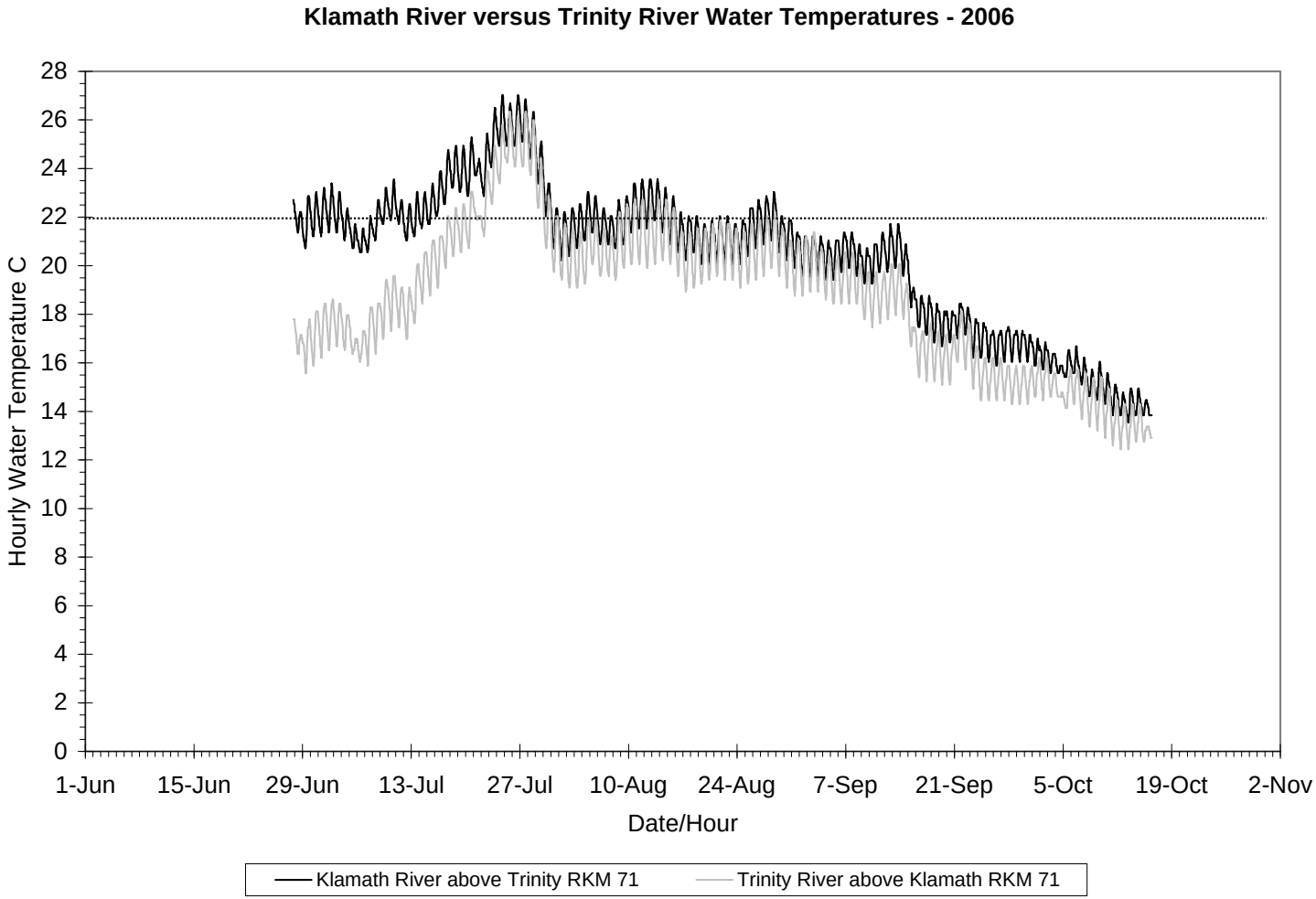


Figure 9. Water temperature at Weitchpec RKM 71 for the Klamath and Trinity Rivers above their confluence during 2006 (USFS). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

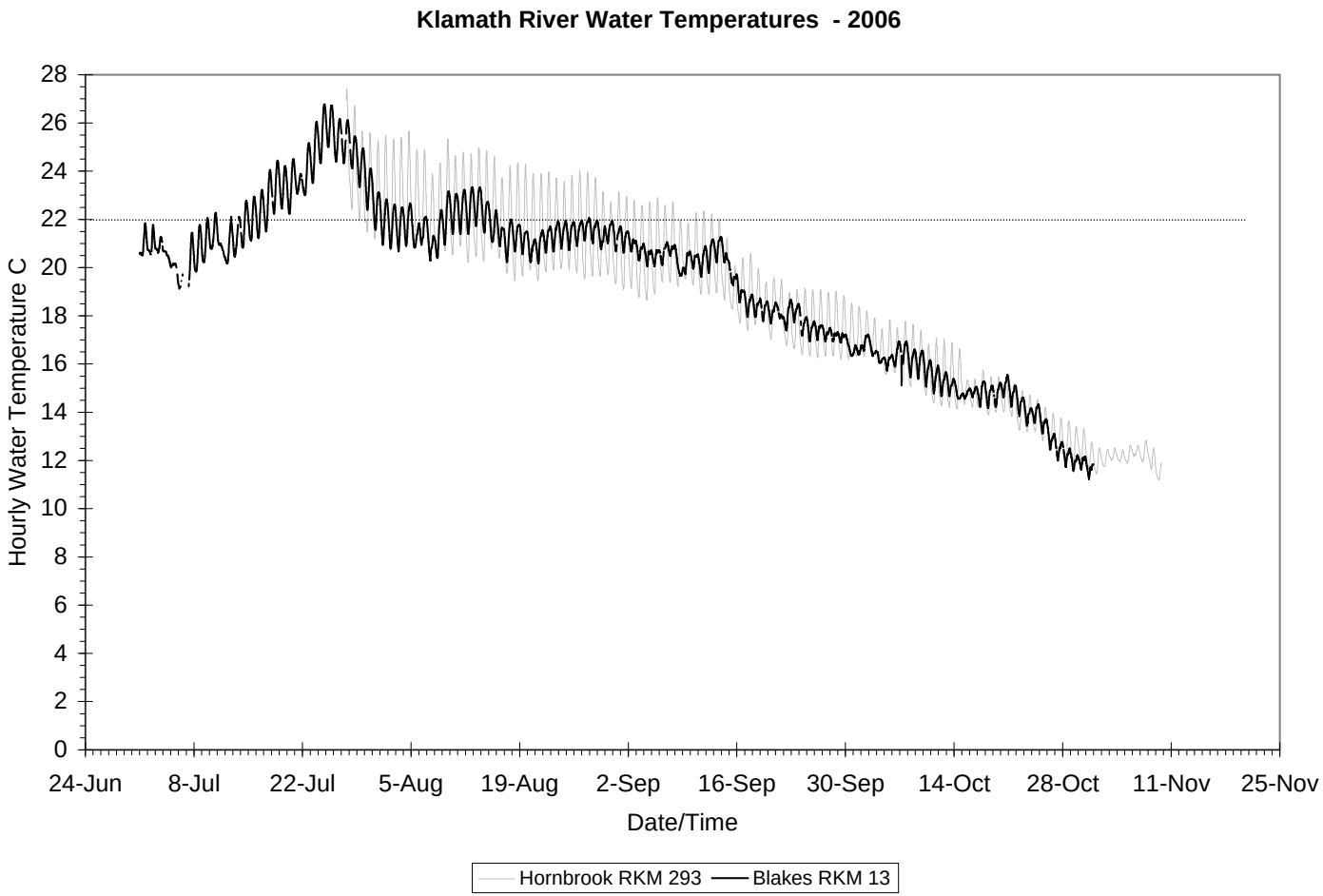


Figure 10. Water temperature of the Klamath River at Hornbrook RKM 293 (iB, hourly) with Blakes RKM 13 (USGS) included for comparison. Hornbrook is near the beginning of the primary spawning area for Klamath fall Chinook and the thermal regime is affected by upstream reservoir dynamics. The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

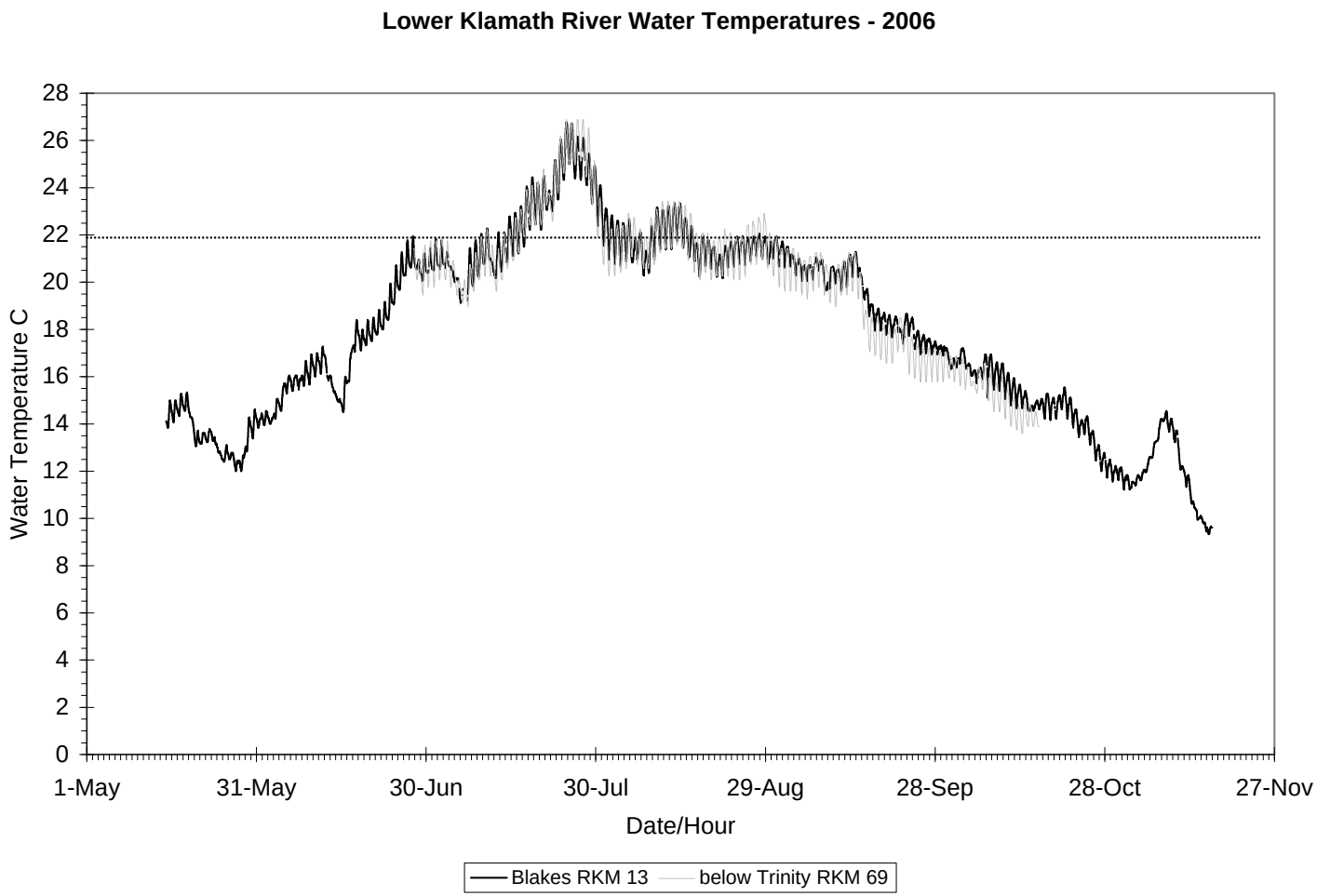


Figure 11. Water temperature of the Klamath River at Weitchpec below the mixing zone of the Trinity River confluence RKM 69 (USFS, hourly) with river temperatures at RKM 13 shown for comparison (USGS, 15-min intervals). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

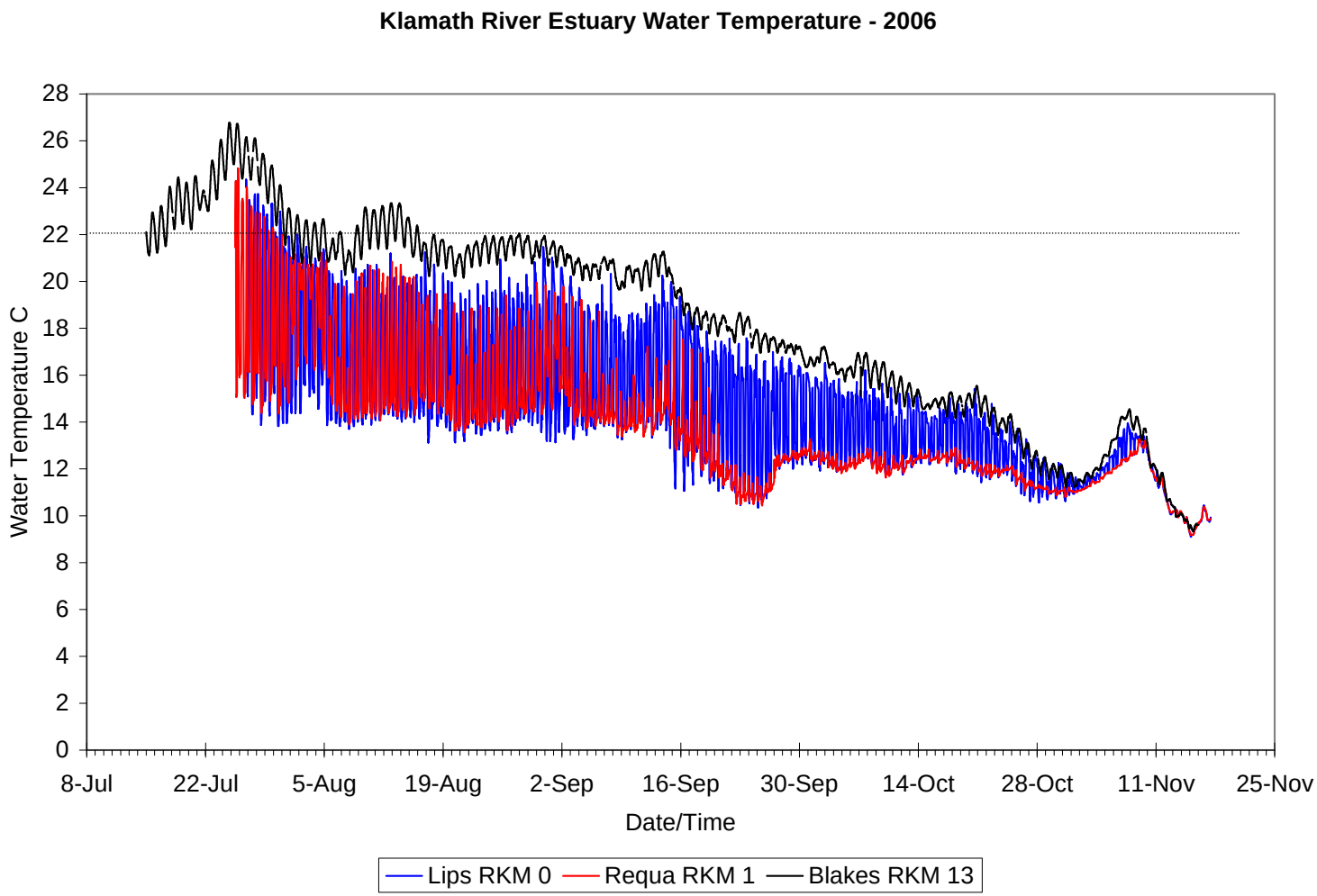
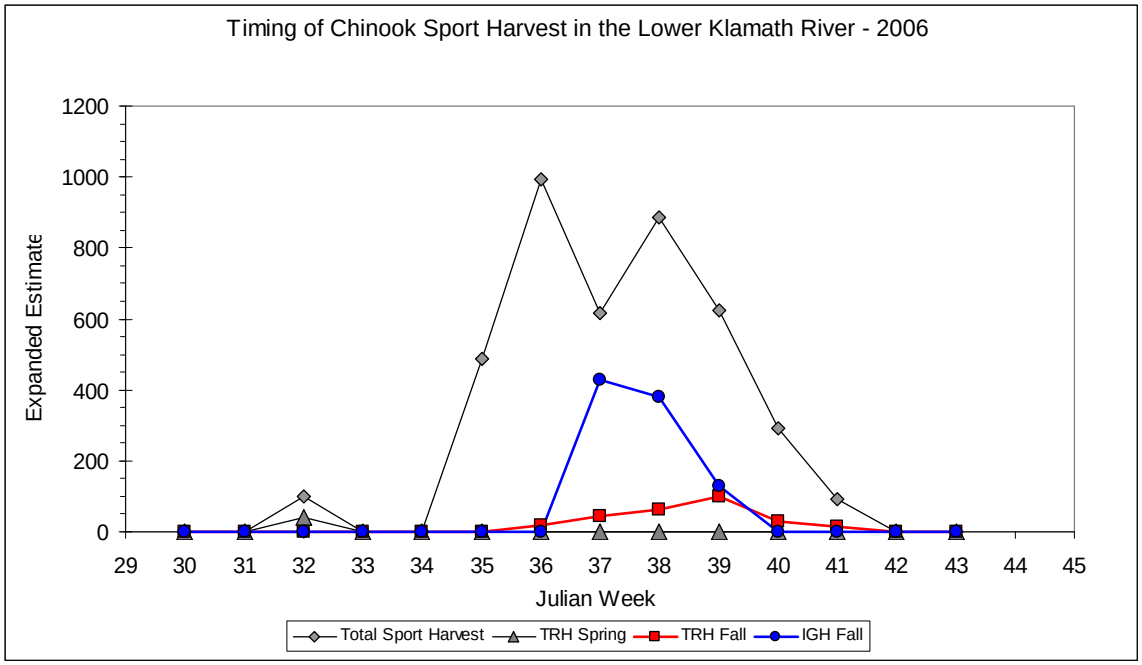


Figure 12. Available water temperature records (at bottom) in the Klamath River estuary near the mouth (iB) plus RKM 13 (USGS), which is well above the influence of the salt wedge.



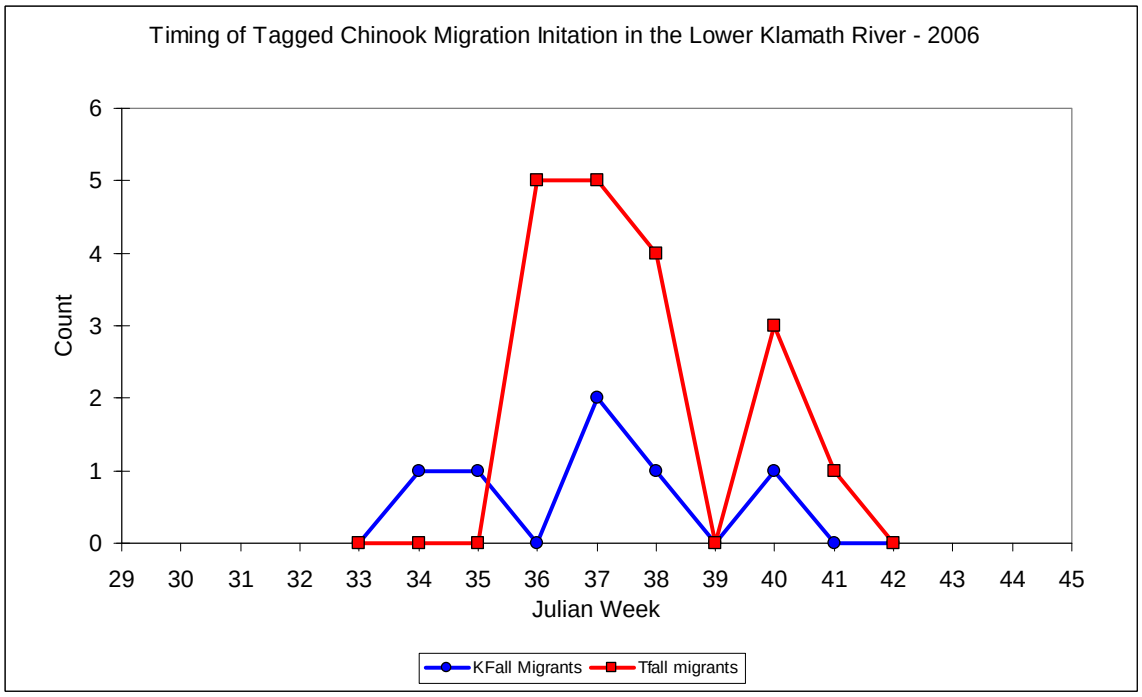


Figure 13. Estimation of run-timing for adult and grilse Chinook salmon during the late summer and fall of 2006 in the lower Klamath River (primarily from RKM 5 to RKM 57) based on sport harvest monitoring data (CDFG) and compared to run-timing for tagged Chinook migrants. Hatchery contribution was estimated by coded wire tag (CWT) recoveries and expansion. In 2006, regulations prohibited the take of Chinook salmon over 22 inches after Aug 15th thus sport harvest was almost exclusively grilse after that date. Julian week 36 started on 9/3/2006.

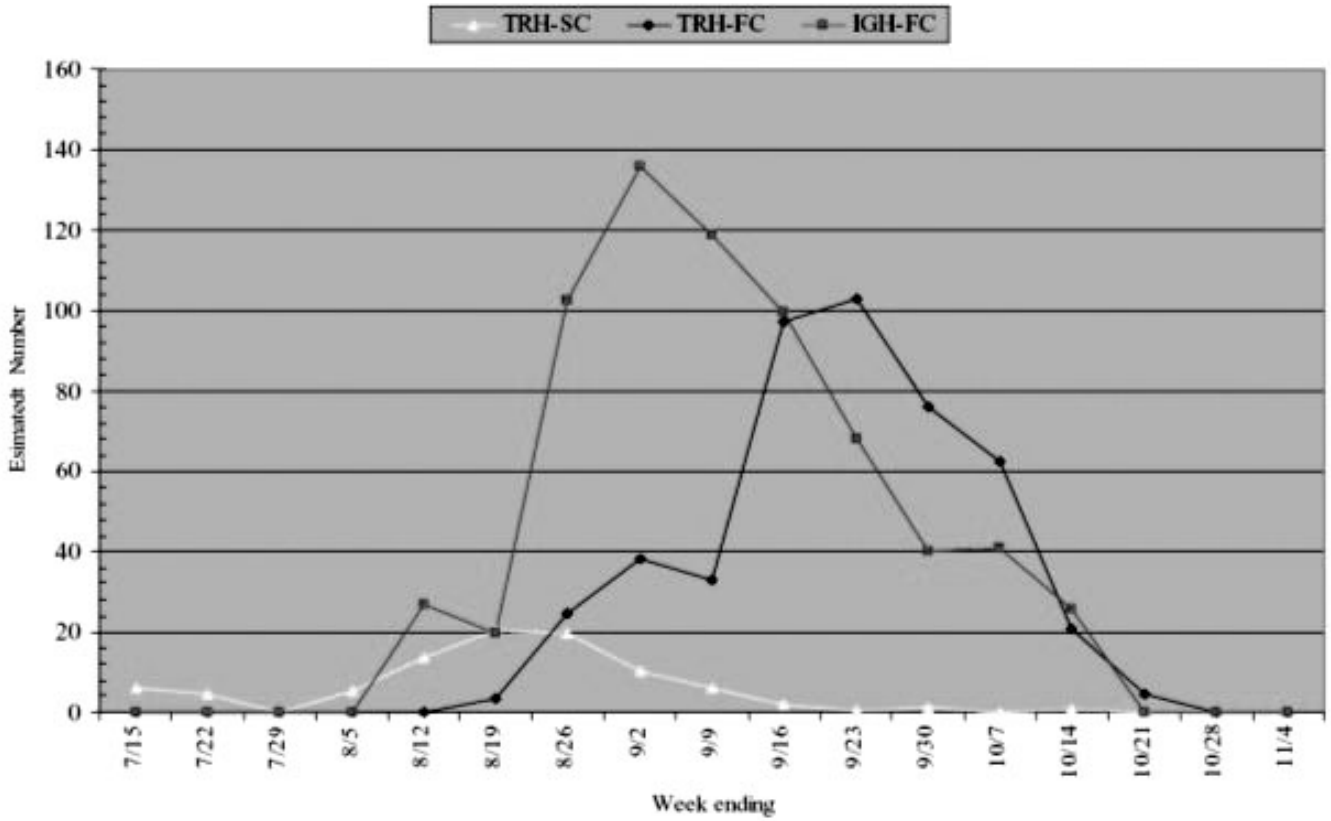


Figure 14. Average run-timing by week for adult Chinook salmon in the lower Klamath River (primarily below RKM 26) based on coded wire tag recoveries form the sport fishery from 1988 to 2001. Trinity River Hatchery spring Chinook salmon (TRH-SC) have bimodal run-timing with the larger peak in the late June (not shown). Iron Gate Hatchery fall Chinook salmon (IGH-FC) consistently run earlier than Trinity River Hatchery fall Chinook salmon (TRH-FC). Source CDFG

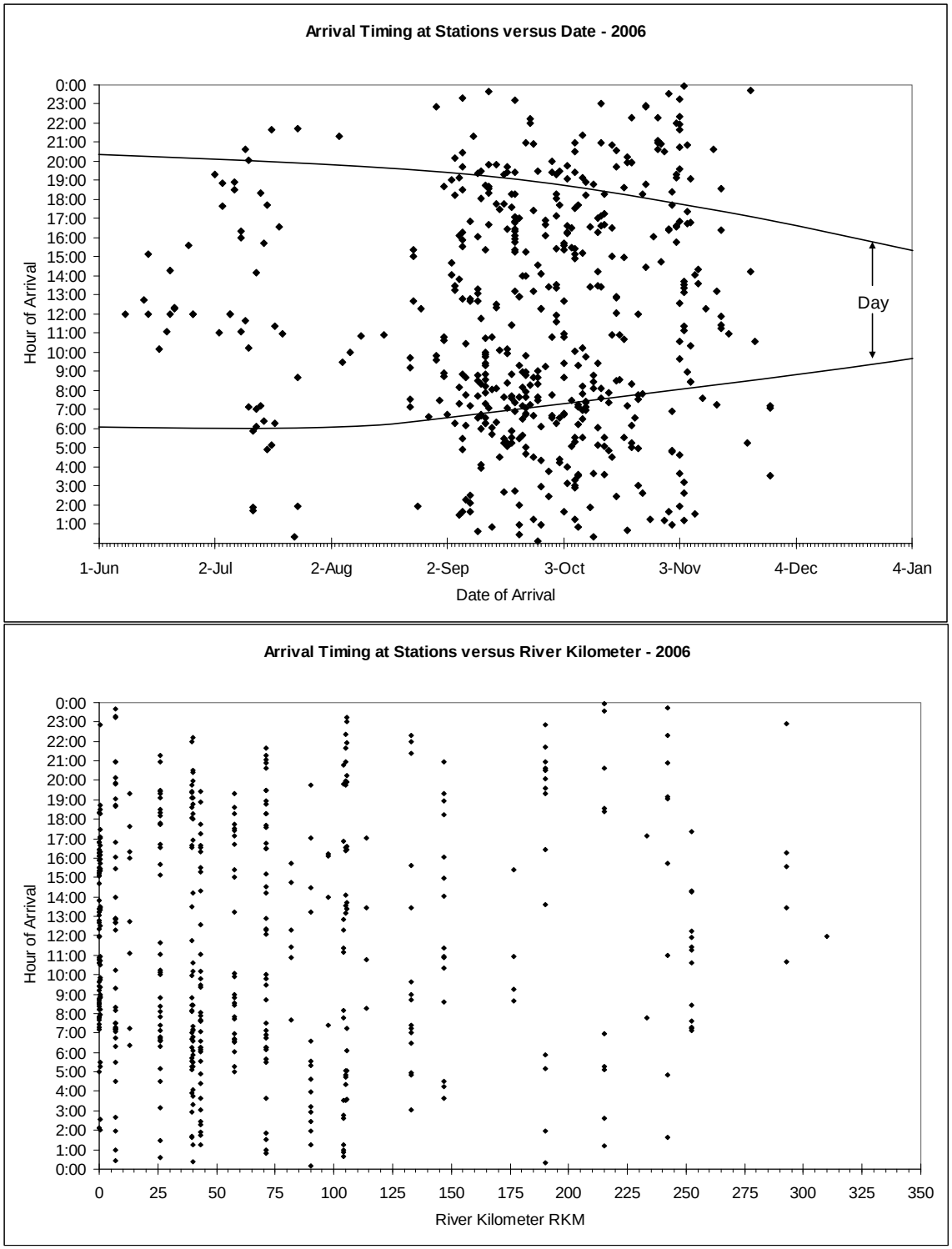


Figure 15. Arrival timing of adult Chinook migrants at fixed site stations in relation to (A, top) date, and (B, bottom) river kilometer. Day is considered from sunrise to sunset at 41.7450N 124.1833W with approximation represented by the curved lines. Fish are assumed to have been actively migrating in order to have been detected at a station for the first time (arrival).

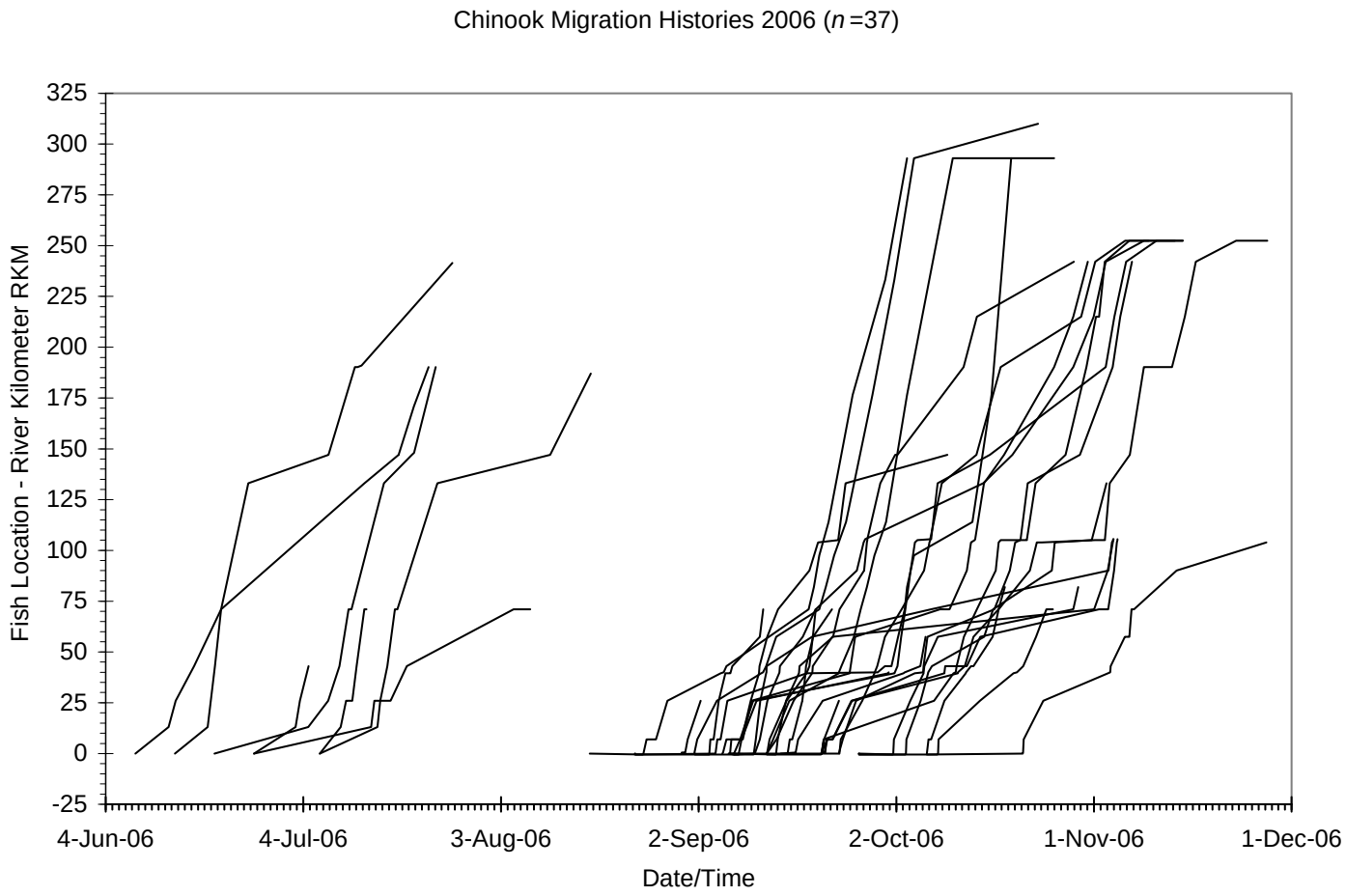
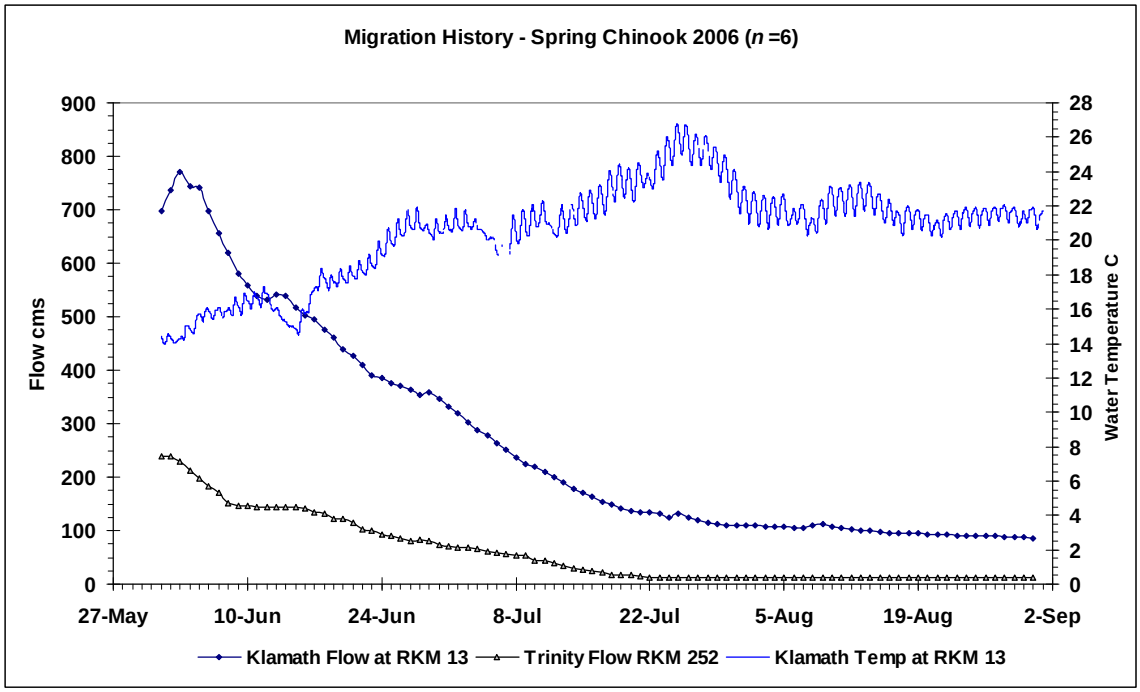


Figure 16. Migration histories for all 37 Chinook salmon tagged in 2006 that migrated upriver from the estuary. All river kilometers are measured from the mouth of the Klamath River.



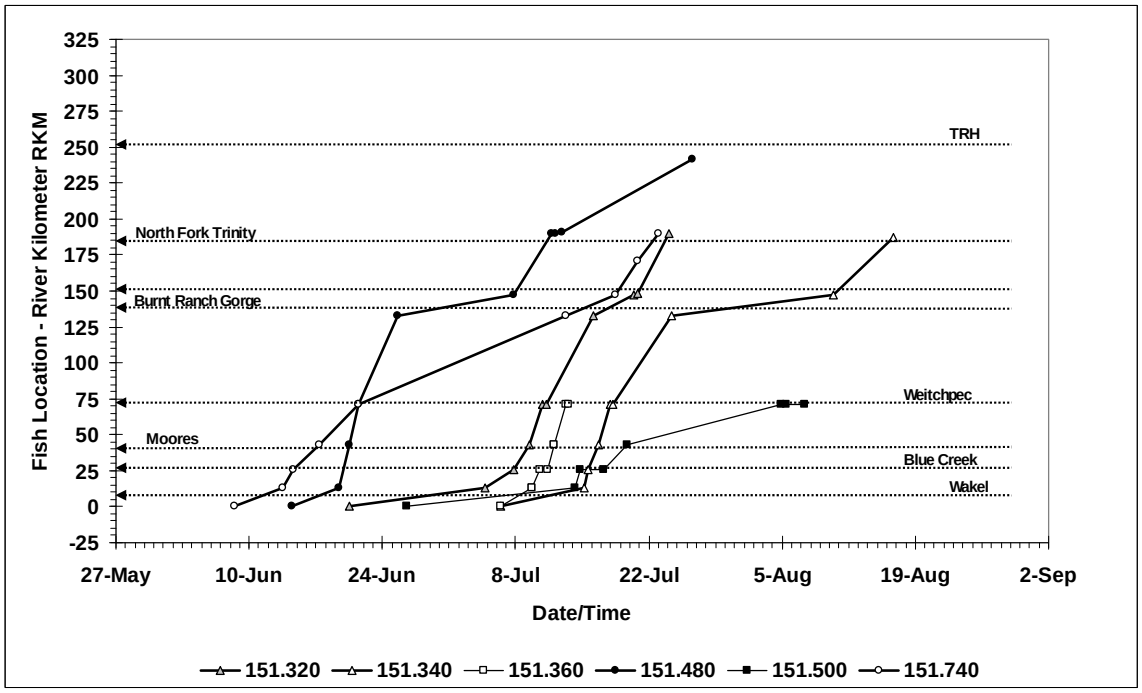


Figure 17. Migration histories for spring Chinook migrants in comparison to temperature and flow using commonly scaled axis. Applicable landmarks are designated by the dotted lines with labels above.

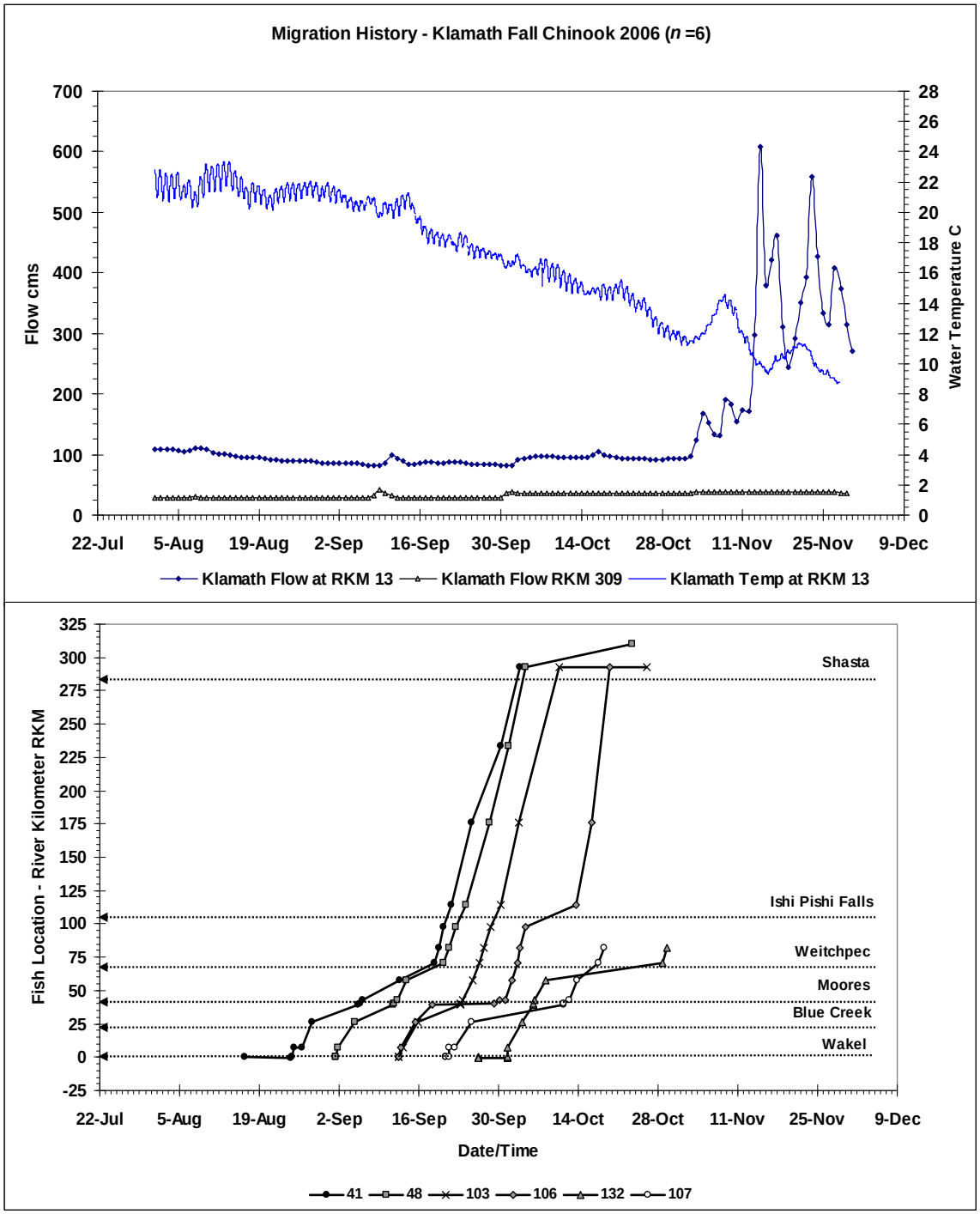


Figure 18. Migration histories for Klamath fall Chinook migrants in comparison to temperature and flow using commonly scaled axis. Applicable landmarks are designated by the dotted lines with labels above.

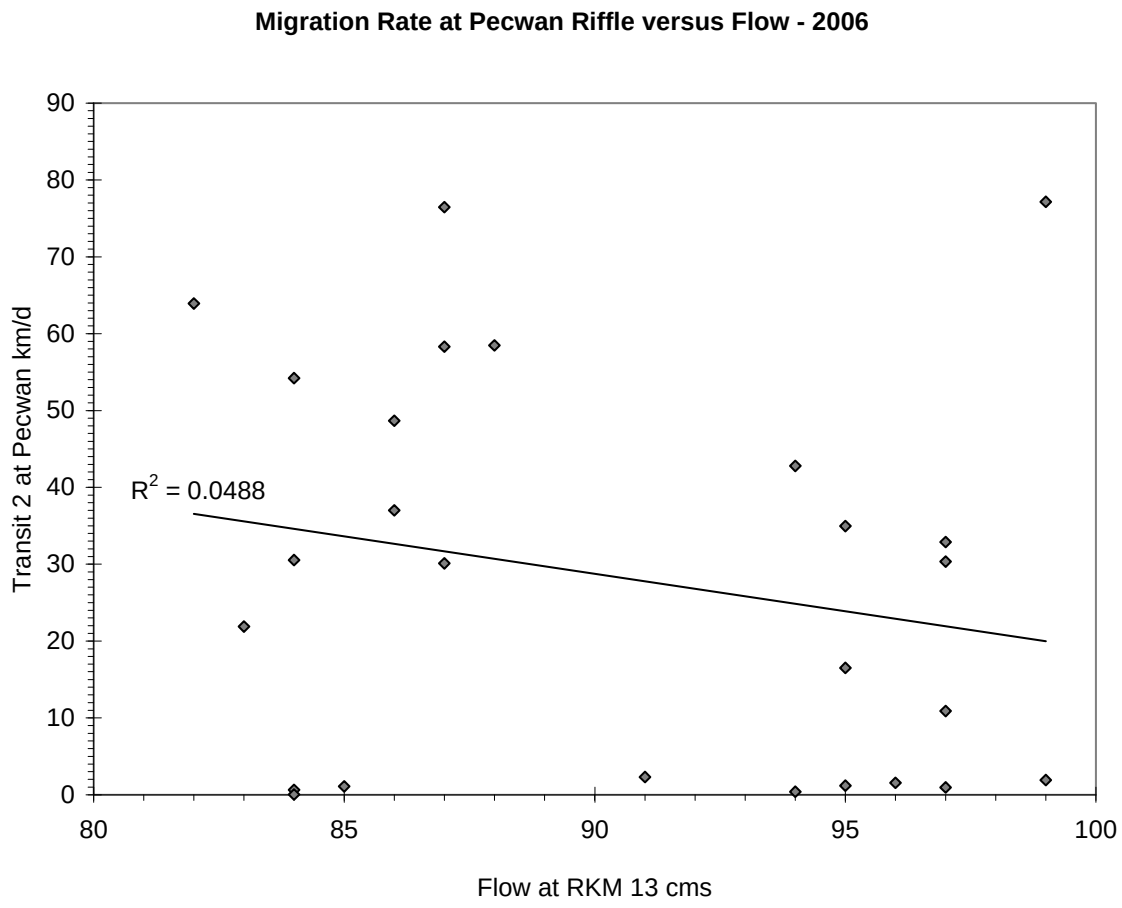


Figure 19. Migration rates for fall Chinook salmon (*n*=26) at the Pecwan Riffle (from RKM 39.5 to 40.0) versus flow (RKM 13), which suggests no consistent relationship between flow and migration rates past the Pecwan Riffle at the flows observed during the fall of 2006 (85 cms = 3,000 cfs).

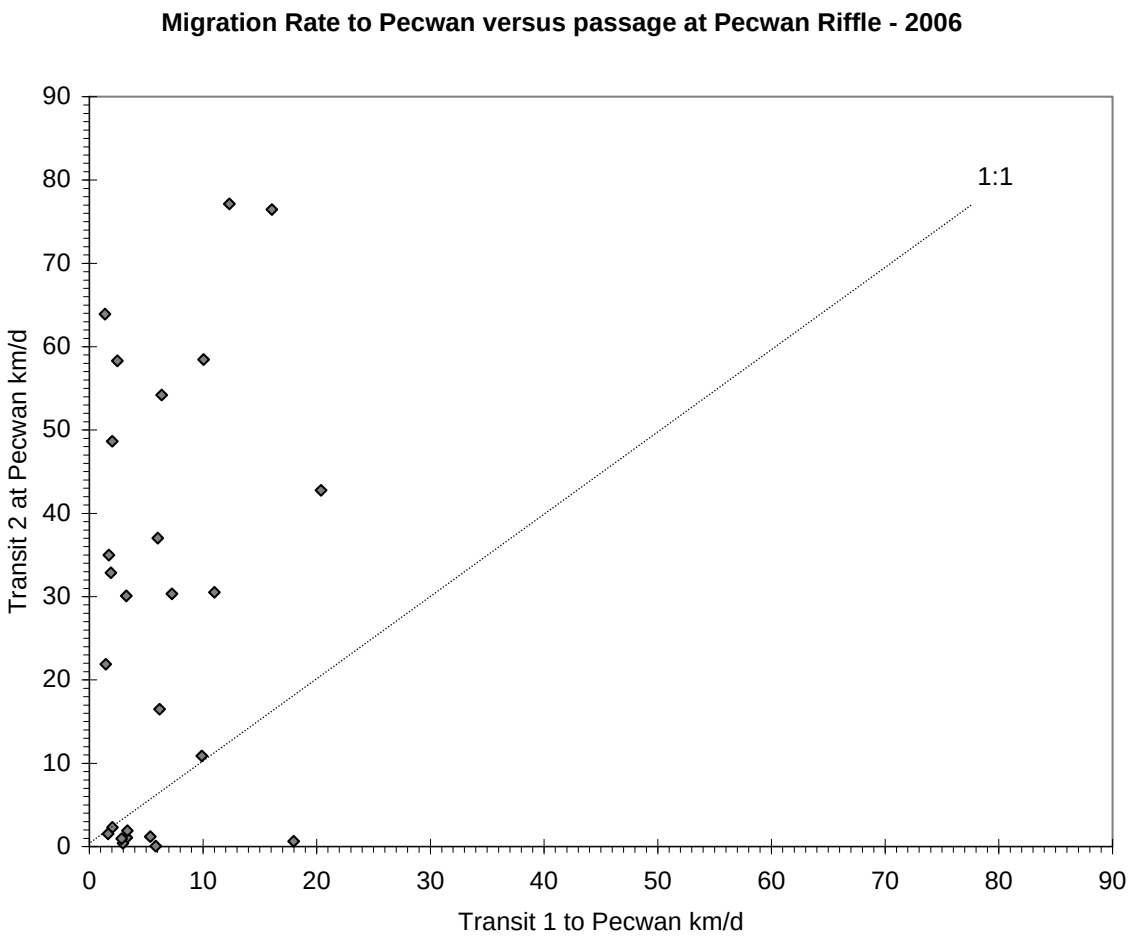


Figure 20. Migration rates for fall Chinook salmon (*n*=26) to the Pecwan Riffle (Transit 1 RKM 7.0 to 39.5) versus migration rates through the Pecwan Riffle (Transit 2 RKM 39.5 to 40.0). The dotted line marks the 1:1 ratio with all points above the line indicating faster migration rate through the Pecwan Riffle than up to it. The majority of tagged Chinook salmon (18 of 26, 69%) were above the 1:1 ratio line.

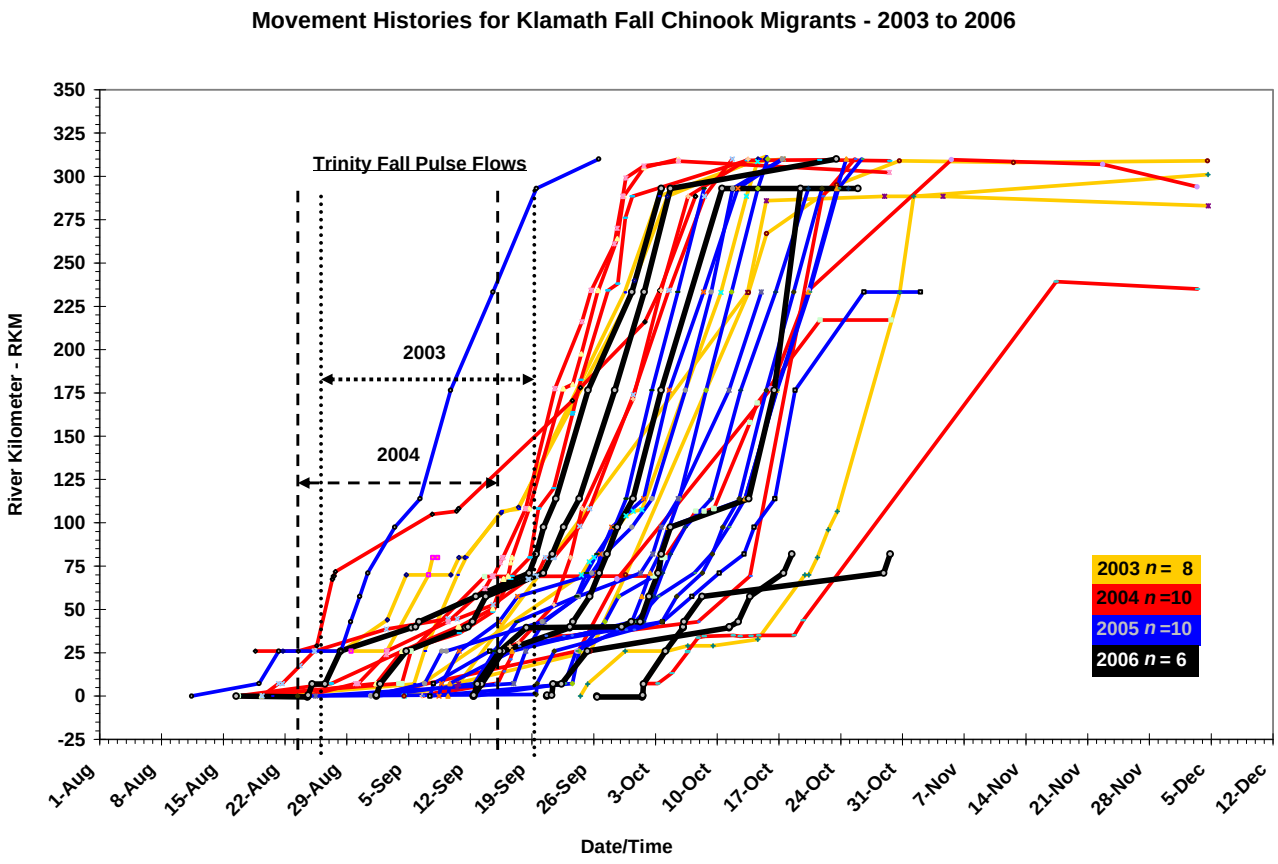


Figure 21. Movement histories for Klamath fall Chinook migrants tagged from 2003 to 2006 color coded by year including the three fish tagged above the estuary in the Blue Creek thermal refuge and an exceptionally early fish in 2005. The dotted and dashed lines show the durations of the Trinity fall pulse flows in the lower Klamath River during 2003 and 2004 respectively. The only pulse flows thereafter were relatively minor ceremonial releases from Lewiston Dam that occurred from 8/29/2005 to 9/1/2005 and from Iron Gate Dam from 9/8/2006 to 9/11/2006.

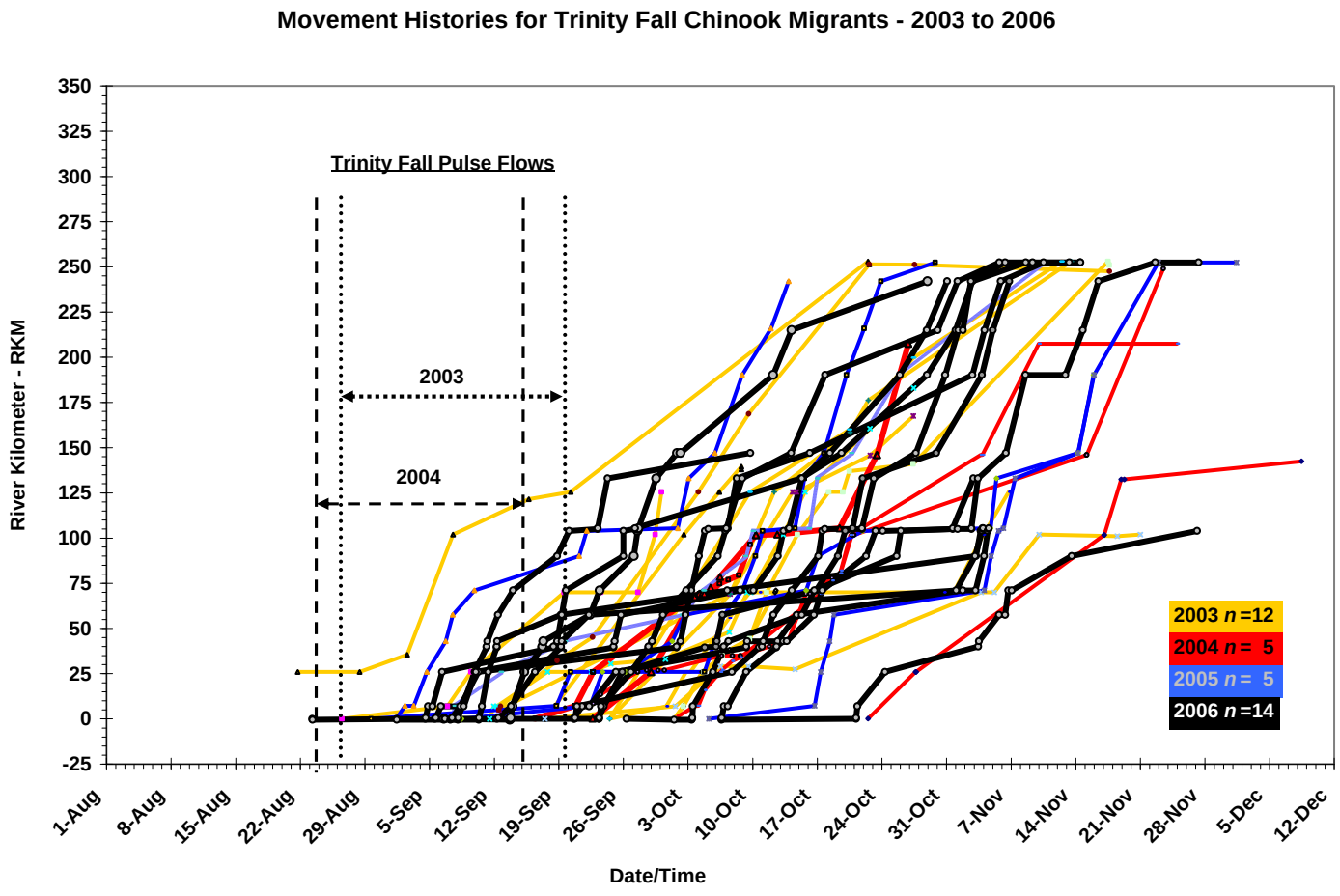


Figure 22. Movement histories for all Trinity fall Chinook migrants tagged from 2003 to 2006 color coded by year. The dotted and dashed lines show the durations of the Trinity fall pulse flows in the lower Klamath River during 2003 and 2004 respectively. The only pulse flows thereafter were relatively minor ceremonial releases from Lewiston Dam that occurred from 8/29/2005 to 9/1/2005 and from Iron Gate Dam from 9/8/2006 to 9/11/2006.

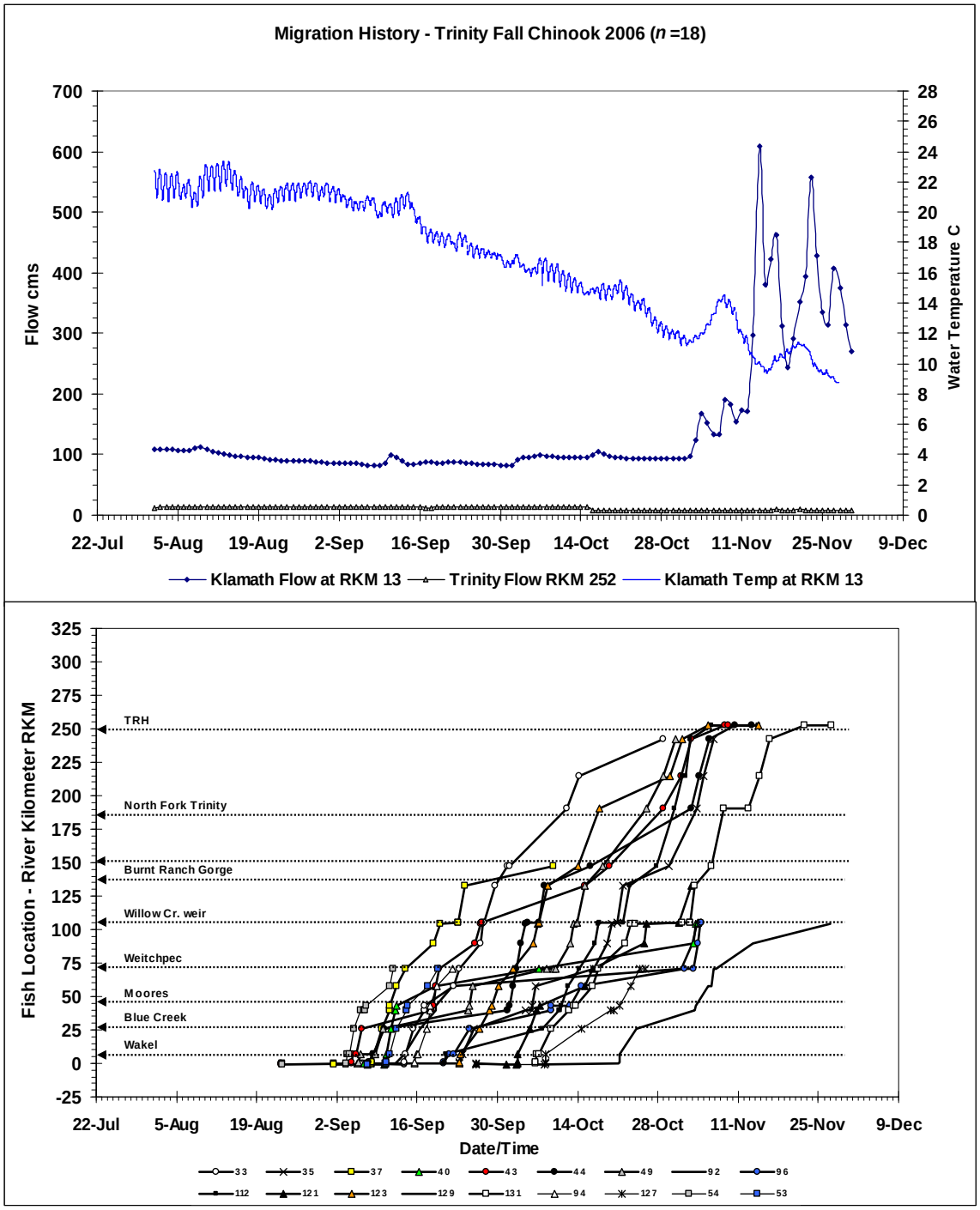


Figure 23. Migration histories for Trinity fall Chinook migrants in comparison to temperature and flow using commonly scaled axis. Applicable landmarks are designated by the dotted lines with labels above.

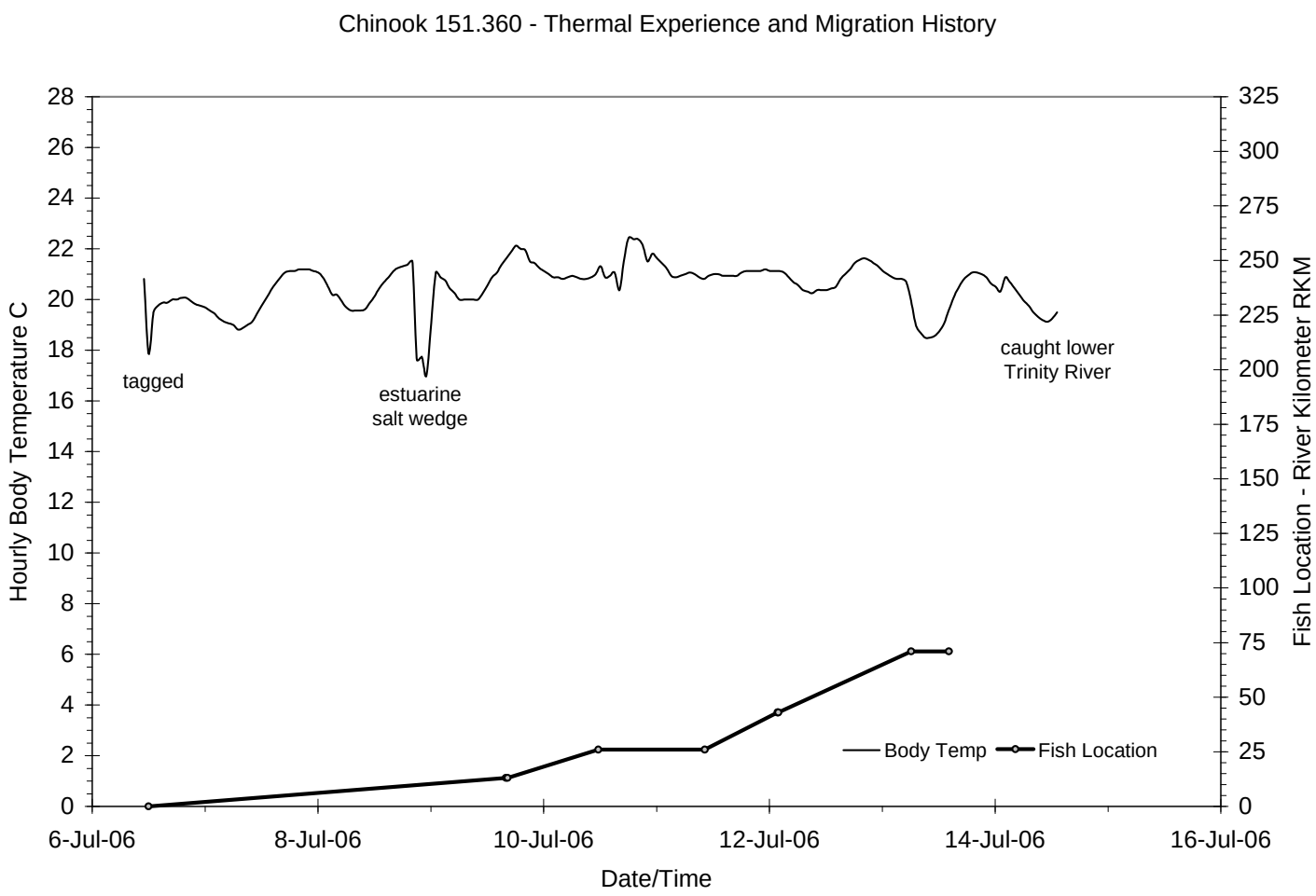


Figure 24. The thermal experience and migration history of spring Chinook 151.360 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). This fish was caught above RKM 71 in the Trinity River on 7/14/2006.

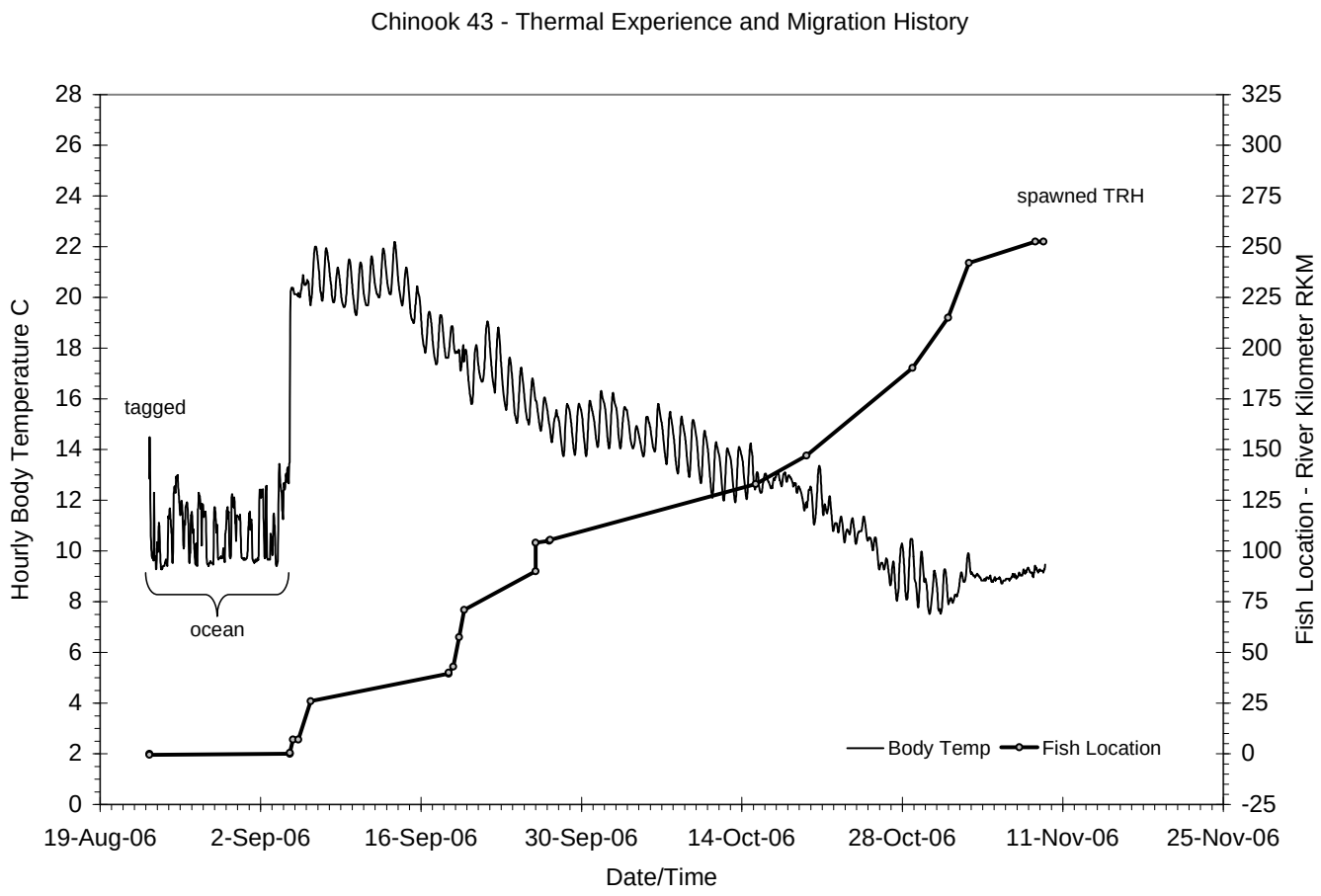


Figure 25. The thermal experience and migration history of Trinity fall Chinook 43 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). This female Chinook was spawned at the Trinity River Hatchery on 11/8/2006.

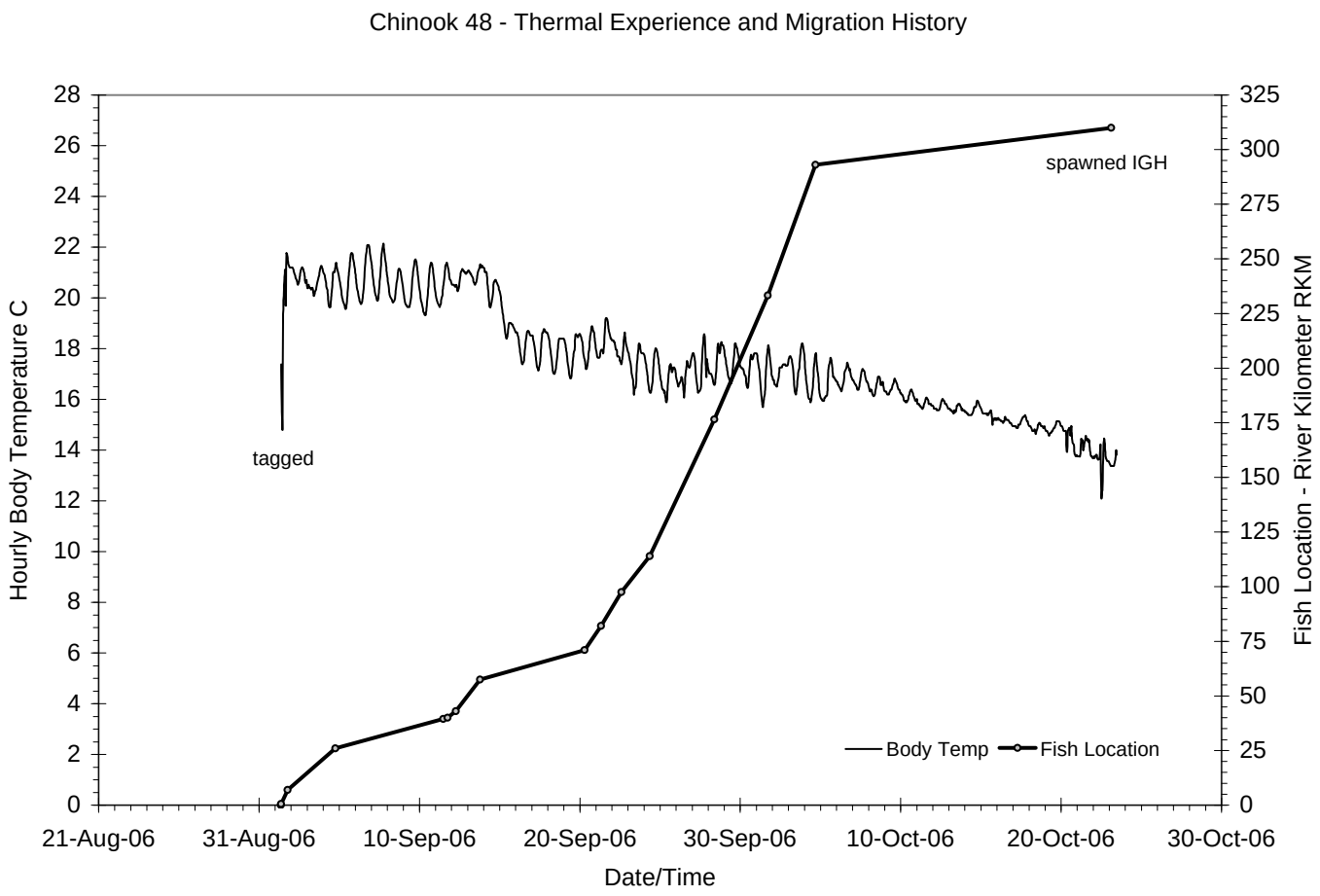


Figure 26. The thermal experience and migration history of Klamath fall Chinook 48 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). This male Chinook salmon was spawned at the Iron Gate Hatchery on 10/23/2006.

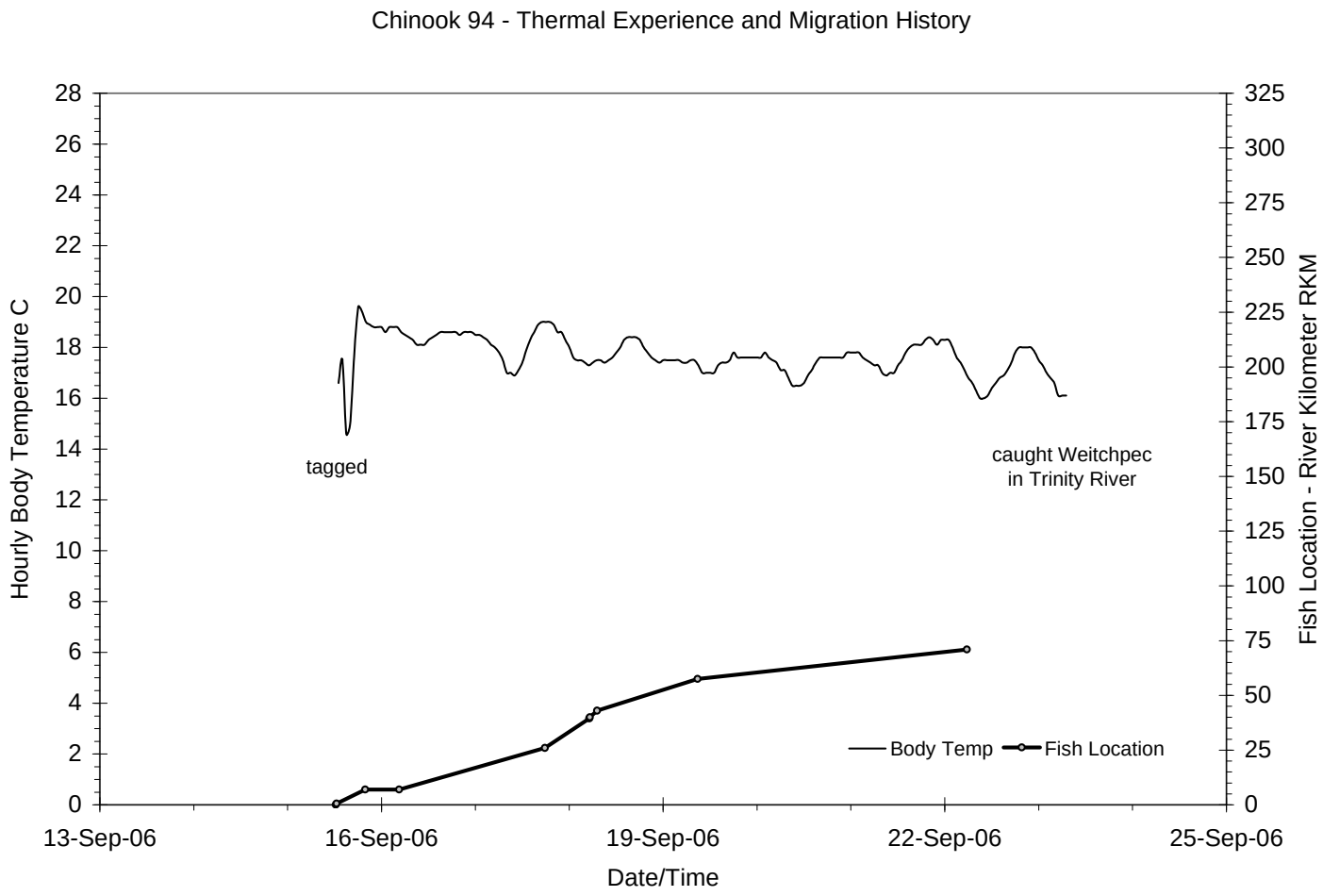


Figure 27. The thermal experience and migration history of Trinity fall Chinook 94 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). This Chinook salmon was caught in the Trinity River above Weitchpec on 9/23/2006.

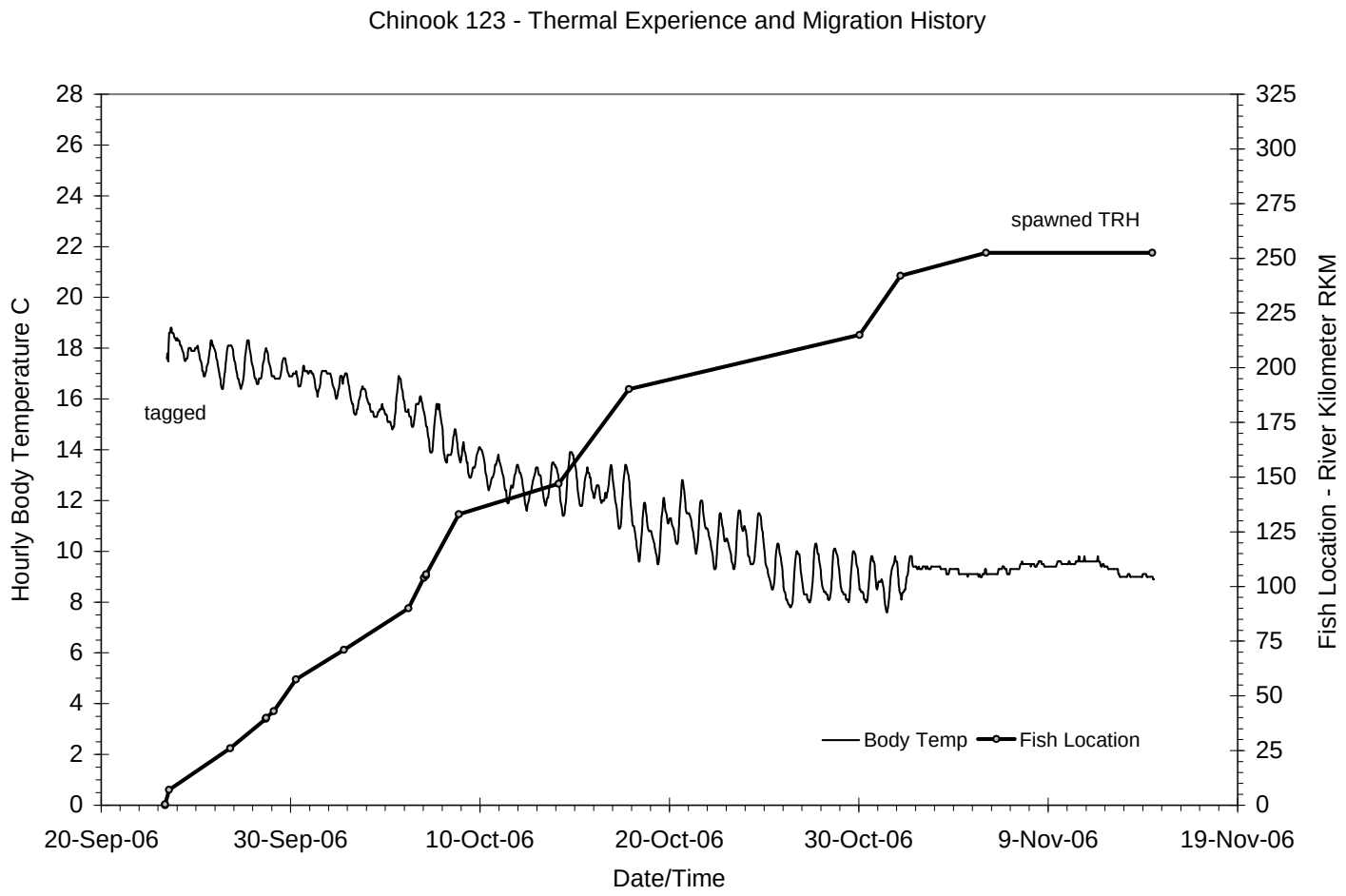


Figure 28. The thermal experience and migration history of Trinity fall Chinook 123 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). This female Chinook salmon was spawned at the Trinity River Hatchery on 11/14/2006.

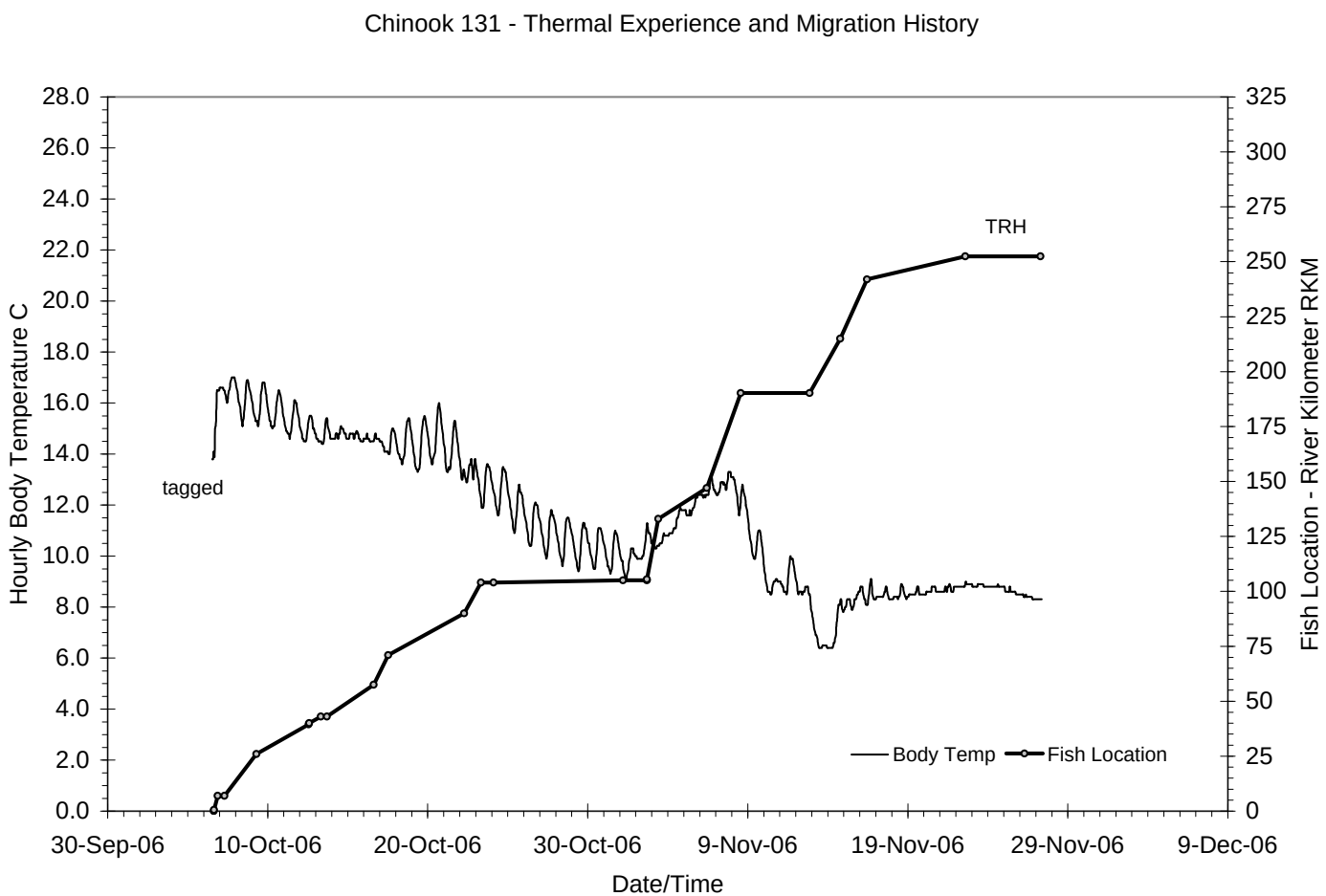


Figure 29. The thermal experience and migration history of Trinity fall Chinook 131 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). This female Chinook salmon was spawned at the Trinity River Hatchery on 11/27/2006.

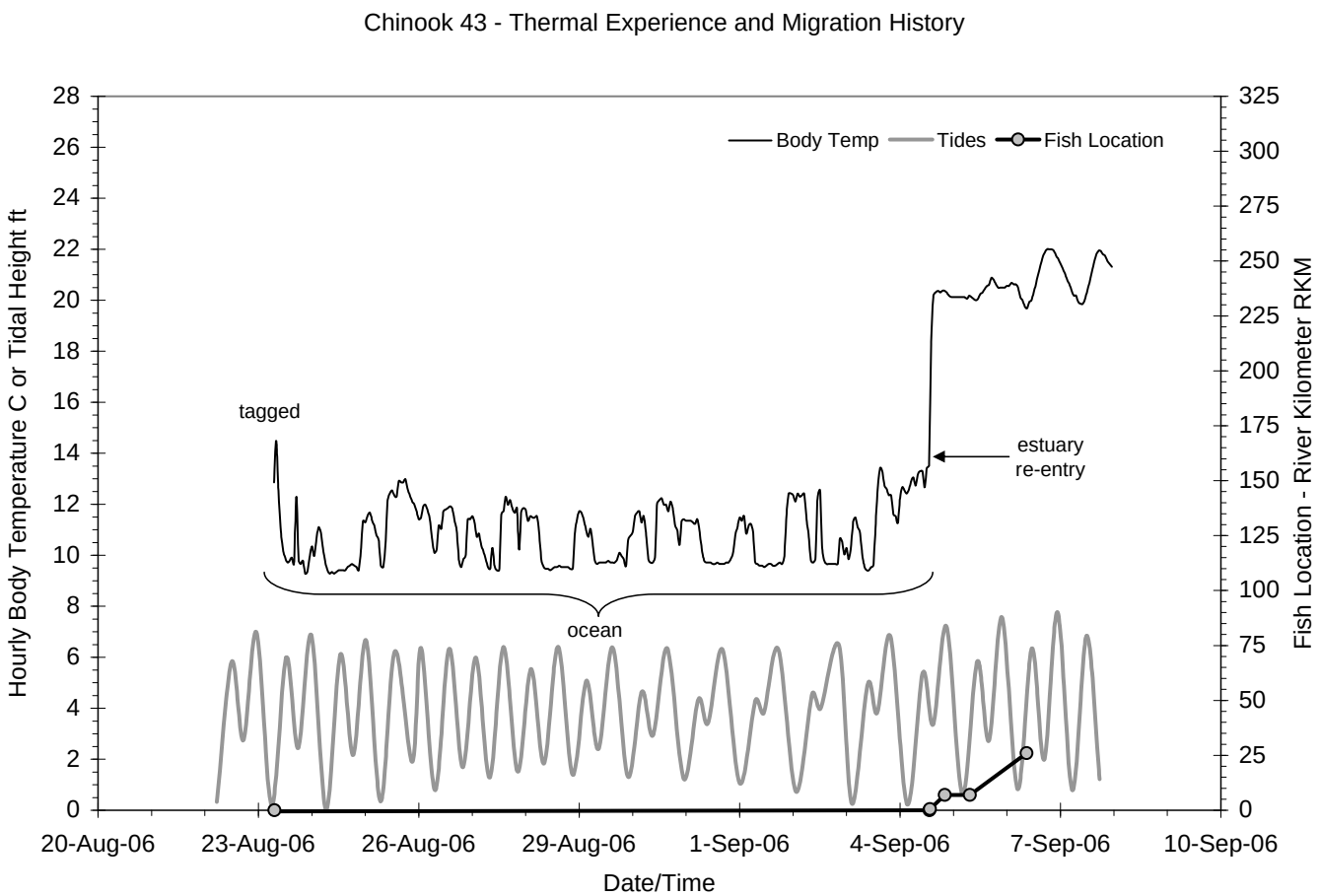


Figure 30. The thermal history of Chinook 43 during its residency in the nearshore ocean and estuary prior to initiation of freshwater migration. Tidal records (at nearby Crescent City harbor) are shown for comparison. The consistent pattern of body temperatures close to 9.5ºC can only be achieved via behavioral selection and is consistent with the thermal histories obtained from immature adult salmonids feeding in the ocean.

5.0 LITERATURE CITED

Alabaster, J.S. 1990. The temperature requirements of adult Atlantic salmon, *Salmon salar* L., during their upstream migration in the River Dee. J. Fish Biol. 37: 659-661.

Aprahamian, M.W., Jones, G.O., and Gough, P.J. 1998. Movement of adult Atlantic salmon in the Usk estuary, Wales. J. Fish Biol. 53: 221-225.

Armour, C.L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. U.S. Fish Wildlife Service Biological Report 90(20).

Banks, J.W. 1969. A review of the literature on the upstream migration of adult salmonids. J. Fish Biol. 1: 85-136.

Bartholow, J.M. 1995. Review and analysis of Klamath River Basin water temperatures as a factor in the decline of anadromous salmonids with recommendations for mitigation. U.S. Geologic Survey, Mid-Continent Ecological Science Center, Ft. Collins, CO. 52 pp.

Bartholow, J.H. 2005. Recent water temperature trends in the lower Klamath River, California. North American Journal of Fisheries Management 25: 152-162.

Bartholow, J.H., Campbell, S.G., and Flug, M. 2005. Predicting the thermal effects of dam removal on the Klamath River. Env. Management 34: 856-874.

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.

Belchik, M., Hillemeier, D., and Pierce, R.M. 2004. The Klamath River Fish Kill of 2002; Analysis of Contributing Factors. Yurok Tribal Fisheries Program. 42pp.

Berman, C.H. 1990. Effects of holding temperatures on adult spring Chinook reproductive success. Master's Thesis. University of Washington, Seattle, WA.

Berman, C.H. and Quinn, T.P. 1991. Behavioural thermoregulation and homing by spring Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. J. Fish Biol. 39: 301-312.

Bernard, D.R., Hasbrouck, J.J., and Fleischman, S.J. 1999. Handling-induced delay and downstream movement of adult Chinook salmon in rivers. Fish. Research 44: 37-46.

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

Beschta, R.L., Bilby, R.E., and Brown, G.W., Holtby, L.B., and Hofstra, T.D. 1987. Stream temperature and aquatic habitat: fisheries and forestry implications. *In* Streamside management: forestry and fisheries interactions. *Edited by* E.O. Salo and T.W. Cundy. Contributions Number 57, Institute of Forest Resources, University of Washington, Seattle, WA. pp. 191-232.

Bilby, R.E. 1984. Characteristics and frequency of cool-water areas in a Western Washington stream. J. Fresh. Ecol. 2: 593-602.

Bjornn, T.C. and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. Am. Fish. Soc. Spec. Publ. 19: 83-138.

Bodensteiner, L.R., Sheehan, R.J., and Wills, P.S. 2000. Flowing water: an effective treatment for Ichthyophthiriasis. J. Aqua. Animal Health 12: 209-219.

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

Brawn, V.M. 1982. Behavior of Atlantic salmon (*Salmo salar*) during suspended migration in an estuary, Sheet Harbor, Nova Scotia, observed visually and by ultrasonic tracking. Can. J. Fish. Aquat. Sci. 39: 248-256.

Brett J.R. 1979. Energetic factors and growth. *In* Fish Physiology, volume 8. *Edited by* W.S. Hoar, D.J. Randall, and J.R. Brett. Academic Press, New York. pp. 599-675.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. California Fish & Game 57: 44-57.

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.

Candy, J.R., and Quinn, T.P. 1999. Behavior of adult Chinook salmon (*Oncorhynchus tshawytscha*) in British Columbia coastal waters determined from ultrasonic telemetry. Can. J. Zool. **77**: 1161-1169.

Dingle, H. 1996. Fish migrations: 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.

Ebersole, J.L., Liss, W.J., and Frissell, C.A. 2001. Relationship between stream temperature, thermal refugia and rainbow trout *Oncorhynchus mykiss* abundance

in arid-land streams in the northwestern United States. Ecol. Freshwat. Fish 10: 1-10.

Gharrett, A.J., Shirley, S.M., and Tromble, G.R. 1987. Genetic relationship among populations of Alaskan Chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 44: 765-774.

Gilhousen, P. 1960. Migratory behavior of adult Fraser River sockeye. Int. Pac. Salmon Fish. Comm. Prog. Rep.: pp. 78.

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., Simpson, K., Todd, I., Murray, P.D., and Buxton, G.A. 1975. Movements of sockeye salmon (*Oncorhynchus nerka*) in the Skeena River estuary as revealed by ultrasonic tracking. J. Fish. Res. Board Can. 32: 233-242.

Guillen, G. 2003. Klamath River Fish Die-off, September 2002: Causative Factors of Mortality. US Fish and Wildlife Service. Report Number AFWOF-02-03. 128pp.

Hamilton, J.B., Curtis, G.L., Snedaker, S.M., and White, D.K. 2005. Distribution of anadromous fishes in the upper Klamath River watershed prior to hydroelectric dams - a synthesis of the historical evidence. Fisheries 30(4): 10-20.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. University of British Columbia Press, Vancouver. pp. 311-393.

Hickey, B., Cochlan, W., Lessard, E., Trainer, V., Trick, C., and MacFadyen, A. 2005. ECOHAB Pacific Northwest 4 Cruise Report, July 2005. Available at: www.ecohabpnw.org/at11_30/report/index.html (February 2006).

Hinch, S.C., and Bratty, J. 2000. Effects of swim speed and activity pattern on success of adult sockeye salmon migration through an area of difficult passage. Trans. Am. Fish. Soc. 129: 598-606.

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.

Hinke, J.T., Foley, D.G., Wilson, C., and Watters, G.M. 2005. Persistent use by Chinook salmon *Oncorhynchus tshawytscha* in the coastal ocean. Mar. Ecol. Prog. Ser. 304: 207-220.

Hodgson, S. 2000. Marine and freshwater climatic influences on the migratory timing of adult sockeye salmon. Master's. University of Washington, Seattle.

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.

Holt, R.A., J.E. Sanders, J.L. Zinn, J.L. Fryer, and K.S. Pilcher. 1975. Relation of water temperature to Flexibacter columnaris infection in steelhead trout (*Salmo gairdneri*), coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*) salmon. J. Res. Fish. Board Can. 32(9):1553-1559.

Hyatt, K.D., Stockwell, M.M., and Rankin, D.P. 2003. Impact and adaptation responses of Okanagan River sockeye salmon (*Oncorhynchus nerka*) to climate variation and change effects during freshwater migration: stock restoration and fisheries management implications. Can. Water Resources J. 28: 689-713.

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

Kaeding, L.R. 1996. Summer use of coolwater tributaries of a geothermally heated stream by rainbow and brown trout, *Oncorhynchus mykiss* and *Salmo trutta*. Am. Midl. Nat. 135: 283-292.

Kaya, C.M., Caddying, L.R. & Burkhalter, D.E. 1977. Use of a cold-water refuge by rainbow and brown trout in a geothermally heated stream. Progressive Fish Culturist 39: 37-39.

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

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

Matthews, K.R., and Berg, N.H. 1997. Rainbow trout responses to water temp and dissolved oxygen stress in two southern California stream pools. J. Fish Biol. 50: 50-67.

McCullough, D.A. 1999. A review and synthesis of effects of alteration to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. EPA 910-R-99-010. pp 74-76.

Newell, J.C., and Quinn, T.P. 2005. Behavioral thermoregulation by maturing sockeye salmon (*Oncorhynchus nerka*) in a stratified lake prior to spawning. Can. J. Zool. 83: 1232-1239.

Nielsen, J.L., Lisle, T.E., and Ozaki, V. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Trans. Am. Fish. Soc. 123: 613-626.

Pacific Fisheries Environmental Laboratory (PFEL). Daily Upwelling Indices for the Last 18 Months. Available at: www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html (February 2006).

Potter, E.C.E. 1988. Movements of Atlantic salmon, *Salmon salar* L., in an estuary in South-west England. J. Fish Biol. 33 (Suppl. A): 153-159.

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.

Rand, P.S., and Hinch, S.G. 1998. Swim speeds and energy use of upriver-migrating sockeye salmon (*Oncorhynchus nerka*): simulating metabolic power and assessing risk of energy depletion. Canadian Journal of Fisheries and Aquatic Sciences **55**: 1832-1841.

Rand, P.S., Hinch, S.C., Morrison, J., Foreman, M.G.G., MacNutt, M.J., Macdonald, J.S., Healey, M.C., Farrell, A.P., and Higgs, D.A. 2004. Watershed dynamics acting on the energetics of salmon to buffer effects of global climate change. Global Change Biol. In press.

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

Schreck, C.B. and Li, H.W. 1991. Performance capacity of fish: stress and water quality. *In* Aquaculture and water quality. Advances in World Aquaculture 3. *Edited by* D.E. Brune and J.R. Tomasso. World Aquaculture Society. Baton Rouge, LA. pp. 21-29.

Smith, G.W., Smith, I.P., and Armstrong, S.M. 1994. The relationship between river and flow and entry to the Aberdeenshire Dee by returning adult Atlantic salmon. J. Fish Biol. 45: 953-960.

Stearns, S.C. 1976. Life history tactics: a review of the ideas. Quarterly Review of Biology 51: 3-47.

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

Stewart, D.C., Smith, G.W., and Youngson, A.F. 2002. Tributary-specific variation in timing of return of adult Atlantic salmon (*Salmo salar*) to fresh water has a genetic component. Can. J. Fish. Aquat. Sci. 59: 276-281.

Schwing, F.B., O'Farrell, M., Steger, J.M., and Baltz, K. 1996. Coastal upwelling indices of the West Coast of North America 1946-95. NOAA-TM-NMFS-SWFSC-231.

Synder, J.O. 1931. Salmon of the Klamath River, California. Calif. Dept. of Fish Game Bull. 34.

Torgersen, C.E., Price, D.M., Li, H.W. and McIntoch, B.A. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. Ecological Applications 9: 301-319.

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.

Traxler, G.S., Richard, J., and McDonald, T.E. 1998. *Ichthyophthirius multifiliis* (Ich) epizootics in spawning sockeye salmon in British Columbia, Canada. J. Aqua. Animal Health 10: 143-151.

Turek, S., Rode, M., Cox, B., Heise, G., Sinnen, W., Reese, C., Borok, S., Hampton, M., and Chun, C. 2004. September 2002 Klamath River Fish-Kill: Final Analysis of Contributing Factors and Impacts. Califronia Department of Fish and Game. 183pp.

Wakabayashi, H. 1991. Effect of environmental conditions on the infectivity of *Flexibacter columnaris* to fish. J. Fish Diseases 14: 279-290.

Walker, R.V., Myers, K.W., Davis, N.D., Aydin, K.Y., Friedland, K.D., Carlson, H.R., Boehlert, G.W., Urawa, S., Ueno, Y., and Anma, G. 2000. Diurnal variation in the thermal environment experienced by salmonids in the North Pacific as indicated by data storage tags. Fish. Oceanogr. **9**: 171-186.

Wertheimer, A.C. 1984. Maturation success of pink salmon (*Oncorhynchus gorbuscha*) and coho salmon (*O. kisutch*) held under three salinity regimes. Aquaculture 43: 195-212.

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.

Williamson, K. and Hillemeier, D. 2001. An assessment of pinniped predation upon fall-run Chinook salmon in the Klamath River estuary, CA, 1999. Yurok Tribal Fisheries Program Technical Report. Klamath, CA. 50p.

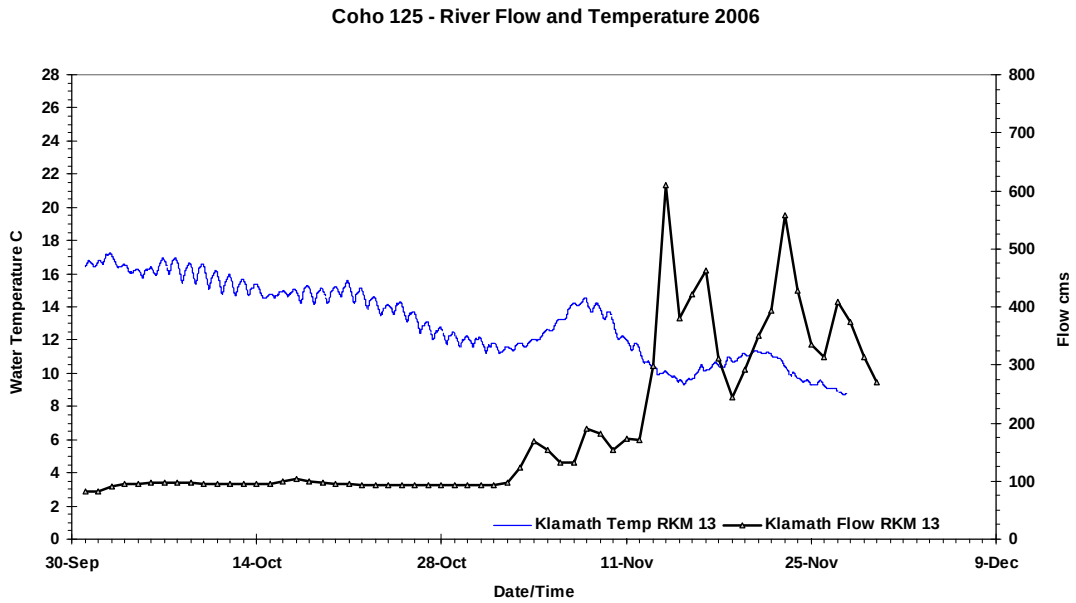
6.0 APPENDIX 1. Tagging data and fate or last observation summary for all 80 adult Chinook salmon tagged in 2006. All fish were tagged at the mouth of the Klamath River. TRH = Trinity River Hatchery. IGH = Iron Gate Hatchery.

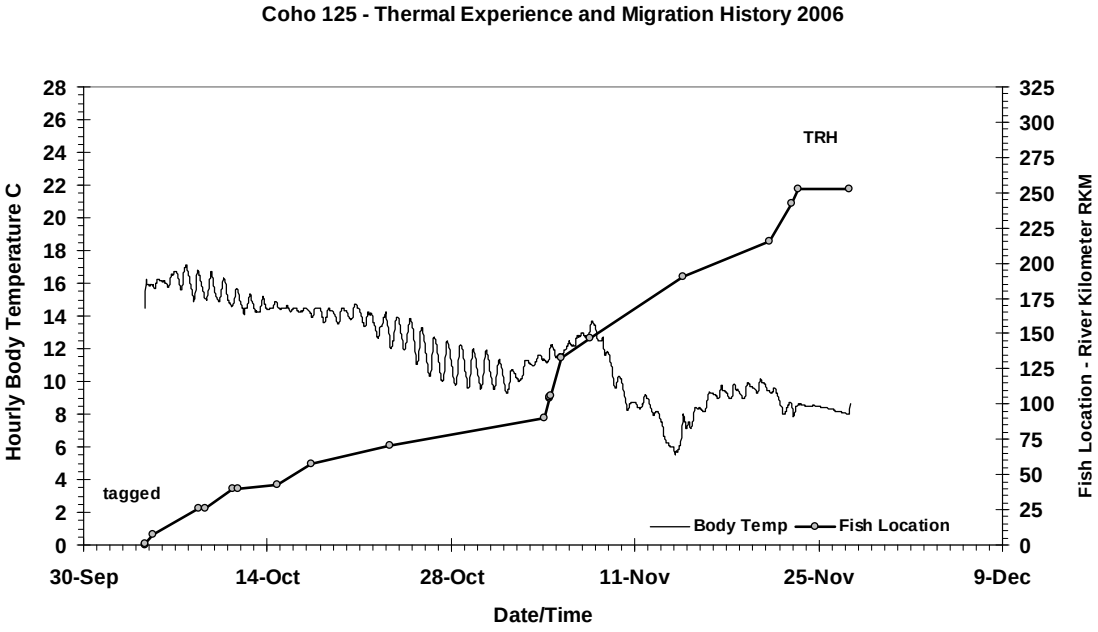
Tagging Date	Tag Code	Jaw Tag #	Sex	Fork Length (cm)	Archival Data Recovery	Adipose Fin Clip	Fate or Last Observation	Last Reach or River
6/8/2006	**151.740**	101		92		N	above Junction City 7/23	Trinity
6/8/2006	**151.520**	102		75		N	no observations	na
6/14/2006	**151.480**	103		81		Y	above Bucktail 7/26	Trinity
6/20/2006	**151.320**	104		70		N	above Junction City 7/24	Trinity
6/26/2006	**151.280**	105		74		N	above Moores 7/4	lower Klamath
6/26/2006	**151.500**	106		75		N	caught Weitchpec 8/7	lower Klamath
7/6/2006	**151.880**	107		79		N	no observations	na
7/6/2006	**151.360**	108		79	y	N	caught in Weitchpec Gorge 7/14	Trinity
7/6/2006	**151.340**	109	female	86		N	moribund Pigeon Point 8/18	Trinity
7/7/2005	**151.620**	110		77		N	caught estuary mouth 8/1	lower Klamath
7/11/2006	**151.600**	112		77		N	no observations	na
7/12/2006	**151.700**	111		79		N	no observations	na
7/19/2006	**151.720**	113		79		N	no observations	na
8/1/2006	**36**	114		77		Y	no observations	na
8/15/2006	**41**	115		91		N	above Hornbrook 10/3	Klamath
8/23/2006	**43**	116	female	79	y	N	TRH 11/8	Trinity
8/23/2006	**54**	117		79		N	Weitchpec Trinity 9/11	Trinity
8/30/2006	**56**	118		75		N	above Blue Creek 9/2	lower Klamath
9/1/2006	**48**	119	male	80	y	N	IGH spawned 10/23	Klamath
9/1/2006	**51**	120		78.5		N	no observations	na
9/1/2006	**37**	121		89		N	above China Slide 10/9	Trinity
9/1/2006	**47**	122		75		N	no observations	na
9/5/2006	**49**	123		92		N	above Bucktail 10/31	Trinity
9/5/2006	**52**	124		69		N	no observations	na

9/5/2006	**55**	125	79		Y	seal predation	na
9/6/2006	**33**	126	80		N	above Bucktail 10/28	Trinity
9/6/2006	**34**	127	87		N	no observations	na
9/6/2006	**35**	128	87		N	above Bucktail 11/6	Trinity
9/6/2006	**38**	129	79		N	caught near Pecwan after 9/30	lower Klamath
9/6/2006	**46**	130	74		N	no observations	na
9/6/2006	**40**	131	82		N	above Ogorman's 11/3	Trinity
9/6/2006	**39**	133	95		N	no observations	na
9/7/2006	**50**	134	67		Y	regurgitation or killed	na
9/7/2006	**44**	135	78		N	TRH 11/10	Trinity
9/7/2006	**53**	136	80		N	Weitchpec 9/19	
9/12/2006	**92**	137	72		N	above Ogorman's 11/3	Trinity
9/12/2006	**103**	138	73		N	Hornbrook 10/10 and 10/26	Klamath
9/12/2006	**93**	139	75		N	seal predation	na
9/12/2006	**105**	140	68		N	Wakel 9/21	lower Klamath
9/12/2006	**106**	160	79		N	above Hornbrook 10/19	Klamath
9/12/2006	**95**	155	76		N	seal predation	na
9/14/2006	**109**	156	76		N	regurgitation or killed	na
9/14/2006	**99**	157	76		N	caught at Weitchpec after 10/6	lower Klamath
9/14/2006	**98**	158	77		Y	seal predation	na
9/15/2006	**228**	154	74		N	seal predation	na
9/15/2006	**229**	153	76		Y	ocean	ocean
9/15/2006	**113**	152	73		N	ocean	ocean
9/15/2006	**94**	151	79	y	N	caught near Hoopa 9/23	Trinity
9/20/2006	**96**	150	75		N	above Orgorman's 11/4	Trinity
9/20/2006	**102**	149	74		?	no observations	na
9/20/2006	**101**	148	73		N	seal predation	na
9/20/2006	**97**	147	73		N	above Blue Creek 9/23	lower Klamath
9/20/2006	**100**	146	78		N	no observations	na
9/20/2006	**107**	145	71		N	above Big Bar 10/18	Klamath
9/20/2006	**112**	144	79		N	TRH 11/4 to 11/14	Trinity
9/20/2006	**108**	143	66		N	caught at RKM 19 on 9/25	lower Klamath

9/20/2006	**115**	142		84		N	seal predation	na
9/22/2006	**124**	141		82		N	regurgitation or killed	na
9/22/2006	**126**	172		80		Y	no observations	na
9/22/2006	**104**	179		78		N	no observations	na
9/22/2006	**111**	175		68		N	regurgitation or killed	na
9/22/2006	**122**	176		100		y	no observations	na
9/22/2006	**119**	177		81		N	regurgitation or killed	na
9/22/2006	**110**	178		68		Y	regurgitation or killed	na
9/22/2006	**135**	180		77		N	seal predation	na
9/23/2006	**133**	172		80		N	no observations	na
9/23/2006	**114**	174		78		N	seal predation	na
9/23/2006	**123**	167	female	78	y	N	spawned TRH 11/14	Trinity
9/26/2006	**127**	168		81		N	above Weitchpec Trinity 10/24	Trinity
9/26/2006	**116**	169		66		N	no observations	na
9/26/2006	**121**	170		70		N	above Hawkins Bar 11/2	Trinity
9/26/2006	**132**	171		81		N	above Big Bar 10/29	Klamath
10/5/2006	**134**	165		72		N	seal predation	na
10/5/2006	**120**	162		76		N	no observations	na
10/6/2006	**131**	161	female	79	y	N	spawned at TRH 11/27	Trinity
10/6/2006	**130**	163		68		N	seal predation	na
10/6/2006	**128**	164		83		N	seal predation	na
10/6/2006	**129**	189		83		?	above Hoopa 11/6	Trinity
10/6/2006	**118**	190		72		N	no observations	na
10/6/2006	**136**	191		74		N	no observations	na

7.0 APPENDIX 2. Migration history and thermal experience of coho 125 in comparison to river temperature and flow in the lower Klamath River at RKM 13. Coho 125 was tagged at the mouth of the Klamath River on 10/4/2006 (fork length 69 cm, male, coded wire tag #47233) and recovered at the Trinity River Hatchery on 11/27/2006.





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