Adult Chinook Salmon Migration in the Klamath River Basin:

2005 Sonic Telemetry Study Final Report

Mouth of the Klamath River with estuary in the background, summer 2005. Photo by author.

Joshua Strange
Yurok Tribal Fisheries Program, and
School of Aquatic and Fishery Sciences - University of Washington;
in collaboration with Hoopa Valley Tribal Fisheries
January 2007

TABLE OF CONTENTS

Acknowledgments ………………………………………………………………….. 3

Executive Summary ……………….…………………………………………….. 4

1.0 Introduction ………………………………………………………………. 6

1.1 Study Objectives ………………………………………………….. 11

2.0 Methods ………………………………………………………………… 12

2.1 Study Area ………………………………………………………. 12

2.2 Tagging and Telemetry ……………………………………………. 13

2.3 Temperature and Flow Monitoring ………………………………… 14

2.4 Data Analysis Approach …………………………………………….. 15

3.0 Results and Discussion………...……………………………………….. 16

3.1 Tagging and Fate Summary 16

3.2 Environmental Conditions ………………………………………… 19

3.3 Migration Behavior and Experience ………………………………. 21

3.4 Summary of Major Conclusions ……………………..…………… 36

3.4 Summary of Major Recommendations ……………………………. 37

4.0 Tables and Figures ………………………………………………….. 39

5.0 Literature Cited ………………………………………………………… 87

6.0 Appendix 1 ……………………………………………………………….. 93

ACKNOWLEDGEMENTS

This project would have not been possible with out the collaborative assistance of numerous entities and individuals, in particular the Yurok Tribal Fisheries Program, Hoopa Valley Tribal Fisheries, and the School of Aquatic and Fishery Sciences (SAFS) at the University of Washington. I graciously thank my SAFS graduate committee members Dr. Robert Wissmar, Dr. Walt Dickoff, Dr. Carl Schreck, and Dr. Tom Quinn for their guidance and expertise in developing this research project. The following individuals provided critical logistical, technical, and/or field support: Michael Belchik, Ryan Benson, Charlie Burns, Rocky Erickson, Dave Hillemeier, Joe Hostler, Gerald Lewis Jr., Josh Lewis, Billy Matilton, Barry McCovey Jr., Arni Nova, Paul Petros, and Dwane Sherman. I would also like to thank Vemco, Alpha Mach, the California Department of Fish Game, the Karuk Tribe, the US Fish and Wildlife Service, US Forest Service Orleans District, numerous volunteers, and 88 anonymous Chinook salmon for risking life and fin to provide valuable data. Funding for this collaborative study was provided by the Klamath Basin Fisheries Task Force, the Trinity River Restoration Program, NOAA Fisheries Arcata Office, the Bureau of Reclamation, the Yurok Tribe, the National Science Foundation – Graduate Research Fellowship Program, and the Pacific Coastal Salmon Recovery Fund. Any views and conclusions presented herein are solely of the author and do not necessarily reflect the official views of any funders or collaborators.

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 migration behavior in the KRB throughout the spectrum of run-timing. Specific components include determining travel 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 2005 study year.

During 2005 a total of 88 adult Chinook were tagged at the terminus of the Klamath River with the Pacific Ocean from 7/28/05 to 10/7/05 with temperature sensitive esophageal ultrasonic transmitters (Vemco V16T-3L-S256), coupled with an archival temperature device (AlphaMach iB22L) 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 88 adult Chinook, 26 (30%) eventually migrated upriver out of the estuary after tagging while 62 (70%) never migrated beyond the estuary. In previous study years this latter ratio ranged from 43 to 56%. Of the 62 fish that did not migrate upriver from the estuary, 2 (3% of 62) were definitively harvested, 6 (10%) likely regurgitated their tags, 25 (40%) disappeared with no further detections, and 29 (47%) were confirmed to have been eaten by pinnipeds, in particular California sea lions. Pinniped predation appeared to be a major driver of adult Chinook behavior in relation to the estuary and contributed to minimal estuary residence. On average tagged Chinook spent 94% of their time in the ocean after tagging and prior to initiation of upriver migration. The behavior and resulting thermal experience of tagged Chinook while in the ocean was consistent with continued feeding, which is the one of the primary potential benefits of additional ocean residency along with reduced cumulative thermal experience and predator avoidance. Of the 26 tagged Chinook that did migrate upriver from the estuary, at least 21 (81% of 26) successfully arrived to spawning grounds (8) or a hatchery (13); at least 3 (11%) were harvested; and 2 (8%) disappeared during migration. Out of these same 26 tagged Chinook, 11 (42%) migrated into the Klamath River above Weitchpec, 12 (46%) migrated into the Trinity River above Weitchpec, and 3 (12%) were never observed migrating above Weitchpec.

Thus 23 tagged Chinook migrated upriver beyond Weitchpec, termed migrants, and served as the basis of analysis of migration behavior by run-timing and destination. Three distinct groupings or runs emerged during the summer and fall of 2005: summer Chinook, Klamath fall Chinook, and Trinity fall Chinook. 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.

Summer Chinook migrants, as defined by their summer run-timing and unique migrational patterns, were tagged from 7/28/05 to 8/18/05 and initiated upriver migration from 8/11/05 to 8/25/05 in response to weak, weather-induced cooling events that

allowed them to swim rapidly to pre-spawn holding habitat in the upper Trinity River as had been generally observed in all previous study years. Racially almost all of these fish were most likely Trinity River "spring" Chinook based on their spawning location and timing, along with the fact that Trinity River Hatchery "spring" Chinook have dominated harvest in the estuary in late July and early August over approximately the last decade. The reason(s) why this has occurred are inconclusive but was likely due to a combination of cross-breeding of spring and fall Chinook at the Trinity River Hatchery and adjacent mainstem, and post-dam selection pressures favoring the creation of summer run-timing.

Klamath fall Chinook migrants were tagged from 8/23/05 to 9/12/05 and initiated migration in a relatively tight cluster from 9/6/05 to 9/23/05 (with one possible exception on 8/19/05), primarily bound for the Iron Gate Hatchery or nearby natural spawning areas. Klamath fall Chinook migrants in 2005 displayed equivalent movement patterns as Klamath fall Chinook migrants in years (2003 and 2004) with autumn pulsed flow releases from the Trinity dams; 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 or without pulse flows is compelling evidence that these flows did not trigger upriver movement or otherwise substantially alter migration behavior. The Trinity boat dance flow of late August 2005 also did not noticeably affect adult Chinook migration behavior. Given that fall Chinook (Klamath stocks in particular) hold extensively (e.g. 19.6 days maximum) and travel slowly (i.e. 3.8 km/d on average) through the lower Klamath River below Weitchpec as part of their apparent normative migration behavior strategy, they are especially vulnerable to infection and mortality from the ciliated protozoan *Ichthyophthirius multifiliis* (*Ich*) with pathogen transmission risk increasing as flows decrease. Thus increasing base flow releases during the fall Chinook migration season is the most effective management tool for reducing the risk of *Ich* outbreaks such as occurred in September of 2002.

Trinity fall Chinook migrants were tagged from 8/29/05 to 9/8/05 (one fish on 10/5/05), and were more dispersed in their timing of initiation of upriver migration, which ranged from 9/2/05 to 9/22/05 (one fish on 10/16/05) with fish bound for the Trinity River Hatchery or nearby natural spawning areas. Trinity fall Chinook migrants also held extensively (e.g. 16.3 days maximum) and traveled slowly (i.e. 4.1 km/d on average) through the lower Klamath River. After entering the lower Trinity River, Trinity fall Chinook encountered a counting weir at Willow Creek, CA. Including summer Chinook migrants, all tagged Chinook that passed the Willow Creek weir during its normal operation experienced migration delays ranging from 3.5 to 31.1 days. Telemetry data showed that adult Chinook do take advantage of daily and weekend openings, but substantial delays still occur possibly because the weir structure itself frightens fish.

No behavioral thermoregulation was observed by fall Chinook migrants at enroute thermal refuges (i.e. cool creek confluences) but 38% of summer Chinook migrants used enroute thermal refuges such as Blue Creek for ≥24 hrs. Based on results from all study years, the thermal threshold for migration inhibition for KRB adult Chinook salmon occurs at mean daily water temperatures above 23.5^{o}C if temperatures are falling, below 21.0^{o}C if temperature are rising, and above 22.0^{o}C if temperatures are stable.

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 its interaction with environmental conditions and variability requires understanding how salmon life histories have evolved. There is an extensive body of literature on life history theory (see reviews by Stearns 1980; Roff 2002), including specifically for fish and salmonid migrations (see reviews by Legget 1985; Dodson 1997). A central assumption of life history theory is that natural selection produces 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 coadapted 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 (*Oncorhynchus nerka*) migration timing and found that in the absence of adverse environmental conditions (defined as water temperatures >19°C) sockeye timed their migration 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 same selective pressures, which appears to be the case with spring and fall run Chinook salmon (*O. tshawytscha*) for example. With spring Chinook, 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 requires foregoing ocean feeding opportunities. With fall Chinook, 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.

In the Klamath River Basin (KRB) of northern California and southern Oregon (Figure 1) for example, Chinook 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 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 of their natal rivers (Gilhousen 1960; Brawn 1982; Potter 1988), which presumably allows them to undergo the process of osmotic transformation, 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). Telemetry and archival temperature tag data from previous study years suggest that adult Chinook use the salt wedge of the Klamath River estuary as a thermal refuge habitat prior to fresh water migration. 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, thus holding in estuaries may present a compromise between the need to delay until after adverse riverine conditions have ceased and 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, thus most stocks have a sufficient 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 enroute 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 stressfully high temperatures during migration. Thermal refuges typically take the form of thermally stratified pools, groundwater or hyporheic seeps and springs, cold tributary confluences, or cool stream reaches (Bilby 1984; Torgersen et al. 1999). Numerous researchers have documented thermal refuge use by salmonids for behavioral thermoregulation (Kaya et al. 1977; Belchik 1997; Nielsen et al. 1994; Kaeding 1996; Ebersole et al. 2001), and thermal refuges play an important role for adult Chinook in the KRB and other similar basins, such as the Yakima (Berman and Quinn 1991) and John Day (Torgersen et al. 1999). The presence and use of thermal refuges may allow for the persistence and increase the carrying capacity of stocks in thermally marginal streams and habitats (Burns 1971; Kaya et al. 1977; Torgersen et al. 1999; Ebersole et al. 2001).

Use of thermal refuges can occur at a wide range of temperatures, but becomes more probable with rising temperatures until it becomes the norm as thermal thresholds are exceeded (sub-lethal 20°C, and upper incipient lethal 25°C, Armour 1991; Bjornn and Reiser 1991; Bartholow 1995). A threshold of particular importance to salmonids is the thermal limit for migration. In the case of both adult sockeye and Chinook salmon, 21°C has emerged as the currently accepted thermal limit to migration (Quinn et al. 1997; McCullough 1999). Regardless of the level of accuracy of such conclusions, 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.

Migrational 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 and quantity of holding habitat. High quality thermal refuge holding habitat in sufficient availability can greatly reduce the costs (Berman 1990; Torgersen et al. 1999), but 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 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 cope with high water temperatures during their spawning migration?

2. What temperatures are adult Chinook experiencing during their migration in comparison to river temperatures?
3. How do adult Chinook respond to environmental variables such as temperature and flow during upriver migration?
4. What spatial and temporal patterns of thermal refugia use (behavioral thermoregulation) are displayed by adult salmonids during their spawning migration?
5. What is the run-timing distribution of Chinook 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 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 Fish and Wildlife Office, the Karuk Tribe's Department of Natural Resources, and the US Forest Service Orleans District Office. In 2005 we continued this approach in cooperation with Hoopa Valley Tribal Fisheries (HVTF), but switched from temperature sensitive radio to temperature sensitive 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 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 Klamath River Basin during the 2005 spawning migration season. Specific objectives of this study were to:

1. Determine the migration behavior and thermal experience of adult Chinook in the KRB throughout the spectrum of run-timing;

2. Analyze behavioral response 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;
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^{o}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 2005 the access to Blue Hole became too shallow for adult Chinook to access during low flow conditions in the summer and fall.

2.2 Tagging and Telemetry

Temperature sensitive sonic transmitters were used to track the movements and internal body temperatures of adult Chinook salmon during summer and fall spawning migration in the KRB in 2005. The sonic transmitters used were Vemco esophageal coded transmitters (V16T-3L-S256; W16 x L73 mm, 28 grams). 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 sonic transmitter to record internal body temperature every hour. All tags were tested prior to use. Each fish was externally marked with a jaw tag (i.e. hog ring).

Adult Chinook were captured using drift gill nets, tagged, and released at the mouth of the Klamath River from 7/28/05 to 10/7/05. No effort was made to capture and tag Chinook at the Blue Creek/Blue Hole thermal refuge during 2005, partly due to the changed configuration of the outlet of Blue Hole resulting in exclusion of most Chinook. Each captured salmon was held and immobilized in a 250 gallon live tank on the shore with the aid of a cradle, measured (fork length cm), tagged, 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 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 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 32 automated sonic listening stations (Vemco VR2s) were placed throughout the KRB at strategic locations to continuously monitor fish presence or absence and 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. No mobile tracking was undertaken.

Hatchery personnel, snorkel count and carcass survey participants within the study area were notified of the study in order to assist with located tagged Chinook 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 fisheries 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 each week throughout the study period. Regardless of the exact degree of representation, the results of this and other similar studies do provide valid illustrative results that allow a window of observation into an otherwise elusive subject.

Telemetry studies allow a determination of behavioral patterns and provide a basis for determining 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 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 tagged Chinook salmon is summarized in Appendix 1. All Chinook were tagged at the mouth of the Klamath River (south shore), and after tagging not all Chinook survived to migrate beyond the estuary. Out of the total sample of 88 adult Chinook, 26 (30%) migrated upriver from the estuary after tagging while 62 (70%) never migrated beyond the estuary. In previous study years this latter ratio ranged from 43 to 56%, 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 2005, the relative contribution of these factors was largely determined through use of sonic transmitters, which are detectable in high salinities, along with a network of five sonic receivers placed throughout the estuary plus one in the nearshore ocean. Results showed that pinniped predation was the primary cause of ‘disappearance’ with 29 (33% of 88 or 47% of 62) tagged Chinook 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 that were eaten whole or nearly so, thus it can be assumed that more than 29 tagged Chinook were killed by pinnipeds. Of the remaining 33 tagged Chinook that disappeared in the estuary/nearshore, 2 (3% of 62) were harvested (claimed), 6 (10%) likely regurgitated their tags (although predation cannot be ruled out), 8 (13%) were last detected in the estuary, 7 (11%) were last detected headed back to the ocean, and 10 (16%) completely disappeared after tagging with no detections.

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 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 33% pinniped predation rate observed for tagged Chinook in the estuary/nearshore during 2005. However, the rate of pinniped predation observed on tagged Chinook in 2005 should definitely not be inferred to reflect the predation rate on the Chinook run as a whole in 2005. Tagged Chinook 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, even without the use anesthesia which would likely increase recovery time. Indeed, most tagged Chinook that were preyed upon were eaten relatively quickly after release (minutes to 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 2005 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. 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. Second, pinniped predation pressure appears to be a major driver of adult Chinook 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.

Determination of percentages of end fates for tagged Chinook that did migrate upriver from the estuary was complicated by the disappearance of fish enroute which could have occurred for a variety of reasons (i.e. disease mortality, unclaimed harvest, tag regurgitation, or migration into an unmonitored tributary). Taking this into account, of the 26 tagged Chinook that did migrate upriver from the estuary at least 21 (81% of 26) successfully made it to spawning grounds (8) or a hatchery (13); at least 3 (11%) were harvested; and 2 (8%) disappeared during migration. Out of these same 26 tagged Chinook, 11 (42%) migrated into the Klamath River above Weitchpec, 12 (46%) migrated into the Trinity River above Weitchpec, and 3 (12%) were never observed migrating above Weitchpec (RKM 70) due to harvest (2) or disappearance (1). Based on a process of elimination, only the three migrants that disappeared during migration could have migrated into unmonitored tributaries. In the three monitored tributaries (Salmon, Scott, and South Fork Trinity Rivers), only one tagged Chinook was detected; Chinook 115 in the lower Scott River, which initially resided in the spawning area on the mainstem Klamath River above the Shasta River confluence.

Thus a total of 23 tagged Chinook 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 in Table 2. These migrants will serve as the basis of analysis of adult Chinook migration behavior by run-timing and destination/stock groups.

Sonic receivers preformed without failure and with no known missed detections of any fish at any station with the exception of the ocean receiver. Based on this, it is recommended that temperature sensitive sonic transmitters remain the featured tag for future studies. 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 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 migration season.

3.2 Environmental Conditions

River Flow

Annual hydrographs for the 2005 study period are presented for the Klamath and Trinity Rivers plus select tributaries in Figures 2 through 9. All flows are reported as mean daily flow measured in cubic feet per second (cfs), and all RKMs are measured from the mouth of the Klamath River.

Based on the Natural Resource Conservation Service (NRCS) April 1, 2005 hydrological forecast for inflow into Upper Klamath Lake, the US Bureau of Reclamation (USBR) classified the water year type as "dry" for Upper Klamath Lake level and Klamath River discharge operations planning. Due to heavy precipitation in early May, NRCS upgraded the UKL inflow forecast to a "below average" water year type, and IGD flows were altered accordingly (Figure 5). In contrast, the water year designation for the Trinity sub-basin was “wet” in 2005 due to overall higher precipitation and snow pack, which resulted in flow releases from Lewiston Dam (Figure 8) 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 2005 are presented in Figure 10. 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 2005, spring snowmelt from unregulated tributaries generally occurred from mid-March to mid-June with a peak on 5/19/05. After the peak, the descending limb occurred uninterrupted except for a smaller peak on 6/18/05 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 7,000 cfs on 5/13/05 followed by an extended bench release of approximately 2,000 cfs that lasted from 5/26/05 to 7/9/05 with the ramp down completed by 7/19/05 (Figures 6 and 8). The timing, duration, and magnitude of spring snowmelt flows are extremely important for in-migrating adults, 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 11).

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 and 2005) (Figure 10). The only special flow release in 2005 was a two-day pulse flow of approximately 1,600 cfs was released from Lewiston Dam on 8/28/05 to 8/30/05 for the purpose of meeting ceremonial obligations to the Hoopa Valley Tribe (boat dance flow). The first substantial natural increase in river flows throughout the KRB from precipitation after the summer dry season did not occur until 11/6/05.

Water Temperature

Hourly water temperatures at various locations throughout the KRB during the adult Chinook salmon migration season are presented in Figures 12 to 17. Water temperatures in the lower Klamath River at Blake's (RKM 13) first ≥20ºC on 6/28/05 and ≥22ºC on 7/14/05 with a maximum of 25.2ºC on 8/8/05 (Figure 12). After the annual peak, water temperatures declined minimally until 8/18/05, during which time mean daily water temperatures (MDTs) did not drop below 22ºC. Seasonal cooling began on 8/28/05 with water temperatures ≥22ºC for the last time on 9/1/05 and ≥20ºC on 9/8/05. This pattern was generally consistent throughout the lower KRB with the exception of the upper Trinity River, which is heavily influenced by cold hypolimnetic releases from Trinity and Lewiston Dams. There was no substantial cooling (decrease of mean daily water temperatures >2ºC) of water temperatures during late July or early August, 2005. In contrast, substantial weather-induced cooling events occurred during this time period during all other previous study years. Hourly water temperatures for the nearshore ocean at the sonic station are presented in Figure 18, and estuarine temperatures are presented in Figure 19.

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’ 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 specific group of fish and generally has four main components: river entry from the ocean into the estuary, initiation of upriver migration from the estuary, arrival at a subjective point along the migration path, and arrival to pre-spawn holding areas or spawning grounds. For example the phrase ‘summer run’ as used herein denotes a group of migrating adult Chinook 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 to other runs require performing the appropriate genetic analysis from tissue samples. Such an analysis is possible but has not yet been conducted and is beyond the scope of this report.

For tagged Chinook 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. Given the later initiation of tagging in 2005, only three runs were tagged and identified: summer Chinook, Klamath fall Chinook, and Trinity fall Chinook.

Chinook tagged from 7/28/05 to 8/18/05 initiated upriver migration from 8/11/05 to 8/25/05 as a distinct group exhibiting a unique combination of migration behaviors and can thus be considered summer run Chinook. Racially almost all of these fish were most likely late-run Trinity River spring Chinook. Trinity River Hatchery (TRH) spring Chinook have dominated harvest in the estuary during late-July and early-August for approximately the last decade (YTFP unpublished data), including 2005 (Figure 20). The reason(s) why this is occurring are inconclusive but is likely due to a combination of cross-breeding of spring and fall Chinook at the TRH and in the upper Trinity River, and post-dam selection pressures favoring the creation of summer run-timing.

The only summer Chinook migrant that did not migrate to the Trinity River during 2005 was Chinook 146, which migrated up the Klamath River to Iron Gate Hatchery (IGH) where it was spawned on 9/26/05. Harvest data from the YTFP indicates that some IGH fall Chinook are typically present in the estuary during the first half of August and every year a few Chinook return to IGH as early as late September (the bulk of the run usually arrives by mid-to-late October; personal communication, Kim Rushton CDFG). This suggests that Chinook 146 was an early migrating Klamath fall Chinook and not a stray fish of Trinity River origin. Interestingly, Chinook 146 displayed migration behavior (e.g. movement history) indistinguishable from Trinity summer Chinook and distinctly different from Klamath fall Chinook migrants. Thus if Chinook 146 was indeed of IGH/Klamath fall Chinook origin as is likely, then its movement history demonstrates that environmental conditions can trump genetic control over migratory behavior.

With the possible exception of Chinook 146, Klamath fall Chinook were tagged from 8/23/05 to 9/12/05, which matched the timing of recoveries of coded wire tags (CWTs) from IGH fall Chinook harvested in the estuary during the 2005 sport fishing season (Figure 20). IGH fall Chinook run-timing was several days later in 2005 than in 2004 or 2003, but was still generally consistent with the average for IGH fall Chinook based on CWT recoveries in the estuary, which usually peaks during late August to early September (YTFP unpublished data). Klamath fall Chinook initiated upriver migration from the estuary in a relatively tight cluster from 9/6/05 to 9/23/05 (one fish on 8/19/05), which matched CWT recoveries for IGH fall Chinook in the lower Klamath River above the estuary (Figure 20).

Trinity fall Chinook were tagged from 8/29/05 to 9/8/05 and on 10/5/05, and were more dispersed in their timing of initiation of upriver migration, which ranged from 9/2/05 to 9/22/05 (one fish on 10/16/05). In 2005, CWT recoveries from TRH fall Chinook in the sport creel displayed a bi-modal peak in both the estuary and lower

Klamath River (Figure 20). The first peak occurred during Julian Week (JW) 36 and generally corresponded to the tagging dates of Trinity fall Chinook migrants, while both peaks (JWs 36 and 38) corresponded to the timing of initiation of upriver migration. This dispersion is also reflected in the average for TRH fall Chinook based on CWT recoveries in the estuary, which usually begins increasing by late-August with a peak in mid-to-late September (YTFP unpublished data).

Migration Histories

Travel rates were highly variable among all migrants and for a given migrant over the course of its migration path (again the term migrant refers to tagged Chinook with known destinations). Travel rates ranged from zero during periods of holding up to 52.4 km/d during rapid upriver migration in certain reaches. No easily discernable universal movement patterns emerged when all migrants were viewed in total (Figure 21). However, when separated into groups by run-timing and destinations, consistent movement patterns did emerge as a function of river kilometer or reach. Simply put, 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 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 (critical thermal refuge), Moore's Rock (deepest pool in Klamath River), Weitchpec (Klamath/Trinity 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 counting weir (if installed), 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 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 behavior.

Specifically, summer Chinook migrants (as defined by run-timing and migration behavior) exhibited similar movement patterns with considerably greater travel rates compared to other migrant groups. Location via river kilometer versus date for the summer Chinook migrant group (*n*=8) is presented with applicable landmarks and compared to river temperature and flow in Figure 22. Essentially the migration strategy of this group is to: 1) enter the estuary during the summer after the onset of temperatures in excess of the migration threshold, which presumably allows extended ocean feeding and improved body energy content as compared to spring entry; 2) wait in the estuary/nearshore until a suitable weather front creates a window of cooling river temperatures that allows a sprint upriver to holding pools in the cool-water reach starting at the North Fork Trinity confluence (RKM 187) near Junction City; and 3) use thermal refuges (e.g. Blue Creek) only if caught enroute by rising temperatures ≥21ºC. These fish arrive well within the spawning window for spring Chinook and indeed four of the migrants in this group were spawned at TRH as "spring" Chinook, and the rest were dead or spawned out by the end of the spring Chinook spawning window. As has been observed in all previous years of this study, at least one summer Chinook migrant traveled relatively rapidly to the TRH or nearby spawning riffles after an extended period of holding in the Junction City area.

There are two notable facts for the summer Chinook migrant group that were unique to 2005: 1) no substantial cooling of river temperatures occurred until late August (i.e. 8/25/05) in contrast to all other study years when weather-induced cooling occurred consistently during the first week of August; and, 2) a presumed Klamath stock fall Chinook (146) was interspersed with this otherwise exclusively Trinity River group of migrants.

The influence of temperature and the importance of weather-induced cooling to summer Chinook migrants can be demonstrated by comparing and contrasting the events of 2002-2004 versus 2005. In 2002-2004, weather-induced cooling events in early August allowed summer Chinook migrants to sprint upriver in response to strongly falling temperatures with MDTs falling below 23.5ºC and 22ºC. In 2005, the absence of a substantial weather-induced cooling event forced summer Chinook migrants to hold longer in the estuary/nearshore, however, five of eight migrants in this group proceeded to sprint upriver in response to weakly cooling temperatures. During these periods of weak cooling, MDTs in the lower Klamath River fell below 23.5ºC coinciding with the timing of initiation of upriver movement, but did not ever fall below 22ºC. As an apparent consequence of the brevity and weakness of these periods of cooling temperatures, two (and likely a third) of these five migrants held in thermal refuges at Blue Creek until river temperatures began falling again. River temperatures began falling again due to seasonal cooling on 8/25/05 with MDTs ≥22ºC for the last time in 2005 on 8/29/05, which prompted the initiation or resumption of migration for the remaining summer Chinook migrants and coincided with estuary entry for the first Trinity fall Chinook migrant. The start of this seasonal cooling preceded the arrival of the boat dance pulse flow from Lewiston Dam by five days.

Regarding the second notable fact, Chinook 146 exhibited a movement pattern indistinguishable from Trinity summer Chinook migrants and distinctly different than Klamath fall Chinook migrants and yet was spawned at IGH on 9/26/05 suggesting either: 1) this fish was a stray Trinity River summer Chinook; or, 2) this fish was an early migrating Klamath fall Chinook and environmental conditions can trump the influence of stock specific genetic control over migration movement patterns. Pending genetic analysis of fin tissue from Chinook 146, the latter explanation is considered most likely because natural variation in run-timing within a given population or run of fish in a given year 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. Figures 20 and 26). Such spread in run-timing enhances persistence on an evolutionary scale by spreading mortality risks (Stearns 1976) and can be caused by numerous factors. For example, 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.

Chronologically the next group of migrants after summer 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*=10) is presented with applicable landmarks and compared to river temperature and flow in Figure 23. 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 moderately 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 steady upriver migration to spawning grounds in response to environmental and/or physiological 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. 9/9/05 to 10/3/05) 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 and have been relatively cold (i.e. 16ºC) during the end of this period. Furthermore, no thermal refuge use has been observed or documented among any tagged fall Chinook 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 Klamath fall Chinook in the lower Klamath River has occurred at a wide range of flows (i.e. 2,500 to 4,530 cfs at RKM 13), during stable flows, and during, after, and in the absence of a fall pulse flow from Lewiston Dam. 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. This is not the case however, which suggests that a physiological cue is involved such as the level of gonadal maturity and body energy content.

In other study years, multiple Klamath fall Chinook migrants initiated upriver migration immediately upon cessation of water temperatures ≥22ºC. In contrast, during 2005 no Klamath fall Chinook migrants initiated upriver migration until several days after water temperatures cooled below 22ºC and generally exhibited a slightly later run-timing compared to other study years (Figure 24). Some degree of variation in migration timing is expected, but one possible explanation for the later timing in 2005 was the exceptionally poor ocean feeding conditions during the spring and early summer. The nearshore ocean food web of western North America is fueled by upwelling of cold, nutrient rich bottom water in a seasonal cycle driven by northerly winds and the Coriolis Effect. 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). The resulting shortage of food caused elevated mortality and breeding failure in numerous sea bird species as was widely reported in popular press, but in addition salmon can be assumed to have been negatively affected also as evidence by the unprecedented observation of several emaciated adult spring Chinook harvested in the estuary (personal communication, Arnie Nova YTFP). Adult Chinook in general, and Klamath fall Chinook migrants in particular, likely stayed in the nearshore ocean longer than usual in 2005 in order to compensate for poor feeding earlier in the season. 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 face tradeoffs between maximizing body energy content and the need to begin freshwater migration with the appropriate window of opportunity.

During the fall of 2003 and 2004 a pulse of water was released from Lewiston Dam (Figure 10) 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 trigger adult Chinook to migrate out of the lower Klamath River, thereby reducing fish densities and the risk of disease infection and mortality. Based on telemetry data from tagged Chinook in 2003 and 2004, upriver movement was not triggered by these pulse flows except for the few Chinook that were already holding in enroute thermal refuges (e.g. Blue Creek). This conclusion is further supported by results from 2005, a year with no fall pulse flow aside from the two-day Trinity boat dance flow. Klamath fall Chinook migrants in 2005 displayed equivalent movement patterns as Klamath fall Chinook migrants in the 2003 and 2004 fall pulse flow years; both before, during, and after the pulse flows. This relationship was especially apparent for Klamath fall Chinook (Figure 24) but also held true for Trinity fall Chinook (Figure 25).

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 to enter the river early. This argument is refuted by the fact that the run-timing of Klamath fall Chinook in 2003 and 2004 was typical (Figure 26) along with the extremely late nearshore upwelling of 2005 (Hickey et al. 2005; PFEL 2006), which provides a likely explanation as to why Klamath fall Chinook were slightly late in 2005. Simply stated, consistent movement patterns with or without pulse flows is compelling evidence that these flows did not trigger upriver movement or substantially alter migration behavior among adult Chinook. The Trinity boat dance flow also did not noticeably affect adult Chinook migration behavior as this flow did not reach the lower Klamath River (at RKM 13) until 8/29/05 (with cessation on 9/1/05). This was before the initiation of upriver migration for any fall Chinook migrants and after the initiation of upriver migration for all summer Chinook migrants.

Understanding why there was virtually no response to any of the fall pulse flows among fall Chinook 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 were well outside the range of long term average conditions to which KRB adult Chinook have adapted. The only natural equivalents are ephemeral and inconsistent flash floods in mountainous tributaries.

In the absence of dispersal of adult Chinook in reaction to a pulsed flow, higher flows (pulsed or base flows) can still substantially reduce the risk of pathogen transmission and disease mortality. This is accomplished primarily by increasing river flow volume and secondarily by reducing water temperatures (thermal effects are location and release specific). Most importantly for *Ich*, higher flows increase turnover rates and water velocities that serve to flush out pathogens and decrease fish-to-fish 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*. Once the fish density threshold was crossed for a given setting, flow via turnover rates and water velocities would be the primary determinants of *Ich* infection and mortality rates (e.g. controlling factors). Given that fall Chinook (Klamath stocks in particular) 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). Since these relationships are likely not field testable in a controlled experimental manner, it is incumbent on river mangers to make risk averse decisions in the face of uncertainty in the exact 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 2005 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*=5) is presented with applicable landmarks and compared to river temperature and flow in Figure 27. Trinity fall Chinook migrants traveled slightly faster through the lower Klamath River than Klamath fall Chinook. Holding occurred at more variable locations but all Trinity fall Chinook migrants held or substantially slowed down for an extended period somewhere between Blue Creek and Hoopa (RKM 90). Also there was no marked increase in travel rates immediately after passing Weitchpec. 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 (WC) weir at RKM 105, which is a counting facility operated by the CA Department of Fish and Game. The influence of the WC weir on the migration behavior of adult Chinook is observable in the movement histories of Trinity fall Chinook migrants, especially when combined with summer Chinook migrants (Figure 28). All tagged Chinook that passed the WC weir during its normal operation experienced delays, ranging from 3.5 to 31.1 days. The individual delays experienced at the WC weir and the ratio of that delay to the travel time from the estuary to the WC weir is reported in Table 3. Only one of the 11 tagged Chinook that passed the WC weir in 2005 was actually trapped and counted; the rest passed during its daily or weekend openings. This demonstrates that adult Chinook take advantage of the openings, which likely serve to reduce delays but are apparently not sufficient to prevent substantial delays from continuing to occur. This could occur if the weir structure itself frightens fish. The deleterious effect of delays at the WC weir on the thermal experience of migrating Chinook can be seen by comparing the thermal experience of summer Chinook migrants 140 versus 143 (Figure 29). Both of these fish were tagged at the mouth of the Klamath River on 8/10/05, but Chinook 143 passed the site of the WC weir during the boat dance flows with minimal delay (1.0 d) while Chinook 140 arrived later and delayed for 31.1 days. Given the negative costs associated with unnatural delays in migration (Traxler et al. 1998; McCullough 1999), operational protocols of the WC weir should be modified to further reduce migration delays. If substantial delays cannot be eliminated, the utility of the WC weir should be reevaluated in the context of monitoring goals and alternative methods for meeting those goals.

Thermal Experience

Data from 11 archival temperature tags were successfully recovered allowing determination of the thermal experience during migration for these tagged Chinook. 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 30 to 40 arranged in order of tagging date.

Eight of these 11 archival tags were recovered from adult Chinook classified as migrants (8 of 23 migrants or 35%), including at least one per migrant group. Summary statistics are reported for a typical migrant from each migrant group in Table 4. The magnitude of the difference between the maximum and mean body temperature experienced is indicative of the extent to which migration behaviors reduced cumulative thermal exposure. For example, summer Chinook migrant 150 (Figure 33; spawned at TRH on 9/26/05) initiated upriver migration on 8/16/05 when minimum water temperatures were still >20ºC and experienced a maximum body temperature of 24.3ºC. In comparison its mean body temperature experienced was only 19.7ºC, thus a difference of 4.5ºC. This difference was largely due its migration behavior, specifically swimming rapidly to the cool water holding habitat of the upper Trinity River.

Estuary and Nearshore Ocean Residence and Behavior

Combined with the network of six sonic receivers in the estuary and nearshore ocean, archival temperature data allowed for a determination of adult Chinook 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 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). For example, summer Chinook migrant 150 was tagged on 8/12/05 but did not migrate upriver from the estuary and pass Wakel until 8/16/05. The archival body temperature data for this fish reflected the pattern described above for previous years, but occurred entirely in the nearshore ocean as revealed by the sonic receiver array and corroborated by water temperature data (Figure 41). Chinook 150 experienced increases in body temperatures close to those of the nearshore ocean surface and the estuarine salt wedge. The timing of these increases coincided with high tides, suggesting that this Chinook remained in close proximity to the mouth of the Klamath River and may have been moving closer inshore with high tides. Klamath fall Chinook migrant 122 also resided entirely in the ocean after tagging prior to initiation of upriver migration, in this case for a period of 10.2 days. In contrast to Chinook 150, Chinook 122 displayed a distinctly different thermal experience while residing in the ocean characterized by remarkably stable body temperatures of approximately 9.5ºC (Figure 42). The pattern in thermal experience displayed by Chinook 122 suggests two important conclusions. First, this fish must have swam further off-shore to colder, deeper waters since water temperatures as low as 9.5ºC were never recorded at the nearshore ocean sonic receiver (at surface or at 15m depth). Second, the remarkable 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).

Residence times in the estuary and/or nearshore ocean are reported for all migrants in Table 5. Residence times in the estuary were generally brief (e.g. mean of 0.7d or 16.8hr) with 94% of the time after tagging and prior to arrival at RKM 7 spent in the ocean on average. Once tagged Chinook moved past Requa and were detected at the Hunter Island station (RKM 2) they had usually initiated upriver migration and were committed to leaving the estuary. The primary meso-habitats used during this time were the deepest areas of the estuary (e.g. mouth, south cove, and along the north bank rip-rap from the vicinity of the Requa boat ramp to Salt Creek), which contained the greatest volume of cold, saline water (i.e. salt wedge) and also afforded more room to avoid hunting pinnipeds. A water quality profile for one such typical deep area along the north bank of the estuary at RKM 1.7 on 8/5/05 is shown in Figure 43. The salt wedge was never detected upriver from RKM 4 and became established for the first time for the season at this vicinity on 7/21/05.

The influence of pinniped hunting pressure on adult Chinook behavior in the estuary/nearshore was paramount, in particular by California sea lions. Adult Chinook 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, 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 gives predators such as humans and pinnipeds a significant advantage. Thus adult Chinook face tradeoffs between behaviors that will accomplish estuarine related tasks in an optimal manner and behaviors that will give the best chances of surviving the concentration of predators. The general lack of substantial residence times in the estuary and reliance on staging in the nearshore ocean indicate that avoiding predation is likely the primary driver of adult Chinook migration behavior (i.e. short residence times) in the Klamath River estuary. While humans are likely the top predator in the estuary in terms of numbers of salmon caught, California sea lions appear to be the top predator in terms of forcing Chinook behavior due to their active hunting, duration of residence, and numbers. This relationship was emphasized in 2005 compared to other study years due to the low returns of adult salmonids to the KRB. While pinniped predation is one of the factors that reduces Chinook 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

During the 2005 season, tagged Chinook were documented behaviorally thermoregulating solely at Blue Creek while enroute and in the estuary and nearshore ocean before commencing upriver migration in freshwater. Thermal refuge habitats associated with the mouth of Blue Creek have been important for adult Chinook during all study years. From 2001 to 2003, large numbers of adult Chinook (100s to 1,000s) have been observed residing in Blue Hole (adjacent to the mouth of Blue Creek) during late July to early August (personal observation). Beginning in 2004, shifting sediments decreased the depth of the outlet of Blue Hole to approximately 18 inches, which apparently behaviorally deterred adult Chinook from entering into Blue Hole. Smaller bodied adult steelhead continued to use this prime thermal refuge; however, adult Chinook began using the mouth of Blue Creek and the outwash of Blue Hole in greater numbers instead.

In 2005, the pattern observed in 2004 repeated itself with almost no adult Chinook observed in Blue Hole. However, the Blue Creek thermal refuge was still important with 75% of summer Chinook migrants spending at least enough time there to cool their body temperatures below that of the mainstem Klamath River. Two of these migrants (Chinook 146 and 155) spent extensive time at the Blue Creek thermal refuge (5 and 7 days), while the rest stayed only briefly (hours). The brief visits exhibited by several of the summer Chinook migrants probably occurs at some, if not many, of the other major enroute thermal refuges and is a behavior analogous to a quick recovery break, and while inconsequential in terms of cumulative thermal experience, it is likely beneficial to physiological performance. Overall in 2005, 38% of summer Chinook migrants and used an enroute thermal refuge for ≥24 hrs. Based on data for all study years, extended enroute thermal refuge use occurs for a minor but important portion of the spring and summer Chinook runs.

In contrast, fall Chinook migrants did not use the thermal refuge at Blue Creek even though many of these fish stayed in the vicinity for a period of days. For example, Trinity fall Chinook 102 resided continuously in the pool into which Blue Creek flowed for 14.5 days (Figure 27) but did not reside in the thermal refuge at any point long enough to cool its body temperature below that of the mainstem Klamath River (based on continuous recordings of its body temperature by the Blue Creek sonic receiver during this period). 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 hold in the lower Klamath River for reasons other than immediate behavioral thermoregulation.

One of the benefits of holding in the estuarine salt wedge and/or nearshore ocean 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 numerous and potentially interacting factors besides thermoregulation as previously discussed. Combined with a large (albeit shifting) volume, the salt wedge makes the Klamath River estuary the largest thermal refuge in the entire KRB with the exception of cold water reaches below Lewiston Dam on the mainstem Trinity River and in the headwaters of mountainous tributaries. Predation pressure reduces the survival benefit of making long term use of the estuarine salt wedge as a thermal refuge, while in comparison the ocean offers less risk of pinniped predation, colder temperatures, and greater feeding opportunities. This logic is borne out in the average amount of time spent in the estuary (0.7d) versus the nearshore ocean (11.5d) for tagged Chinook in 2005. Regardless of the proportion of residence spent in the estuary versus the nearshore, the presence of large volumes of cold water to hold in prior to initiation of upriver migration in freshwater is a critical component of the migration behavior strategies for all migrant groups.

Understanding behavioral thermoregulation requires understanding the thermal threshold for migration inhibition which is a critical trigger for thermal refuge use. Values for this threshold reported in relevant literature are typically 21ºC (e.g. see review by McCullough 1999). However, unpublished results from the 2002 study year indicated that adult Chinook migration in the KRB was inhibited when mean daily water temperatures ≥22ºC, at which point adult Chinook would seek out and reside in thermal refuges or delay migration and continue to hold in the estuary/nearshore. Since 2002 this relationship has been determined to be dependent on whether river temperatures were rising or falling. Tagged Chinook were observed migrating and ignoring thermal refuges at mean daily water temperatures up to 23.6ºC during periods of falling temperatures, and observed ceasing migration and retreating to thermal refuges at mean daily water temperatures of only 20.9ºC when water temperatures had started rising. In 2005 this relationship held true with the initiation of migration occurring when mean daily water temperatures where as high as 23.5ºC (e.g. 8/11/05). Thermally induced cessation of migration occurred at mean daily water temperatures as low as 22.3ºC (e.g. 8/21/05), although temperature dynamics during 2005 did not create a situation where mean daily water temperatures dropped below 21ºC followed by a subsequent rise. 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 if temperatures are falling, at mean daily water temperatures below 21.0ºC if temperatures are rising, and at mean daily water temperatures above 22.0ºC if temperatures are stable.

3.4 Summary of Major Conclusions

- Four distinct major runs of adult Chinook salmon occur in the Klamath River Basin: spring Chinook, summer Chinook, Klamath fall Chinook, and Trinity fall Chinook.
- The summer Chinook run, defined by their summer run-timing and unique migration strategy, is comprised almost entirely of Trinity River natural and hatchery fish that are most likely racially ‘spring’ stream-type Chinook. This phenomenon could have been produced by cross-breeding of spring and fall Chinook in the upper Trinity River and the Trinity River Hatchery, by post-dam selection pressures favoring creation of summer run-timing, or some combination thereof.
- Pinniped predation, in particular by California sea lions, was the single biggest factor resulting in loss of adult Chinook after tagging and before commencement of upriver migration out of the estuary. Pinniped predation also appears to be a major driver of adult Chinook behavior in the estuary contributing to minimal estuarine residence. However, it is important to consider 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 appears to reduce the probability of pinniped predation and also provides continued feeding opportunities and the lowest available water temperatures.

- Fall pulse flows exert minimal influence over adult Chinook migration behavior and have not triggered upriver movement by tagged Chinook migrants with the exception of the relatively few fish that were previously residing in enroute thermal refuges.
- The slow movement and extended holding observed during 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 to disease pathogen infection and mortality, especially for *Ich*. This vulnerability can be reduced by higher minimum flows because greater flow result 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 Klamath River Basin adult Chinook occurs at mean daily water temperatures above 23.5ºC if temperatures are falling, at mean daily water temperatures below 21.0ºC if temperatures are rising, and at mean daily water temperatures above 22.0ºC if temperatures are stable.
- The thermal refuge complex associated with the mouth of Blue Creek receives more use than any other enroute thermal refuge by adult Chinook migrants. Use of enroute thermal refuges occurs for a minor but important portion of the spring and summer Chinook runs with negligible use by fall Chinook.
- The Willow Creek weir causes substantial migration delays to adult Chinook salmon even with the implementation of daily and weekend openings.
- Critically important migration behaviors used by all major runs of adult Chinook include: estuary/nearshore ocean residence, quick reaction to changing river conditions, reach and condition specific adjustment of travel rates, and use of enroute thermal refuges only if acutely needed.

3.5 Summary of Major Recommendations

- Ensure adequate flows during the fall Chinook migration season in the lower Klamath River starting in late August in order to provide turnover rates and water velocities high enough to significantly reduce the probability of *Ich* infection and mortality. River 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 reduce disease risk, while also ensuring the ecological health and integrity of the mainstem Klamath and Trinity Rivers. Any proposed strategy of attempting to manipulate adult Chinook 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 in the Trinity River, the genetic origins of summer run Chinook, and implications and management options arising thereof.
- Improve operational protocols at the Willow Creek weir to further reduce migration delays. If substantial delays cannot be eliminated, the utility of the Willow Creek weir should be reevaluated in the context of impacts to adult salmonids, the value of monitoring goals, and alternative methods and costs for meeting those goals.
- 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 telemetry research to obtain data for all water year types using temperature sensitive 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 2005 adult Chinook telemetry study. All river kilometers (RKM) are measured from the mouth of the Klamath River.

ID Number	Site Location	RKM	River
1	Klamath Near Shore	-0.5	Ocean
2	Estuary 1 - Mouth	0.0	Klamath
3	Estuary 2 - South Cove	0.3	Klamath
4	Estuary 3 - Requa	1.0	Klamath
5	Estuary 4 - Hunter Point	2.0	Klamath
6	Estuary 5 - Jet Tours	3.0	Klamath
7	Wakel	7.3	Klamath
8	Blue Creek	26.0	Klamath
9	Moore's Rock	43.0	Klamath
10	Coon Creek Falls	57.5	Klamath
11	Weitchpec Klamath	71.0	Klamath
12	Weitchpec Trinity	71.0	Trinity
13	Hoopa	90.0	Trinity
14	Riverdale	104.0	Trinity
15	above Willow Creek weir	105.5	Trinity
16	Hawkins Bar	133.0	Trinity
17	China Slide	147.0	Trinity
18	Lower Junction City	190.3	Trinity
19	Steiner Flat	216.0	Trinity
20	Bucktail	242.0	Trinity
21	TRH	252.5	Trinity
22	Lower SF Trinity	135.8	SF Trinity
23	Salmon River at Oak Flat	108.0	Salmon
24	Lower Scott River	233.5	Scott
25	Big Bar	82.0	Klamath
26	Dolans Bar	97.5	Klamath
27	Green Riffle RB	114.0	Klamath
28	Green Riffle LB	114.0	Klamath
29	Happy Camp	176.5	Klamath
30	Blue Heron	233.3	Klamath
31	Hornbrook	293.0	Klamath
32	IGH	310.0	Klamath

Table 2. Tagging and fate summary for all 23 adult Chinook migrants in 2005. All Chinook were tagged at the mouth of the Klamath River. 'Spring' Chinook were spawned at the TRH from 9/8/05 to 10/11/05 and 'fall' Chinook were spawned from 10/24/05 to 12/8/05. All Chinook are considered 'fall-run" at IGH. *Chinook 146 displayed summer run-timing and behavior but was likely an early run Klamath fall Chinook.

Tagging Date	Tagging Time	Sonic Tag Frequency	Jaw Tag #	FL (cm)	Ad Fin Clip	Sex	Migrant Group	Fate/Last Observation	Archival Data Recovery
8/1/2005	15:00	**137**	2	74	n		Summer	MIA above Weit Trinity RKM 71 - 8/20	n
8/10/2005	9:10	**140**	5	84	n	F	Summer	spawned Junct. City RKM 206 - 10/14	**y**
8/10/2005	11:05	**143**	8	70	n	F	Summer	caught Bucktail RKM 242 - 9/22	**y**
8/11/2005	9:30	**145**	10	75	n		Summer	TRH - 10/7	n
8/11/2005	9:55	**146**	11	67	n		Summer*	IGH - 9/26	n
8/11/2005	10:00	**147**	12	73	n		Summer	TRH - 9/30	n
8/12/2005	10:30	**150**	15	77	n	M	Summer	TRH - 9/26	**y**
8/18/2005	16:00	**155**	20	83	n		Summer	TRH - 10/1	n
8/23/2005	9:52	**158**	23	94	n		KFall	above Hornbrook RKM 293 - 10/21	n
8/25/2005	11:31	**100**	28	78	n		KFall	above Blue Heron RKM 233 - 10/15	n
8/29/2005	16:01	**102**	30	79	n		T Fall	TRH - 10/29	n
8/31/2005	18:13	**112**	40	87	n		KFall	IGH - 10/17	n
9/1/2005	8:39	**115**	43	83	n		KFall	above Hornbrook 10/24; died Scott R.	**y**
9/1/2005	9:19	**117**	45	89	n		T Fall	spawned below TRH - 10/30	**y**
9/7/2005	9:38	**41**	50	76	n	M	KFall	IGH - 10/15	n
9/7/2005	10:03	**43**	52	76	y		KFall	Blue Heron - 11/2	n
9/7/2005	11:20	**47**	57	82	y	F	T Fall	TRH - 11/10	**y**
9/8/2005	10:45	**59**	59	76	n	M	KFall	IGH - 10/17	**y**
9/8/2005	11:23	**52**	62	83	n		T Fall	above Junct. City RKM 190 - 11/15	n
9/9/2005	11:13	**53**	63	73	n	M	KFall	IGH - 10/24	**y**
9/12/2005	12:09	**122**	70	73	n	F	KFall	IGH - 10/26	**y**
9/12/2005	12:15	**123**	71	81	n		KFall	above Hornbrook - 10/8	n
10/5/2005	17:55	**226**	87	68	n		T Fall	TRH - 11/22	n

Table 3. Summary table of delays at the Willow Creek (WC) weir (located at RKM 105) for all Trinity Chinook migrants in 2005. Delay is defined as the travel time from the sonic station below the WC weir (RKM 104) to the sonic station above the WC weir (RKM 105.5). Ratio is defined as and the ratio of that delay to the travel time from the estuary terminus (RKM 7.25) to the site of the lower WC weir station (RKM 104); i.e. delay at weir/travel time to weir. Calculating this ratio adjusts the magnitude of the delay for the preceding rate of upriver migration. The WC weir was fully installed and operational from the evening of 8/22/05 to 11/3/05; partially disassembled from 8/26/05 to the evening of 8/31/05 (tripods only due to the boat dance flows); while in operation the weir was fished from Sunday night to Friday afternoon (1300), plus left open of fishing days (Mon-Thur) from 1300 to sunset. Boat dance flows at Hoopa (RKM 90) lasted from 8/29/05 to 9/1/05 with a peak late on 8/30/05. Chinook 102 was the only Chinook migrant trapped at the weir.

Fish	Tag Date	Delay (d)	Ratio
	Before Weir Installation		
150	12-Aug	**0.1**	**0.02**
143	10-Aug	**0.3**	**0.06**
	During Boat Dance Flows		
155	18-Aug	**0.3**	**0.04**
145	11-Aug	**1.0**	**0.15**
	After Weir Removal		
226	5-Oct	**0.5**	**0.02**
	During Weir		
147	11-Aug	**10.4**	**0.95**
117	1-Sep	**9.9**	**0.48**
140	10-Aug	**31.1**	**1.08**
102	29-Aug	**6.1**	**0.16**
47	7-Sep	**3.5**	**0.19**
52	8-Sep	**13.9**	**0.47**

Table 4. The thermal experience as determined by archival body temperature records for three tagged Chinook typical of their migrant group. The summary statistics reported include estuary/nearshore residence but excluded pre-spawn holding in the vicinity of spawning grounds.

	Thermal Experience (°C)		
Group	Summer	K Fall	T Fall
Fish Code	150	59	47
Mean	19.7	16.8	16.6
Minimum	11.1	13.6	12.8
Maximum	24.3	20.2	21.1
Std. Dev.	3.6	1.8	2.1

Table 5. Estuary and nearshore ocean residence times for all 23 Chinook migrants in 2005, arranged in order by tagging date. Estuary residence is defined as the total amount of time spent between the mouth (RKM 0) and Wakel (RKM 7). Ocean residence is defined as the total amount of time spent in the ocean after tagging. The mean ocean residence time excludes Chinook migrants that did not go to the ocean after tagging.

Fish Code	**Ocean Residence (d)**	**Estuary Residence (d)**	**Total (d)**	**Tagging Date**	**Migrant Group**
137	5.0	4.6	9.6	1-Aug	summer
143	6.0	0.4	6.4	10-Aug	summer
140	12.0	0.3	12.3	10-Aug	summer
146	7.2	0.5	7.7	11-Aug	summer*
145	13.2	0.5	13.7	11-Aug	summer
147	12.0	1.9	13.9	11-Aug	summer
150	3.4	0.5	3.9	12-Aug	summer
155	1.5	1.4	2.9	18-Aug	summer
mean	**7.5**	**1.3**	**8.8**		
158	26.6	0.4	27.0	23-Aug	Kfall
100	22.1	0.3	22.4	25-Aug	Kfall
112	6.0	0.1	6.1	31-Aug	Kfall
115	11.0	0.1	11.1	1-Sep	Kfall
41	16.1	0.1	16.2	7-Sep	Kfall
43	0.0	0.4	0.4	7-Sep	Kfall
59	0.0	0.3	0.3	8-Sep	Kfall
53	0.0	0.2	0.2	9-Sep	Kfall
122	9.8	0.4	10.2	12-Sep	Kfall
123	0.0	0.2	0.2	12-Sep	Kfall
mean	**15.3**	**0.2**	**9.4**		
102	18.1	2.0	20.1	29-Aug	Tfall
117	0.0	1.0	1.0	1-Sep	Tfall
47	0.0	0.3	0.3	7-Sep	Tfall
52	13.8	0.1	13.9	8-Sep	Tfall
226	11.3	0.2	11.5	5-Oct	Tfall
mean	**14.4**	**0.7**	**9.4**		

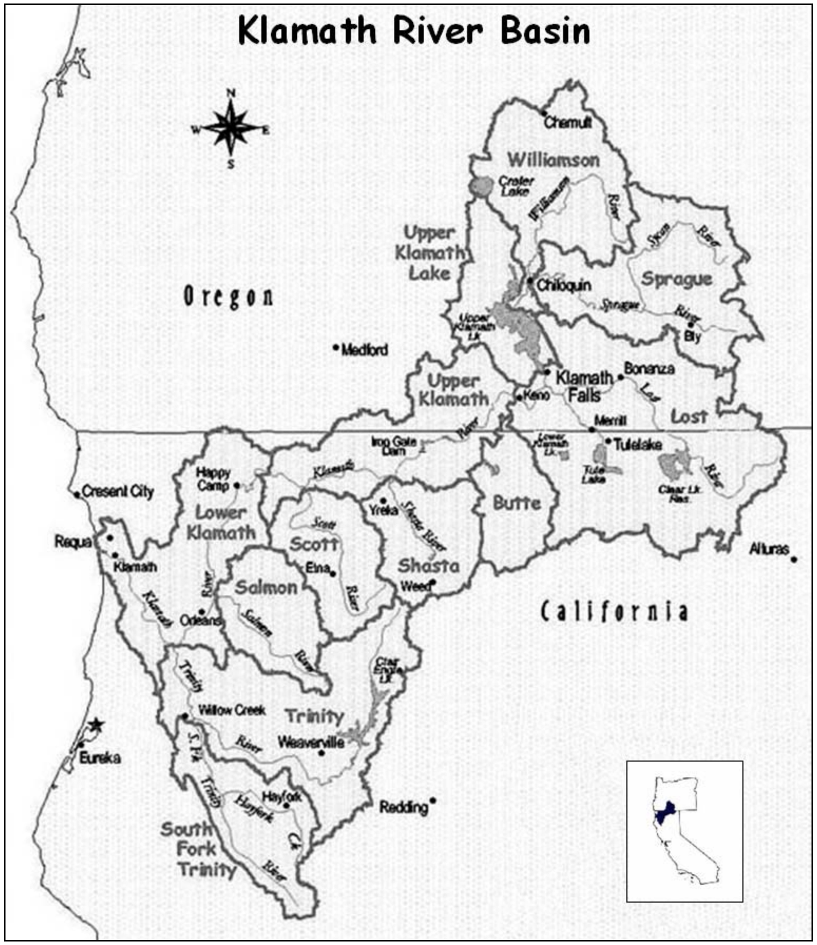

Figure 1. The Klamath River Basin of northern California and southern Oregon with sub-basins. Iron Gate Dam on the mainstem Klamath and Trinity Dam on the mainstem Trinity River both currently limit the upriver distribution of anadromous fishes within the watershed. Historically spring Chinook were distributed throughout large areas of the Basin, presently however, spawning populations of spring Chinook are found in the Salmon River, South Fork Trinity, and mainstem Trinity sub-basins.

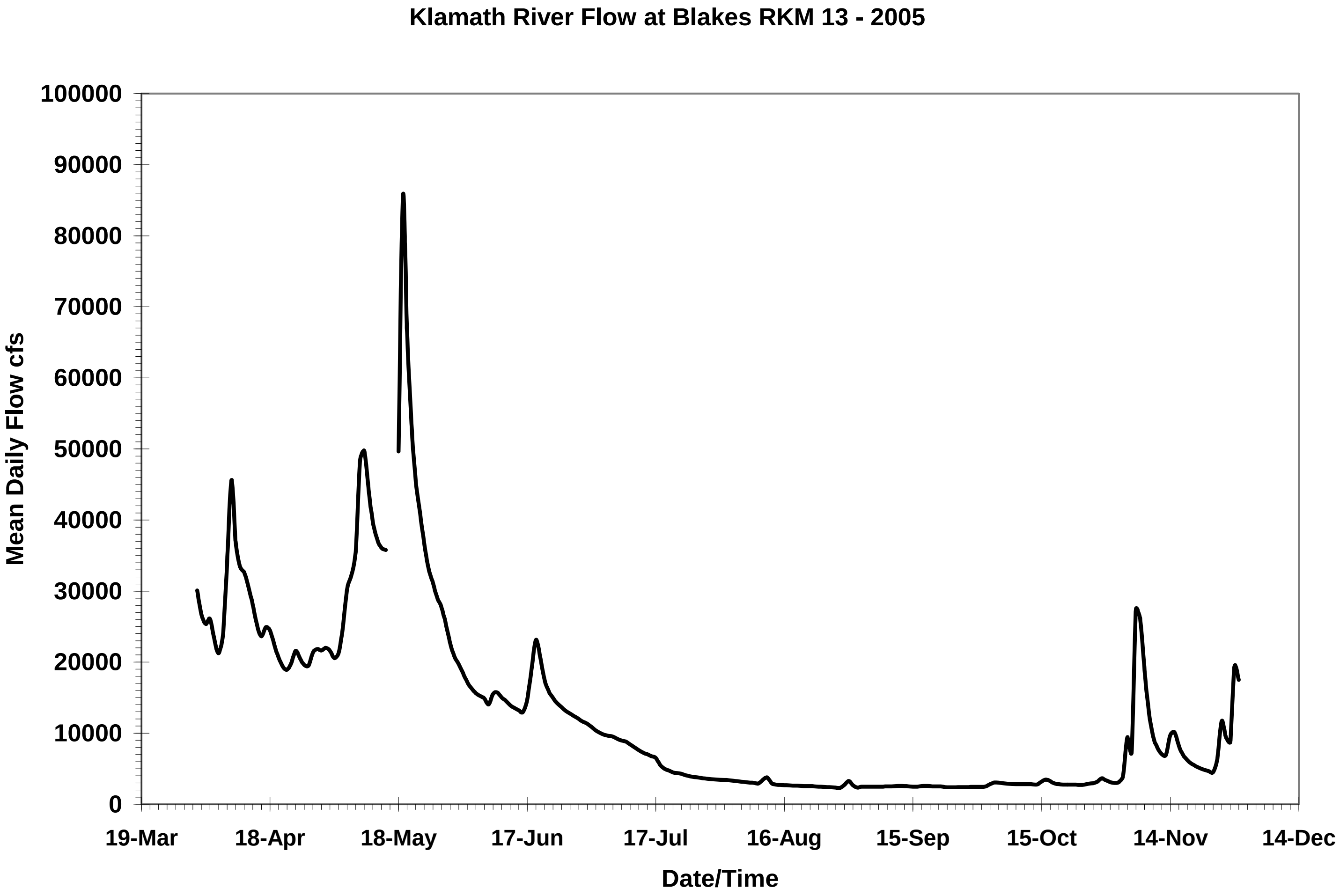

Figure 2. Flows for the Klamath River at Blakes RKM 13 during the 2005 adult Chinook migration season (USGS data).

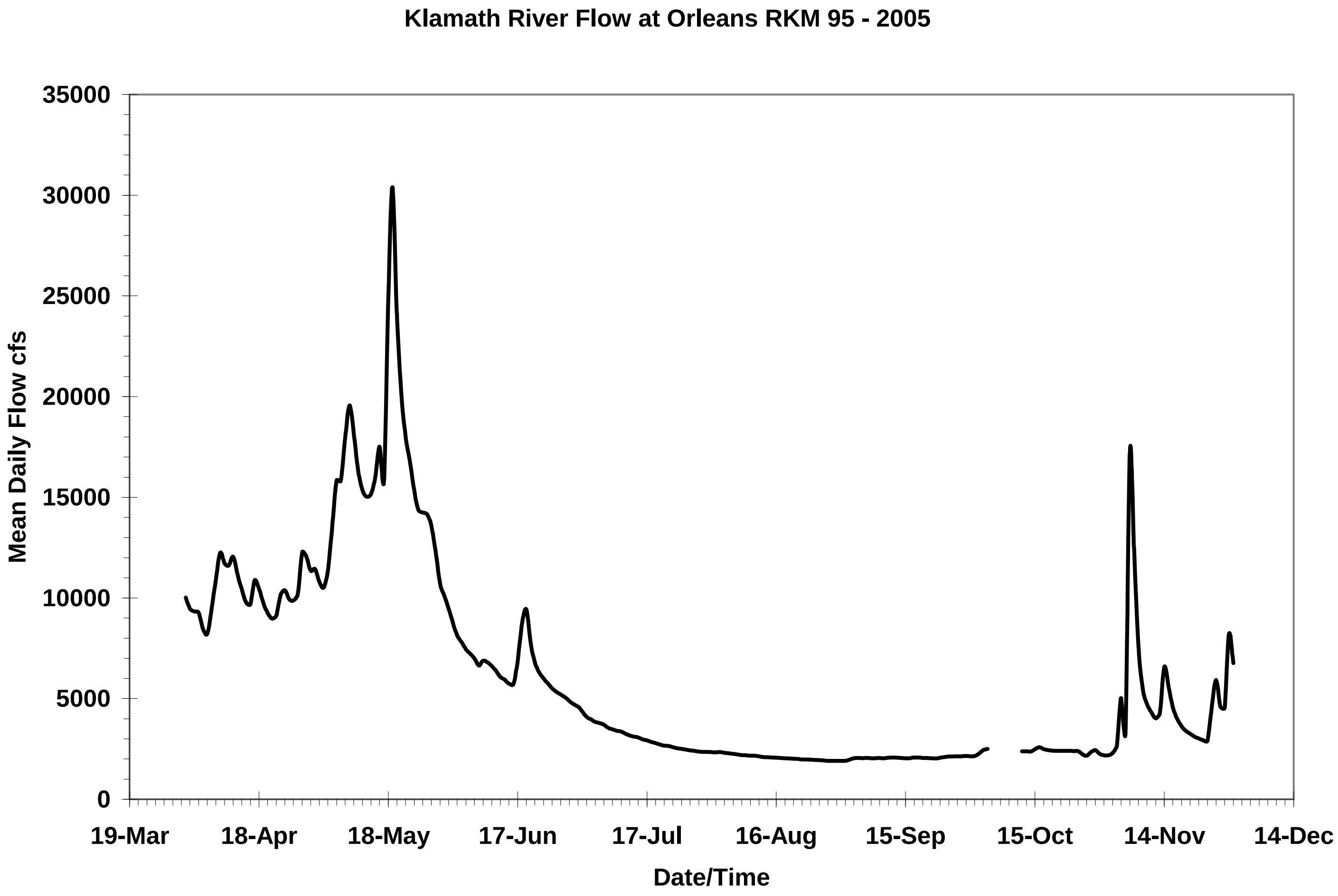

Figure 3. Flows for the Klamath River at Orleans RKM 95 during the 2005 adult Chinook migration season (USGS data).

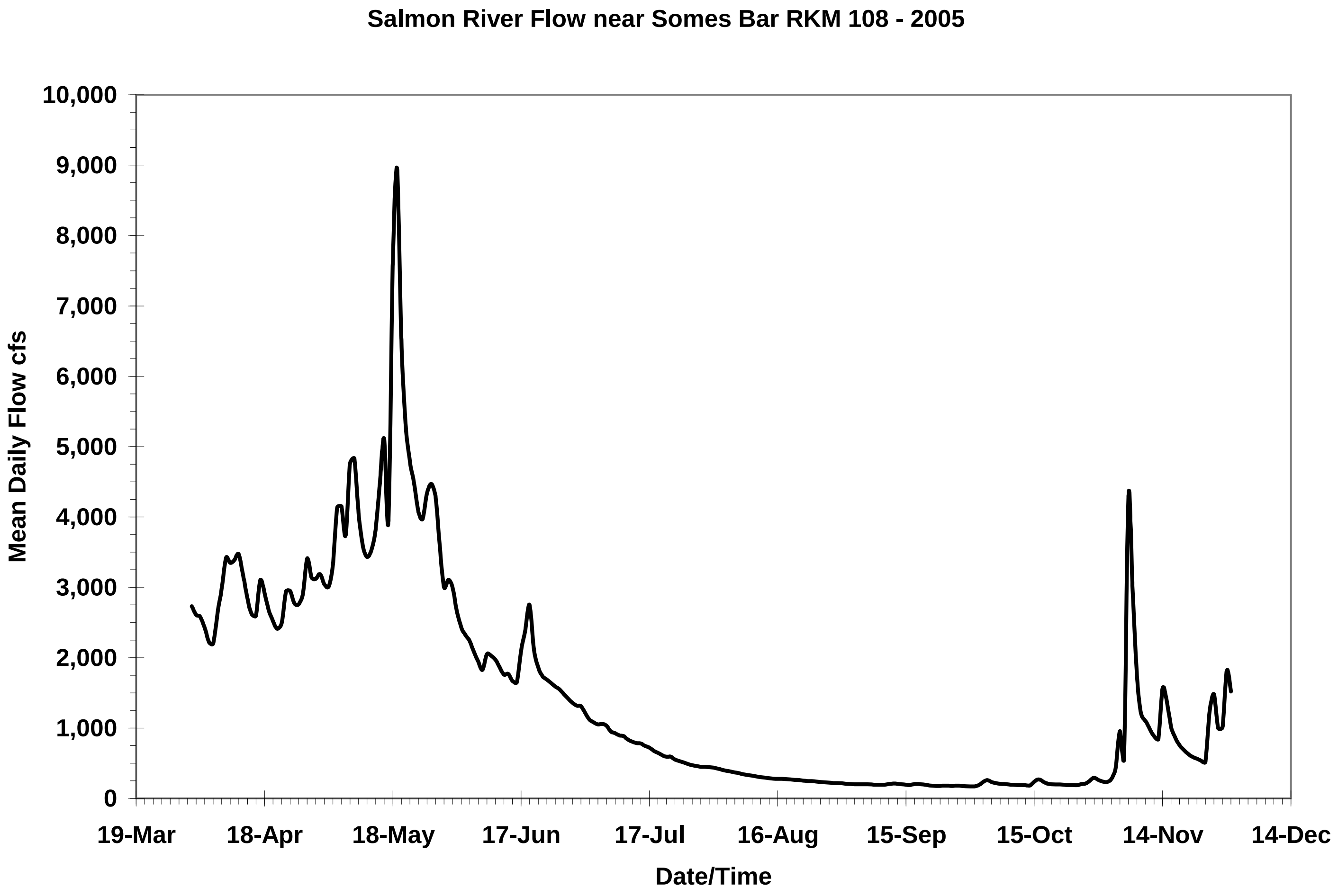

Figure 4. Flows for the Salmon River near Somes Bar RKM 108 during the 2005 adult Chinook migration season (USGS data).

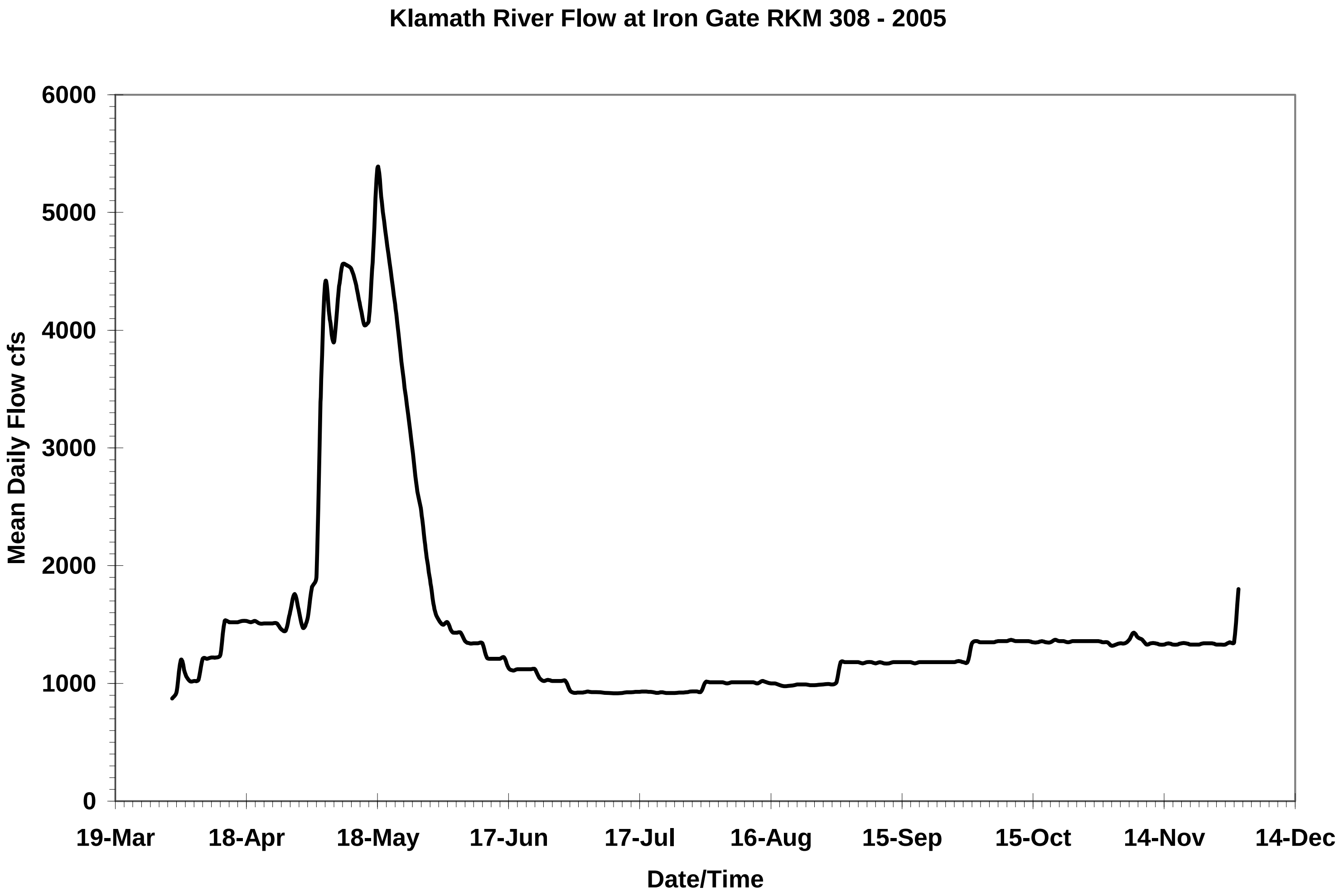

Figure 5. Flows for the Klamath River below Iron Gate Dam RKM 308 during the 2005 adult Chinook migration season (USGS data).

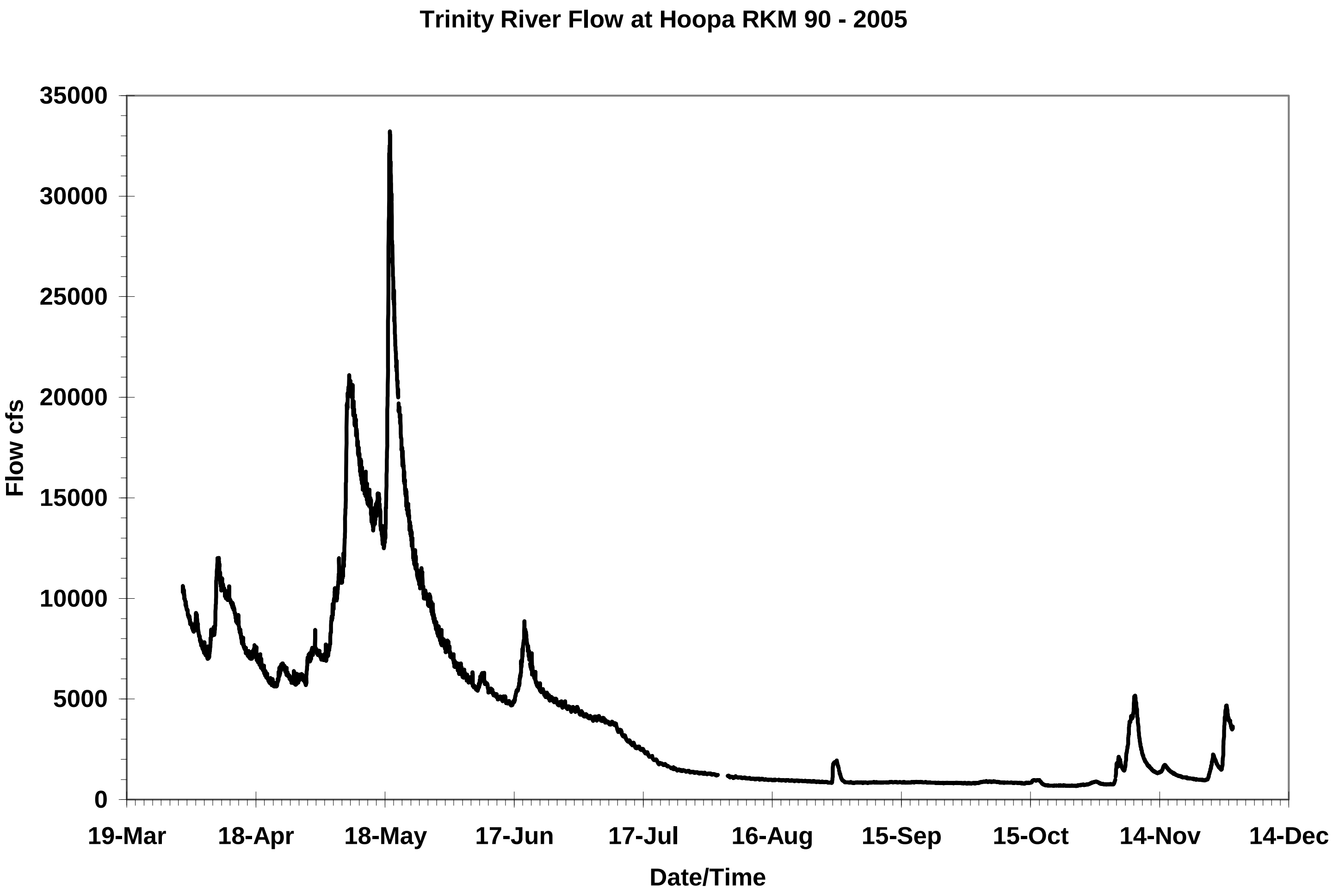

Figure 6. Flows for the Trinity River at Hoopa RKM 90 during the 2005 adult Chinook migration season (USGS data).

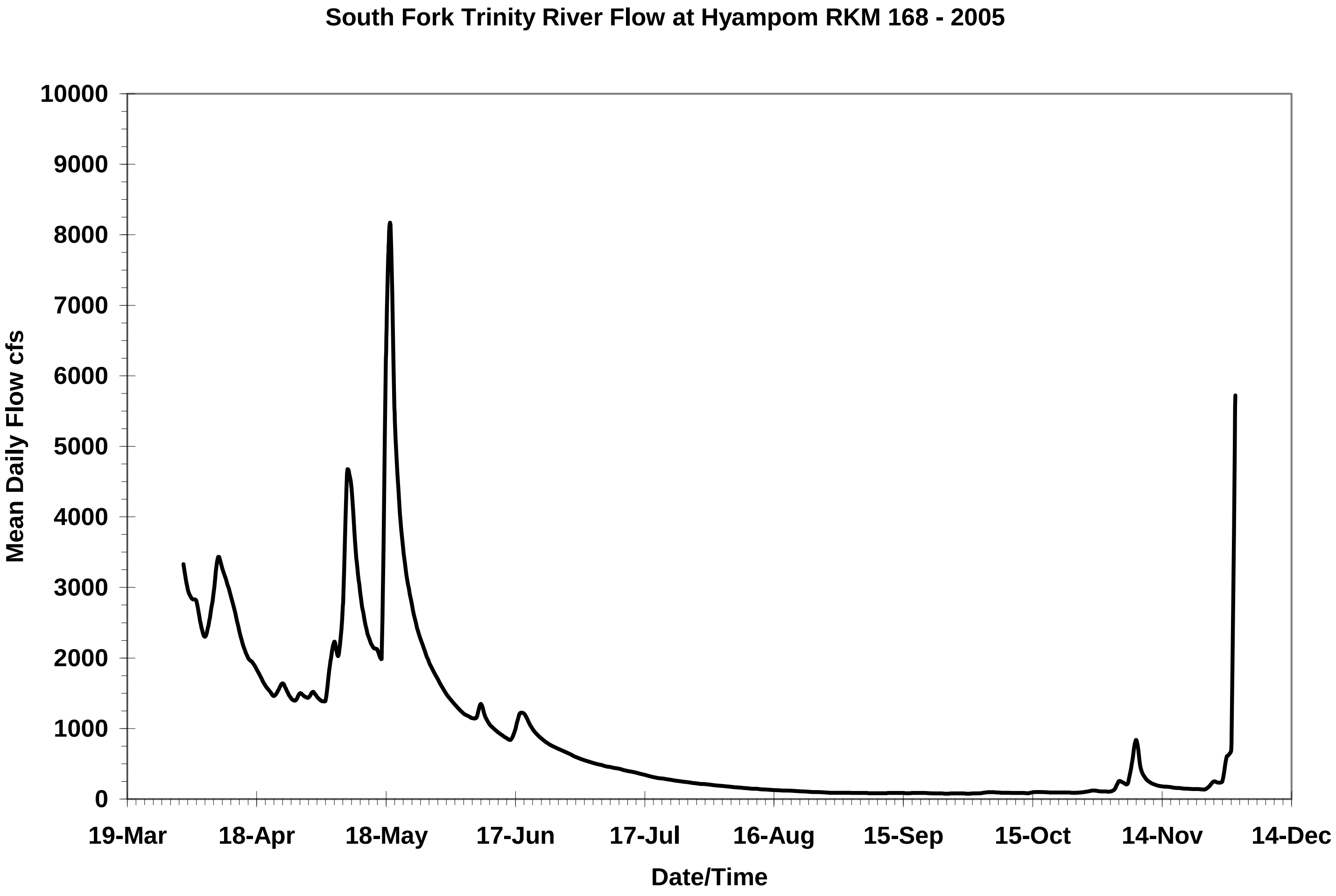

Figure 7. Flows for the South Fork Trinity River below Hyampom RKM 168 during the 2005 adult Chinook migration season (USGS data).

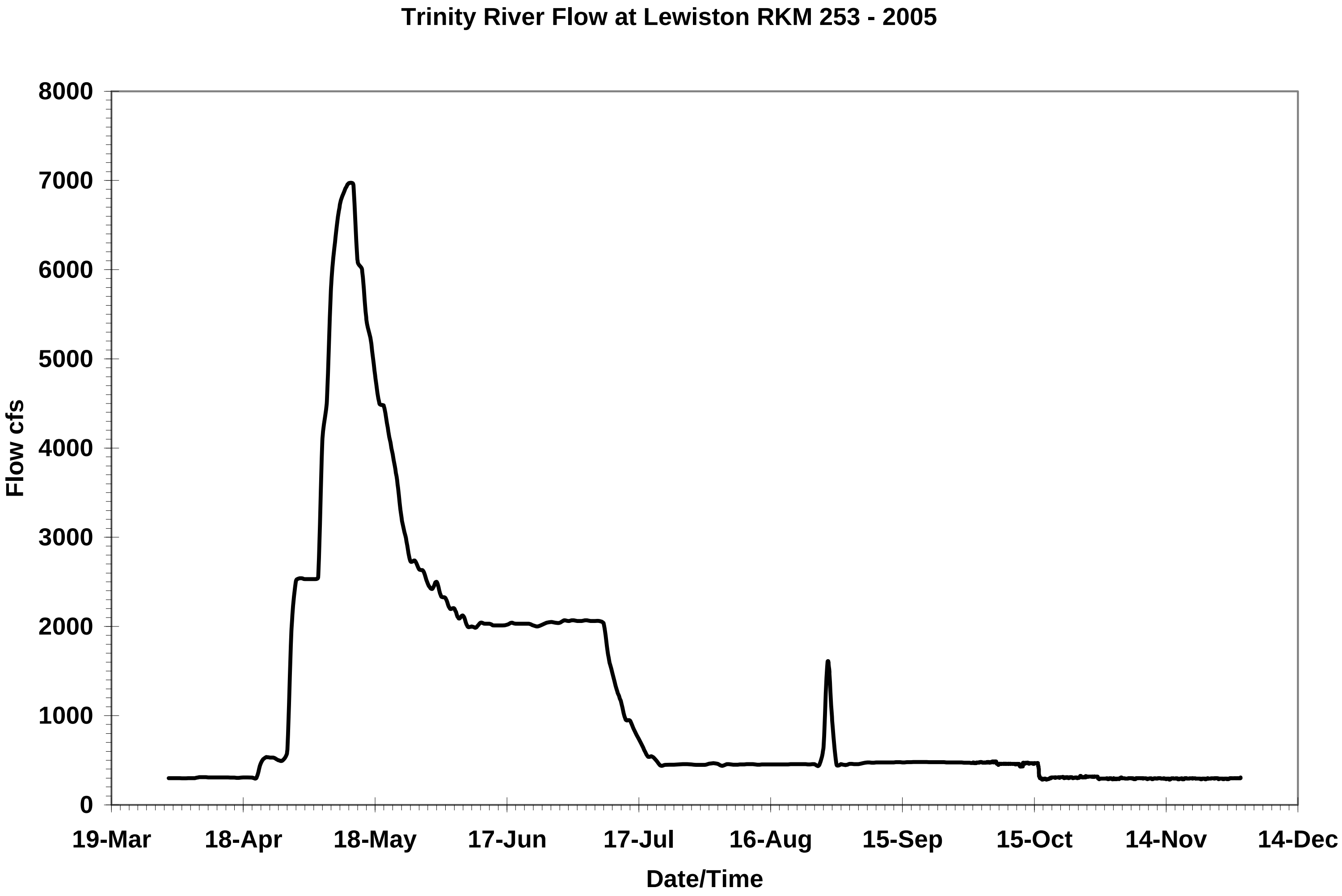

Figure 8. Flows for the Trinity River below Lewiston Dam RKM 253 during the 2005 adult Chinook migration season (USGS data).

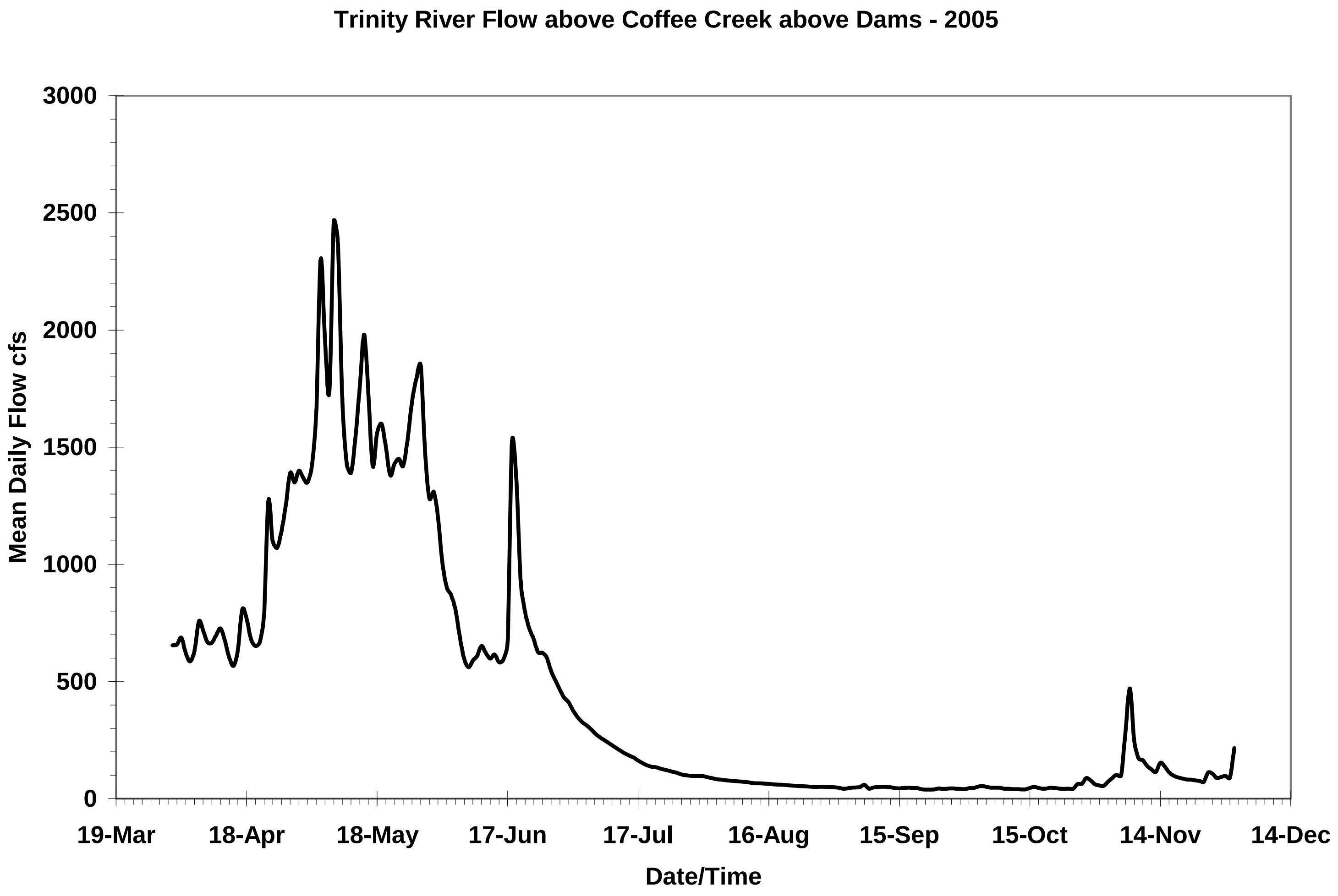

Figure 9. Flows for the Trinity River above Coffee Creek and above Trinity and Lewiston Dams during the 2005 adult Chinook migration season (USGS data).

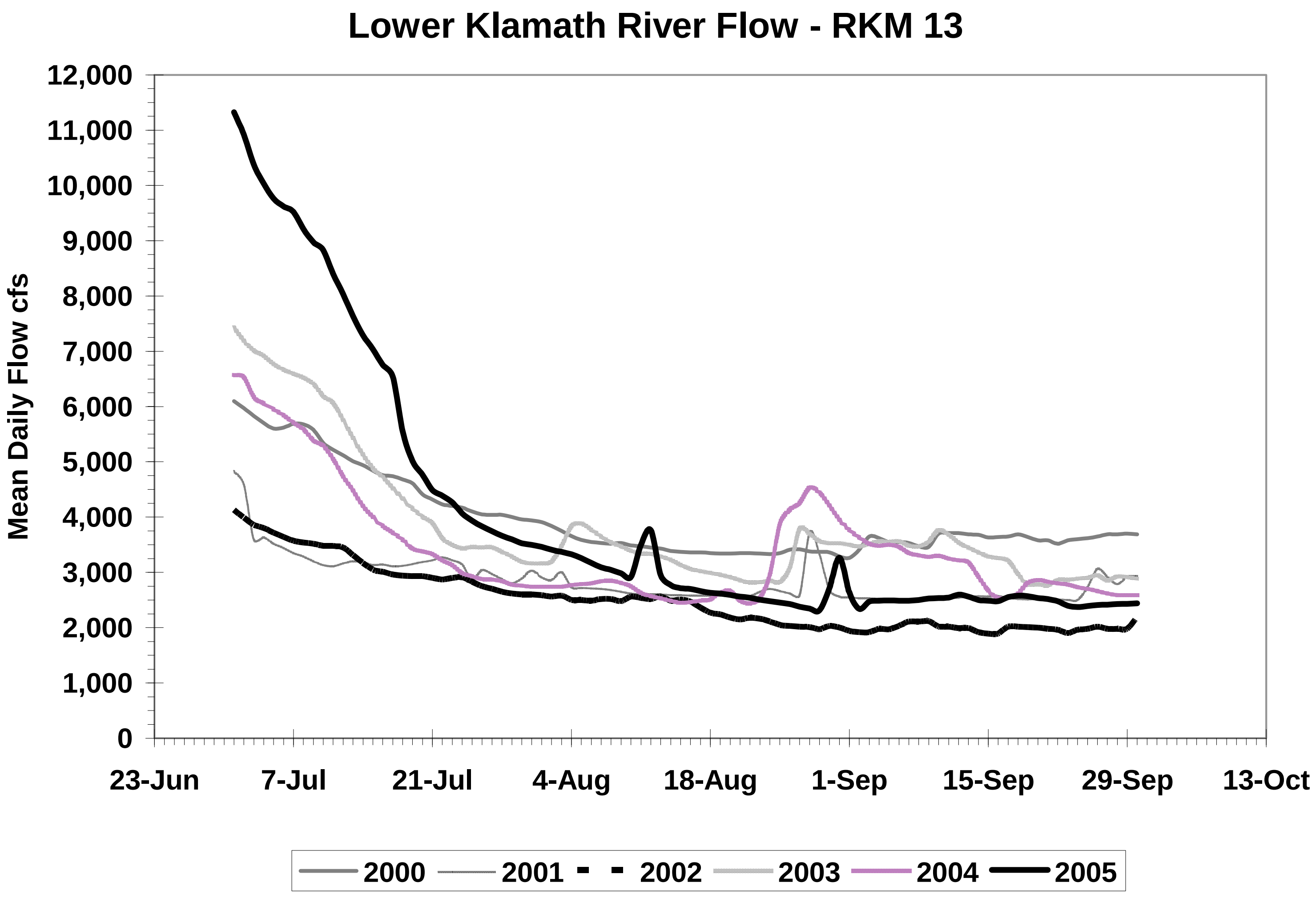

Figure 10. Summer and fall flows for the Klamath River from 2000 to 2005 (USGS data).

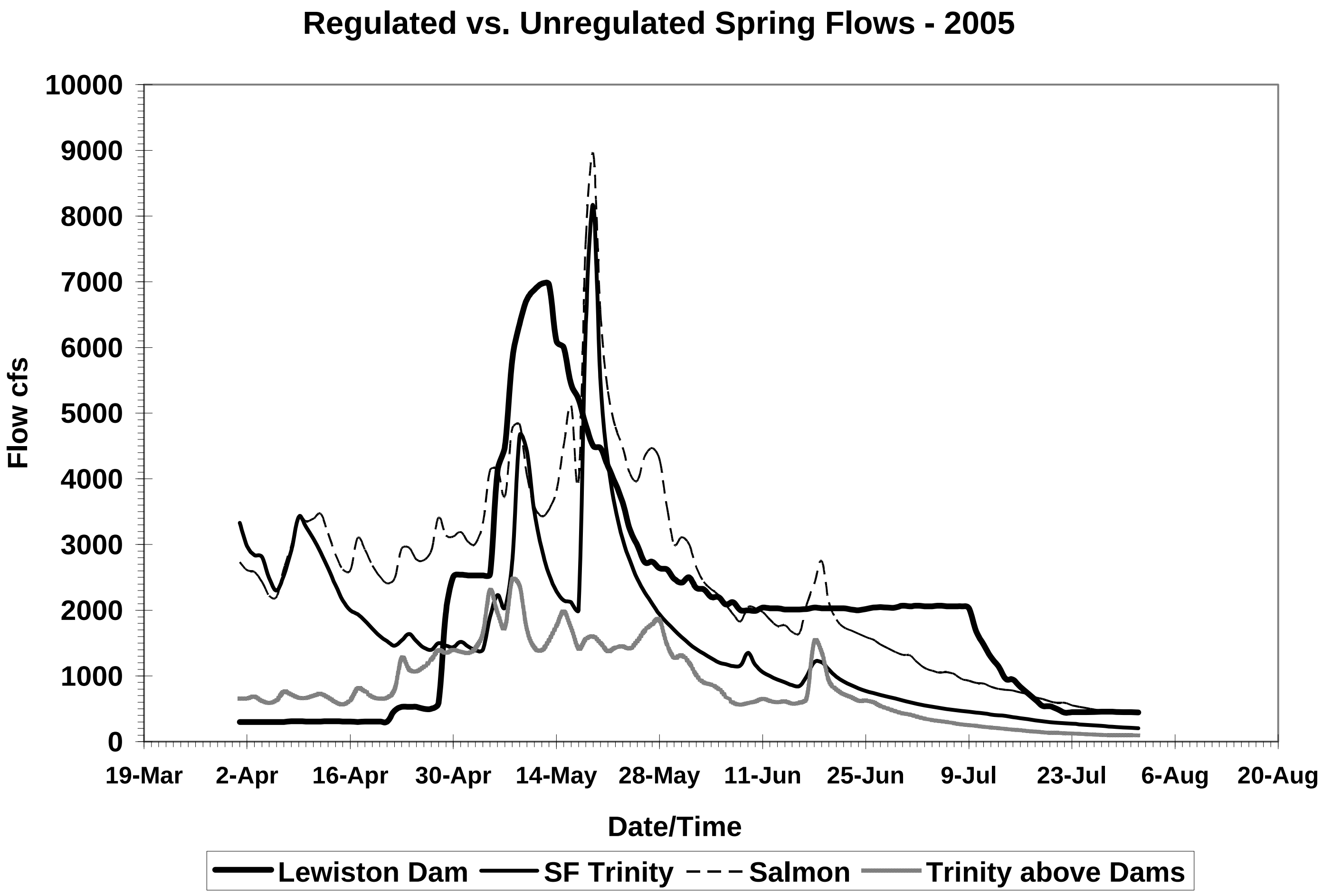

Figure 11. The regulated spring hydrograph for the Trinity River at Lewiston versus the spring hydrographs for several unregulated KRB tributaries showing the discontinuity between the timing and rate of the descending limb (USGS data).

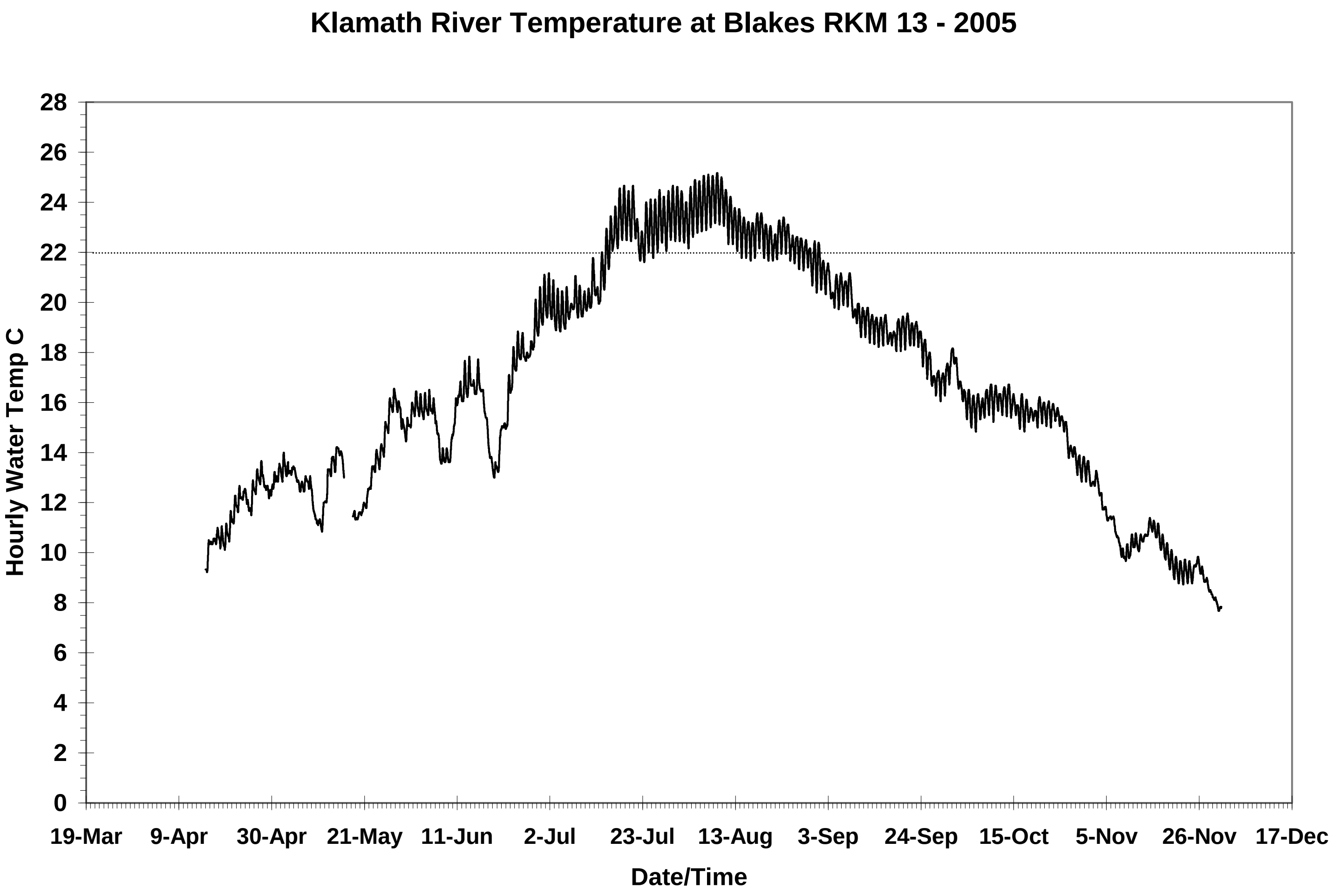

Figure 12. Water temperature of the lower Klamath River at Blake's RKM 13 during the adult Chinook migration season (USGS data). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

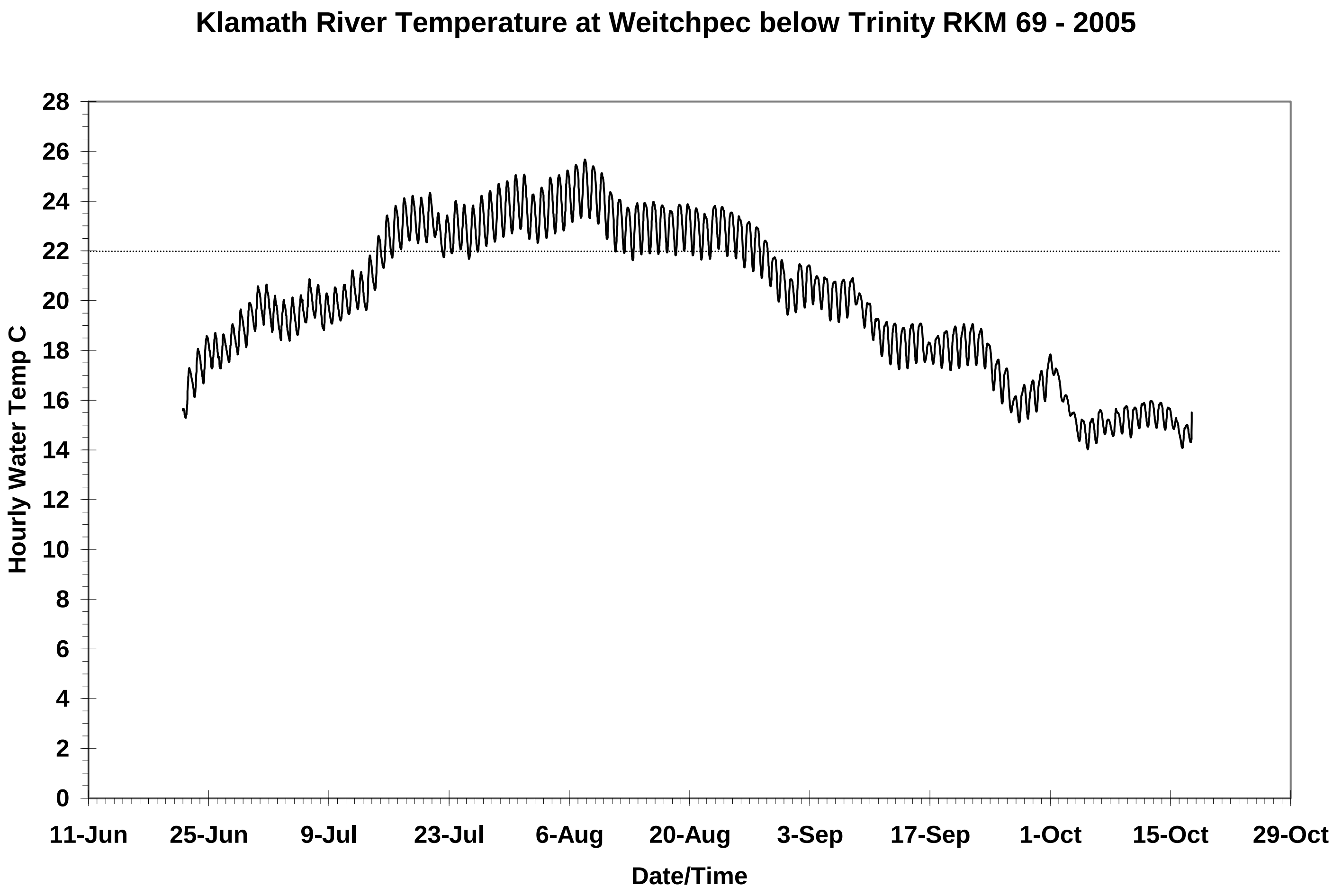

Figure 13. Water temperature of the Klamath River at Weitchpec below the mixing zone of the Trinity River confluence RKM 69 during the adult Chinook migration season (USFS). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

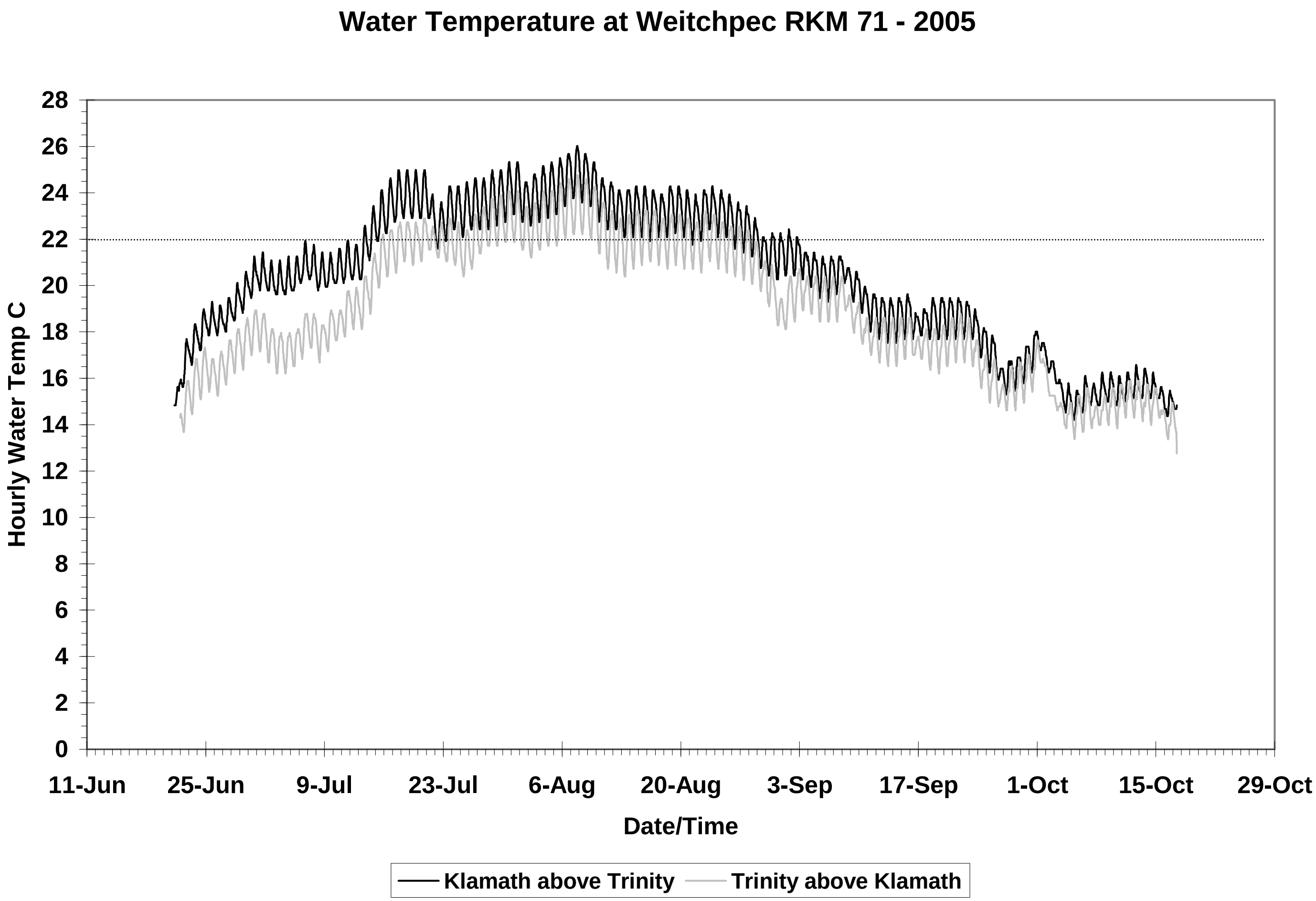

Figure 14. Water temperature at Weitchpec RKM 71 for the Klamath and Trinity Rivers above their confluence during the adult Chinook migration season (USFS). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

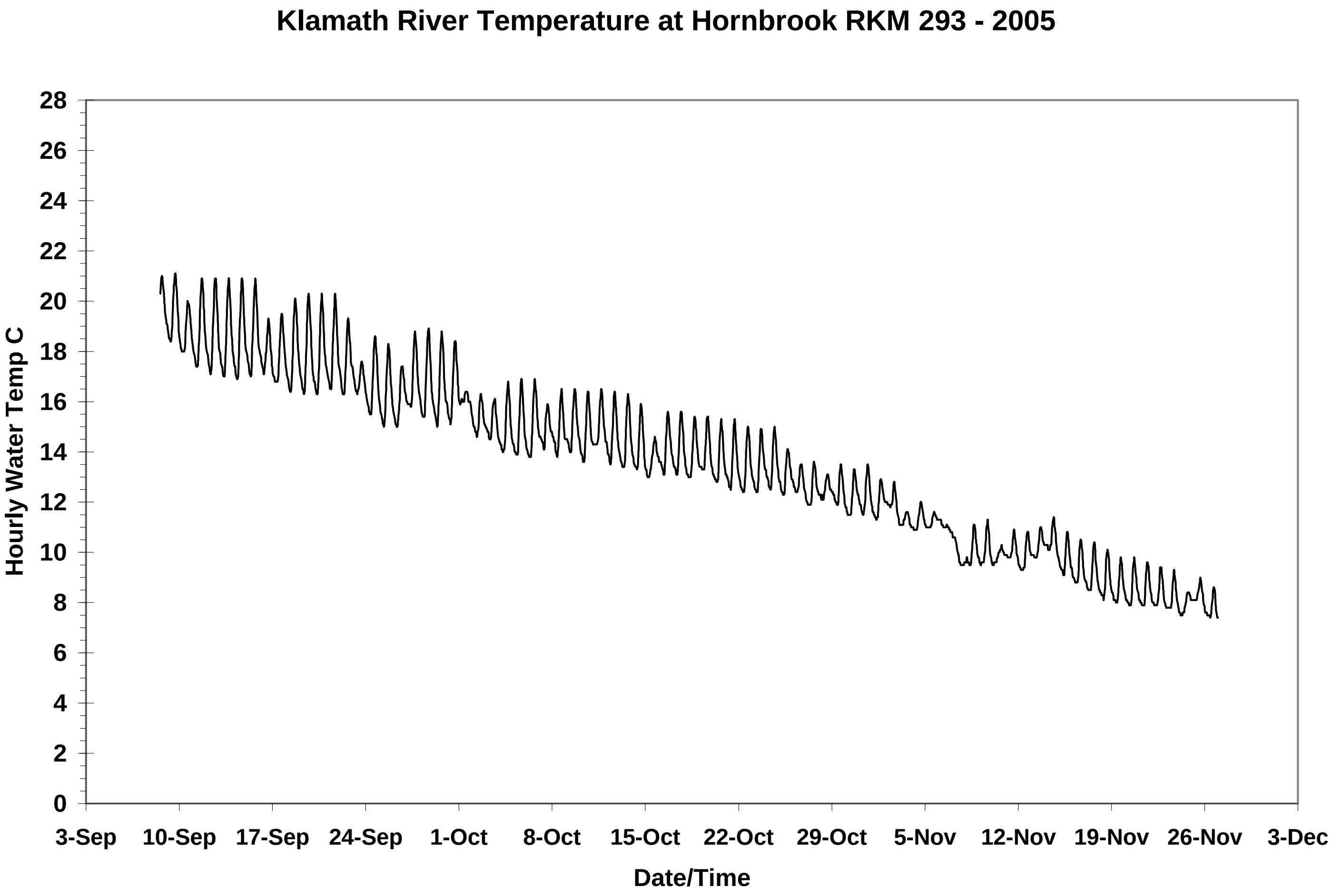

Figure 15. Water temperature of the Klamath River at Hornbrook RKM 293 during the adult fall Chinook migration and spawning season for this area (Alpha Mach). Hornbrook is near the beginning of the primary spawning area for Klamath fall Chinook.

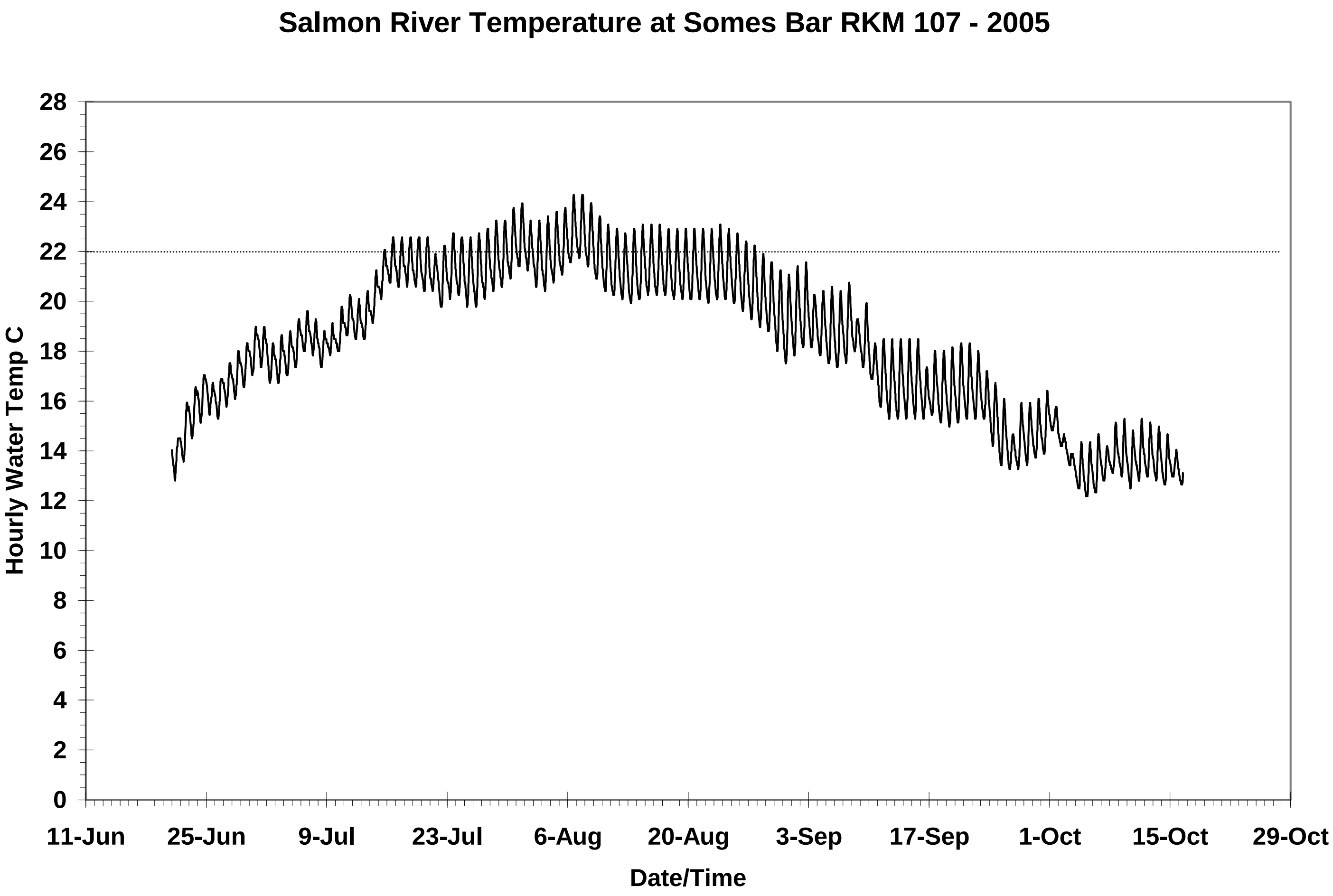

Figure 16. Water temperature of the Salmon River at Somes Bar at RKM 107 during the adult Chinook migration season (USFS). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

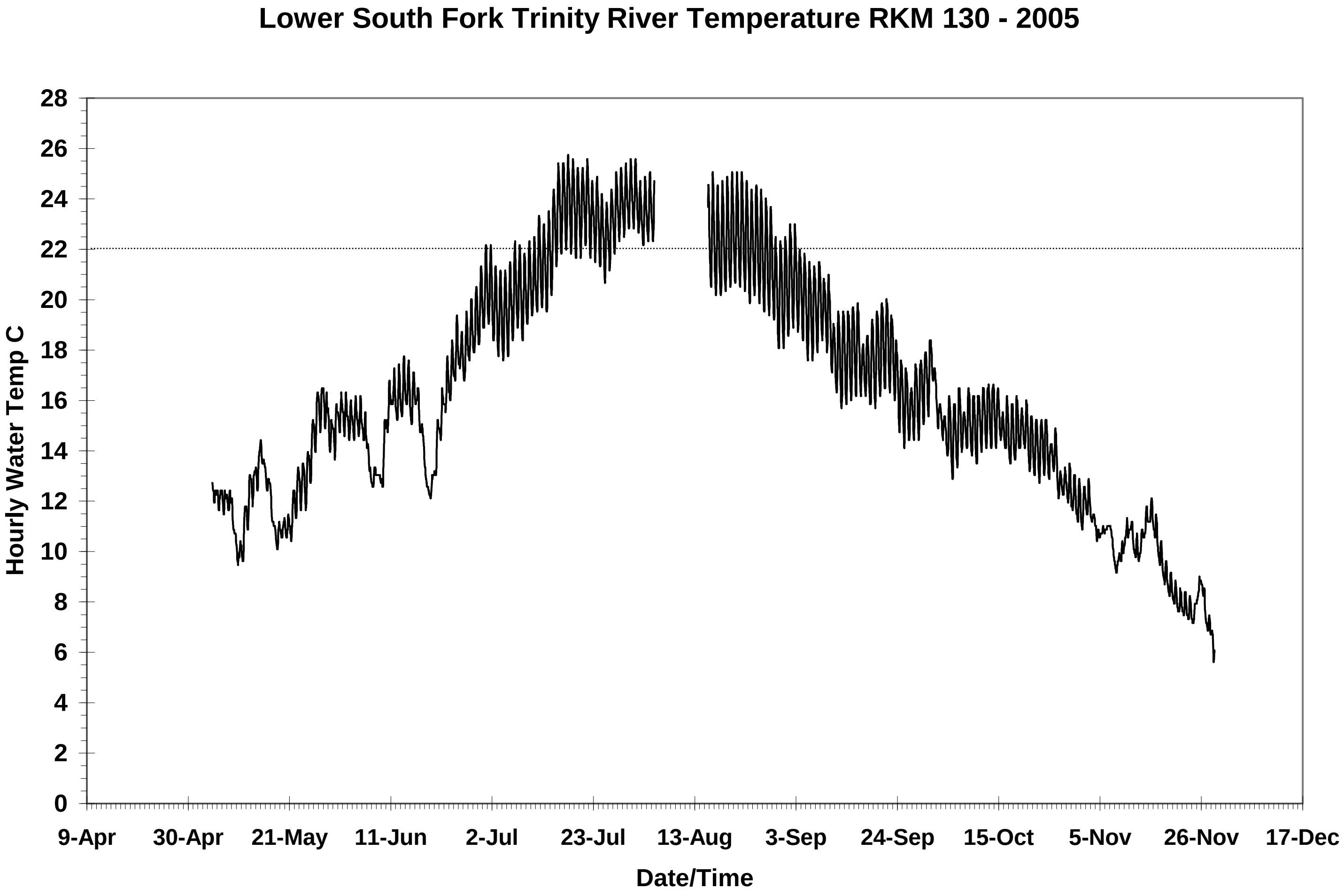

Figure 17. Water temperature of the lower South Fork Trinity River 10 kilometers upstream from the Trinity River during the adult Chinook migration season (Onset). The dotted line at 22ºC is to provide approximate visual reference for the migration inhibition threshold.

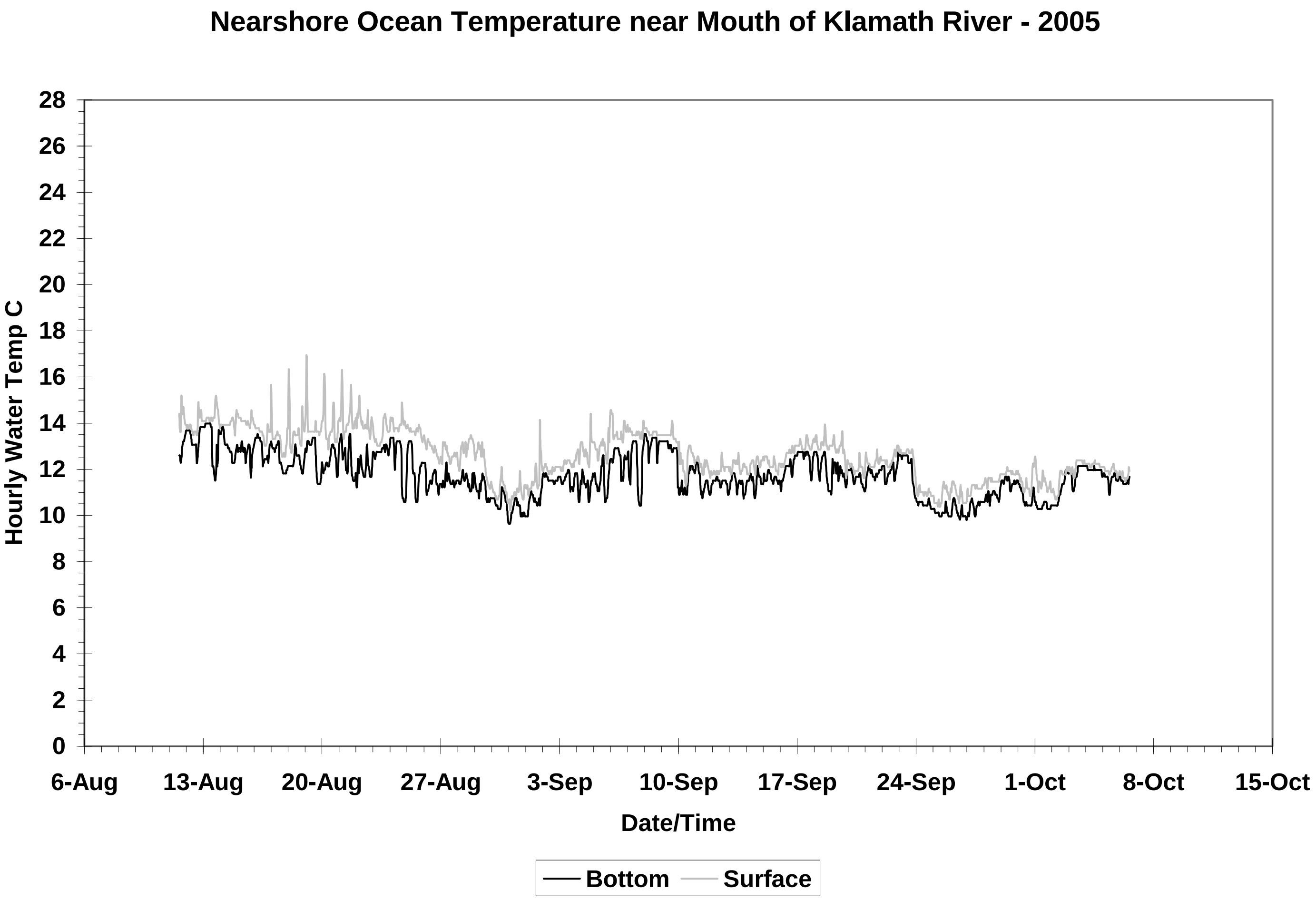

Figure 18. Surface (1m) and bottom (~15m) water temperature for the nearshore ocean approximately 0.5 kilometers west northwest from the mouth of the Klamath River during the majority of the 2005 tagging period (Onset).

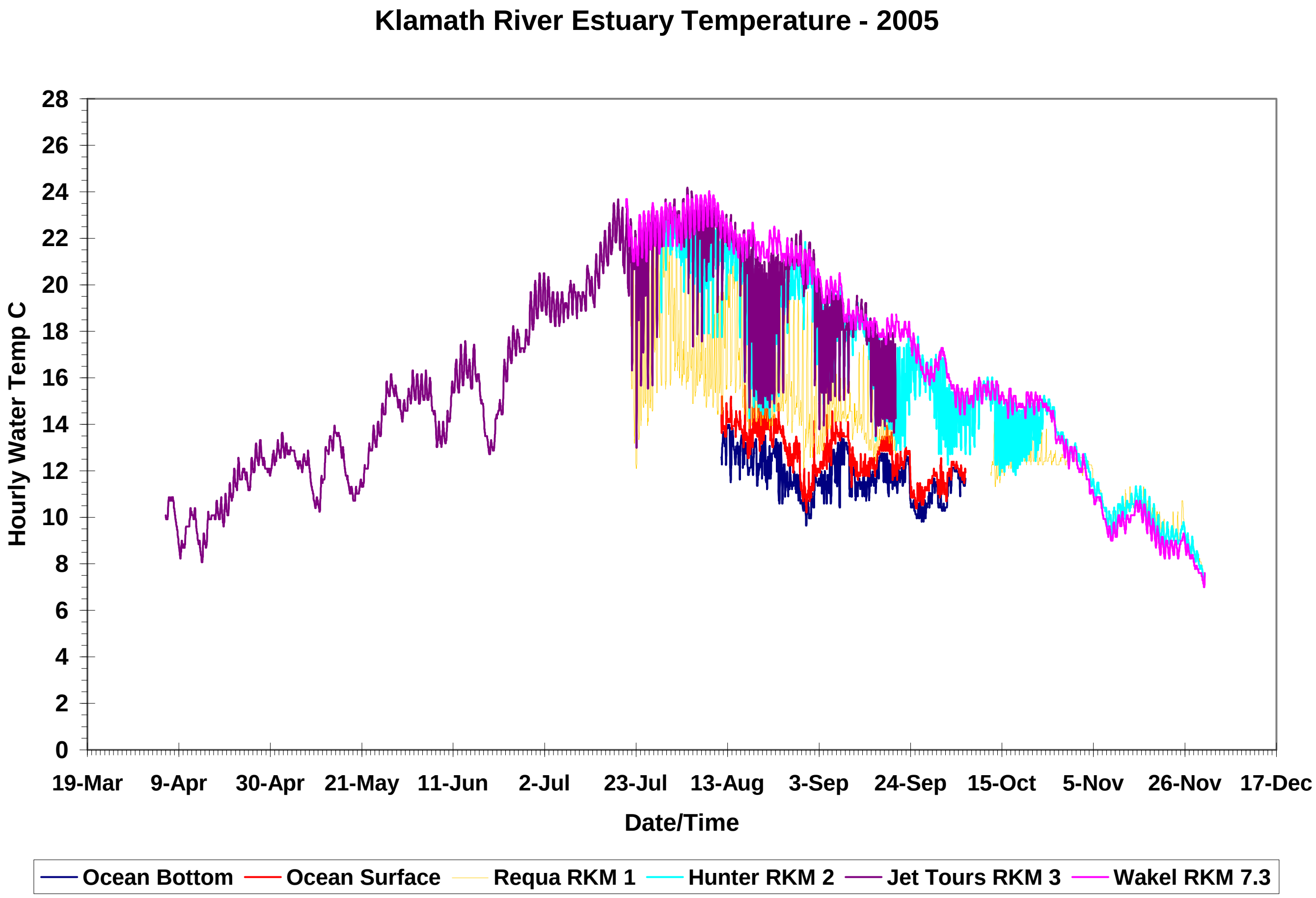

Figure 19. Water temperatures (bottom) in the Klamath River estuary at each sonic station for the study period or migration season plus the nearshore ocean (Onset). The salt wedge was established at RKM 3 beginning on 7/21/2005 coinciding with river flows of <5,000 cfs. The salt wedge did not influence river temperatures at Wakel RKM 7 and was not detected above RKM 4.

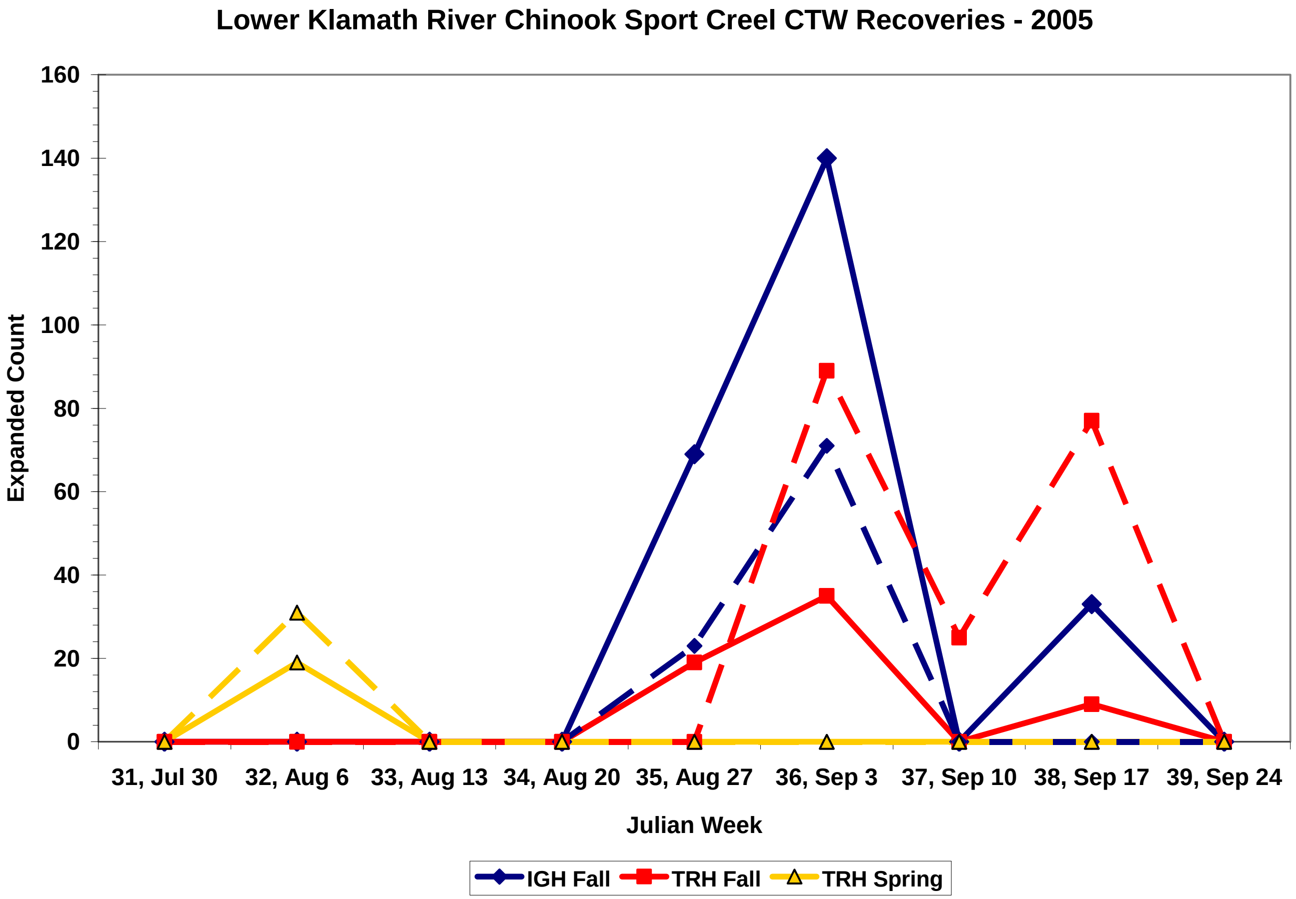

Figure 20. Run-timing of adult Chinook during the late summer and fall of 2005 in the lower Klamath River as estimated by CWT recoveries in the sport fishing harvest. The dashed lines are expanded hatchery fish counts for the estuary (Area 1 from the Highway 101 Bridge downstream to the mouth) and the solid lines are for approximately the lower 50 km of the Klamath River above the estuary (Area 2 from the Highway 101 Bridge upstream to Coon Cr. falls).

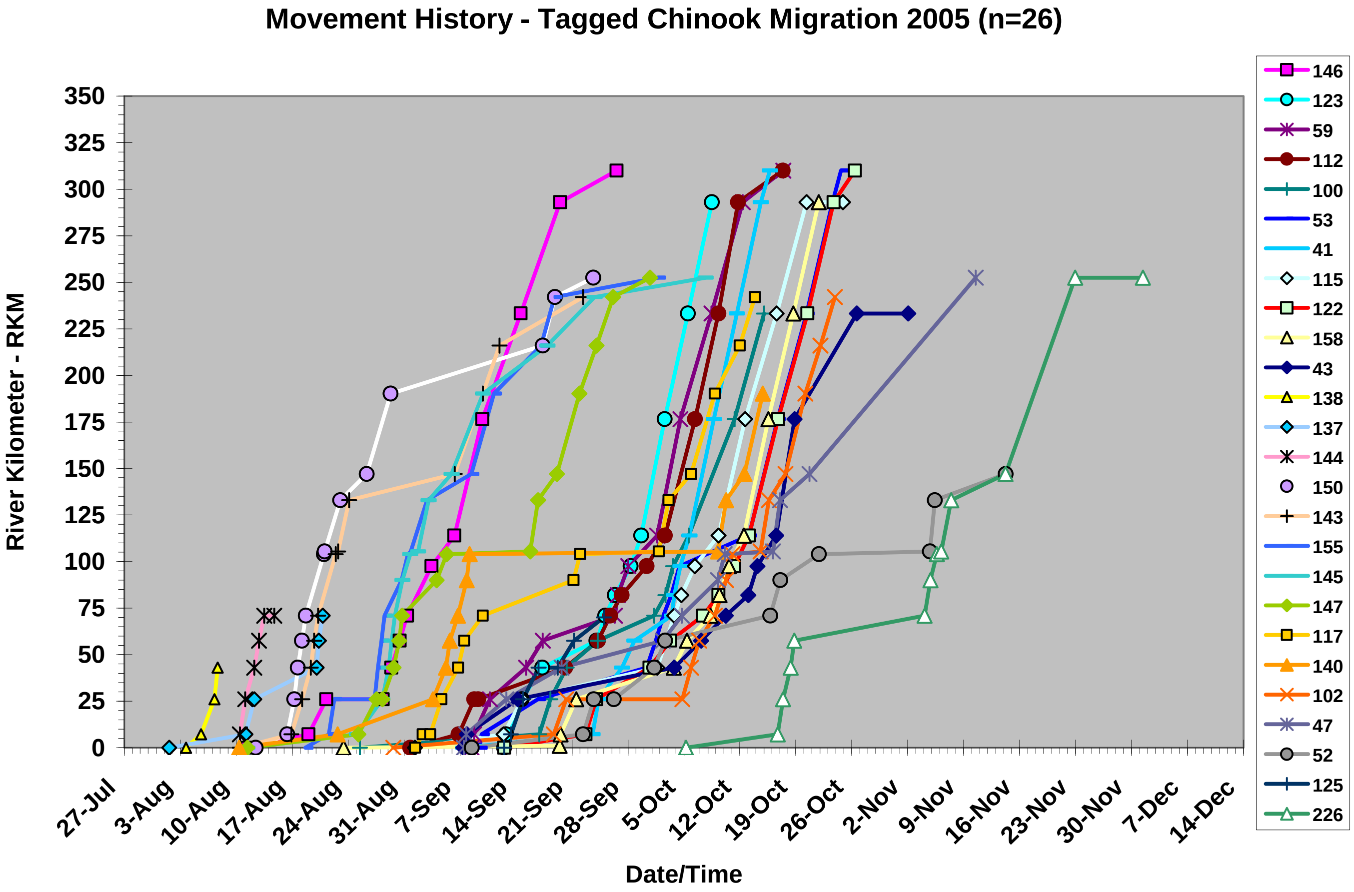

Figure 21. Movement histories for all Chinook tagged in 2005 that migrated upriver from the estuary. All river kilometers are measured from the mouth of the Klamath River.

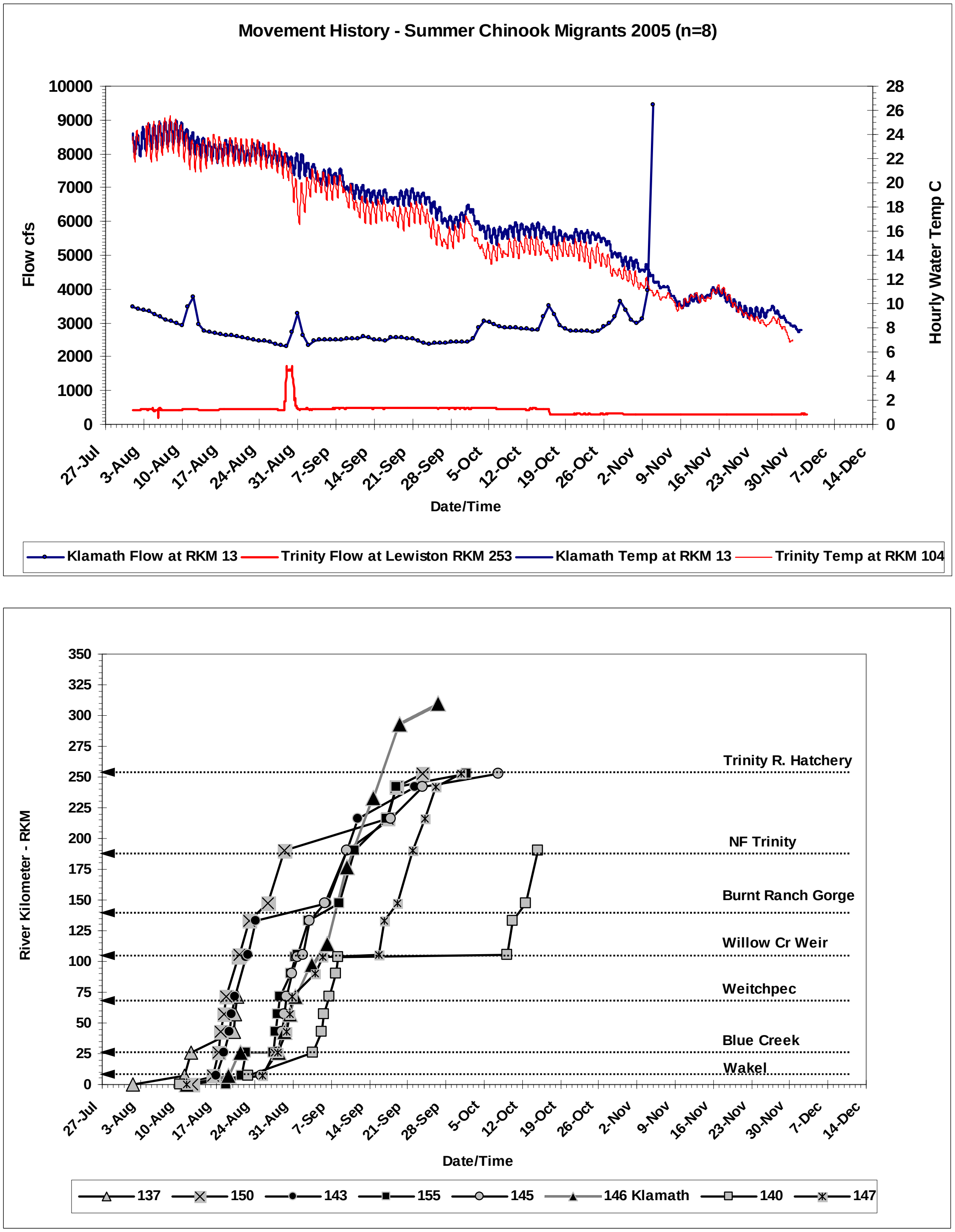

Figure 22. Movement histories for summer Chinook migrants in comparison to temperature and flow using commonly scaled axis. Applicable landmarks are designated by the dotted lines.

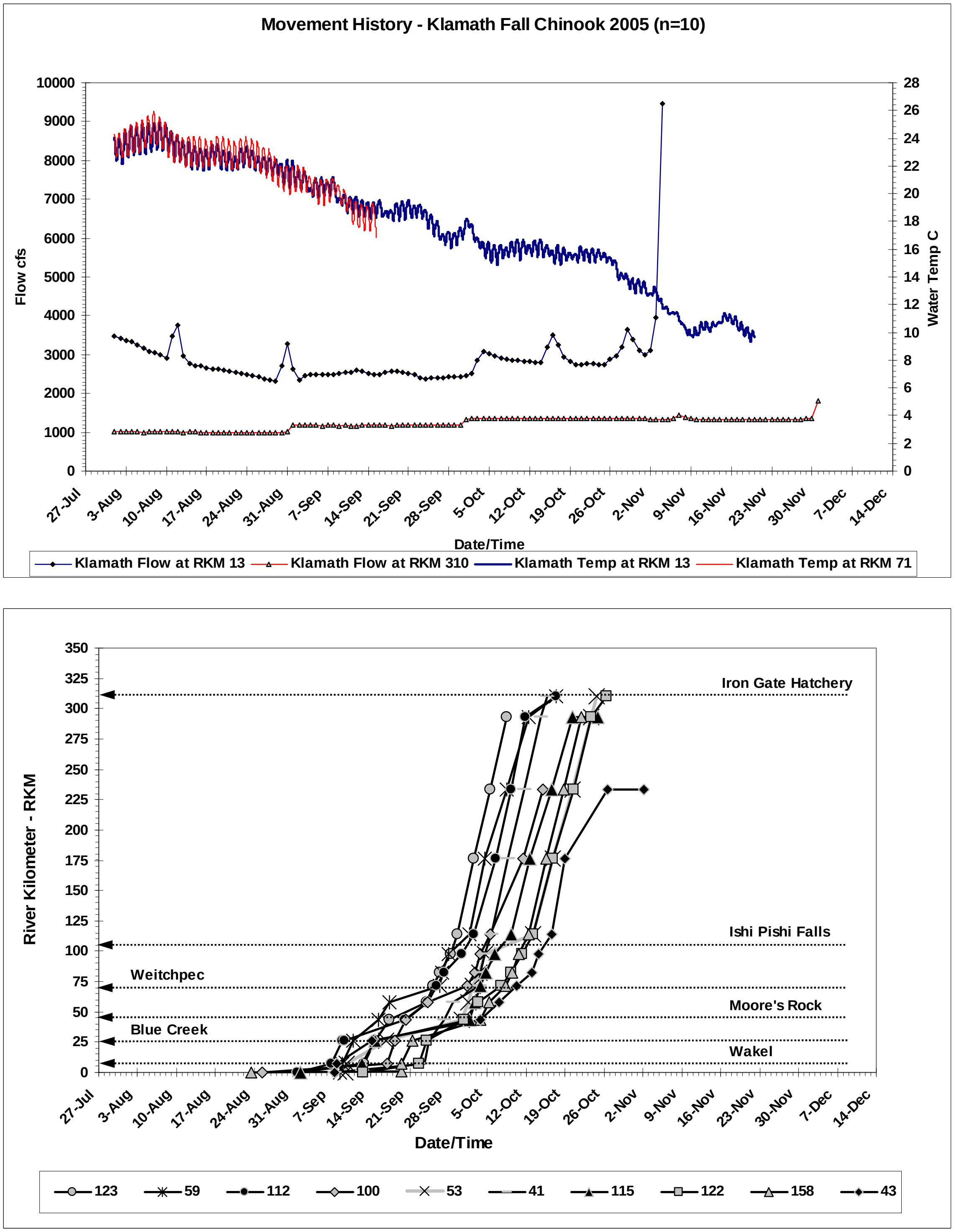

Figure 23. Movement histories for Klamath fall Chinook migrants in comparison to temperature and flow using commonly scaled axis. Applicable landmarks are designated by the dotted lines.

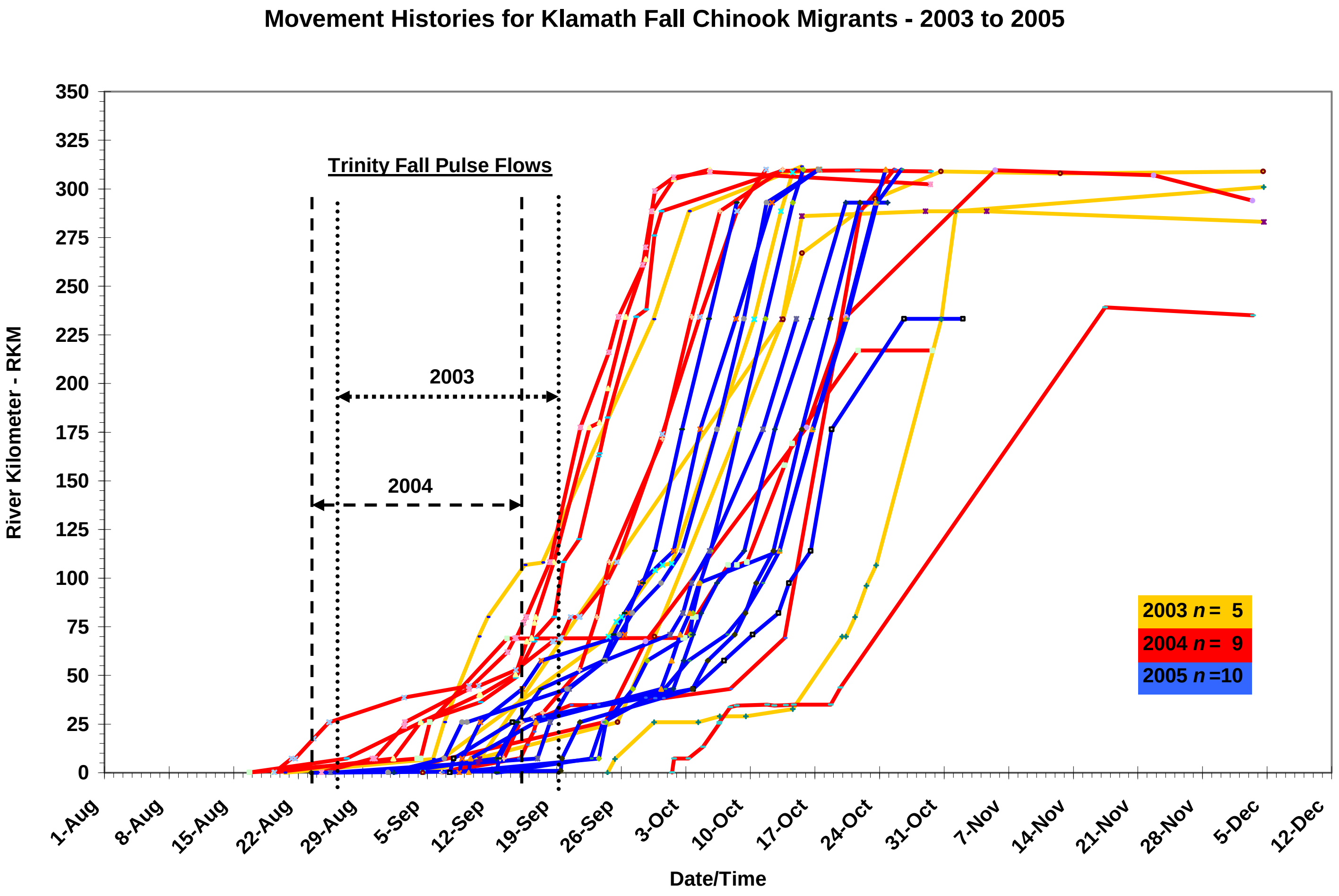

Figure 24. Movement histories for Klamath fall Chinook migrants tagged from 2003 to 2005 color coded by year excluding the three fish tagged above the estuary in the Blue Creek thermal refuge. The dotted and dashed lines show the durations of the Trinity fall pulse flows in the lower Klamath River during 2003 and 2004 respectively. The only pulse flow in 2005 was a relatively minor two day ceremonial release from Lewiston Dam that occurred from 8/29/05 to 9/1/05.

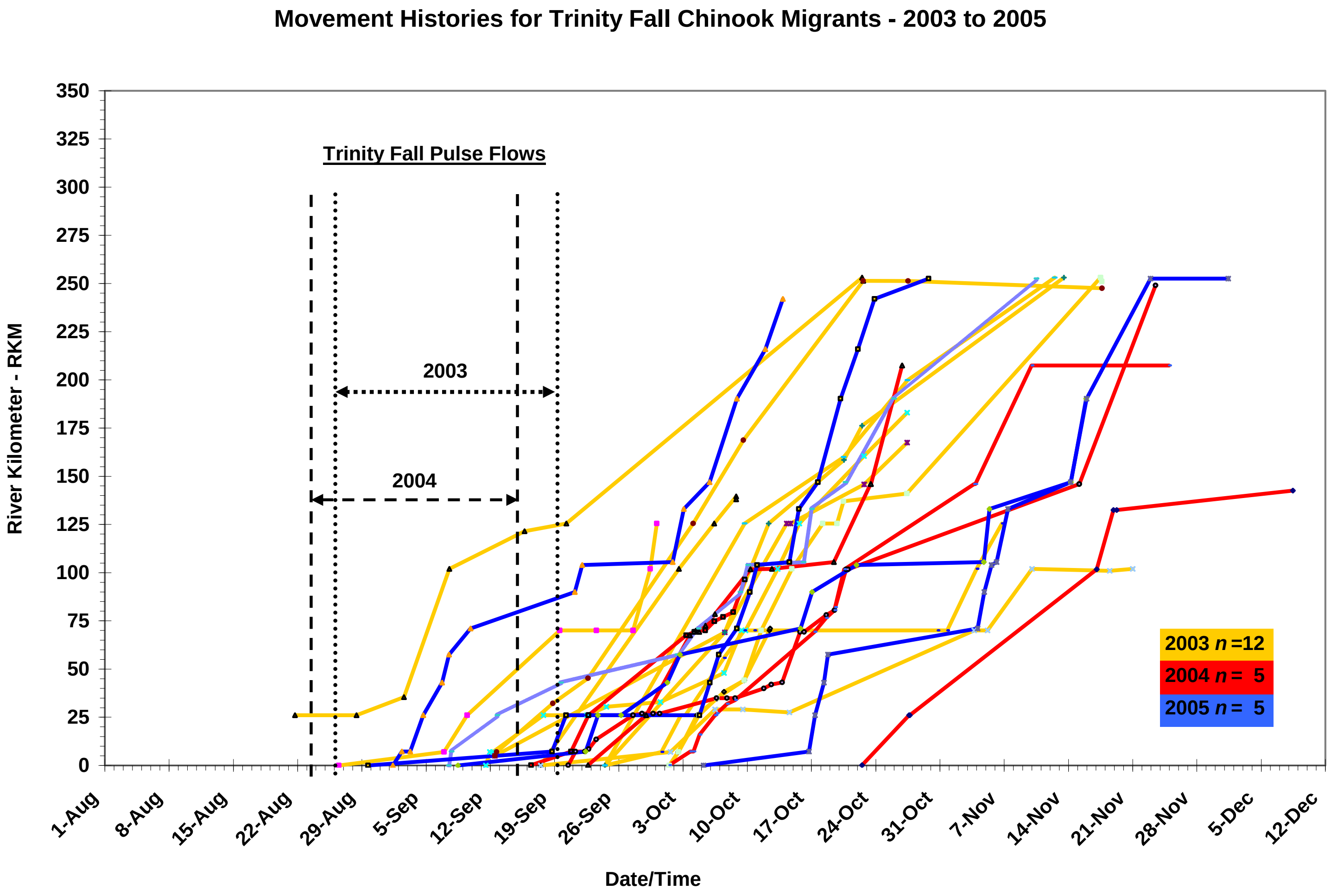

Figure 25. Movement histories for all Trinity fall Chinook migrants tagged from 2003 to 2005 color coded by year. The dotted and dashed lines show the durations of the Trinity fall pulse flows in the lower Klamath River during 2003 and 2004 respectively. The only pulse flow in 2005 was a relatively minor two day ceremonial release from Lewiston Dam that occurred from 8/29/05 to 9/1/05.

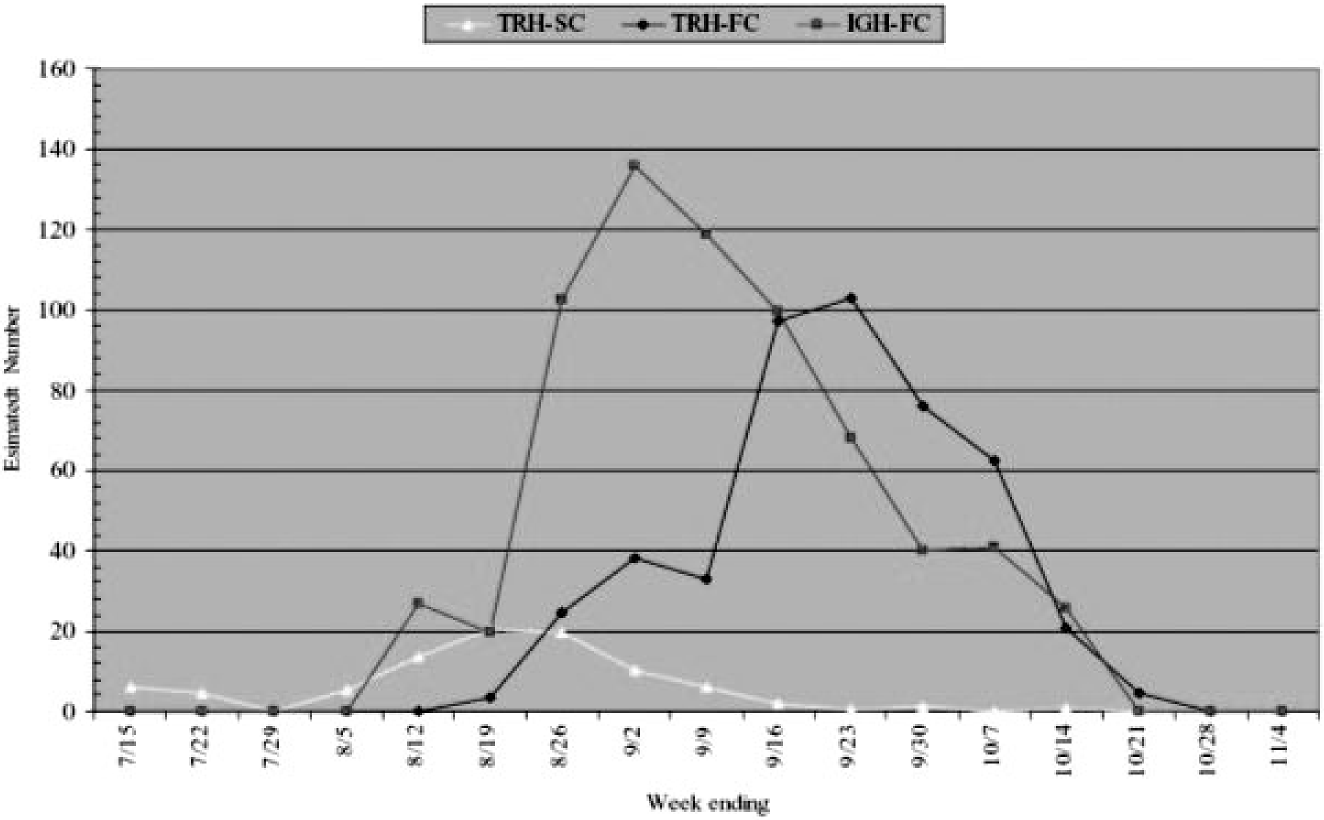

Figure 26. Average run timing by week for adult Chinook in the lower Klamath River (primarily below RKM 26) based on coded wire tag recoveries form the sport fishery from 1988 to 2001. Trinity River Hatchery spring Chinook (TRH-SC) have a bimodal run timing with the larger peak in the late June (not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

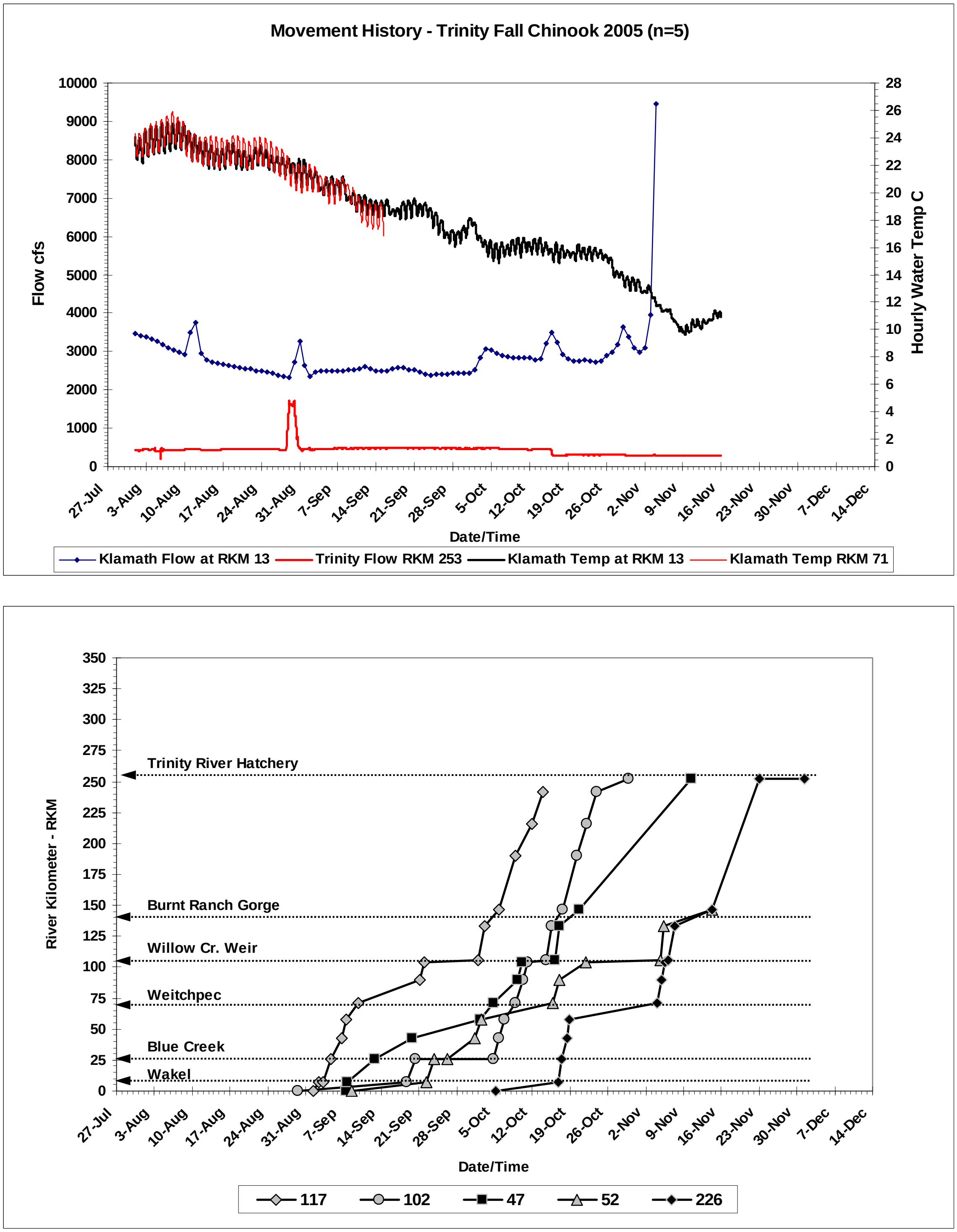

Figure 27. Movement histories for Trinity fall Chinook migrants in comparison to temperature and flow using commonly scaled axis. Applicable landmarks are designated by the dotted lines.

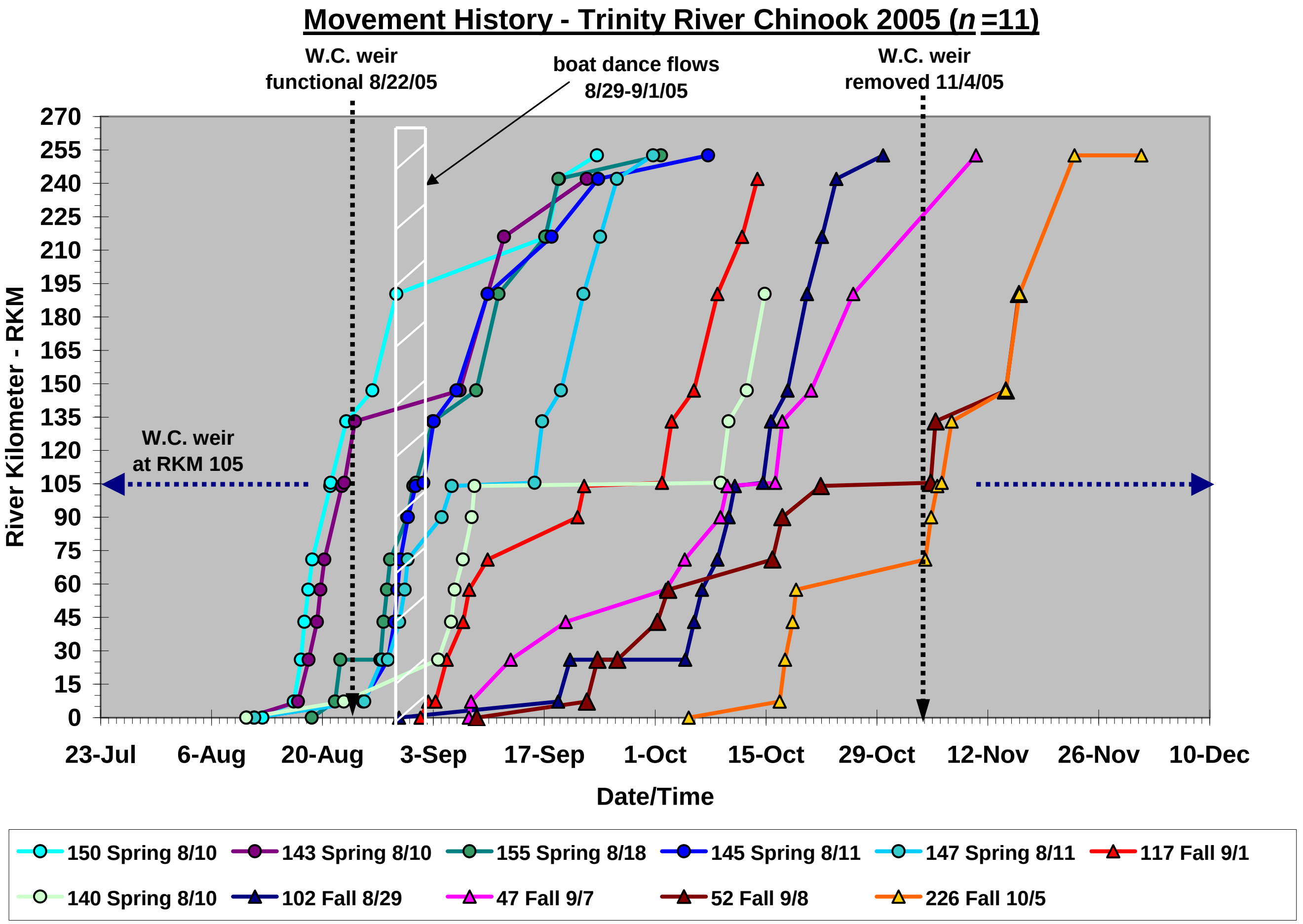

Figure 28. Movement histories for all Trinity Chinook migrants in 2005 in relation to the Willow Creek (WC) weir, which is at RKM 105 and was operated from 8/22/05 to 11/3/05. The gate of the WC weir was left open from 1300 hours to sunset daily and from 1300 hours Friday to Sunday at sunset in order to discourage fish delays at the weir. The white-lined box shows the duration of the boat dance flows at Hoopa RKM 90 during which time the WC weir was partially dismantled and operations modified. Tagging dates and race are reported for each Chinook in the legend.

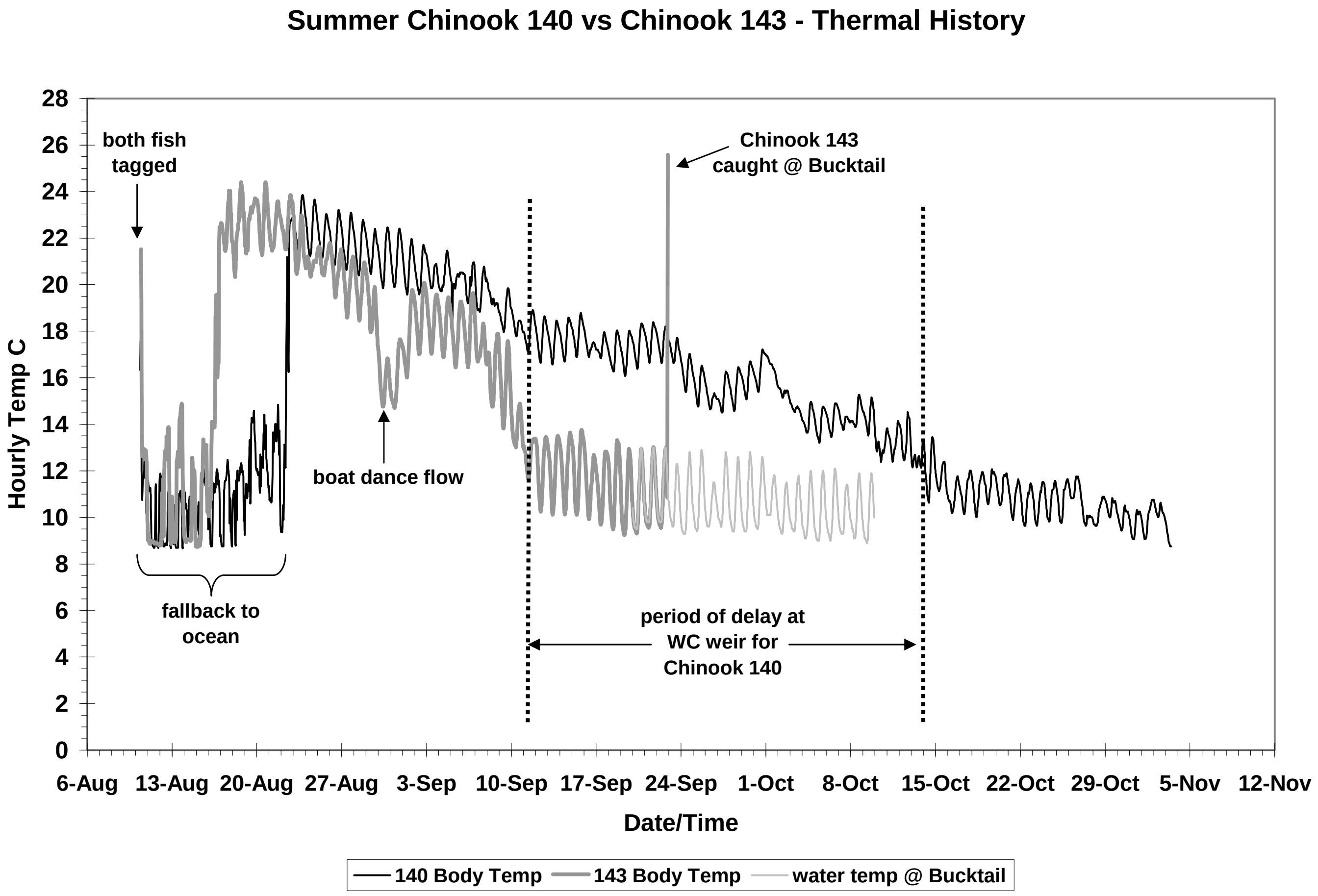

Figure 29. Thermal histories of Chinooks 140 and 143 during their migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach). Both fish were tagged at the mouth of the Klamath River on 8/10/05, but Chinook 143 passed the site of the WC weir during the boat dance flows when the weir was partially dismantled with virtually no delay while Chinook 140 arrived later and delayed for 31.1 days. Bucktail is at RKM 242.

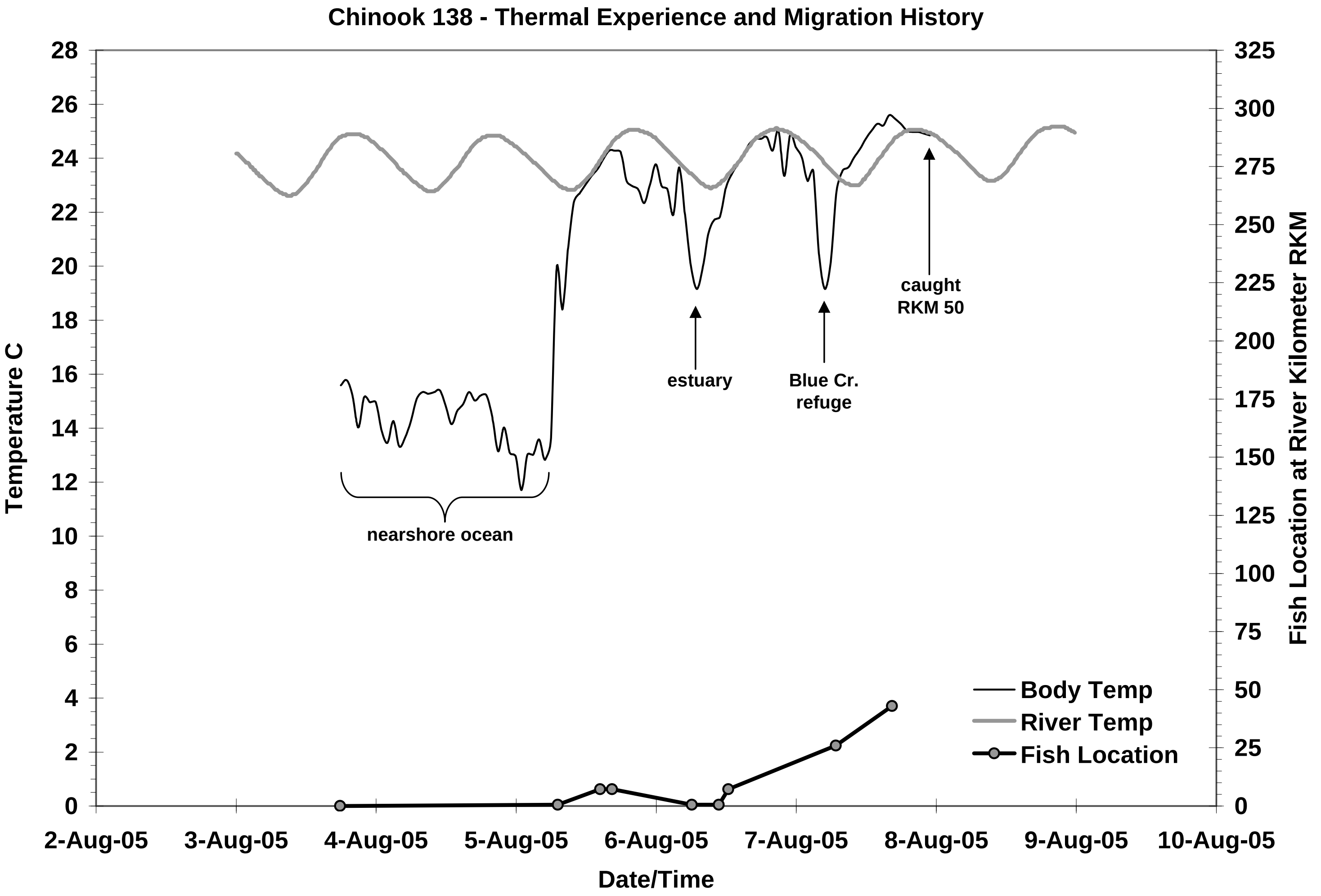

Figure 30. The thermal experience of summer Chinook 138 during its migration in the lower Klamath River as determined from archival body temperature data (Alpha Mach) along with its migration history and river temperature at RKM 13. This fish was harvested at RKM 50.

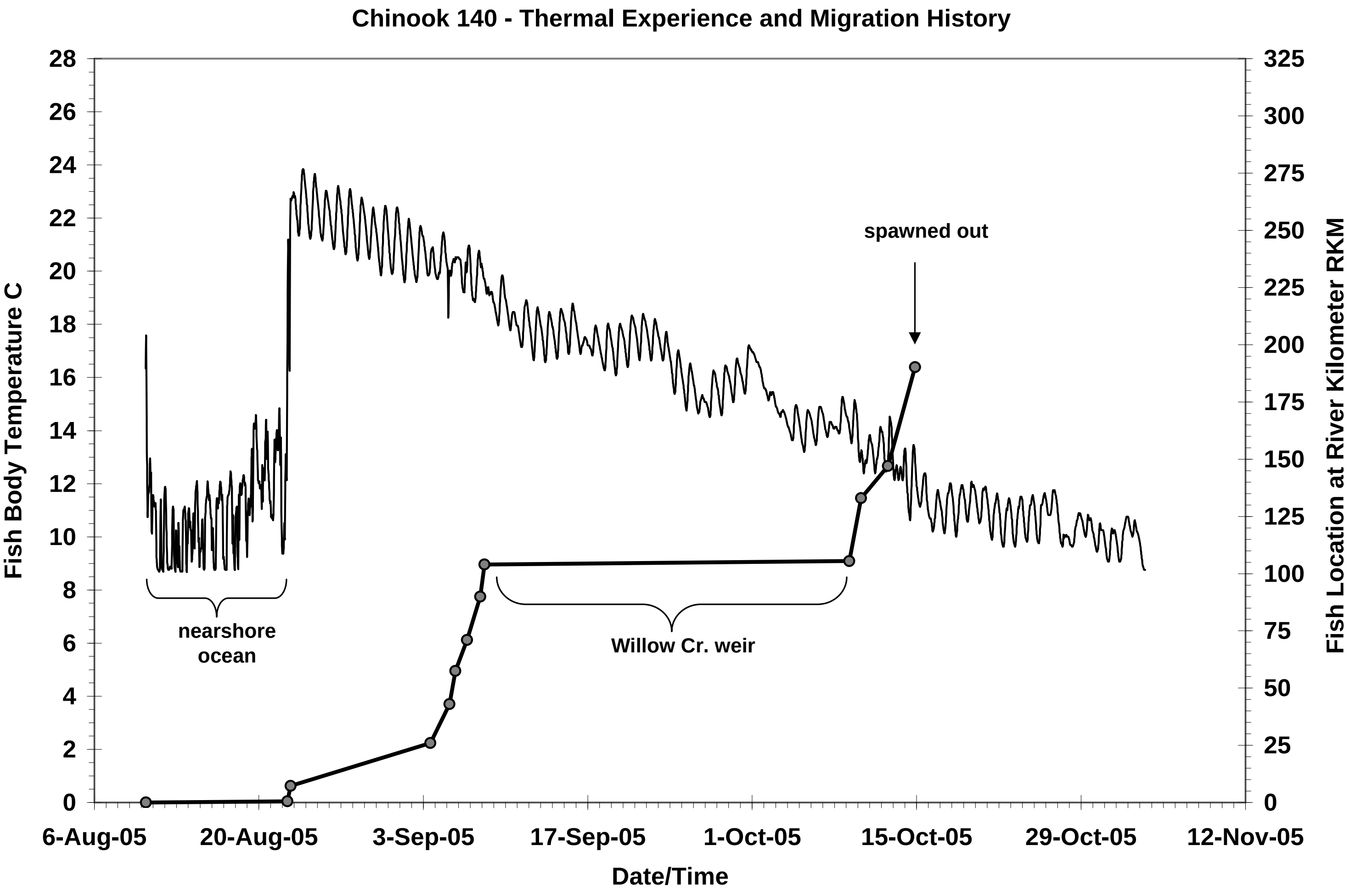

Figure 31. The thermal experience of summer Chinook 140 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish spawned just above the site of the Junction City weir at RKM 206.

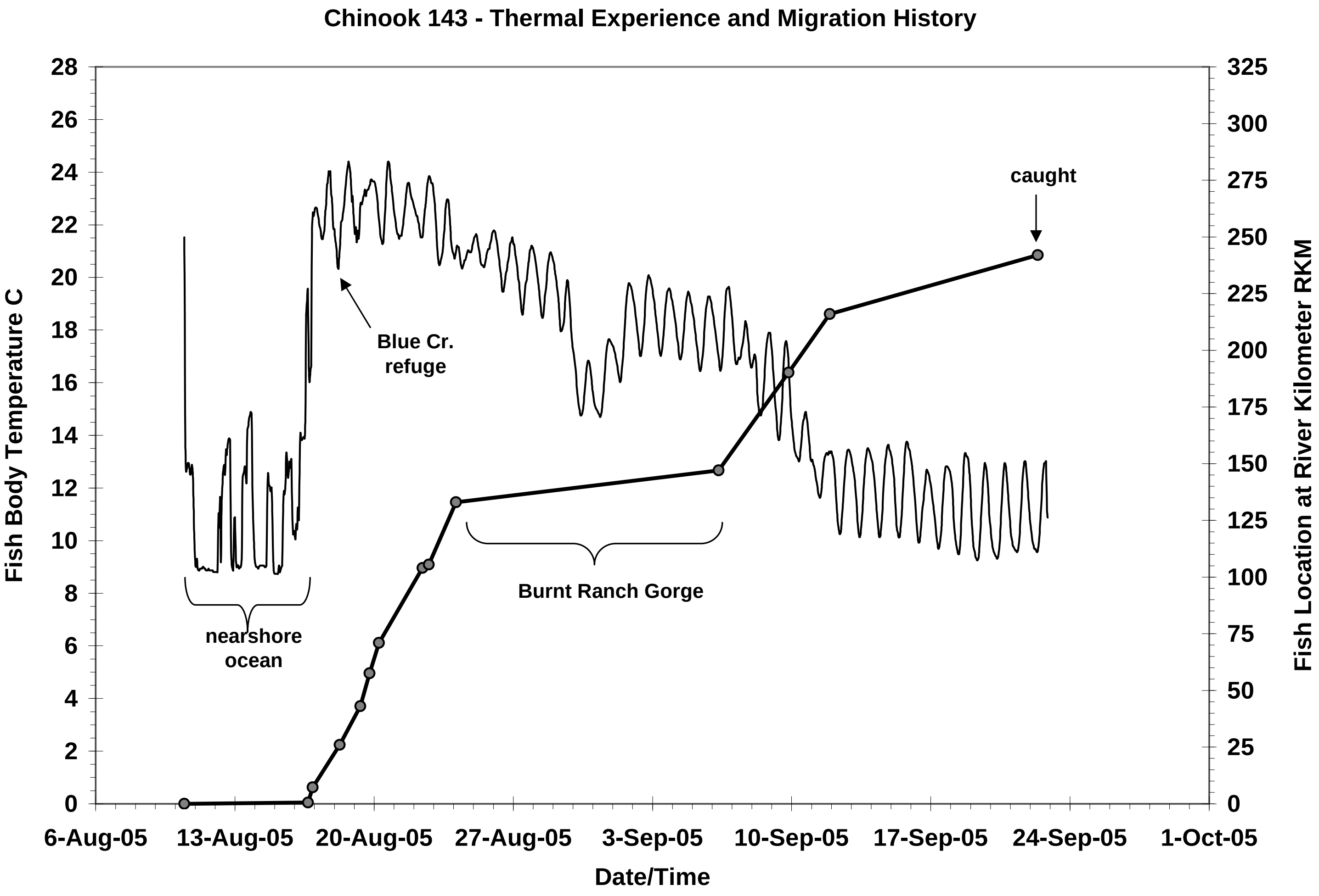

Figure 32. The thermal experience of summer Chinook 143 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was harvested in the pool below the Bucktail Bridge at RKM 241.

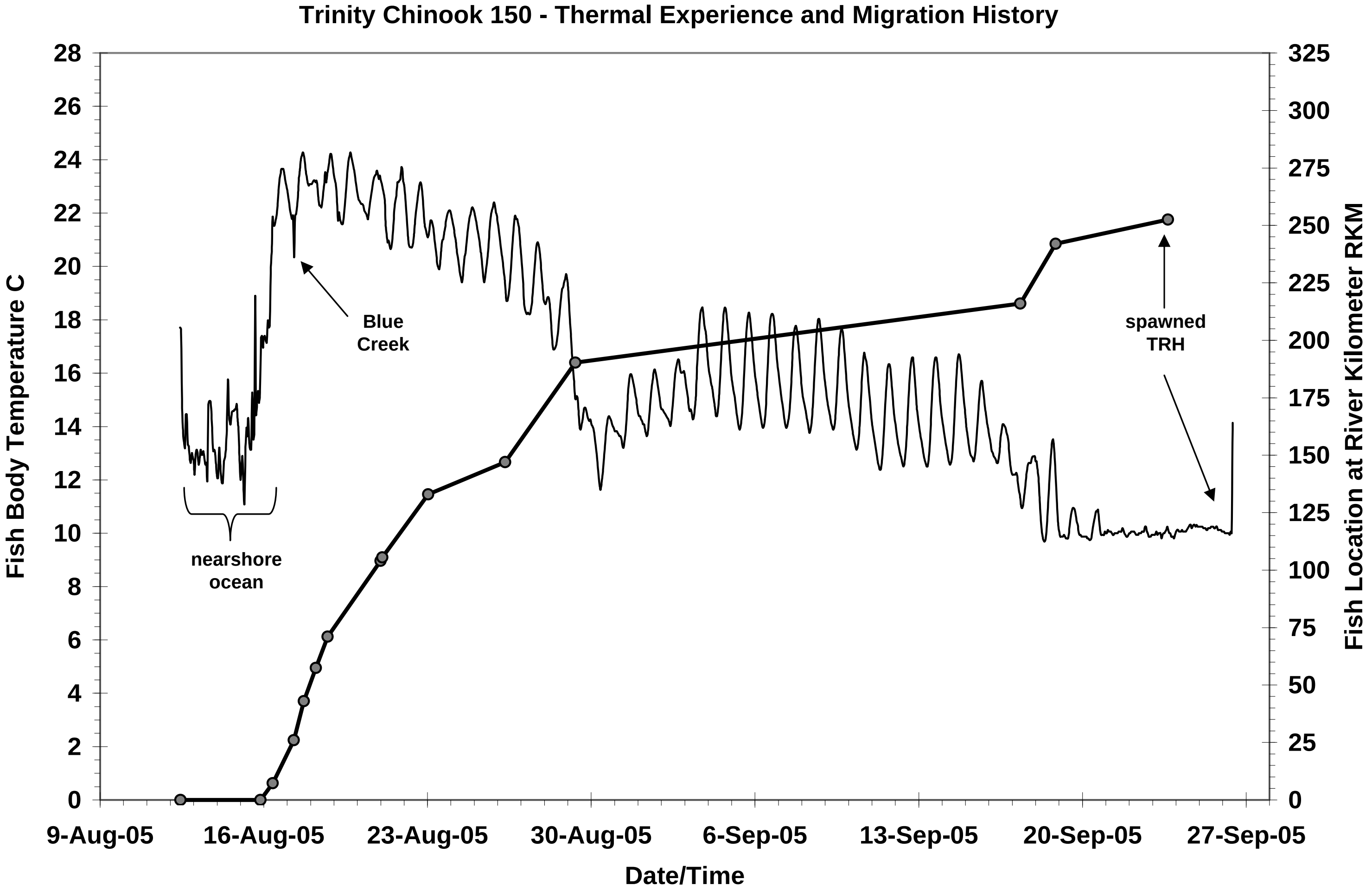

Figure 33. The thermal experience of summer Chinook 150 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was spawned at the TRH.

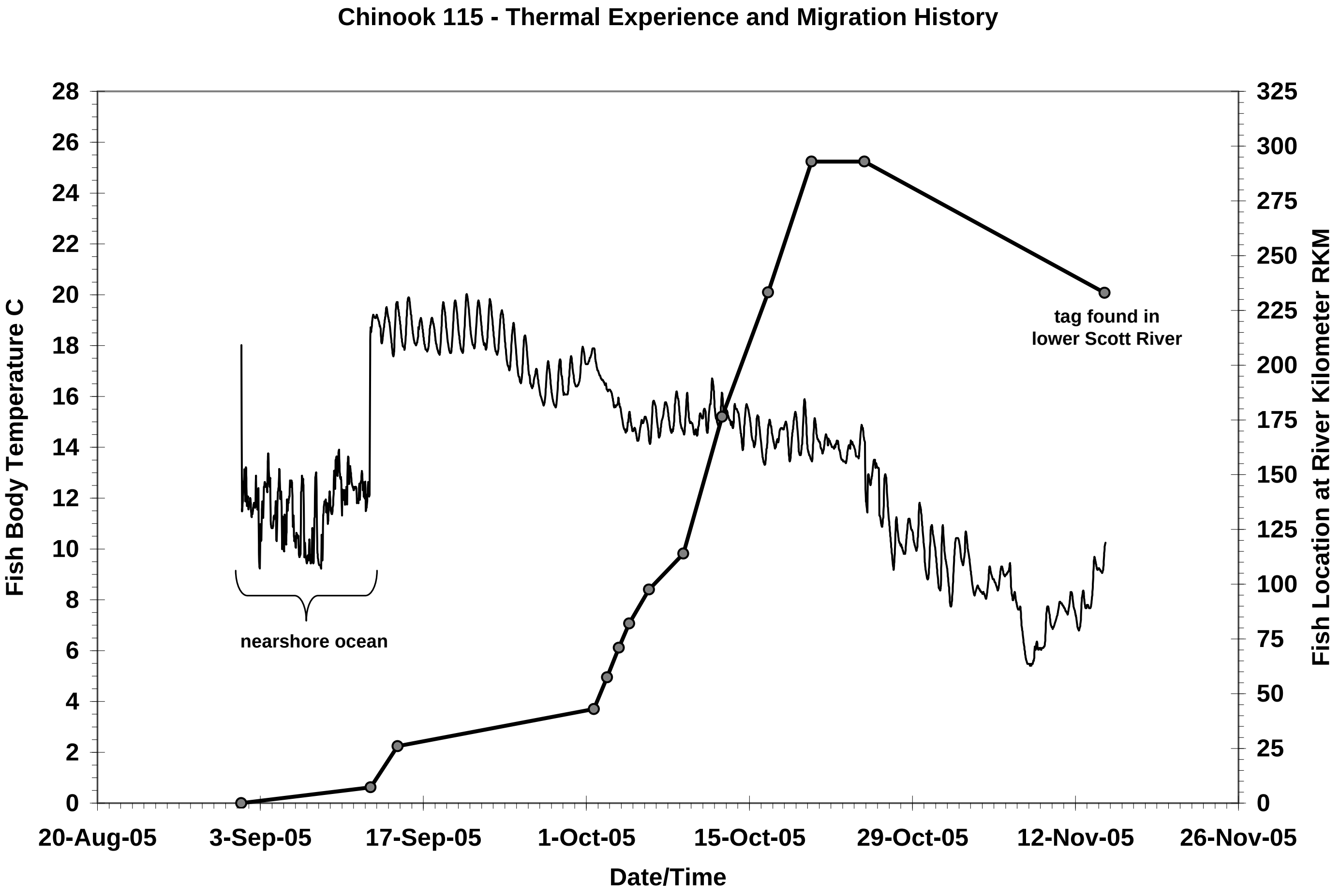

Figure 34. The thermal experience of Klamath fall Chinook 115 during its migration in the Klamath River as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was spent a portion of the spawning season in the mainstem Klamath River above the confluence of the Shasta River but the tag was ultimately found in the lower Scott River.

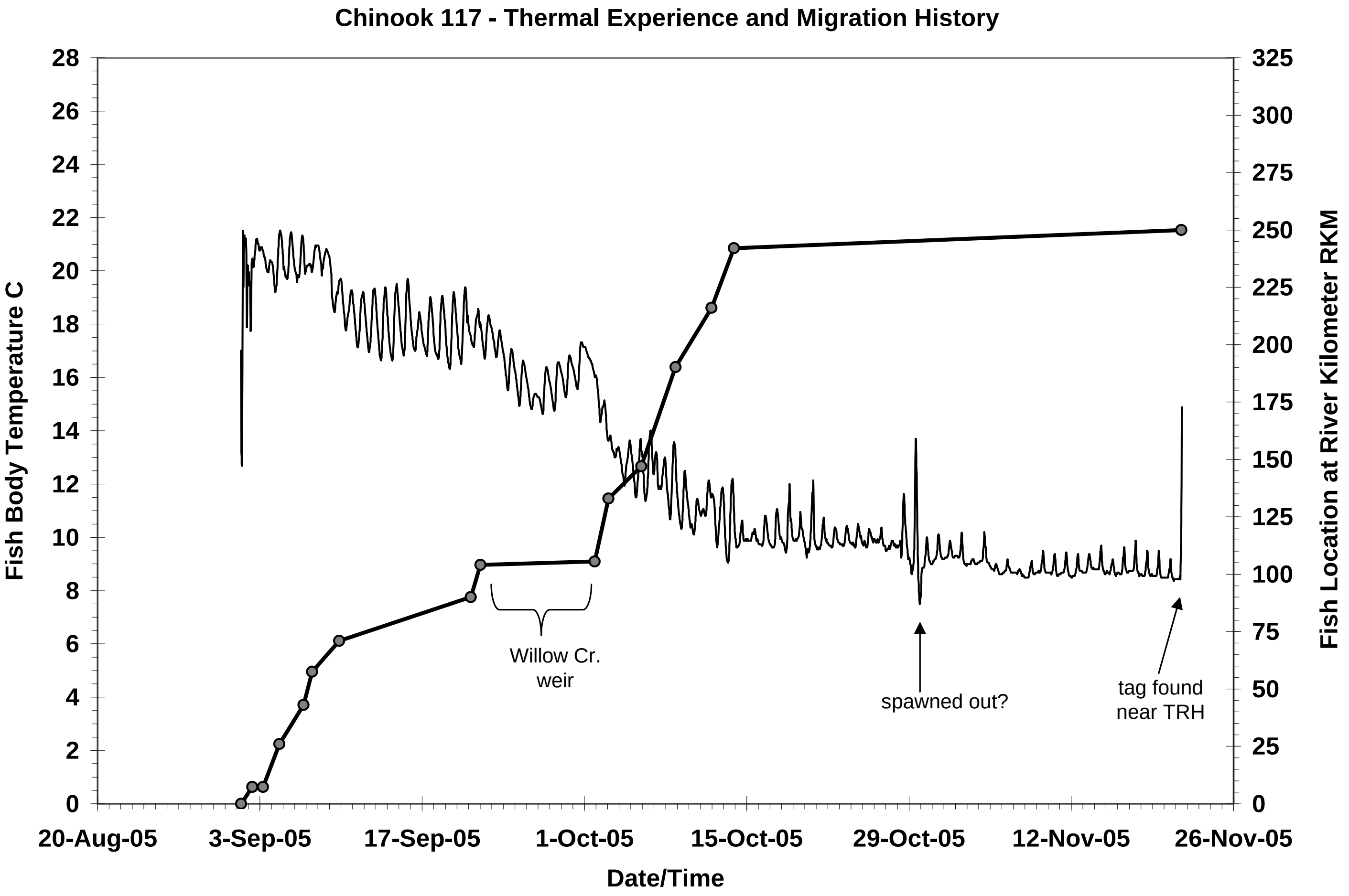

Figure 35. The thermal experience of Trinity fall Chinook 117 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish presumably spawned below TRH where its tag was found.

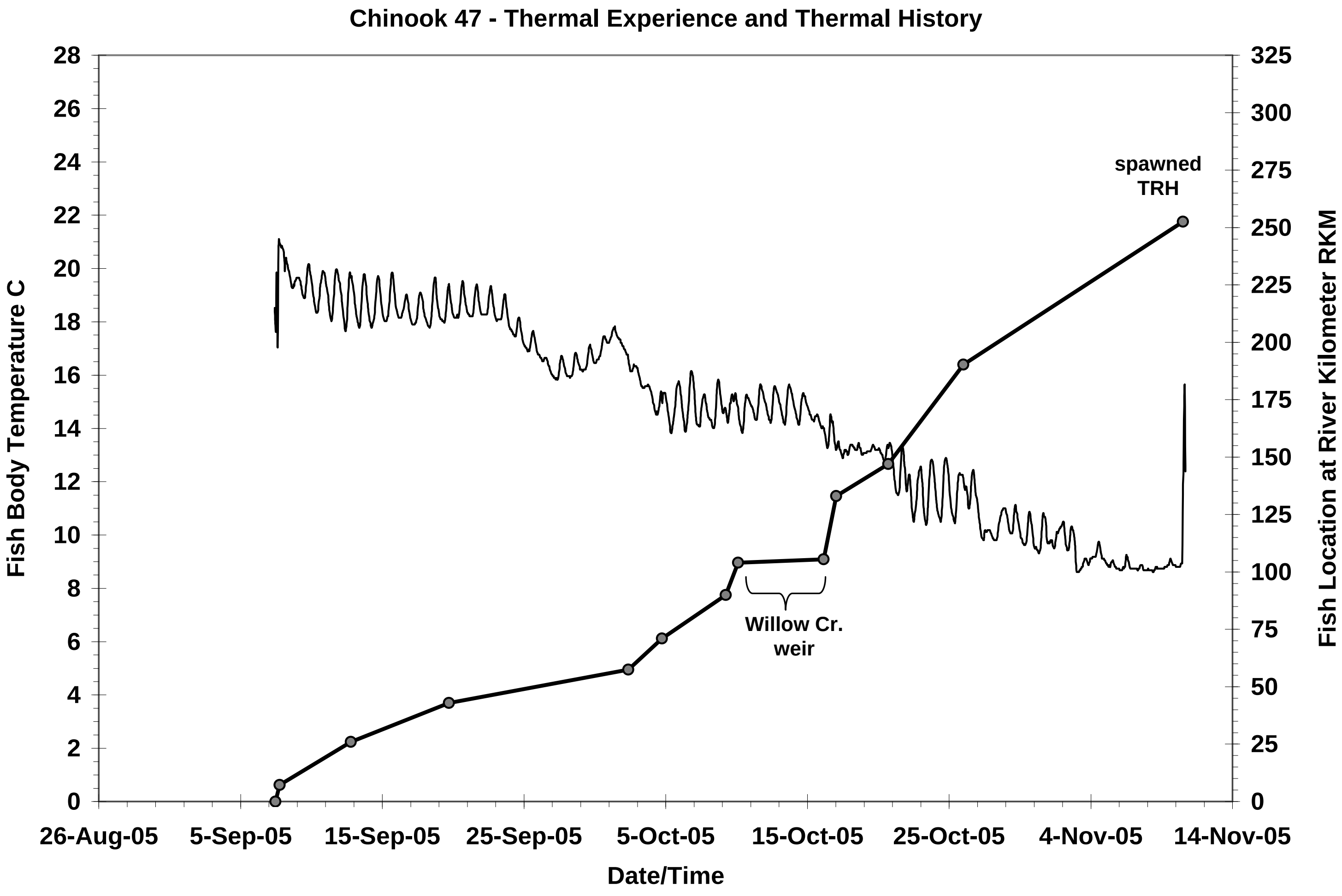

Figure 36. The thermal experience of Trinity fall Chinook 47 during its migration in the Klamath and Trinity Rivers as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was spawned at the TRH.

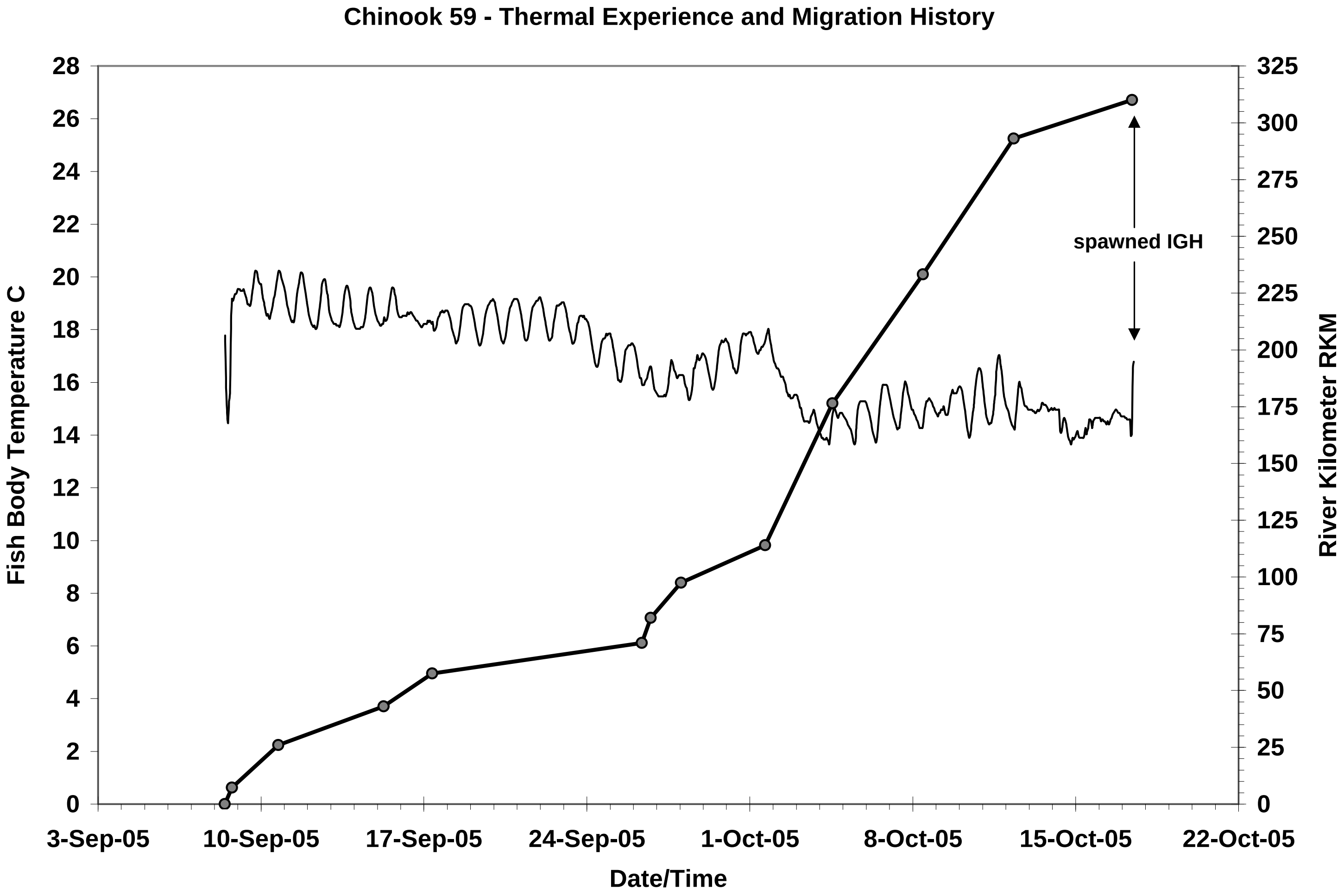

Figure 37. The thermal experience of Klamath fall Chinook 59 during its migration in the Klamath River as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was spawned at IGH.

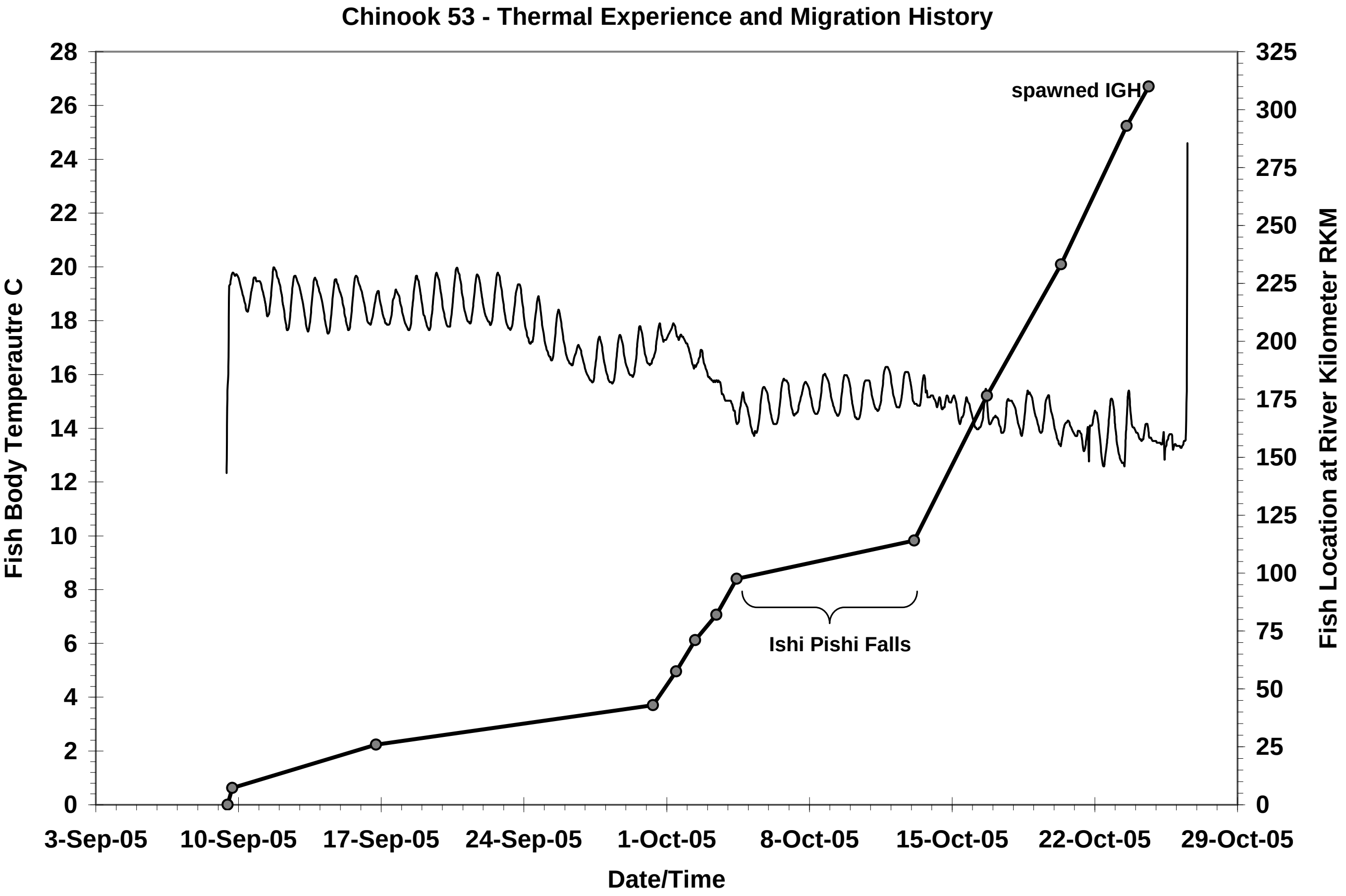

Figure 38. The thermal experience of Klamath fall Chinook 53 during its migration in the Klamath River as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was spawned at IGH.

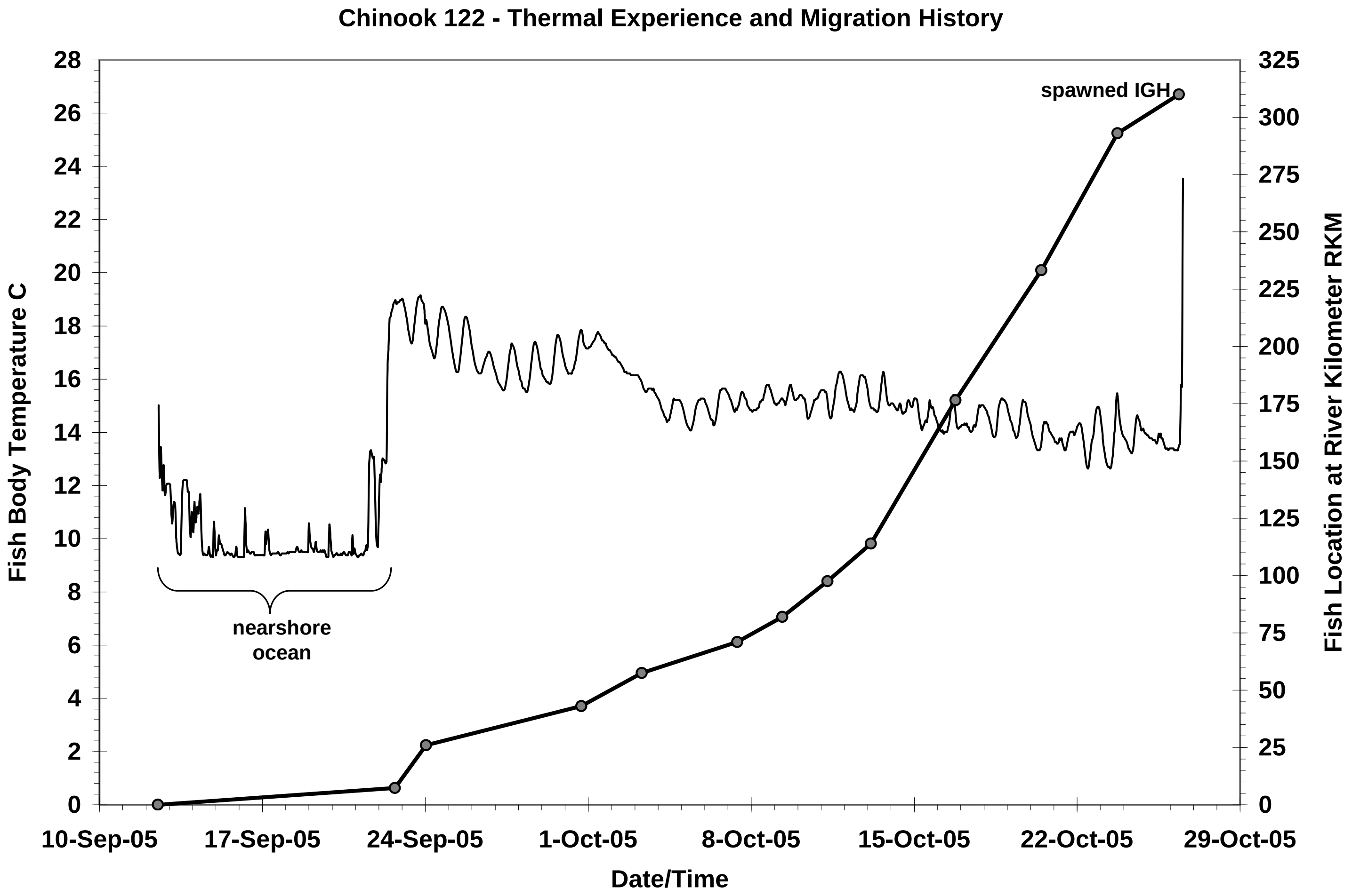

Figure 39. The thermal experience of Klamath fall Chinook 122 as determined from archival body temperature data (Alpha Mach) along with its migration history. This fish was spawned at IGH.

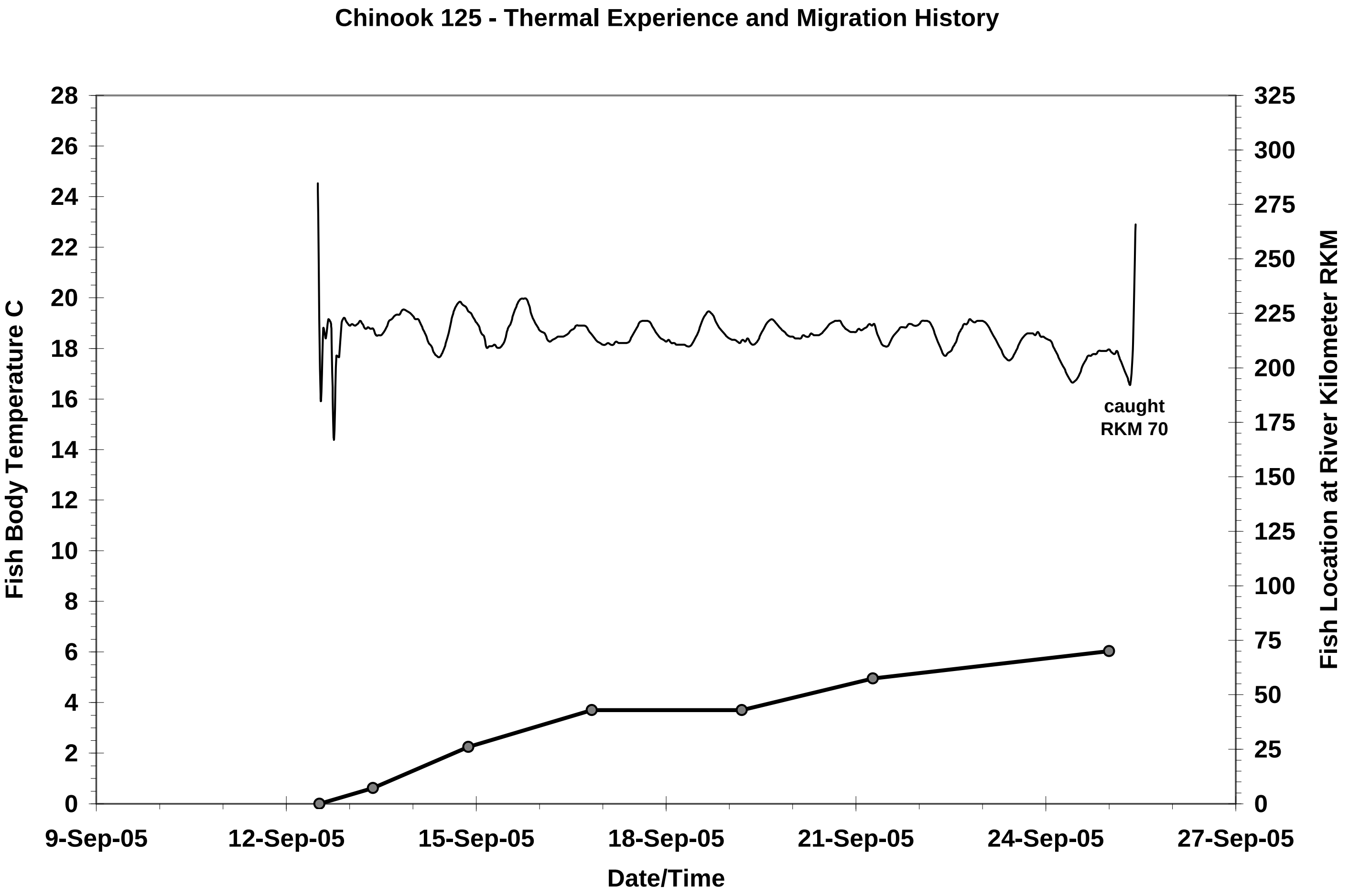

Figure 40. The thermal experience of Chinook 125 as determined from archival body temperature data (Alpha Mach) during its migration through the lower Klamath River along with its migration history. This fish was harvested at Weitchpec RKM 70.

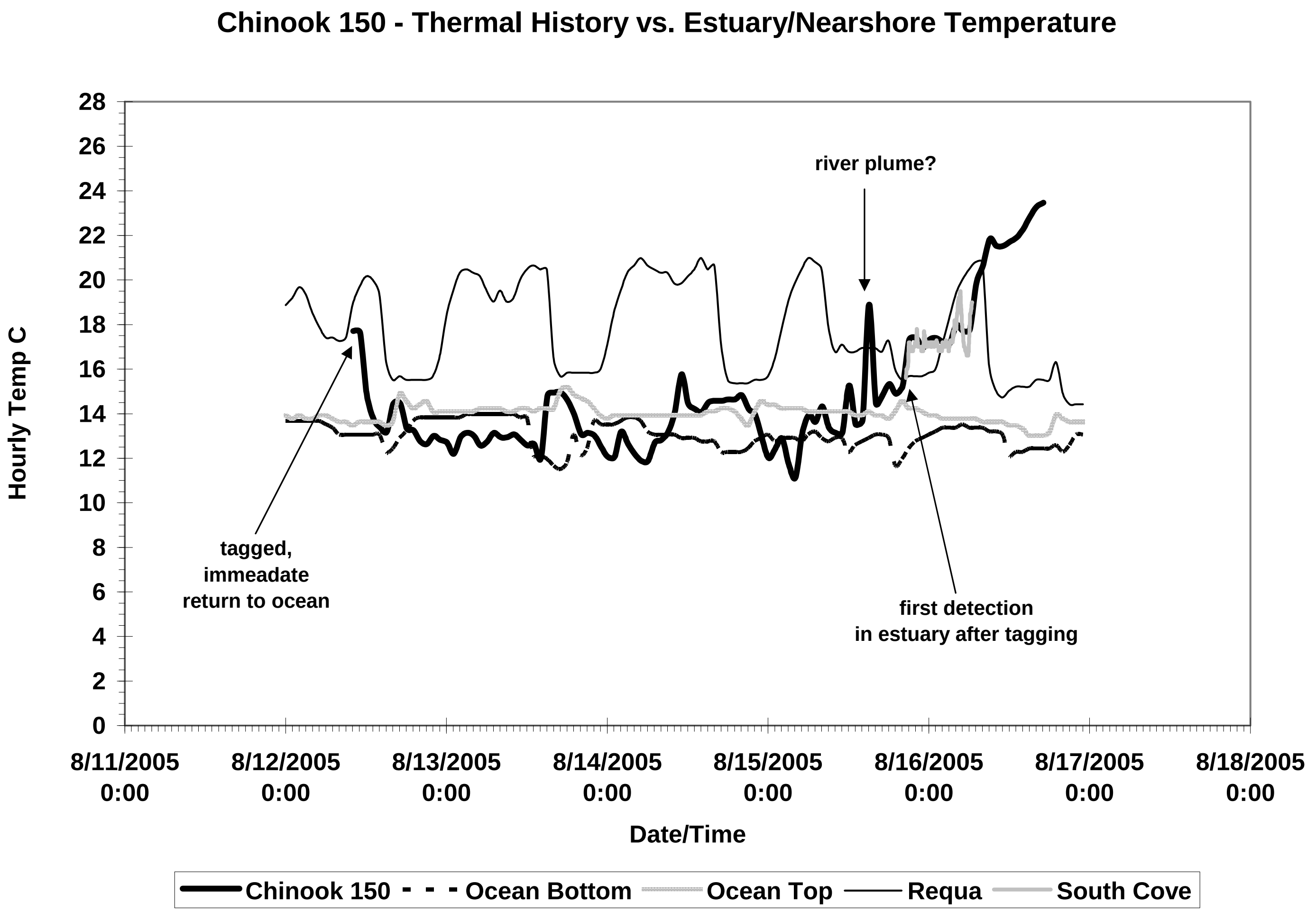

Figure 41. The thermal history of Chinook 150 during its residency in the nearshore ocean and estuary prior to initiation of freshwater migration. Water temperatures in the lower estuary and nearshore ocean are shown for comparison.

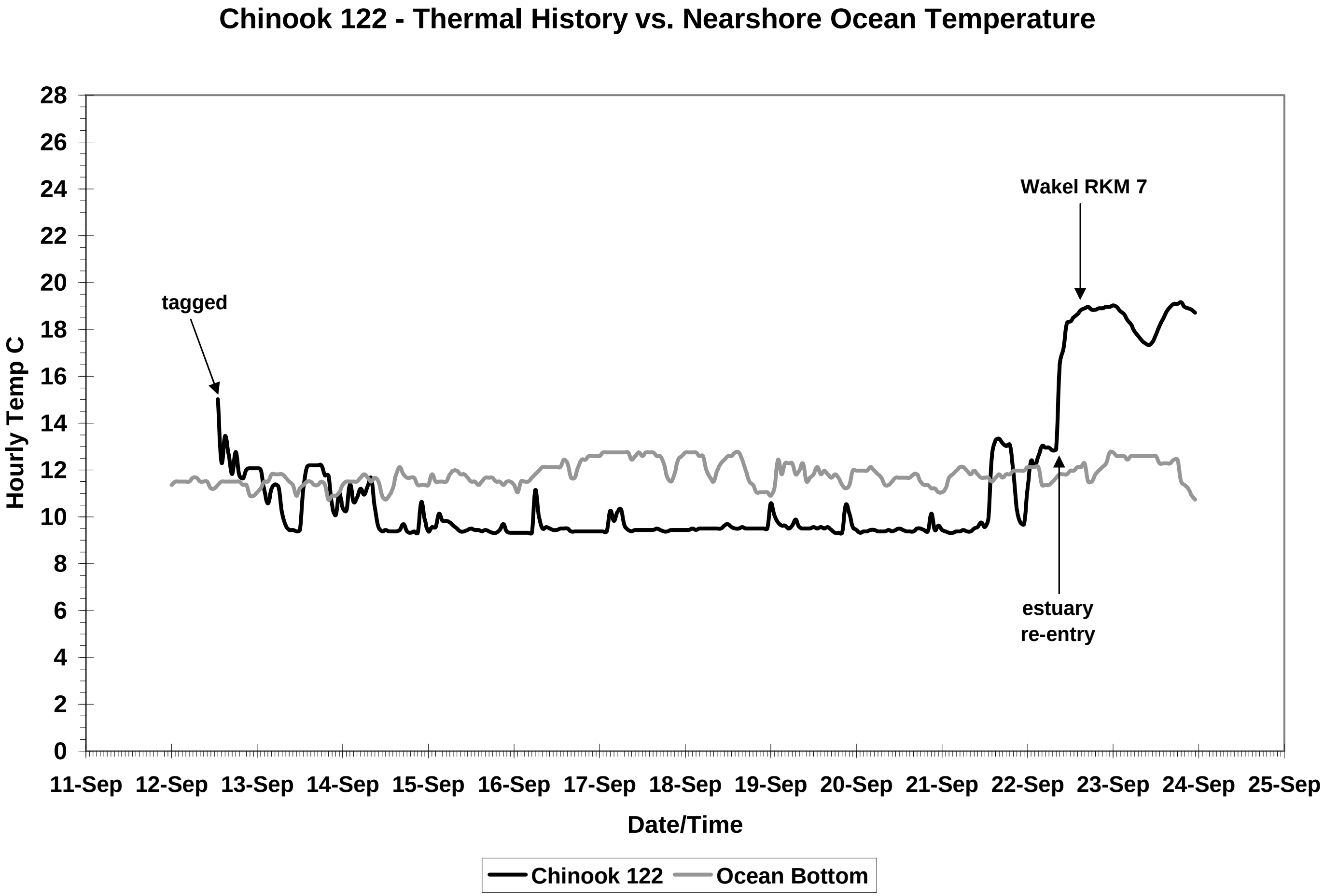

Figure 42. The thermal history of Chinook 122 during its residency in the nearshore ocean and estuary prior to initiation of freshwater migration. Bottom water temperatures at the nearshore sonic receiver are shown for comparison. The consistent pattern of body temperatures close to 9.5ºC can only be achieved via behavioral selection and is consistent with the thermal histories obtained from immature adult salmonids feeding in the ocean.

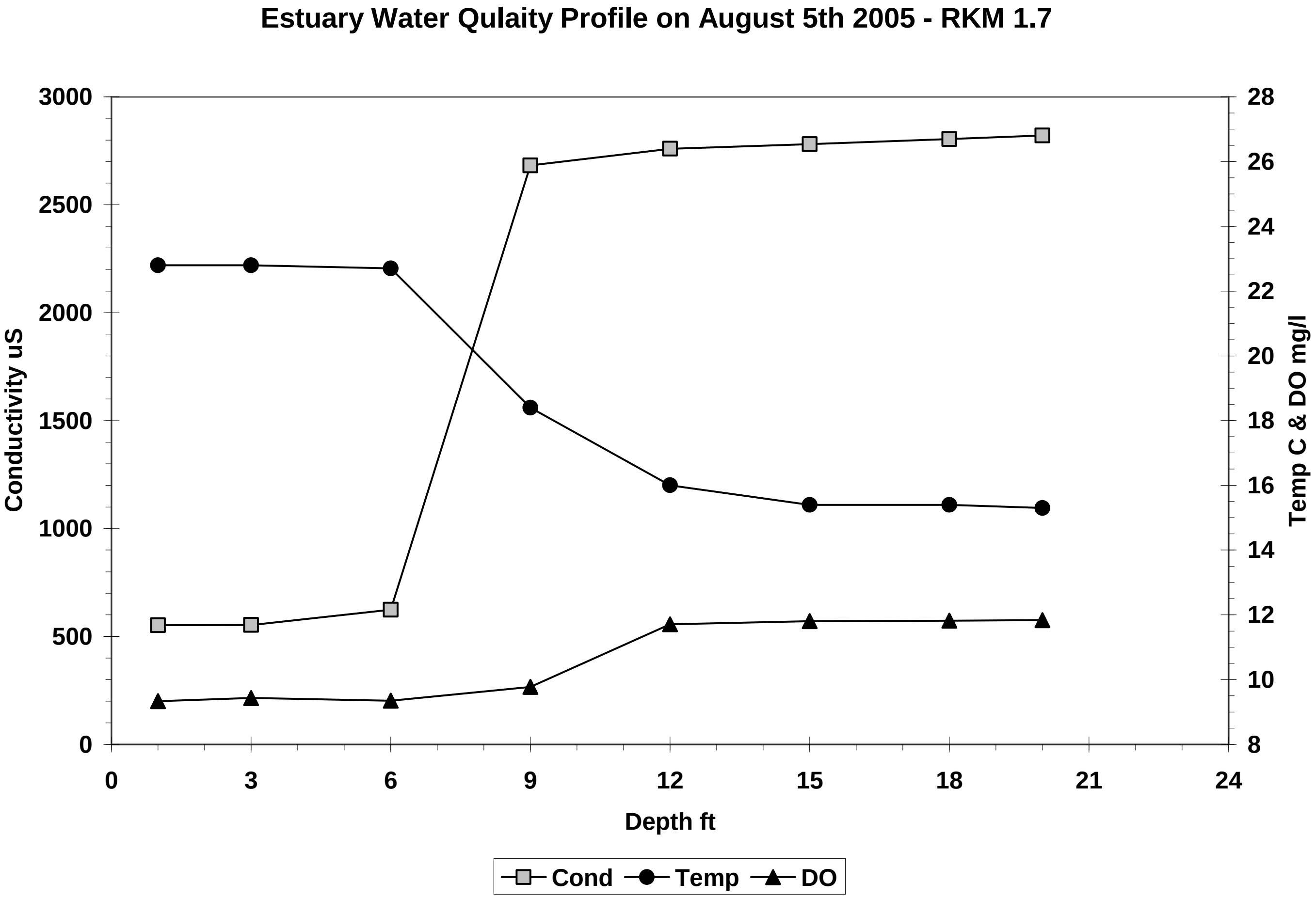

Figure 43. Water quality profile at one of the deeper pools in the Klamath River estuary at RKM 1.7 near the right bank (below Requa Inn). These measurements were taken on 8/5/05 during a high outgoing tide.

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.

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.

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.

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

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

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

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.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.

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.

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., 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.

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 date and fate summary for all 88 adult Chinook tagged in 2005. All fish were tagged at the mouth of the Klamath River.

Tagging Date	Tagging Time	Sonic Tag Code	Jaw Tag #	Fork Length cm	Ad Fin Clip	Sex	Fate/Last Observation	Last River/Reach	Archival Data Recovery
28-Jul-05	12:15	**136**	1	69	n		no observations	estuary	n
1-Aug-05	15:00	**137**	2	74	n		MIA up Trinity 8/20	Trinity	n
3-Aug-05	17:50	**138**	3	73	n		caught 8/7 at Young's Bar	LK	y
5-Aug-05	11:25	**139**	4	72	n		no observations	estuary	n
10-Aug-05	9:10	**140**	5	84	n	F	spawned Junction City weir 10/14	Trinity	y
10-Aug-05	10:00	**141**	6	71	n		no observations	estuary	n
10-Aug-05	10:10	**142**	7	68	n		MIA ocean	ocean	n
10-Aug-05	11:05	**143**	8	70	n	F	caught Bucktail 9/22	Trinity	y
10-Aug-05	11:10	**144**	9	71	n		MIA at Weitchpec 8/14	Klamath	n
11-Aug-05	9:30	**145**	10	75	n		TRH 10/7	Trinity	n
11-Aug-05	9:55	**146**	11	67	n		IGH 9/26	Klamath	n
11-Aug-05	10:00	**147**	12	73	n		TRH 9/30	Trinity	n
11-Aug-05	10:24	**148**	13	72	n		no observations	estuary	n
11-Aug-05	11:30	**149**	14	76	n		MIA ocean	ocean	n
12-Aug-05	10:30	**150**	15	77	n	M	TRH 9/26	Trinity	y
12-Aug-05	11:42	**151**	16	100	n		MIA ocean	ocean	n
16-Aug-05	13:45	**152**	17	86	n		pinniped predation	estuary	n
17-Aug-05	13:36	**153**	18	66	n		MIA ocean	ocean	n
18-Aug-05	15:20	**154**	19	80	n		pinniped predation	estuary	n
18-Aug-05	16:00	**155**	20	83	n		TRH 10/1	Trinity	n
23-Aug-05	8:40	**156**	21	79	n		no observations	estuary	n
23-Aug-05	8:45	**157**	22	76	n		pinniped predation	estuary	n
23-Aug-05	9:52	**158**	23	94	n		above Hornbrook 10/21	Klamath	n
25-Aug-05	9:52	**96**	24	74	n		caught estuary 8/25 4pm	estuary	n

25-Aug-05	10:14	**97**	25	88	n		MIA ocean	ocean	n
25-Aug-05	10:18	**98**	26	71	n		pinniped predation	estuary	n
25-Aug-05	11:15	**99**	27	?	n		pinniped predation	estuary	n
25-Aug-05	11:31	**100**	28	78	n		above Blue Heron 10/15	Klamath	n
25-Aug-05	12:30	**101**	29	74	n		pinniped predation	estuary	n
29-Aug-05	16:01	**102**	30	79	n		above Bucktail 10/23	Trinity	n
29-Aug-05	16:22	**103**	31	88	n		pinniped predation	estuary	n
29-Aug-05	16:34	**104**	32	75	n		pinniped predation	estuary	n
30-Aug-05	16:00	**105**	33	93	y		MIA ocean	ocean	n
30-Aug-05	16:50	**106**	34	74	n		MIA mouth	estuary	n
30-Aug-05	16:55	**107**	35	76	n		pinniped predation	estuary	n
30-Aug-05	17:06	**109**	37	95	n		MIA ocean	ocean	n
30-Aug-05	17:11	**108**	36	74	n		MIA estuary South Cove	estuary	n
31-Aug-05	17:39	**110**	38	82	y		no observations	estuary	n
31-Aug-05	18:12	**111**	39	76	n		pinniped predation	estuary	n
31-Aug-05	18:13	**112**	40	87	n		IGH 10/17	Klamath	n
31-Aug-05	18:29	**113**	41	76	n		MIA mouth	estuary	n
1-Sep-05	8:31	**114**	42	73	n		regurgitation or predation	estuary	n
1-Sep-05	8:39	**115**	43	83	n		Hornbrook 10/24; died Scott R.	Klamath	y
1-Sep-05	8:59	**116**	44	72	y		pinniped predation	estuary	n
1-Sep-05	9:19	**117**	45	89	n		above Bucktail 10/13	Trinity	y
1-Sep-05	17:11	**118**	46	72	n		pinniped predation	estuary	n
1-Sep-05	17:27	**119**	47	94	y		MIA estuary mouth	estuary	n
1-Sep-05	18:02	**120**	48	68	n		pinniped predation	estuary	n
7-Sep-05	9:12	**40**	49	79	n		pinniped predation	estuary	n
7-Sep-05	9:38	**41**	50	76	n	M	IGH 10/15	Klamath	n
7-Sep-05	9:46	**42**	51	68	n		MIA estuary mouth	estuary	n
7-Sep-05	10:03	**43**	52	76	y		above Blue Heron 11/2	Klamath	n
7-Sep-05	10:44	**44**	53	83	n		pinniped predation	estuary	n
7-Sep-05	11:00	**54**	54	99	n		regurgitation or predation	estuary	n
7-Sep-05	11:10	**45**	55	74	n		no observations	estuary	n
7-Sep-05	11:18	**46**	56	68	y		pinniped predation	estuary	n

7-Sep-05	11:20	**47**	57	82	y	F	TRH 11/10	Trinity	y
8-Sep-05	9:20	**48**	58	73	n		pinniped predation	estuary	n
8-Sep-05	10:45	**59**	59	76	n	M	IGH 10/17	Klamath	y
8-Sep-05	10:49	**50**	60	83	n		regurgitation or predation	estuary	n
8-Sep-05	11:19	**51**	61	83	n		no observations	estuary	n
8-Sep-05	11:23	**52**	62	83	n		above China Slide 11/14	Trinity	n
9-Sep-05	11:13	**53**	63	73	n	M	IGH 10/24	Klamath	y
9-Sep-05	11:15	**55**	64	74	n		pinniped predation	estuary	n
9-Sep-05	11:18	**56**	65	74	n		pinniped predation	estuary	n
9-Sep-05	11:45	**57**	66	79	n		pinniped predation	estuary	n
9-Sep-05	12:13	**58**	67	82	y		MIA ocean	ocean	n
9-Sep-05	12:30	**49**	68	81	n		no observations	estuary	n
12-Sep-05	12:04	**121**	69	72	n		no observations	estuary	n
12-Sep-05	12:09	**122**	70	73	n	F	spawned IGH 10/26	Klamath	y
12-Sep-05	12:15	**123**	71	81	n		above Hornbrook 10/8	Klamath	n
12-Sep-05	12:35	**124**	72	79	n		MIA estuary mouth	estuary	n
12-Sep-05	12:37	**125**	73	82	n		caught Weitchpec 9/25	LK	y
13-Sep-05	12:19	**126**	74	83	n		pinniped predation	estuary	n
13-Sep-05	12:22	**127**	75	83	n		pinniped predation	estuary	n
13-Sep-05	12:38	**128**	76	78	n		pinniped predation	estuary	n
13-Sep-05	12:41	**129**	77	76	y		pinniped predation	estuary	n
13-Sep-05	12:45	**130**	78	69	y		pinniped predation	estuary	n
14-Sep-05	14:30	**131**	79	76	n		regurgitation or predation	estuary	n
14-Sep-05	14:33	**132A**	80	75	n		caught immeadately	estuary	na
14-Sep-05	14:35	**133**	81	84	n		regurgitation or predation	estuary	n
14-Sep-05	14:58	**134**	82	82	n		pinniped predation	estuary	n
14-Sep-05	15:01	**225**	83	71	n		pinniped predation	estuary	n
22-Sep-05	9:12	**132**	84	83	n		pinniped predation	estuary	n
26-Sep-05	13:13	**159**	85	72	n		regurgitation or predation	estuary	n
28-Sep-05	17:06	**224**	86	92	n		MIA estuary mouth	estuary	n
5-Oct-05	17:55	**226**	87	68	n		TRH ladder 11/22	Trinity	n
7-Oct-05	18:54	**227**	88	85	y		pinniped predation	estuary	n

Last page left intentionally blank.